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Research Article

Geochemical Exploration for Gold and Associated Elements in the Granite Rocks at Wadi Al Marsad, Southwest Jordan

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Abstract: This study aimed to conduct a geochemical exploration for gold (Au) and associated elements from the granitoids rocks, to an attempt to outline the areas of abnormal concentration of gold and other elements such as As, Sn, Zn, Cu, Pb, Bi, Li, Be, Y, Nb, La, Ce, Mo, Fe_2O_3 and TiO_2. The geochemical anomalies areas were identified by using rock and Heavy Mineral geochemical methods. A total of 57 rock geochemical samples were collected from the granite, pegmatite, rhyolite dyke, quartz veins and ultration zone from the study area; and 37 Heavy Mineral (HM) geochemical panned concentrate samples were collected from the hillside sediments along the main valley and tributary from 30 cm depth and then sieved to <1 mm grain size in the field. The geochemical samples caver about 18 km^2 from the Northern part of Wadi El Marsad. Geochemical exploration for the abnormal concentration of gold and associated elements are used to identified the geochemical anomalies areas. The geochemical samples were chemically analyzed for their element components using Inductively Coupled Plasma Atomic Emission Spectrometry method (ICP-AES) and graphite furnace Atomic Absorption Spectrometer (AAS) method was used for the analysis of gold.. The results of geochemical analysis indicated the presence of gold in the study area; this result was considered abnormal for rock samples, while the gold was associated with vein, pegmatite and quartz veins. The presence of HM in the samples served as good indicators of gold in the area due to the detritus of gold-traces bearing rocks in the area. The Pearson's correlation coefficients for the rock geochemical samples shows strong positive correlation was recorded for Au with As ($r = 0.72$), Cu ($r = 0.78$), Bi ($r = 0.76$), Y ($r = 0.97$), Nb ($r = 0.94$) and Ce ($r = 0.50$), respectively. The positive correlations for these metals revealed that the hydrothermal alterations affects the association of the metals in ultration zone, quartz veins and pegmatite dyke. The combination of both rock and HM concentrate samples showed three anomalous areas of gold. The interpretation of geochemical data for multi-elements of the rock samples shortlisted six geochemical anomalous areas and high concentration of Fe_2O_3, TiO_2, As, Sn, Zn, Cu, Pb, Bi, Li, Be, Y, Nb, La, Ce and Mo. The HM samples indicated mineral concentration in the sulfide vein and pegmatite dyke at the sampled points; these elements are usually associated with sulfide minerals.

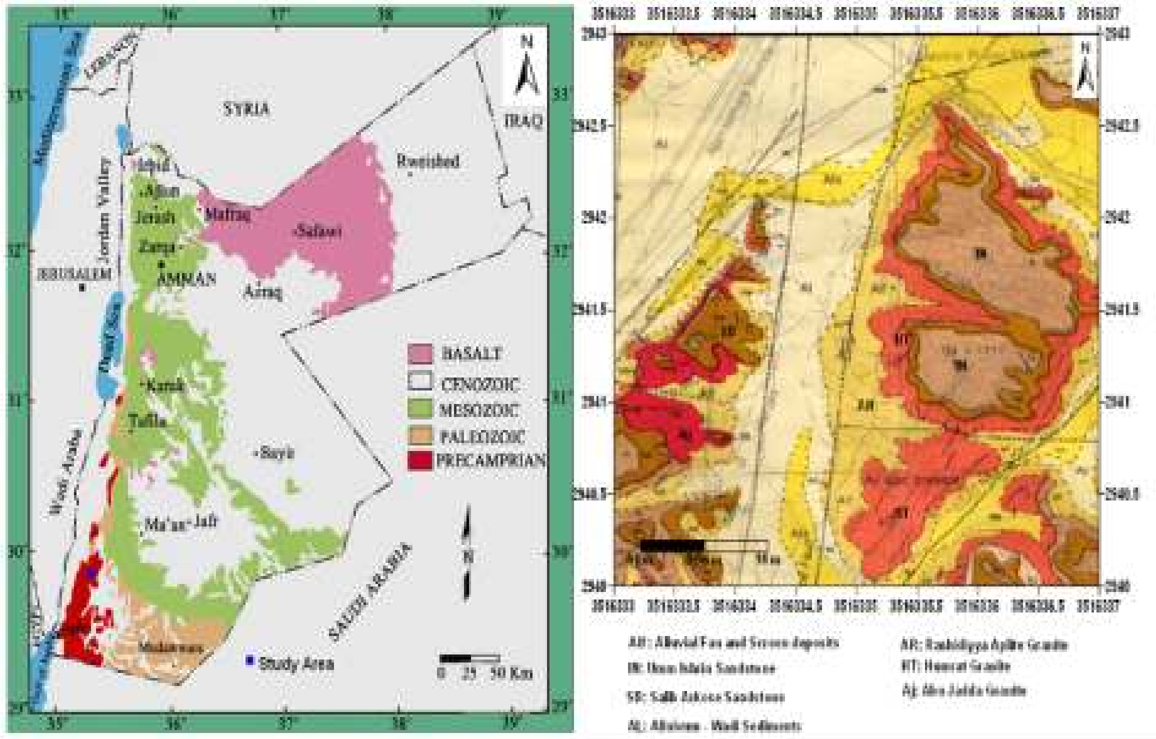
Keywords: Geochemical exploration, gold, rock and heavy mineral samples, WadiAl Marsad,Jordan

INTRODUCTION

Geochemical prospecting for minerals includes any method of mineral exploration based on the systematic measurement of one or more chemical properties of naturally occurring materials. The systematic collection and analysis of drainage samples has been established as method of mineral exploration at both the reconnaissance and detailed scales in many parts of the earth (Ottesen and Theobald, 1994). The maximum efficiency from a geochemical exploration program necessitates a balance between minimizing the density of sampling/maximizing the length of the detectable dispersion trains and significantly reducing the cost and time requirements (Cohen *et al*., 2005). The representative samples for gold explorations can vary markedly as a result of varying hydraulic processes in the stream and the different responses of high to low density minerals during transport (Nichols *et al.*, 1994). The changes in the slope of a stream bed, coupled with the particle scarcity effects on sample representatives may lead to the inhomogeneous Au distribution (Huseyin, 2007).

The chemical property measured was most commonly the trace content of some element or group of elements. The purpose of the measurements was to discover abnormal chemical patterns or geochemical anomalies related to mineralization deposit.

The Southwestern Jordan has been a focus of geochemical exploration for gold and associated elements caver the upper Proterozoic rocks for Aqaba and Arabacomplexes, by using rock, HM and stream



(a) (b)

Fig. 1: (a): Simplified Geological map of Jordan show the Area study; (b): Geological map of the study area after (Ghassan, 1986)

sediment geochemical sample within the regional geochemical survey project. However, although geochemical surveys form a major part of most company's strategies; much information is available on the geochemical dispersion of elements from deposits and prospects in Southwestern Jordan by which survey design may be optimized (NRA and BRGM PROJECT Staff, 1994).

