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Lithochemical Surveys for Ore Metals in Arid Region, Central Eastern Desert, Egypt: Using Landsat ETM+ Imagery

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Abstract: Lithochemical overburden, stream sediment and bed rock surveys for mineral deposits were undertaken in Hamrat Ghannam area, located in the arid Eastern Desert of Egypt. Landsat ETM+ ratio image helped in discriminating the different rock units and associated alteration zones in the study area. Forty fresh bedrock samples were petrographically studied. Besides 18 altered rock samples as well as 20 overburden and stream sediment samples were mineralogically and chemically analyzed using ICP technique. The lithochemical surveys recorded several dispersion aureoles of Au, Sn, Mo, Zn, Pb, U, Th, Nb, Ta, REE, Y, Zr and Hf. The ophiolitic listwaenites and the muscovite albite granite exposures in the study area point to possible presence of new sites of gold mineralization. Lithochemical maps and variation diagrams of the ore metals content in the different grain size fractions were constructed. The optimum grain size classes to be analyzed for Au is 2 – 0.25 mm and 0.5 – 0.25 mm for the other ore metals. A high gold concentration is also recorded in the grain size 0.5 – 0.25 mm and encountered in pyrite and its pseudomorph goethite. The recorded anomalous contents of Y and REE recommend undertaking detailed mineralogical and geochemical studies particularly on the altered muscovite albite granites.

Key words: Lithochemical surveys, Landsat ETM+, stream sediments, listwaenites, altered muscovite albite granites.

INTRODUCTION

Lithogeochemical exploration for ore metals is undertaken by the authors in Wadi Hamrat Ghannam-Wadi El Sherm El Bahari area, Central Eastern Desert. This area is located between Lat. 25°44′ and 25°52′N and Long. 34°15′ and 34°19′ E (Fig. 1). Arid to semi arid climate alternated with humid tropical climate prevailed during the Plio-Pleistocene with higher percentage of humidity during the last 10000 years (Sutherland, 1985). Several pluvial intervals prevailed around 3000, 5000 and 8000 years ago (Hassaan, 2001). Presumably these humid phases were responsible for weathering, transportation and sediments reworking, as well as formation of dispersion aureoles and occasionally placers of ore metals. Sutherland (1985) suggested that the alternation between periods of fluvial activity and times of perennial flow may be more important in placer formation than periods of flow alone, which is responsible for the formation of dispersion aureoles in the residual overburden and transported stream sediments. The geologic setting of the area under investigation has been studied by several authors i.e., Abu El Leil *et al.* (1977); Hassaan (1990); EGSMA (1992) and Ramadan *et al.* (1999). The exposed igneous and metamorphic rocks are represented by ultramafic rocks and metavolcanics as well as granitoid rocks and the post granite dykes. The sedimentary cover is represented by Late Cretaceous sandstones of the Nubian facies.

The study area is part of Quseir-Marsa Alam district in which gold, Pb-Zn, celestite, niobium-tantalum and tungsten-tin deposits and occurrences were previously recorded (Moharam *et al*., 1970).

A regional lithochemical survey at scale 1:100,000 was undertaken by Abu El Leil *et al.* (1977) during the period 1969 – 1972, who recorded anomalous contents of Y, Ta, Nb, Sn and Yb in the stream sediments of Wadi Hamrat Ghannam-Wadi El Sherm El Qibli area.

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Remote sensing techniques were applied in geologic mapping and ore minerals exploration in the Eastern Desert of Egypt by Sultan *et al.,* (1986); O'Connor *et al.,* (1987); Ramadan *et al.,* (1999); Hassaan *et al.,* (2000) , Hassan (2001) and Ramadan and El Lithy, (2005). In this respect, Sultan *et al.* (1986) used the 5/7, 5/1, 5/4 x 3/4 Landsat TM ratio images for identifying the serpentinite rocks in the Eastern Desert of Egypt. O'Connor *et al.* (1987) and Hassaan *et al.* (2000) used the 5/7, 5/1, 4, 4/3, 5/7- 5/1, 3/7, 5/7-5/1-4 and 2-4-7 Landsat TM ratio images to map the igneous rocks in the Central Eastern Desert, Egypt.

Ramadan *et al.* (1999) used remote sensing techniques and airborne processed data to distinguish the mineralized zones associated with basement rocks as well as with Miocene sediments in the central part of the Eastern Desert of Egypt. Ramadan and Kontny (2004) and Ramadan *et al.* (2006) mentioned that the listwaenites and talc carbonate rocks (gold- bearing mineralization) gave a yellowish colour on the Landsat TM ratio image (5/7,5/1,4 in R,G,B) in the South Eastern Desert of Egypt. Ramadan and El Lithy (2005) integrated the Landsat ETM+ and airborne radiometric data and distinguished the granites bearing Nb, Ta and REE in the Central Eastern Desert of Egypt.

The present work aims at undertaking lithochemical overburden, stream sediment and bedrock surveys to reveal the mineralization potential of the study area.

For this purpose, the area is subjected to detailed geologic study using Landsat ETM+ image, petrography, identification of ore forming minerals and geochemical distribution of the elements in the overburden, stream sediments and bedrock.

MATERIALS AND METHODS

In this study, one scene of Enhanced Landsat ETM+ data (Path 174 and Raw 42, acquired on March, 2000) covering the investigated area, has been geometrically corrected and radiometrically balanced using the ERDAS imagine 9.1 at the National Authority for Remote Sensing and Space Sciences (NARSS), Cairo. The applied techniques include false colour composite image (bands 7,4,2) to produce drainage maps and ratioing image (5/7,5/1,4 in R,G,B) to distinguish the different rock units and the alteration zones associated with these rocks. Field work was also carried out to verify the interpreted rock units and to collect samples from the bedrocks and both the residual overburden (regolith) and the transported stream sediments.

Forty fresh bedrock samples were collected for petrographic studies. Also, a total of 38 samples were collected (18 samples from the altered bedrocks, 3 samples from the regolith covering the slopes and 17 samples from the stream sediments) from Wadi Hamrat Ghannam, Khor Abu Herida, Wadi El Sherm El Bahari and Khor Abu Merewa. The stream sediment samples were collected along traverses at intervals of 0.5 -1 km excluding the sites of accumulated aeolian sands. Regolith and stream sediment samples were collected at variable intervals (100 to 500 m) from the outcrops hosting the three known gold occurrences of Hamrat Ghannam Abu Harida and Abu Merewa.

The overburden and stream sediment samples were subjected to mechanical analysis by dry sieving using a standard set of sieves of aperture size 2, 1, 0.5, 0.25, minus 0.25, 0.125 and 0.0.063 mm. Heavy minerals were separated from the three sand-size classes (0.5-0.25, 0.25-125, 0.125-0.063 mm) using bromoform of specific gravity 2.87 gm/cc. The separated heavy fractions mounted in canada balsam were examined using a stereoscopic microscope and counted under a polarizing microscope and Energy Dispersive Spectrometer (EDS) coupled with a scanning electron microscope. Therefore, powdered bulk bedrock samples and heavy mineral fraction samples were analyzed for trace elements and ore metals using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) in the Geochemical Labs of Friderich-Alexander University, Germany.

The Clark of Concentration (CC) for the ore metals in bedrock samples was calculated to recognize the anomalous concentration using the following formula: $CC = Ci/Cb$, where Ci = element concentration in the sample, Cb = element average concentration in the corresponding rock type given in Turekian and Wedepohl, (1961).

Lithochemical maps were prepared using the results of the ICP-MS analyses to illustrate the distribution of the ore metals in the studied regolith and the stream sediments and to reveal their anomalous contents in relation to the known mineralization of the various exposed rock types in the area of study.