Two geochemical prospecting methods was used to discover the study area (Fig.1a), Heavy Minerals (HM) and rock sampling methods were selected for this study, because they are more effective methods and suitable for the study area. Heavy Mineral samples were collected from the alluvium in stream sediment of grain size <1 mm, providing a useful tool for verifying any decision made during the geochemical exploration for gold. It gives supplementary information about the mode of occurrence of gold, nugget transport distance and ultimately about the origin of the element dispersion halo (Vladimir *et al*., 2000). The fine fraction usually used in geochemical exploration owing to its small grain size enabled the use of a small sample weight and, to some extent, eliminated the reduction and secondary sub-sampling errors. For exploration mineralogists, the key problems arise from the low concentration thresholds of gold anomalies and the small particle size(Vladimir *et al*., 2000). Composite rock geochemical samples were collected for the outcrop, pegmatite, quartz veins and ultration rock zone. According Wang *et al*.(2013),the gold deposit is associated with hydrothermally altered rocks across the fault zone, during the formation and evolution of the fault zone, the stress mechanism changed from compression to tension resulting in increased structural permeability of rocks that favored hydrothermal fluid-flow and eventually hydrothermal alteration of surrounding rocks and formation of the gold mineralization.

This study aimed to conduct a geochemical exploration for gold (Au) and associated elements from the granitoids rocks in the study area. In an attempt to outline the areas of abnormal concentration of gold (Au) and other elements such as As, Sn, Zn, Cu, Pb, Bi, Li, Be, Y, Nb, La, Ce, Mo, Fe_2O_3 and TiO_2, the areas of geochemical anomalies were identified and the presence of the ore minerals in the target areas were studied using rock and HM geochemical methods.

Geological setting: The study area covered by the pre-Cambrianplutonicgranitoids rocks complex is shown in Fig.1b. Bender (1974) identified the pre-Cambrian granitoids rocks in Jordan. The basement complex in Jordan is divided into two broad lithostratigraphic divisions: Aqaba and Araba Complex (McCourt and

Ibrahim, 1990). Accordingly, Jarrar*et al*. (1993, 2003)reported the history and geochronology of the Aqaba complex (800-600 Ma), which includes the metamorphic (800-750 Ma) and intrusive calc-alkaline plutonic rocks (625-600 Ma). The Aqaba complex lies below the regional nonconformity, which was marked by the Saramuj Conglomerate and which includes the Yutum granitic suite caver, the study area. The Araba complex (600-545 Ma) includes the Araba mafic to intermediate (570-595 Ma) suite, HumratFeinan suite (568 Ma) and Aheimir Alkaline peralkaline rhyolite (553-458 Ma) suite, but below the nonconformity marked by the SalibArkosic or Abu Khushiba sandstone formations, which is the basal formations of the Ram Group in the study area. The study area covered outcropping from the late Proterozoic calc alkaline granitoids for the Yutum suite included by Humrat Granite, ArRashidiyyaAplite granite and Abu Juddah granite (Fig. 1b). The granitites are cross-cut by numerous dykes of varying composition from acidic to basic, thin quartz veins and an alteration zone. The lower Paleozoic sedimentary rocks for the Ram Sandstone group include SalibArkoze Sandstone formation and Umm Ishrin Sandstone, which are unconformable and overlaid the Proterozoic igneous rocks (Ghassan, 1986; Abdulhamid,1990). The area under the study was located at 35°16'333"E to 35°16'337"E and 29°40'N-29°43'N) covering about 18 km^2 area. The geological units can be described as follows:

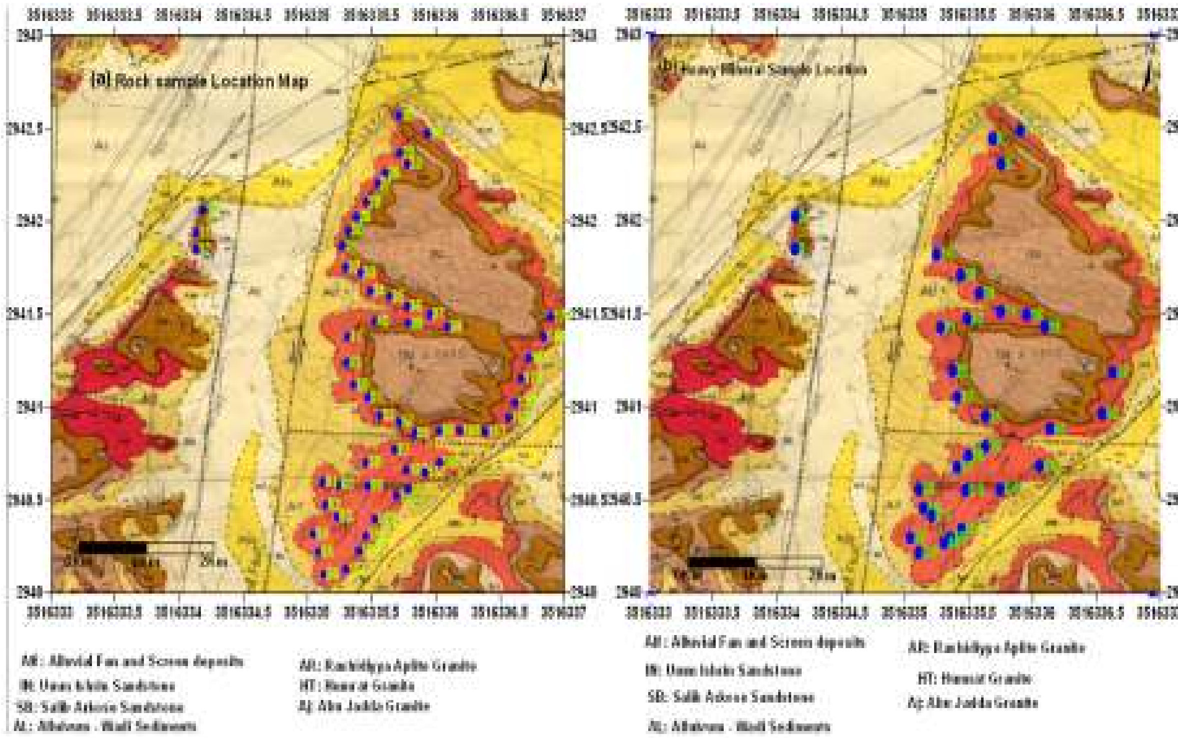
Abu Jadda Granite unit comprises of massive, medium to coarse grains, in diverse composition from biotitesynogranite to alkali feldspar granite and it is characteristically cross-cut in intrusive contact with other gratitude units and often produces pervasive brick red alteration of the host phase due to potassicmetasomatism (Abdulhamid, 1990). Humrat granite unit is composed of synogranite to alkali-feldspar granite, usually with characteristic pale red to pink colors, reflecting the high content of orthoclase; it is coarse-grained with porphyritic texture and a simple pegmatite dyke are used to cut the granitite. Numerous dykes acidic and basic rocks cross the gratitude and thin quartz vein (10-50-cm thick) are used to cross the granite in the field(Abdul Rahem and BanyYaseen, 2007). ArRashidiyyaAplite Granite unit distinguished micro granite, fine grain, pink to whitish pink colors, mafic poor, sugary with aplitic texture. Acidic dyke and thin quartz veins cut this unit (Ghassan, 1986). SalibArkosic Sandstone Formation: Early Cambrian in age, it consists predominantly of yellow, pink and purple-brown colors and their texture is very coarse to medium-grained cross-bedded arkosic and subarkosic sandstone. The pebbles to cobble conglomerates were locally present. Rounded to sub-rounded pebbles of milky-white quartz, pink feldspar, granitic and dyke rock clastic were common near the base of the unit, indicating that they have been derived from the Aqaba complex. Umm Ishrin Sandstone Formation, middle to late Cambrian age, brown, red-brown, to violet colors, medium to coarse-grained sandstone, arkosic in part, with rounded granules and pebbles of quartz. Thin beds of fine-grained, micaceous ferruginous sandstone were also detected presenting with secondary ferruginous and manganese ferrous color banding on steep massive-weathering faces and a typical large trough cross-bedding with pebbles, occasionally overturned for sets. Angular clastic siltstone in locally eroded channels were also present close to the gradational upper boundary of the formation (Abdul Rahem and BanyYaseen, 2007).