RESULTS AND DISCUSSION

Results:

Lithological Interpretation:

Digital processing of Landsat ETM+ images for the study area generated several products ranging from false colour composite image (bands 7,4,2 in R,G,B) and ratio image (5/7, 5/1 and 4 in R,G,B). The Landsat ETM+ false image (bands 7, 4, 2 in R,G,B) for the study area provided an excellent base map for further investigation. Also, Landsat ETM+ ratio image (5/7, 5/1, 4) discriminated the different rock units in the study area, where the serpentinites indicated by red colour, the talc carbonates and listwaenites indicated by yellow colour, the biotite granites indicated by green colour and the muscovite albite granites indicated by pale yellow colour (Fig. 1).

The interpreted Landsat ETM+ ratio image (5/7, 5/1, 4, 4/3 and 5/7- 5/1 and 3/1) verified by field study enabled to discriminate the serpentinites, talc-carbonates and listwaenites (the ophiolitic assemblage), metabasalts, meta-andesites, metadacites, metagabbros (the island arc assemblage), granodiorites, biotite granites and muscovite albite granites (Figs.1 and 2). These rocks were injected by pegmatite and quartz veins and also cut by basic and acidic dykes. They were overlain by Late Cretaceous sandstones of Nubia facies and Quaternary sediments (Fig. 2).

The talc carbonates and listwaenites were previously mapped by EGSMA (1992) as tectonic mélange. The field study indicated that these rocks occur along thrust zones between the serpentintes and island arc meta-andesites and metadacites at Kohr Abu Harida and at the upper reaches of Wadi El Sherm El Bahari (Fig. 2). Petrographically, these rocks are composed essentially of actinolite, talc, and carbonate minerals together with iron oxides. The granitiod rocks are well exposed along Wadi Hamrat Ghannam, Khor Abu Harida, Khor Abu Merewa and at Gabal El Dillihimmi. These granites are represented by granodiorites, biotite granites and muscovite albite granites (Fig. 2).

The muscovite albite granites at Hamrat Ghannam were mapped previously as biotite granites by EGSMA (1992). They exhibit pale yellow colour on Landsat ETM+ ratio image and show alteration zones possibly related to the presence of gold mineralization. Petrographically, the granodiorite consists mainly of plagioclase, K-feldspar, quartz and biotite mineral constituents. The biotite granite consists of orthoclase, microcline perthites (~50 %), quartz (~39 %), plagioclase (~ 8 %) biotite and muscovite (~3 %). The accessory minerals are mainly sphene, zircon, ilmenite and magnetite. The muscovite albite granites consists essentially of microcline-albite perthites ~60-65 %, quartz ~20-25 %, albite ~10-5 % and muscovite 10~ 5 %. The recorded accessory minerals are represented by zircon, rutile, ilmenite and iron oxides.

Quaternary Overburden and Stream Sediments:

Hassaan *et al*. (1980) dealing with the arid Quaternary detrital and transported clastic sediments in the Eastern Desert of Egypt, mentioned that the residual regolith covering the slopes of the exposed rocks comprises: eluvial diluvium (talus) and diluvial colluvium. The transported clastics comprise colluvium, colluvial alluvium and alluvium. The contours of eluvial diluvium debris approximately match with the area of occurrence of the mineralized source rocks, while its front may go as far as the foot of the slopes. The colluvium is the accumulated weathering products at the foots of the slopes, while the other two transported types fill the tributaries and the main wadis respectively.

Mineralogically, the light minerals separated from the overburden and stream sediment samples are chiefly quartz, feldspar and mica. The separated heavy mineral fractions (129 fractions) range in weight from 0.58 to 33.3 wt. % of each sample (Table 1). The heavy minerals content is higher in the fraction -0.25 to + 0.125 mm than in the fraction - 0.5 to + 0.25 mm in the eluvial diluvium regolith and transported colluvium sediments. The microscopic studies of the separated heavy fractions using ore and ordinary microscopes recorded the following minerals: gold, altered pyrite, goethite, chalcopyrite, arsenopyrite, magnetite (Fig 3a – 3f), ilmenite, rutile, REE rich minerals (apatite and xenotime), zircon and monazite. The study of these fractions using (EDS) recorded presence of silver, goethite after pyrite, chalcopyrite, ilmenite, magnetite, zircon, monazite, and xenotime (Figs. 3e and 3f).

Table 1: The amounts of heavy minerals (wt %) and their statistical parameters.

Statistical data / Grain size	Overburden		
	Maximum	Minimum	Average
0.5-0.25	28.02	1.24	14.63
0.25-0.125	33.28	0.58	16.93
	Colluvium - Alluvium		
	Maximum	Minimum	Average
0.5-0.25	26.25	1.30	13.78
0.25-0.125	17.51	1.34	9.43
	Alluvium		
	Maximum	Minimum	Average
0.5-0.25	20.57	5.56	13.06
0.25-0.125	19.99	2.17	11.08

Table 2: The trace elements and REE contents (ppm) in the analyzed overburden and stream sediments.

Area	Wadi Hamrat Ghannam					Khor Abu Harida				Wadi El Sherm El Bahari		
S.No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Sample	Co-Al	Co	Co-Al	Co-Al	Al	Al	Al	Al	Al	Co-Al	D-Co	Al	Al
Au	3.92	2.997	1.347	0.02	0.01	0.02	0.02	0.02	0.01	0.012	14.26	0.021	3.372
Sn	5	6	5	0	0	0	0	0	0	1	8	0	4
Mo	1	2	2	0	0	0	0	0	0	0	1	0	2
Sb	1	1	1	0	0	0	0	0	0	0	3	0	1
Zn	140	1908	310	45	32	36	36	26	29	30	251	21	193
Pb	19	264	28	4	4	3	2	1	2	2	14	1	5
Cu	34	47	52	3	5	3	7	7	7	9	175	2	38
Cd	1	2	1	0	0	0	0	0	0	0	1	0	0
Zr	342	1135	398	88	58	51	54	28	25	48	204	35	62
Hf	10	62	27	3	2	2	2	1	1	1	6	1	2
Yb	4	34	5	1	1	1	1	0	0	0	3	1	1
Y	37	205	44	20	13	19	14	2	2	7	26	9	6
Nb	16	81	86	13	5	16	6	2	2	3	6	5	3
Ta	0	4	3	0	0	0	0	0	0	0	1	0	0
U	3	54	4	1	1	1	1	0	0	0	2	0	1
Th	10	59	18	2	2	2	1	0	1	1	5	1	2
La	21	18	20	22	3	4	3	2	3	3	15	2	4
Ce	45	80	50	46	12	19	14	4	5	14	32	13	8
Pr	5	6	5	3	1	1	1	0	1	1	4	1	1
Nd	23	20	18	14	3	5	4	2	3	4	16	4	4
Sm	5	8	4	4	1	2	2	1	1	1	4	1	1
Eu	1	0	0	0	0	0	0	0	0	0	1	0	0
Tb	1	4	1	0	0	0	0	0	0	0	1	0	0
Gd	7	13	5	4	1	3	2	1	1	1	4	2	1
Dy	7	38	6	4	2	4	2	1	1	1	4	2	1
Ho	1	5	1	0	0	0	0	0	0	0	1	0	0
Er	4	35	5	1	1	1	1	0	0	1	3	1	1
Tm	1	6	1	0	0	0	0	0	0	0	0	0	0
Yb	4	34	5	1	1	1	1	0	0	0	3	1	1
Lu	1	6	1	0	0	0	0	0	0	0	0	0	0
Cs	1	7	3	0	0	0	0	0	0	0	3	0	0

Area	Khor Abu Merewa						
S.No.	14a	14b	16	17	18	19	20
Sample	D-Co	Co-Al	Co-Al	Co-Al	Co-Al	Al	Al
Au	1.919	1.7	1.4	0.9	0.9	0.7	0.6
Sn	2	2	2	2	3	2	4
Mo	6	5	6	2	2	2	1
Sb	1	1	1	0	1	1	1

Table 2: Continued

Zn	121	64	175	85	110	138	118
Pb	48	36	59	36	30	33	14
Cu	21	15	120	33	56	75	22
Cd	1	0	0	0	0	0	1
Zr	229	147	136	251	131	104	192
Hf	9	8	8	12	6	5	6
Yb	5	5	5	6	3	3	3
Y	42	40	37	45	29	28	26
Nb	47	36	37	44	33	25	24
Ta	6	9	9	4	6	4	2
U	9	10	10	13	7	5	2
Th	23	17	20	53	13	12	5
La	14	5	4	5	4	4	11
Ce	35	20	26	35	15	18	25
Pr	4	2	2	2	1	1	3
Nd	17	8	7	10	7	6	13
Sm	5	3	3	4	2	2	4
Eu	1	0	0	0	0	0	0
Tb	1	1	1	1	1	1	1
Gd	6	4	4	7	4	3	4
Dy	7	6	6	10	5	5	5
Ho	1	1	1	1	1	1	1
Er	5	5	5	7	4	3	3
Tm	1	1	1	1	1	0	0
Yb	5	5	5	6	3	3	3
Lu	1	1	1	1	1	1	0
Cs	3	4	3	2	3	2	1

- Symbol 0: represent the elements content beyond detection limit of the method
- Al : alluvium; Co-Al: colluvial- alluvium; Co: colluviums; D-Co : diluvial- colluviums.

Table 3: The trace elements and REE contents (ppm) in the analyzed mineralized bed rock samples.

Area	Wadi Hamrat Ghannam					Khor Abu Harida			Wadi El Sherm El Bahari	
S.No.	2	3gr	3qz	4	6	8	9	10	12	13
Rock type	Altered granites		Quartz vein	Quartz vein	Altered granites	Listwaenites	Listwaenites	Listwaenites	Quartz vein	Listwaenites
Au	0.92	24.02	2.90	0.58	1.51	0.81	0.05	0.41	0.03	0.05
Sn	7	7	2	3	8	2	2	5	1	2
Mo	1	1	0	1	1	1	3	1	1	4
Sb	1	1	0	1	1	1	4	0	0	1
Zn	164	77	47	108	250	55	531	53	99	180
Pb	17	16	2	7	24	2	46	5	3	4
Cu	16	8	13	21	13	15	73	20	24	57
Cd	0	1	0	0	0	0	0	0	0	0
Zr	88	732	5	2	188	6	10	4	46	3
Hf	7	53	0	0	14	0	0	0	1	0
Y	13	93	2	1	65	2	4	3	16	2
Nb	64	147	1	5	43	0	0	0	1	0
Ta	2	10	0	0	1	0	0	0	0	0
U	7	31	0	0	9	0	0	0	0	0
Th	9	25	0	0	24	0	1	0	0	0
La	1	35	0	0	18	0	2	1	2	0
Ce	5	84	0	0	35	0	4	2	4	1
Pr	0	7	0	0	5	0	0	0	1	0
Nd	1	21	0	0	22	0	2	1	3	0
Sm	1	5	0	0	7	0	1	0	1	0
Eu	0	0	0	0	0	0	0	0	0	0
Tb	0	1	0	0	1	0	0	0	0	0
Gd	1	6	0	0	9	0	1	0	2	0

Table 3: Continued

Dy	3	12	0	0	12	0	1	0	2	0
Ho	0	1	0	0	1	0	0	0	0	0
Er	3	10	0	0	7	0	0	0	1	0
Tm	0	2	0	0	1	0	0	0	0	0
Yb	3	11	0	0	7	0	0	0	1	0
Lu	0	3	0	0	1	0	0	0	0	0
Cs	2	0	0	0	3	0	0	0	0	0

Area	Khor Abu Merewa							
S. No.	I4b	14d	14e	14f	14g	14i	15	16 qz
Rock type	Quartz vein	Quartz vein	Quartz vein	Quartz vein	Quartz vein	Quartz vein	Quartz vein	Quartz vein
Au	0.15	0.06	0.25	0.05	0.20	0.43	0.45	0.39
Sn	3	6	8	7	6	10	1	2
Mo	7	3	7	1	1	8	3	2
Sb	1	1	1	1	0	1	0	0
Zn	106	1902	99	40	142	42	72	78
Pb	10	43	18	9	17	22	24	24
Cu	75	12	8	13	10	14	15	18
Cd	1	0	0	0	0	0	0	0
Zr	370	11	73	8	75	98	1	2
Hf	9	0	6	0	6	8	0	0
Y	29	9	14	10	10	42	7	6
Nb	16	0	27	1	23	58	0	0
Ta	1	0	3	0	2	6	0	0
Ce	33	1	0	1	0	3	1	1
Pr	4	0	0	0	0	1	0	0
Nd	18	2	1	1	0	3	0	1
Sm	5	1	0	1	0	2	0	0
Eu	1	0	0	0	0	0	0	0
Tb	1	0	0	0	0	1	0	0
Gd	5	1	1	1	1	4	0	0
Dy	5	1	3	1	2	9	1	0
Ho	1	0	0	0	0	1	0	0
Er	3	1	2	1	2	7	0	0
Tm	0	0	0	0	0	1	0	0
Yb	3	1	2	1	2	7	0	0
Lu	0	0	0	0	0	1	0	0
Cs	0	0	2	0	1	2	0	0

Symbol 0: represent the elements content beyond detection limit of the method.

Geochemical Distribution of Ore Metals:

The results of the ICP-MS analysis of the collected altered bed-rock samples, overburden and stream sediments are used in preparing lithochemical maps for the studied area to show the distribution of the ore metals (Figs. 4a – 4d and Tables 2 and 3). The prepared lithochemical maps given in figures 4a-4d show the distribution of the ore metals in the collected overburden and stream sediment samples (20 samples) along Wadi Hamrat Ghannam, Khor Abu Harida, Wadi El Sherm El Bahari and Khor Abu Merewa. These maps recorded variable anomalously high contents of Au, Sn, Mo, Pb, Zn, Zr, Hf and Nb in nine samples, viz. samples No. 1,2, 3, 13, 14a, 14b, 16, 17 and 20.