The study area was affected by the tectonic activity of the late Proterozoic to the early Cambrian age for the extension of the Arabian-Nubian shield that plunges to the south of Jordan (Bender, 1974; Barjous, 1987). The northwest striking faults and tension joints affected the early Paleozoic rocks of the Aqaba and Araba complexes of the Precambrian basement. The NN-SSW faults, parallel to the rift, extend south into Saudi Arabia, showing normal faulting and sinistral strike-slip movements (Clark, 1985). Major faults within the Aqaba complex were oriented to the north-northeast (0°–15°) trend, as revealed by the extensive WadiRumman, Wadi Rum and al Marsad fault. Wadi sediments and alluvium sand had filled the fault valleys and graben structure. The study area (Wadi Al Marsad) was affected by these faults, having recorded 100 m downthrows and a few kilometers of sinistral lateral displacement (Abdulhamid, 1990). The principal and subsidiary joints are shown in the various study units in the E-W, ENE-WSW and NE-SW directions in the study of the granitoid units and the NW-SE, N-S and E-W trends in the direction shown for the Salibarkose sandstone formation (early Cambrian) and Umm Ishrin sandstone formation (middle to late Cambrian).

SAMPLING AND ANALYTICAL TECHNIQUES

Two geochemical methods were used for the geochemical survey of the study area. Rock and HM geochemical samples were used to investigate the geochemical exploration of the study area. A total of 57 rock chip samples were collected from the outcropping of granitic rocks and included simple pegmatite, rhyolite dyke, quartz veins and ultration zone at a density of six samples per 1 km^2 (Fig. 2a). The samples were crushed and powdered using a stainless steel Jaw Crasher and Agate Ball Mill machine was used to obtain a grain size of <-63 μ. The samples were quartered in order to get a statistically representative (splitter) fraction and powdered using two geochemical techniques at the Natural Resources Authority (NRA) labs.

A total of 37 HM concentrated samples were collected along the main valley and tributary at a depth of 10-30 cm from the sediments in the stream sediment within the catchment area of the study at a density of three samples per 1 km^2 (Fig. 2b). The collection of about 20 L of HM sediments were sieved through dry stainless steel at the sampling site to get about 4 L by volume of alluvium of grain size <1 mm. The samples



(a) (b)

Fig. 2: (a): Rock sample location map; (b): Heavy mineral sample location map

were then placed in 8 L of stainless steel pans and washed in seawater close to Aqaba to eliminate material by the law of specific gravity and collect the remaining (about 200 g) HM concentrates. The concentrates were rinsed thoroughly in fresh water, placed on plates and dried in the sun.

The major (Fe_2O_3, TiO_2), trace elements (As, Sn, Zn, Cu, Pb, Bi, Li, Be, Mo) and REE (Y, Nb, La, Ce) were analyzed by decomposition using ione conductive coupled plasma emission spectroscopy (ICP-AES) at the Natural Resources Authority Labs. A total of 1 g of the powdered of the powdered (-63 µ) sample was mixed with 3 g of sodium peroxide (Na_2O_2) and placed in a zirconium crucible. Subsequently, 72 mL of deionized water was added to it, stirred for a few minutes and 28 mL of the diluted HCl (ratio 1:1) was added to obtain clear solutions that was used for the further analysis.

The gold element analyzed by graphite furnace Atomic Absorption Spectrometer (AAS) (3030; PerkinElmer) at the Natural Resources Authority Labs. The analytical method consisted of dissolving the Au in the sample by heating within aqua regia solution (3 mL conc. HCl + 1 mL conc. HNO_3) plus iron or (40% HCl, 20% H_2O, 20% HF, 20% HNO_3). The gold (Au) was then extracted with methylisobutylceton (MIBK) solution by introducing the organic phase into a pyrocoated graphite furnace and then analyzed for gold by the atomic absorption spectrometer (Meier, 1980). The gold concentration was expressed in parts per billion (ppb). The lower detection limit of this analysis method was 10 ppb. Excel 2007 and Surfer 8 were used to perform statistical analyses of the data and to produce the geochemical map, respectively. Thin section preparation were conducted at the Geology Department, University of Jordan. Thin sections polished to a standard thickness of 30 µm, covered with a glass cover slip and examined under polarizer microscope.

RESULTS AND DISCUSSION

Petrography and mineralogy: The rock samples varied with the sample type. The rock samples (pegmatite, rhyolite dyke, quartz veins and ultration zone) had leucocratic, holocrystalline and hypidiomorphic to allotriomorphic fine-to-medium-sized grains with phaneritic to megaprophyritic texture. The mineral composition was of feldspar, biotite, muscovite and opaque minerals such as iron oxide and magnetite. The secondary minerals present included calcite, sericite, kaolinite and chlorite, while the rare mineral found was cassiterite (Sn).The common textures of the rock samples were perthitic, poikilitic interstitial, zoning of plagioclase and polysynthetic twinning. The lithology and petrography of the area under study showed an alteration zone with high

Table 1a: Statistical analysis data for the rock samples and (b) the correlation matrix of the trace elements for rock samples

	Fe_2O_3	TiO_2	Au	As	Sn	Zn	Cu	Pb
Unite	wt%	mg/ton	Ppm					
Number of values	40	40	57	12	23	34	37	25
Minimum	0.3	0.01	10	5	3	1	4	2
Maximum	13.2	3.1	55	82	130	387	30	277
Mean	1.90	0.28	12.9	28.3	39.13	71.09	11.5	63.43
Median	1.00	0.08	10	20	12	17.5	10	9
Average	1.90	76.83	12.93	28.3	39.13	71.1	11.54	63.43
Standard deviation	2.97	0.69	9.39	22.9	47.91	104.5	6.7	100.9
Threshold 1 = mean+2 SD	7.84	1.66	31.68	74.1	134.95	280.1	22.9	265.2
Threshold 2 = median+2 SD	6.94	1.46	28.78	65.8	107.82	226.5	21.4	210.8