Au, Sn, Mo and Sb:

High contents of Au, Sn, Mo and Sb are recorded in the overburden of the altered muscovite albite granites hosting Wadi Hamrat Ghannam gold occurrence. The recorded high gold contents are: 3.9, 3 and 1.3 g/t in the overburden and stream sediment samples (Table 2 and Fig. 4a). The recorded gold contents in the altered muscovite albite granite samples are 2.4 g/t and 0.9 g/t and reach up to 2.9 g/t Au is in the quartz vein (Table 3). These samples recorded the highest CC value (~ 79). Moreover, the distribution of Sb in the stream sediments and altered muscovite albite granite samples is similar. In this respect, one ppm Sb is recorded in the stream sediments and altered muscovite albite samples (Tables 2 and 3). The

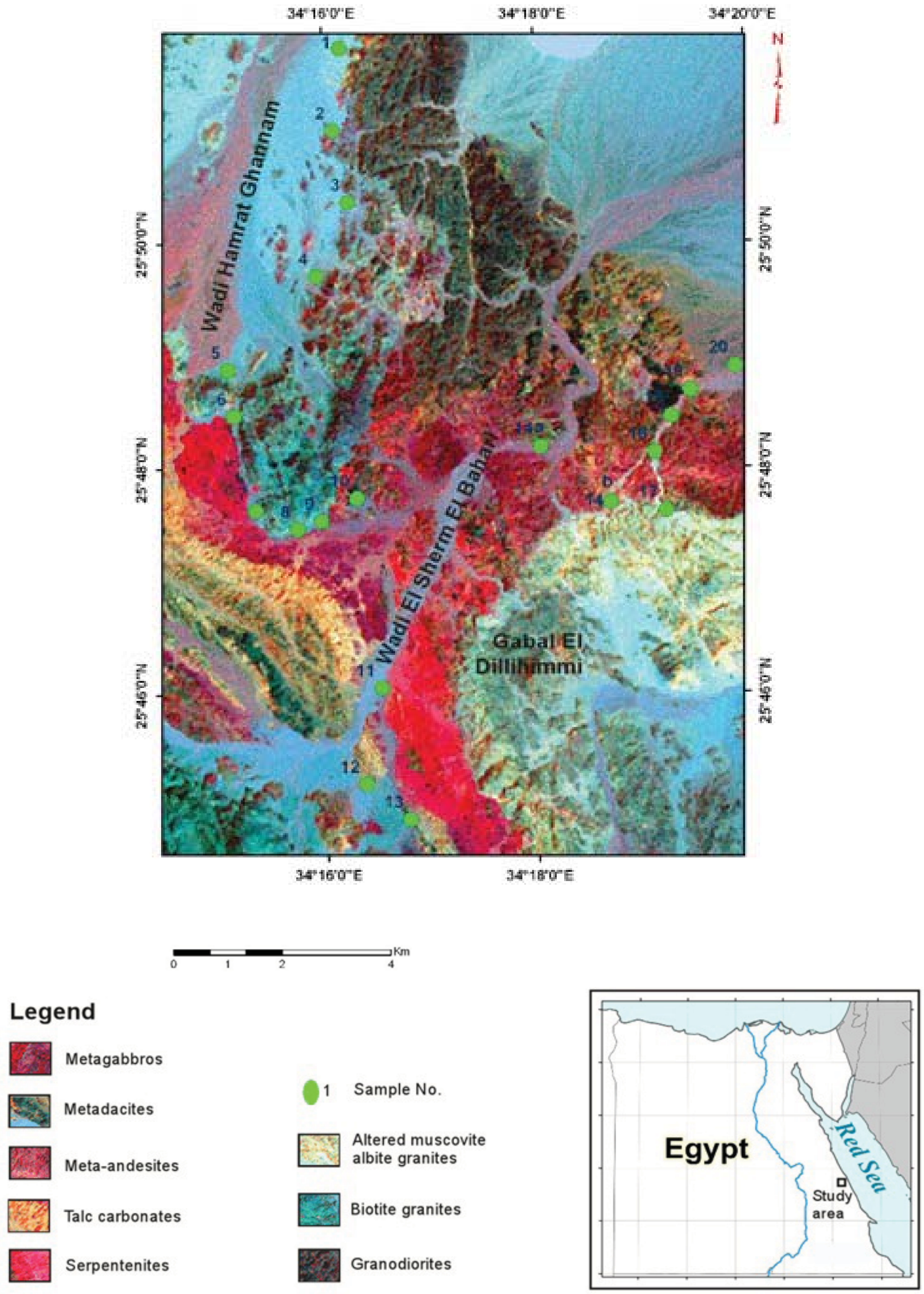
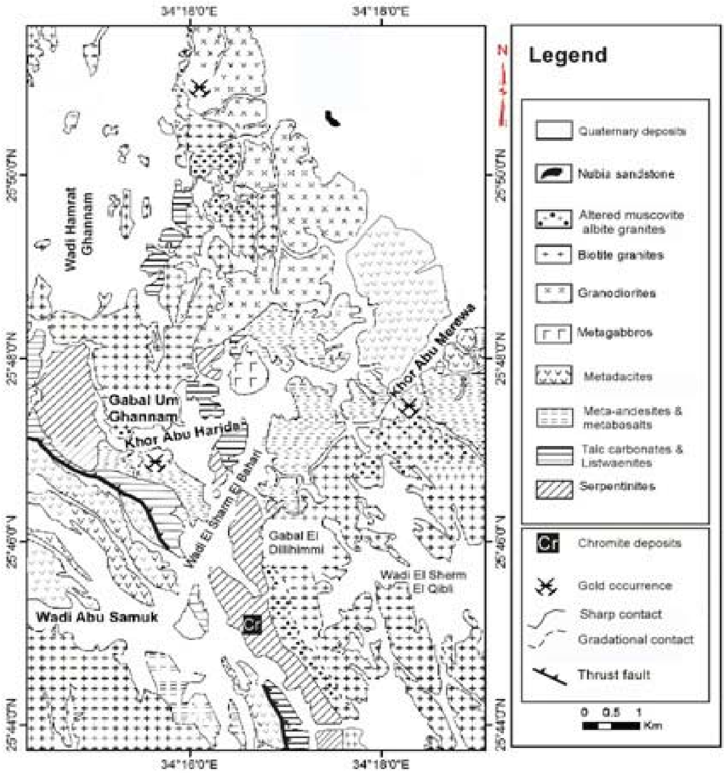


Fig. 1: Landsat ETM+ ratio image (5/7,5/1,4 in R,G,B) for the study area.

antimony contents are considered high compared to that given by Wedepohl, (1990) for sandstones, clays and granites (0.01, 0.14 and 0.2 ppm respectively). The recorded Sb contents suggest that these samples may represent the upper level of the known Hamrat Ghannam gold occurrence. This is based on the general sequence of the geochemical zoning of deposition of ore metals given by Kviatkoviski (1977) and Hassaan, (1999) from deeper to upper levels, viz. Be, Ni, Co, B, Sn, U4+, Mo, W, As+, Bi, Cu+, Zn, Pb, Sm3, Au, Ag, Ba, As2+, Cu2+, Sb, Hg, F and I.



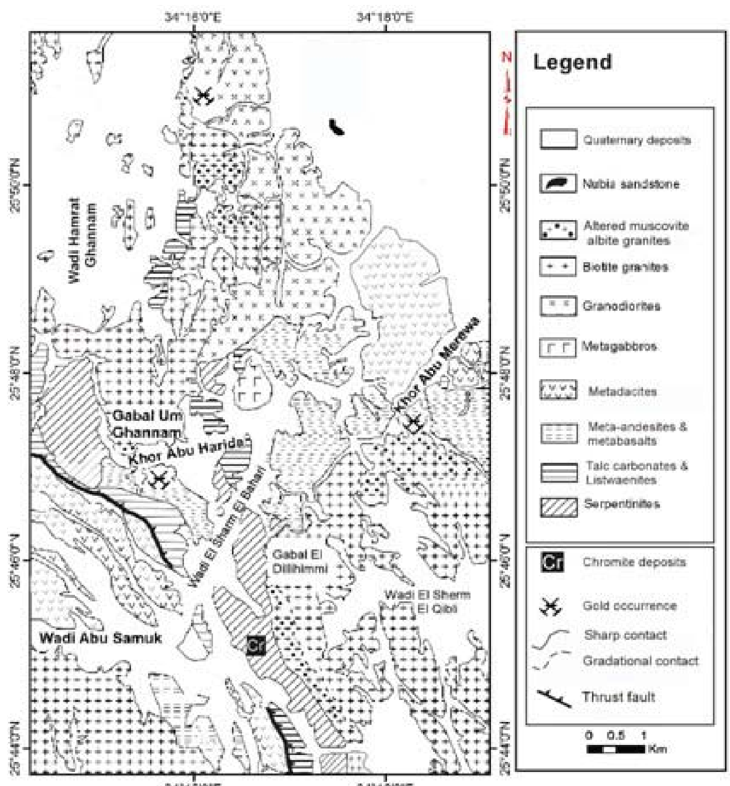


Fig. 2: Geological map for the study area. Modified after EGSMA (1992).