	Bi	Li	Be	Y	Nb	La	Ce	Mo
Unite	ppm							
Number of values	23	37	37	36	33	32	33	9
Minimum	8	1	1	4	2	3	5	1
Maximum	42	22	8	48	54	39	78	15
Mean	27.5	4.76	3.1	18.5	15.2	14	24.3	6.78
Median	28	4	2	17	12	13	19	6
Average	27.52	4.75	3.1	18.5	15.18		10.34	177.15
Standard deviation	9.87	4.54	2.2	10.6	12.3	8.92	17.7	4.12
Threshold 1 = mean + 2 SD	37.37	13.84	7.5	39.7	39.8	31.84	59.7	10.90
Threshold 2 = median + 2 SD	37.87	13.08	6.4	38.2	36.6	30.84	54.4	10.12

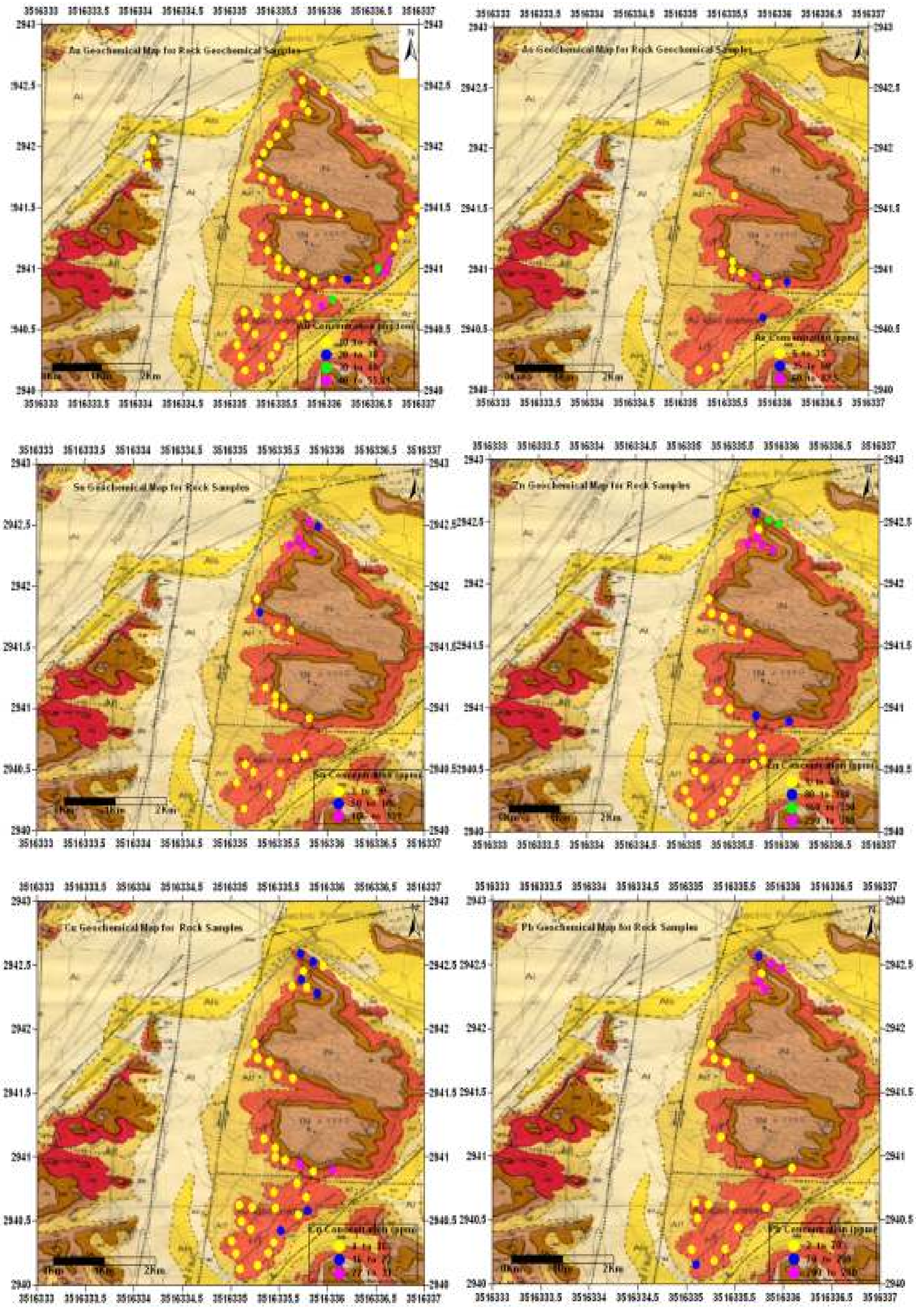
Table 1b: Correlation matrix of the trace elements for rock samples