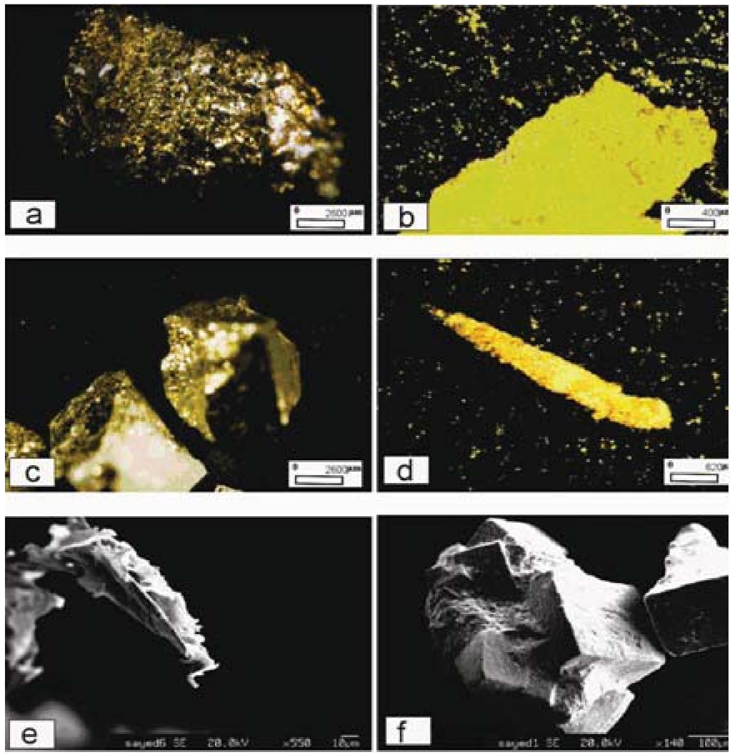


Fig. 3 a-f: a) A stereoscopic photomicrograph showing a silver-bearing grain in the stream sediments of Wadi Hamrat Ghannam, sample No. 4 (-0.125+0.063 mm). b) A stereoscopic photomicrograph showing a gold flake in the stream sediments of Wadi Hamrat Ghannam, sample No. 4 (-0.125+0.063 mm). c) A stereoscopic photomicrograph showing altered pyrite crystal in the stream sediments of Khor Abu Merewa, S. No. 14a (-1+0.5mm). d) Stereoscopic photomicrograph showing a chalcopyrite crystal in the stream sediments of Khor Abu Harida, S. No. 9 (-0.5+0.25mm). e) SEM, backscattered image showing a silver grain in the stream sediments of Wadi Hamrat Ghannam, S. No.2, (-0.5+0.25mm). f) SEM, backscattered image showing gold bearing pyrite in the stream sediments of Khor Abu Merewa, S. No.14a (-0.5+0.125 mm).

The recorded high gold contents in Khor Abu Herida are related to the gold occurrence hosted in the meta-andesites occurring in this site as well as to the exposed listwaenites. The listwaenites contain gold ranging from 0.4 to 0.8 g/t (Table 3) and are similar to the records at other sites of the Eastern Desert (Wadi Hodein area, Hassaan *et al.*, 1996; Um Khasila area, Ramadan, 2002; Um El Tiyur El Foqani area Ramadan, *et al.*, 2005). The recorded high gold contents (14.3 and 3.4 g/t) in the overburden and stream sediment samples (Table 2) from the upper reaches of Wadi El Sherm El Bahari is related to the listwaenites exposed there. Moreover, 3 ppm Sb (Table 2) is recorded in the overburden sample No. 11. The gold content (1.9 – 0.7 g/t) in Khor Abu Merewa overburden and stream sediment samples (Table 2 and Fig. 4a) is slightly higher than its content in the muscovite albite granite samples (0.5 – 0.1 g/t, Table 3). Meanwhile, one ppm Sb content is recorded in the quartz vein samples at Khor Abu Merewa (Table 3).

High Sn contents (5, 6 and 5 ppm, Table 2) are recorded in Hamrat Ghannam stream sediments samples. Both high Sn and gold contents follow the down stream direction of Wadi Hamrat Ghannam. The recorded Sn content in its granitic samples and the quartz vein sample ranges from7 to 2 ppm (Table 3). Meanwhile, abnormal Sn contents (8 and 4 ppm Table 2) are recorded in the overburden and stream sediments from the upper reaches of Wadi El Sherm El Bahari. These abnormal contents may be related to the muscovite albite granites recorded from the Landsat ETM+ ratio image at Gabal El Dillihimmi. Molybdenum contents (6, 5 and 6 ppm) are recorded in Khor Abu Merewa overburden and stream sediment samples (Table 2 and Fig. 4b). Also, the recorded Mo in the muscovite albite granite samples ranges from 7 to 8 ppm (Table 3), which matches with the stream sediment samples.

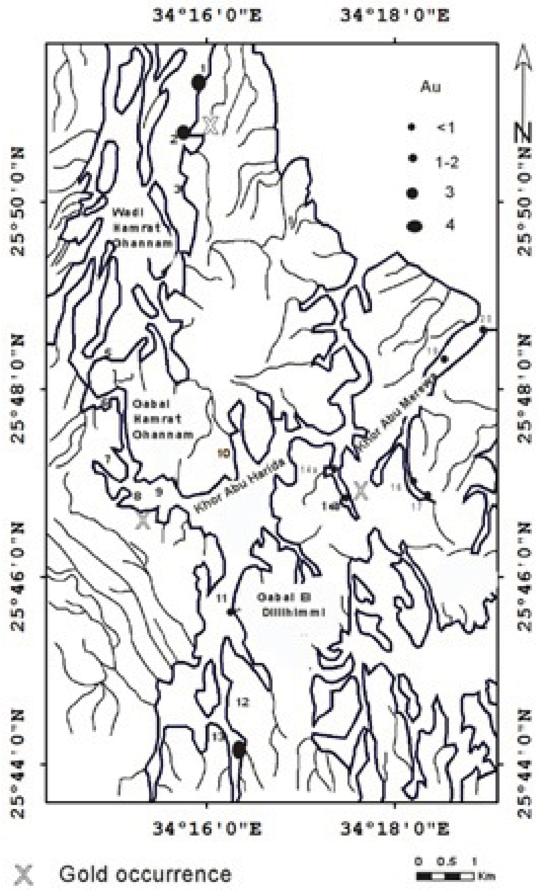


Fig. 4a: Au distribution in the stream sediment samples plotted on the drainage map.