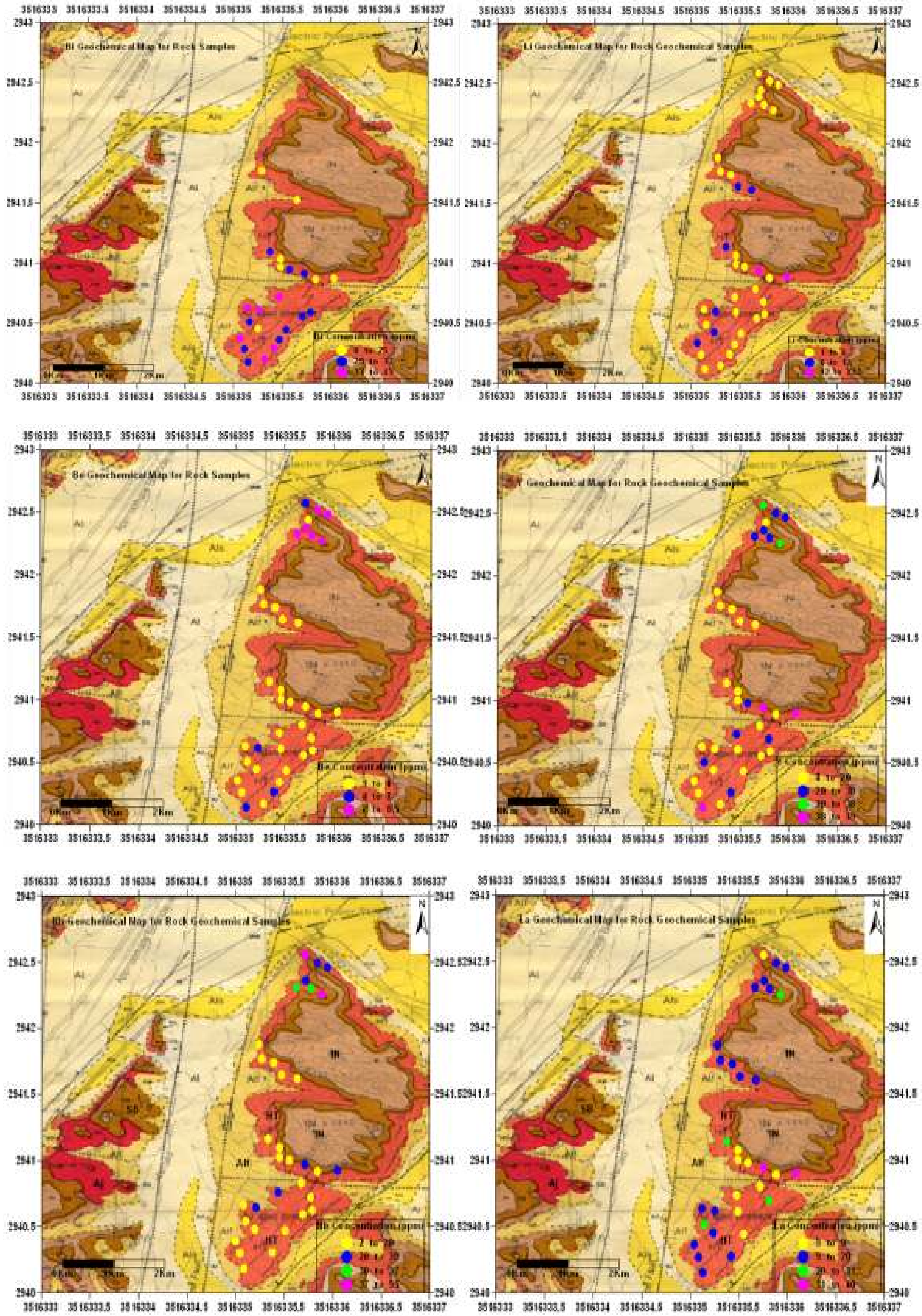
	Au	As	Sn	Zn	Cu	Pb	Bi	Li	Be	Y	Nb	La	Ce	Mo
Au	1.00													
As	0.72	1.00												
Sn	-0.09	-0.05	1.00											
Zn	-0.12	-0.10	0.31	1.00										
Cu	0.78	0.72	-0.20	-0.02	1.00									
Pb	0.23	0.18	-0.17	0.10	0.91	1.00								
Bi	0.76	0.75	0.02	0.03	0.40	0.52	1.00							
Li	-0.07	-0.12	-0.18	0.22	0.89	0.96	0.26	1.00						
Be	-0.12	-0.08	0.34	0.08	-0.31	-0.36	-0.11	-0.48	1.00					
Y	0.97	0.75	0.31	0.50	0.61	0.37	-0.09	0.35	0.59	1.00				
Nb	0.94	0.94	0.59	0.72	0.52	0.69	-0.28	0.02	0.69	0.61	1.00			
La	-0.14	-0.17	0.31	0.21	0.54	-0.07	0.06	0.71	-0.02	0.53	0.17	1.00		
Ce	0.50	0.50	-0.05	0.07	0.49	-0.23	0.07	0.74	-0.10	0.54	0.15	0.95	1.00	
Mo	-0.14	-0.05	-0.24	-0.27	-0.45	-0.28	-0.15	0.04	-0.27	-0.28	-0.33	-0.09	-0.03	1.00

concentration of secondary oxide and clay minerals.. The study area thus revealed an indication of the mineralization oreminerals association, documented by chemical analysis for gold and the pathfinders for the geochemical elements association.

Rock geochemistry: Regional geochemical survey were used to caver the upper Proterozoic rocks for Aqaba and Araba complexes to the southwest of Jordan by using rock, HM and stream sediment geochemical sample within the regional geochemical survey project. Accordingly, the NRA and BRGM PROJECT Staff (1994) reported the average concentration of the trace elements to be 10 mg/ton for Au, 15 ppm for As, 7 ppm for Sn, 5 ppm for Zn, 20 ppm for Cu, 15 ppm for Pb, 9 ppm for Bi and 5 ppm for Li. The epithermal gold mineralization investigated in the Wadi Abu Khushayba for the outcropping calc-alkaline granitic rocks has been included within the late Proterozoic rocks for the Araba complex (Al-Hwaiti*et al*., 2010). The area under the study included granitoids of the Aqaba complex and the outcropping of the late Proterozoic granitoids.

According to Wang *et al*. (1999), the background values were taken for the mean and median values, but Levinson (1974)suggested that the background was used as the median. The separation between the background and anomalous values can be defined by using the classical statistical treatment with the threshold calculation from the mean and median +2 Standard Deviations (SD) (Rose *et al*., 1979). The results from the data for the study area was subjected to statistical analysis (Table 1a and 1b). The statistical calculations for the data of the study were more or less similar, reflecting the search for a similar target of lithology. The statistical treatment of the rocks data adoption of two threshold values (threshold 1 = mean +2 Stander Deviation (SD) and threshold 2 = median +2 SD; (Table 1a) and the background values were equal to the mean value. The data obtained shows the value of the detection limits as assumed to be the minimum value of the analyzed element and the statistical parameters were computed on this assumption to draw the maps of geochemical anomalies (Fig. 3). The calculated thresholds 1 and 2 were 31.68 and 28.78 for Au, 74.10 and 65.80 for As, 134.95 and 107.82 for Sn, 280.10 and 226.50 for Zn, 22.90 and 21.40 for Cu, 265.23 and 210.80 for Pb, 47.24 and 47.74 for Bi, 13.84 and 13.08 for Li, 7.50 and 6.40 for Be, 39.7 and


Au Geochemical Map for Rock Geochemical Samples
As Geochemical Map for Rock Geochemical Samples
Sn Geochemical Map for Rock Samples
Zn Geochemical Map for Rock Samples
Cu Geochemical Map for Rock Samples
Pb Geochemical Map for Rock Samples


Bi Geochemical Map for Rock Samples
Li Geochemical Map for Rock Geochemical Samples
Be Geochemical Map for Rock Samples
Y Geochemical Map for Rock Geochemical Samples
Nb Geochemical Map for Rock Geochemical Samples
La Geochemical Map for Rock Geochemical Samples

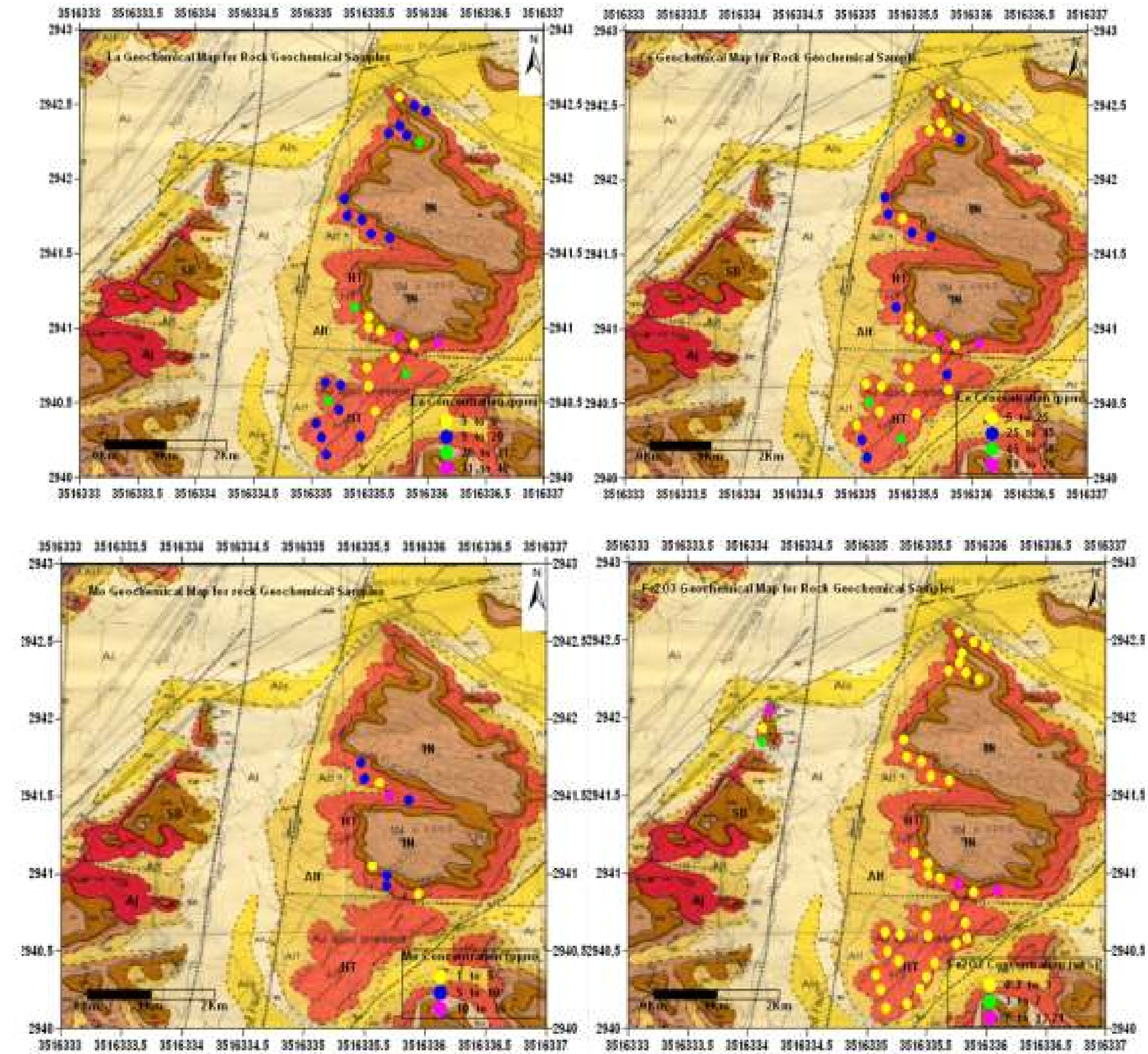


Fig. 3: Geochemical map showing the distribution of (Au, As, Sn, Zn, Cu, Pb, Bi, Li, Be , Y, Nb, La, Ce, Mo, F_2O_3 and TiO_2) for Rock samples

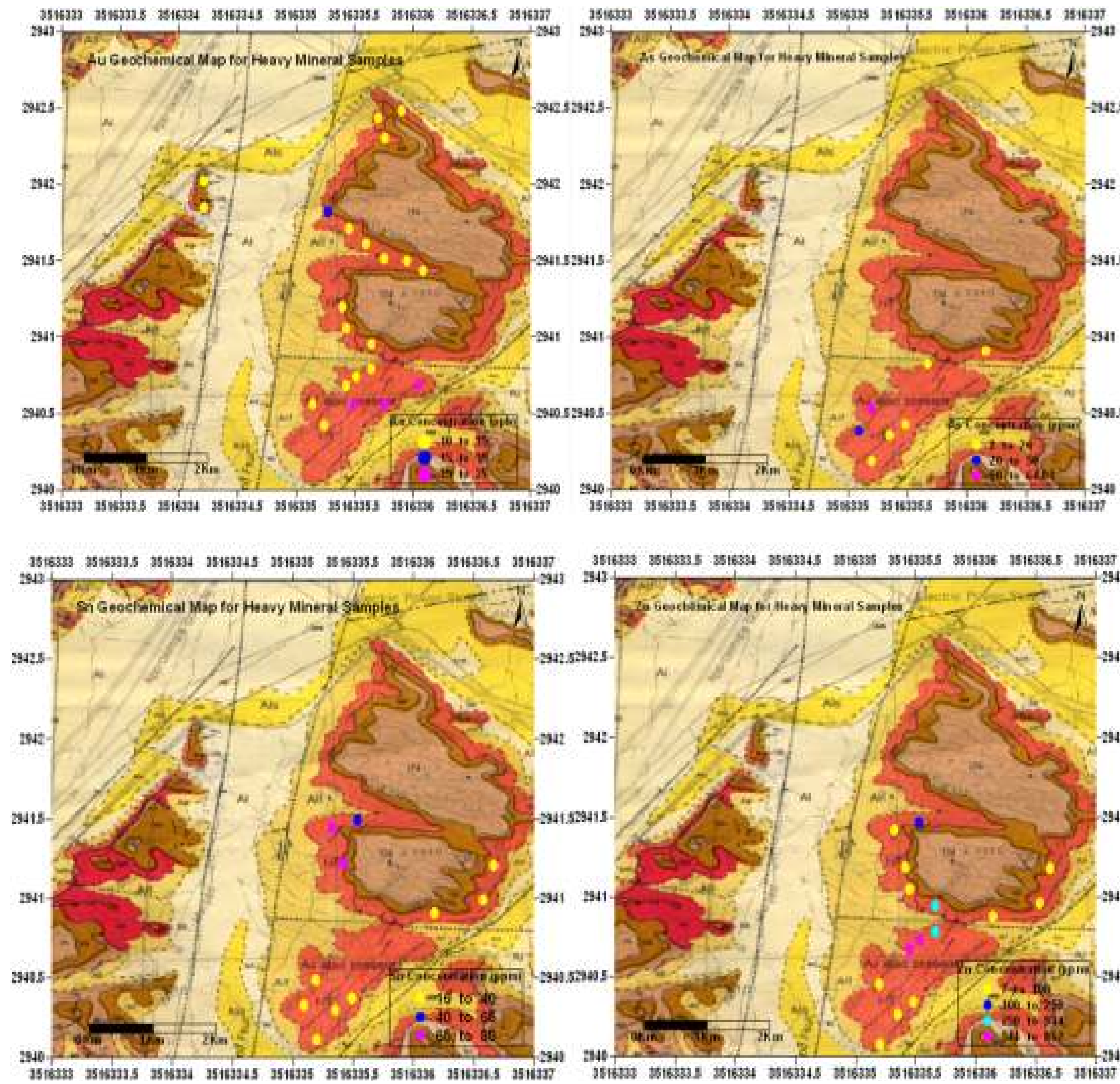
38.2 for Y, 39.8 and 36.6 for Nb, 31.84 and 30.84 for Be, 59.7 and 54.4 for Ce, 15.02 and 14.24 for Mo, 7.84 and 6.94 for Fe_2O_3 and 1.66 and 1.46 for TiO_2, respectively (Table 1a).