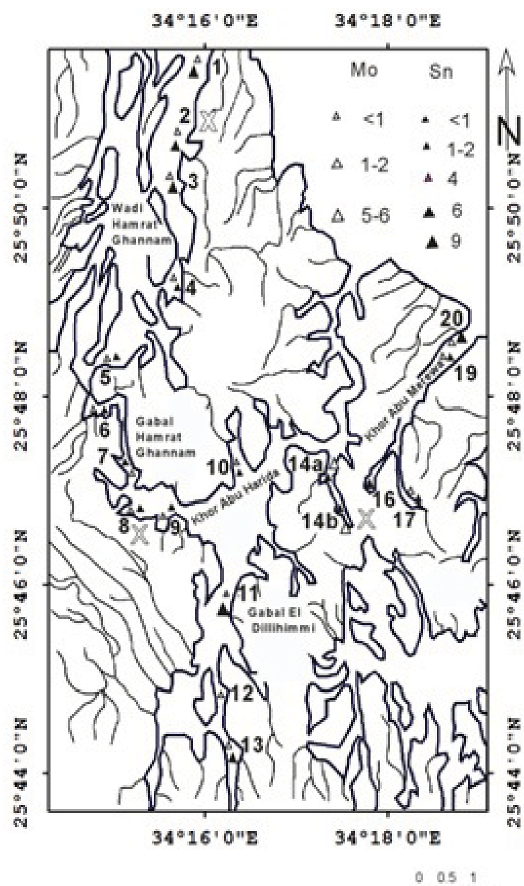


Fig. 4b: Distribution of Sn and Mo in the stream sediment samples plotted on the drainage map.

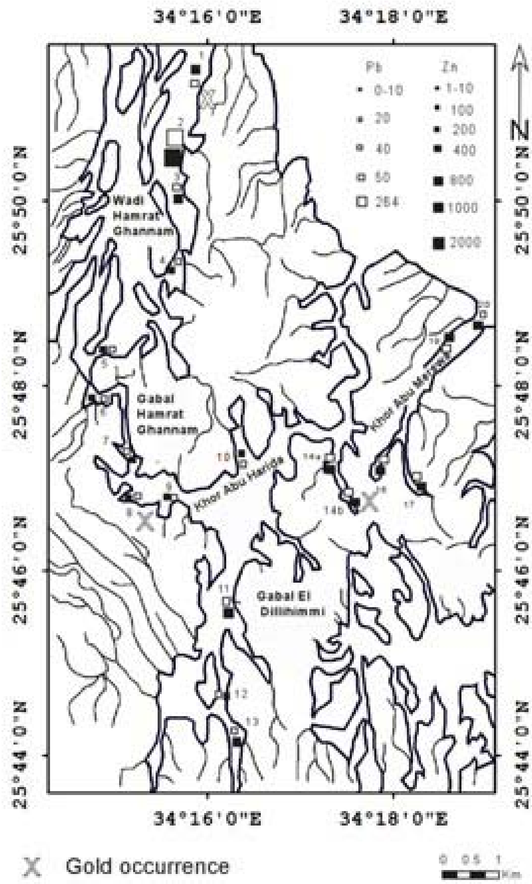


Fig. 4c: Distribution of Pb and Zn in the stream sediments map.

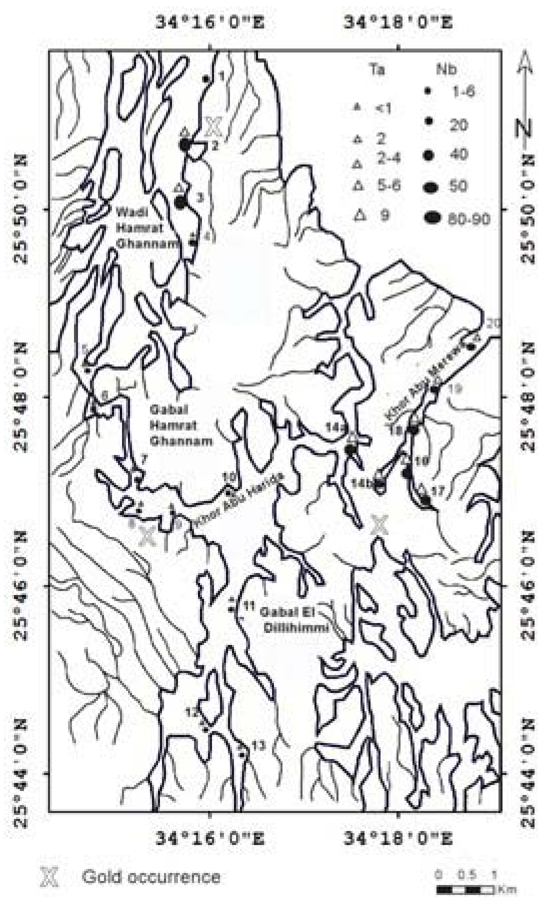


Fig. 4d: Distribution of Nb and Ta distribution in the plotted on the drainage stream sediment samples plotted the drainage map.

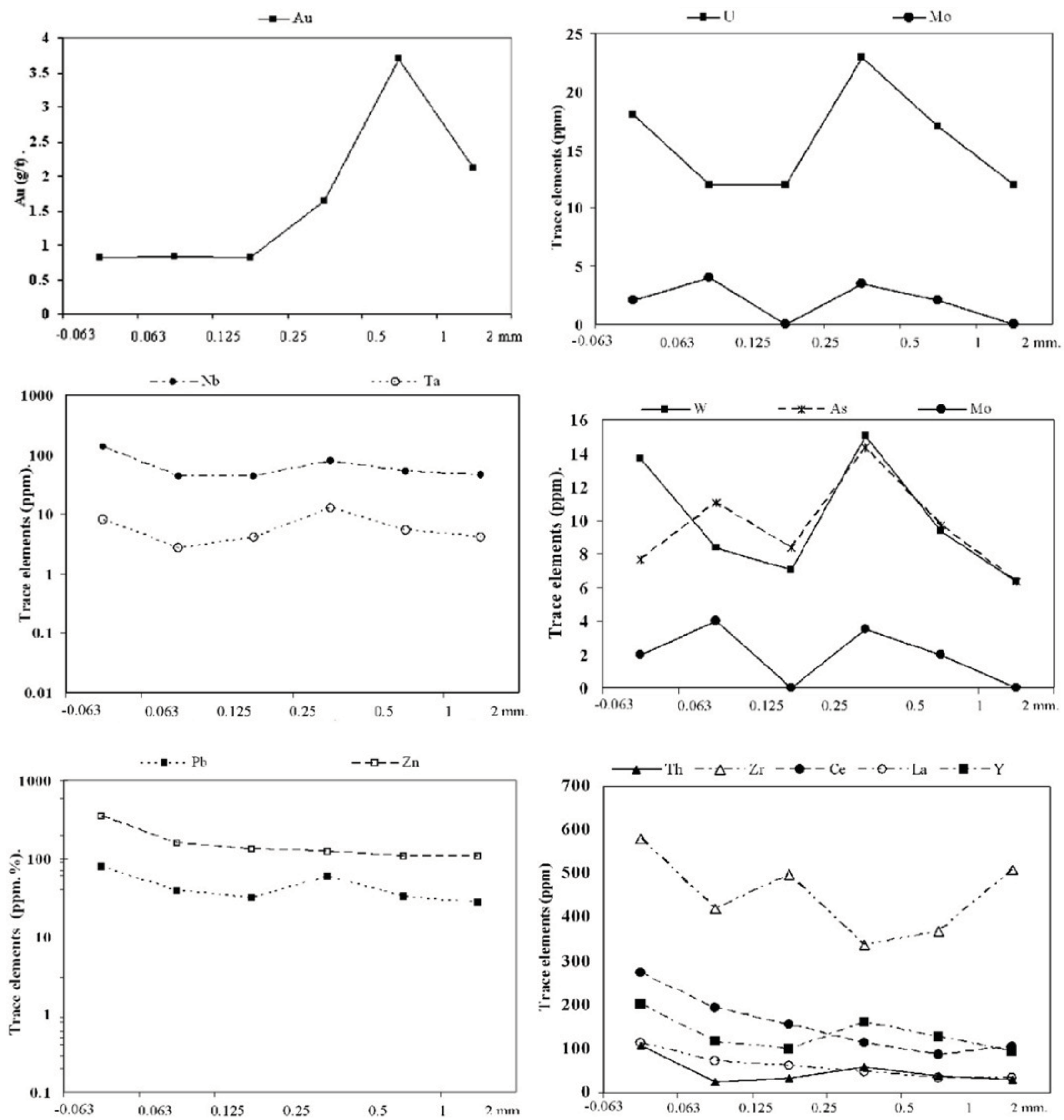


Fig. 5: Average distribution curves of ore metals in the grain size fractions in the study area

Zn, Pb and Cu:

Both Zn and Pb (Fig. 4c) possess similar geochemical distribution in Hamrat Ghannam stream sediments. Their high contents (1908 - 264 ppm and 310-28 ppm respectively, Table 2) are recorded in the overburden samples. Also, the recorded Pb and Zn contents in Khor Abu Harida listwaenite samples are 531 and 46 ppm (Table 3). At the upper reaches of Wadi El Sherm El Bahari, Cu, Pb and Zn in the overburden sample No.11, show relatively high contents (175, 14 and 251 ppm respectively, Table 2). These high contents may point to probable occurrence of a sulphide-gold mineralization in the listwaenites exposed at Khor Abu Harida and Wadi El Sherm El Bahari. Both Zn and Pb in the quartz vein samples located nearby Khor Abu Merewa gold occurrence recorded high contents (1902 and 43 ppm respectively, Table 3). In this respect, the altered pyrite, chalcopyrite and arseopyrite are recorded in the heavy minerals separated from Khor Abu Merewa samples. These give criteria for presence of a sulphide-gold mineralization in these granites.

Zr, Nb, Ta, U, Y and REE:

The minerals zircon, monazite, rutile and sphene are recorded in the heavy fractions of the studied overburden and stream sediment samples. These mineral constituents contain high amounts of high field strength elements (HFSE) and related trace elements: lanthanides Y, Th, U, REE, Nb and Ta (Chandrajith *et al.,* 2001). Consequently, these minerals are considered responsible for the recorded high contents of Zr, Nb, Ta, U, Y and REE in the stream sediment samples and the bedrock samples (Table 4).

Distribution of Ore Metals* in the *Grain Size Classes:

The problem of delineation of ore metal contents in dispersion aureoles from the barren detrital overburden and stream sediments has been attempted by studying the distribution of ore metals in coarse and fine detrital sediments. This study suggests that the most favorable grain size class to be analyzed in which higher contents of ore metals occur. The use of the coarse (>0.5 or 1.0 mm) fraction for chemical or heavy mineral analysis assumes that stable ore-related primary or secondary minerals have either this grain-size or are retained in the coarse grains of quartz gangue (Hassan, 2001).

For the present study, six grain size classes of 8 stream sediment samples containing high ore contents were analyzed for both major oxides and trace elements. The study of geochemical distribution of ore metals was concentrated on the grain size fractions (less than 2 mm) separated from the collected samples. As a rule the coarse grain sizes (more than 1 mm) are the product of physical weathering, whereas the – 0.5 + 0.2 mm and smaller fractions are mainly the products of chemical weathering. Fractions larger than 0.5 mm are composed mainly of grains of primary and secondary minerals of the bedrock, while the – 0.1 mm fraction is mainly composed of 60 - 90 % clayey minerals. The grain size less than – 0.5 and more than +0.01 mm is composed mainly of the iron and manganese hydroxides and /or ore minerals (Hassaan, 1974 and Hassaan and Khaoud, 1978, Hassan, 2001).

The distribution of ore metals in both coarse and detrital sediments were successfully undertaken in the Eastern Desert of Egypt, for Pb-Zn-Cu, Au, Sn, Mo-W, Nb-Ta-REE mineralization (Hassaan, 1974; Hassaan, 2001; Hassaan *et al.,* 1984 and El Bakry *et al.*, 1995). Higher concentrations in the coarse admixtures points to the dominant role of mechanical dispersion, while the higher contents in the finer admixtures, suggest predominant chemical dispersion (Hassaan, 1974; Hassaan and Kaoud, 1978; Hassaan *et al.,* 1984).

The ore minerals of W, Mo, Sn are not recorded in the heavy fractions. The adsorption of these elements on iron and Mn oxides hydrate is the chief process acting after their chemical liberation from the sulphide or silicate minerals (Ivanov, 1974 and Hassaan *et al.,* 1984). This supports that the ore metals were liberated chemically from the recorded sulphide mineral constituents and/or other silicate minerals. The average contents for each ore metals were plotted vs. the grain sizes (Fig. 5) where the following results are reached:

- The highest gold content is recorded in the grain size 1 -0.5 mm. However, another relatively high gold content is also recorded in the grain size fractions 0.5 - 0.25 mm and 2 - 1 mm compared to the finer grain size fractions less than 0.25 mm. Such data is related to the recorded native gold and gold encountered in goethite pesudomorph after pyrite.
- The elements Mo, As and U show similar distribution, where their highest content is recorded in the grain size 0.5 – 0.25 mm. Moreover, both Mo and As contents in the grain size 0.125 -0.063 mm are high compared to the other fractions. High U content is also recorded in the grain size less than 0.063 mm.
- Highest Pb and Zn concentrations are recorded in the grain size less than 0.063 mm. Moreover, a similar Pb concentration value is also recorded in the grain size 0.5 – 0.25 mm.
- The variation curves of W, Nb and Ta show a main peak indicating high concentration in the grain size 0.5 – 0.25 mm and a small peak for W in the grain size 0.25 – 0.063 mm and for both Nb and Ta in the grain size less than 0.063.
- The distribution curves of Th, Ce and La are similar, where the recorded concentrations increase in grain sizes from 0.5 to 0.25 mm, to 0.125 – 0.063 mm.
- It is worth to mention that extremely high contents of Cr, Ni, Co and V are recorded March 30, 2009in the grain size fractions 2 – 0.25 mm of samples No. 9 and 11, which represent the weathering product of chiefly ultramafic rocks. However, Zr content reaches its maximum in the fractions 0.25 – 0.063 (Table 5). Such results are supported by the detected primary and secondary ore minerals as mentioned before.

Table 4: The trace elements contents (ppm) in the analyzed grain size fractions of the studied samples.

Element in ppm	Range in the stream sediment samples	Range in the bedrock samples
Zr	1135 - 192	732 - 73
Nb	86 - 16	93 - 13
Ta	9 -1	10 -6
U	54 - 3	31 - 7
Y	205 - 37	93 - 13
Nb	86 - 16	93 - 13
Ta	9 -4	10 -6
U	54 - 3	31 - 7
REE	280-74	198-42

Table 5: The trace elements contents (ppm) in the analyzed grain size fractions of the studied samples.

Element in ppm	S.N.	Grain size class			
		<0.063	0.5 - 0.25	1 - 0.5	2 – 1
Ni	9	96	622	539	481
	11	111	725	844	1005
Cr	9	125	1312	920	1006
	11	166	2152	1750	1986
Co	9	20	49	42	39
	11	23	63	67	69
V	9	109	135	135	132
	11	106	176	176	203
Zr	9	596	114	117	134
	11	942	121	77	64

Discussion:

There are three gold occurrences recorded in the study area, namely Hamrat Ghannam in granitic rocks and both Khor Abu Herida and Khor Abu Merewa in meta-andesites. Chromite deposits also occur in the serpentinite rocks at the upper reaches of Wadi El Sherm El Bahari (Moharram, *et al*., 1970).