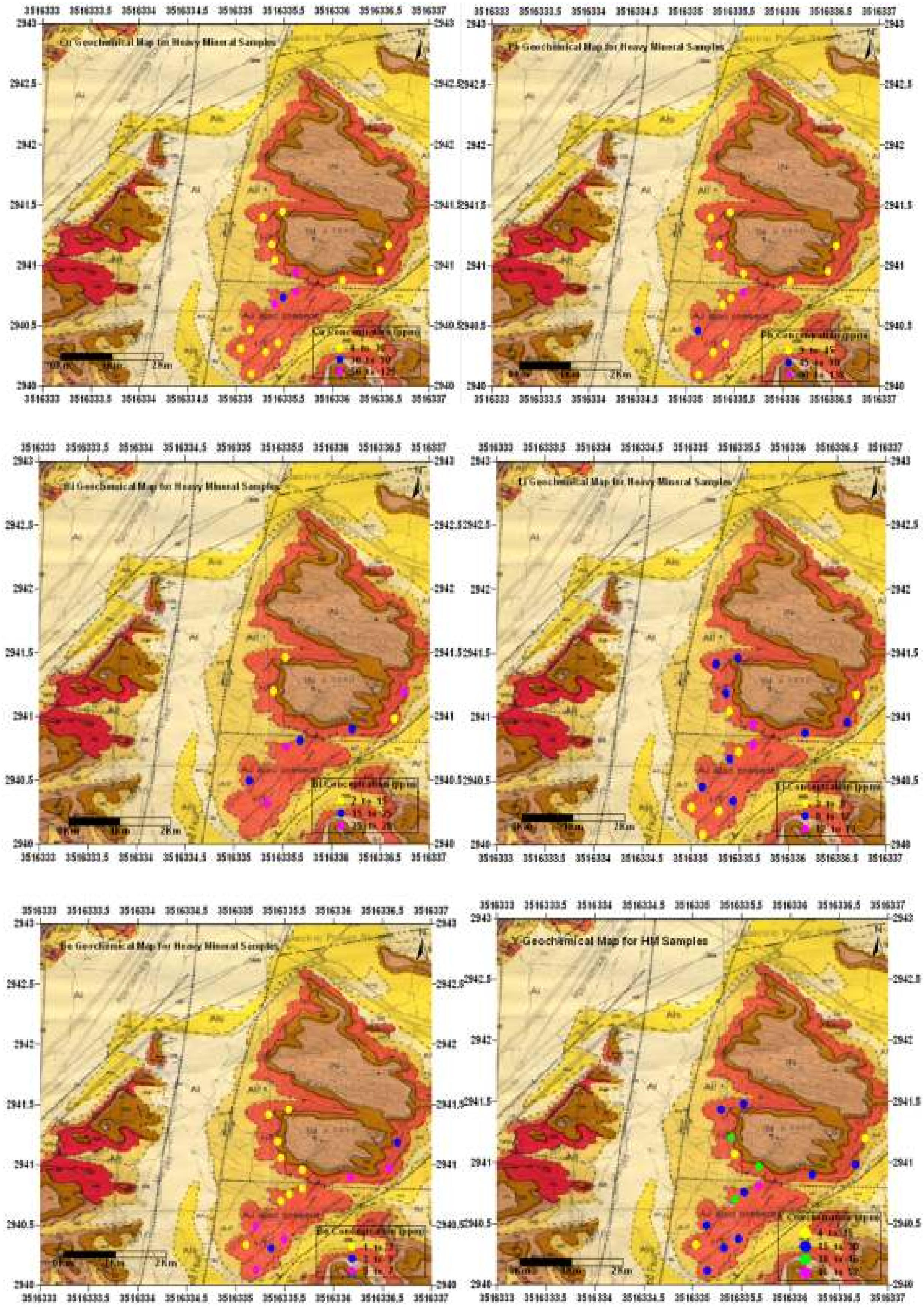
The Pearson's correlation coefficients from among the concentrations of Au, As, Sn, Zn, Cu, Pb, Bi, Li, Be, Y, Nb, La, Ce and Mo for the rock samples are presented in Table 1b. High positive linear correlations were noted among the concentrations of Au for As (r = 0.72), Cu (r = 0.78), Bi (r = 0.76), Y (r = 0.97), Nb (r = 0.94) and Ce (r = 0.50), respectively. Strong positive correlation of As were noted for Cu (r = 0.72), Bi (r = 0.75), Y (r = 0.75), Nb (r = 94) and Ce (r = 0.50); Cu for Pb (r = 0.91), Li (r = 0.89), Y (r = 0.61), Nb (r = 0.52) and La (r = 0.54); Nb for Sn (r = 0.59) and Zn (r = 0.72); Pb for Li (r = 0.96); Li for La (r = 0.71) and Ce (r = 0.74); Be for Nb (r = 0.64); Y for Nb (r = 0.61), La (r = 0.53) and Ce (0.54); La for Ce (r = 0.95), respectively.

The positive correlations for these metals revealed that the hydrothermal alterations affects the association of the metals in the study area and the documented field shows the outcrop of the ultration zone. The positive correlation for Au and some metals, such as As, Cu and Bi, is a good indication pathfinder for Au (Taivalkoski*et al*., 2015).The major correlation for the Sn, Zn, Pb, Cu and Be components indicated their association within the sulfide veins. The positive correlation between REE such as Y, Nb, Ce and La for Au, As, Sn, Cu, Be and Li served as an indication for mineralization within pegmatite dyke sources as a result of magmatic deposition, such as of petalite ($LiAlSi_4O_{10}$) and phenacite (Be_2SiO_4). The high positive correlation between REE (Y, Nb, La, Ce) revealed the pegmatite mineralization sources such as the pollucite minerals ($CeAlSi_2O_6.H_2O$) (Perkins, 2002).

Negative correlations were observed for Au with Sn, Zn, Li, Be and La; As with Zn and La; Sn with Bi, Li, Cu and Li; Pb with Be and Ce; Bi with Nb; Li with Be; Be with Ce; Y with Mo; and Nb with Mo (Table 1b). These results indicated that the analysis of these metals is not linked with each other and that these metals have different natural sources such as hydrothermal alteration zone, quartz veins and pegmatite dyke, depending upon the lithology of the study area.

The geochemical anomaly map for the rock samples of Fe_2O_3, TiO_2, Au, As, Sn, Zn, Cu, Pb, Bi, Li, Be, Y, Nb, La, Ce and Mo are shown in Fig. 3. Six geochemical anomaly areas represent the rock geochemical analysis map (Fig. 5a). The filed study of the area showed that the anomalous areas were concentrated within the pegmatite dyke, alteration zone, trace oxidation with sulfide viens and quartz veins. The anomaly's area 1 and 2 for Au, As and Cu were concentrated into the sulfide veins and ultration zone. Strong geochemical anomalous areas for Au overlapped for As and Cu, as represented by the outcrop of pegmatite dyke, quartz veins and alteration zone. The anomaly 1 (Au value = 55 mg/ton) and anomaly 2 (Au value = 40 mg/ton) overlapped with As + Cu. The anomaly 3 association of As + Cu + Li + Ce + Fe_2O_3 + TiO_2 + Mo represented the pegmatite and ultration and oxidation zones within the area of the fulat zone. Li has the major of alkali metals and it substitutes for the alkaline earth metals, as it is concentrated in the silicate rocks in the granitoids and pegmatite veins.