The processed Landsat ETM+ ratio image of the study area distinguished the following rock units: serpentinites indicated by red colour and the talc carbonates and listwaenites indicated by yellow colour. These talc carbonates and listwaenites were mapped previously by EGMSA (1992) as tectonic mélange. The ophiolitic listwaenite exposures at the study area are similar to the gold-bearing liswaenites, previously recorded in the Eastern Desert of Egypt at Wadi Hodein, Um Khasila and Um El Tiyur El Faqani (Hassaan *et al*., 1996; Ramadan, 2002 and Ramadan *et al.,* 2005). This suggests that the listwaenites are gold bearing and are to be considered as a possible source of the gold recorded in the stream sediment samples.

Also, Landsat ETM+ ratio image distinguished between the biotite granites (green colour) and the muscovite albite granites (pale yellow colour) at Hamrat Ghannam, Gabal El Dillihimmi and Khor Abu Merrewa. The investigated muscovite albite granites are similar to the granites bearing Nb, Ta and REE mineralizations at Hamrat Wagat, El Qasia and Um Naggat located in the Central Eastern Desert of Egypt as revealed by Ramadan and El Leithy, (2005). The recorded high contents of Au, Sn, Mo, Pb, Zn, Nb and REE from the prepared geochemical maps at scale 1:50,000 from Wadi Hamrat Ghannam, Khor Abu Harida, upper reaches of Wadi El Sherm El Bahari and Khor Abu Merewa are as follows:

- The high gold content in Hamrat Ghannam friable sediments is related to the gold bearing quartz veins, hosted in the altered muscovite albite granites.
- The high gold content in Khor Abu Merewa stream sediment samples (1.9 – 0.79 g/t), is little higher than its content in the altered muscovite albite granites samples (0.5 – 0.1 g/t).
- The high gold content in Khor Abu Harida stream sediments is related not only to the gold occurrence in the meta-andesites but also to the gold-bearing listwaenites recorded there. Also, the recorded gold contents (3.4 -1.4 g/t) in the stream sediments from the upper reaches of Wadi El Sherm El Bahari is related to the listwaenites recorded there. Also, these results favor probable presence of placer gold in Wadi Hamrat Ghannam, Khor Abu Herida, Khor Abu Merewa and the upper reaches of Wadi El Sherm El Bahari sites.
- The recorded abnormal Sb contents and its similar distribution with gold in the stream sediments point to that the bedrock samples of the known Hamrat Ghannam gold represent an upper level of the mineralization. This favors a probable occurrence of gold accumulation at deeper levels.

- The similar distribution of both Au and Sn in Wadi Hamrat Ghannam stream sediment samples as well as in the altered muscovite albite granites and associated quartz veins, indicate that these granites are the host rocks of the mineralization. Tin is one of the elements associated with the gold mineralization in the Eastern Desert of Egypt (Hassaan and El Mezaen, 1995). In this respect, the altered muscovite albite granites and the stream sediments are recommended for more detailed lithochemical exploration.
- The study of the heavy mineral fractions, separated from of the stream sediment samples recorded the presence of gold, silver, goethite after pyrite, chalcopyrite, ilmenite, magnetite, zircon, monazite, rutile and xenotime (Figs. 3a-3). These ore mineral explain the obtained results of the geochemical exploration.
- Both Zn and Pb possess a similar geochemical distribution in Hamrat Ghannam stream sediments. The recorded high contents of Zn and Pb are most probably related to the recorded Pb and Zn contents in the altered muscovite albite granites. Most probably, Pb in the stream sediments is adsorbed onto manganese oxides hydrate and clay minerals (Perel'man, 1979). Also, high Zn and Pb contents (1902 and 43 ppm respectively) are recorded in Khor Abu Merewa altered muscovite albite granites suggests the probable presence of a new gold mineralization of the sulphide-gold-type.
- The recorded minerals: zircon, monazite and rutile in the heavy fractions of the stream sediment samples are responsible for the recorded contents of Zr, Y, Nb, Ta, U, Th and REE in the study area.
- The optimum grain size classes to be analyzed for Au is 2 – 0.25 mm and 0.5 – 0.25 mm for the other ore metals. Gold is mechanically dispersed as its maximum content is recorded in the coarser admixtures. The high Au concentration is detected in the grain size 0.5 – 0.25 mm and encountered in pyrite and its pseudomorph goethite.
- The ore minerals of W, Mo, Sn are not recorded in the heavy fractions. The adsorption of these elements on the iron and Mn oxides hydrate is most probably the chief process after their chemical liberation from sulphide and/or silicate minerals (Hassaan *et al.,* 1984).

These interpretations favor that gold is the chief mineralization occurring in the study area. The other recorded anomalous ore metals are related not only to the three known gold occurrences but also to the exposed liswaenites and altered muscovite albite granites.

Conclusions:

The use of Landsat ETM+ ratio image (5/7,5/1,4) discriminated the alteration zones, chiefly listwaenites associated with serpentinites and altered muscovite albite granites. Both rock types represent the source rocks for the recorded dispersion aureoles of gold and other associated ore metals. The ophiolitic listwaenites and the altered muscovite albite granite exposures in the study area point to possible presence of new sites of gold mineralization. The results of the lithochemical surveys showed that these two rock types in the area of Hamrat Ghannam, Abu Harida, Abu Merewa and the upper reaches of Wadi El Sherm El Bahari are promising targets for more detailed geochemical exploration for several ore metals, chiefly gold and REE. The recorded gold contents in Hamrat Ghannam, Abu Harida and Abu Merewa are related to the known gold occurrences, as well as to probable new sites which favor probable presence of placer gold there. The study of the heavy mineral fractions separated from the stream sediment samples recorded the presence of gold, silver, goethite after pyrite chalcopyrite, ilmenite, magnetite, zircon, monazite, rutile and xenotime. These ore mineral constituents are responsible for the recorded high contents of gold and other ore metals.

The recorded high Sb contents as well as its similar distribution with gold in the stream sediments at Wadi Hamrat Ghannam point to that the sampled bedrocks there represent an upper level of the known gold occurrence. This suggests probable presence of gold accumulation at deeper levels. Detailed bedrock survey followed by drilling at this site is recommended. High contents of both Zn and Pb in Khor Abu Merewa altered muscovite albite granites give criterion to the presence of a gold mineralization of the sulphide gold-type.

The area of study is promising for undertaking detailed stream sediments survey at a scale of 1:50,000 and bedrock survey at a scale of 1:10,000 for the occurrences of listwaenites and altered muscovite albite granites. The optimum grain size classes to be analyzed for Au is 2 – 0.25 mm and 0.5 – 0.25 mm for the other ore metals. Gold is mechanically dispersed as its maximum content is recorded in the coarser admixtures, in which native gold is microscopically detected. The high Au concentration in the grain size 0.5 – 0.25 mm is encountered in pyrite and its pseudomorph goethite. The elements Mo, Sn, W, U, Pb and Zn are chemically dispersed and possibly adsorbed onto Fe and Mn oxides hydrate. The recorded contents of Y and REE recommend undertaking detailed mineralogical and geochemical studies on the altered muscovite albite granites at Hamrat Ghannam and Abu Merrewa.

This study favors that the geochemical exploration method for these ore metals as an efficient method for exploration in the Eastern Desert of Egypt and in other arid regions.

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