Cu Geochemical Map for Heavy Mineral Samples
Pb Geochemical Map for Heavy Mineral Samples
Bi Geochemical Map for Heavy Mineral Samples
Li Geochemical Map for Heavy Mineral Samples
Be Geochemical Map for Heavy Mineral Samples
Y Geochemical Map for HM Samples

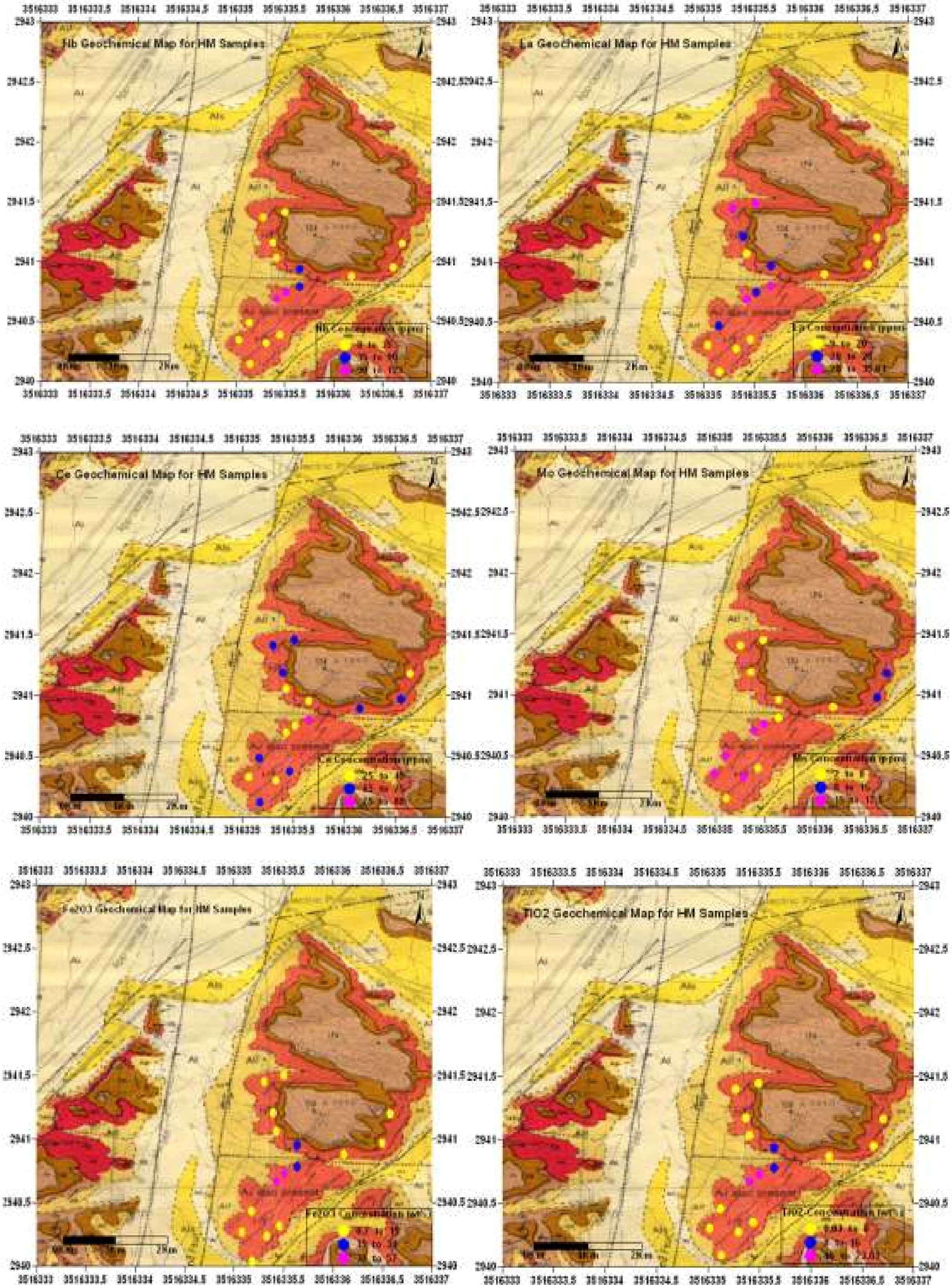


Fig. 4: Geochemical map showing the distribution of (Au, As, Sn, Zn, Cu, Pb, Bi, Li, Be, Y, Nb, La, Ce, Mo, Fe_2O_3 and TiO_2) for heavy mineral samples

Anomaly 4 association within Zn + Cu + Pb +Be + Sn + Nb is represented in the sulfide vein within the alteration zone. The high concentration of Zn, Cu, Pb, Be and Sn in anomaly 4 explains the presence of the expected ore minerals, such as sphalerite (ZnS), chalcocite (Cu_2S), covellite (CuS), cassiterite (SnO_2), galena (PbS); the alteration rocks had undergone albitization and sericitization for rocks that often have a crisp wall (Anthony, 1993;Costa *et al*.,1999). The anomaly 5 associated with Pb + Be + Sn + Nb reflected pegmatite occurrence within beryl [$Be_3Al_2(Si_6O_{18})$] mineral or an association with tin ore (Perkins, 2002). The anomaly 6 represented high concentration of bismuth (Bi) and Y, as this mineral is relatively rare and occurs with lead and tin in the granite and pegmatite rocks.

The result of rock geochemistry agreement and documented for proivous study (BanyYaseen, 2015) in wadiRumman area, for the same geological einviroment and for gold and assocceated elements to hydrothermal alterations for pegmatite, ultration zone and quartz viens.

Heavy minerals geochemistry: HM analysis is a more sensitive indicator of sediment provenance than whole rock geochemistry due to the presence of multiple and complex mineralogical controls on major trace element distributions (Ratcliffe*et al*., 2007). The HM method was found to be more sensitive for detection and discovery in mineral exploration. The HM survey was applied to the concentrates from the drainage sediment samples as a beneficial geochemical and mineralogical guide to mineralization (Bill and Geo, 2015).

The prediction analysis of the HMs is yet to become popular as the common exploration methods to detect the anomalous areas. These methods have been successfully applied and used in the study of the granitoid rock cover in the southwest Jordan (NRA and BRGM PROJECT Staff, 1994). Stream sediment has been used to study and caver the geochemical HM in south Jordan. It was found to be the best method for detailed geochemical surveys in the arid region, as well as in a wide variety of environment from large gravel bars in rivers to tiny pools of sediment in rock narrow creeks and to dry washes in arid climates. The sample sites selected from bars showed the presence of sand and gravel because the concentration of HMs typically occurred in these specific areas. The best HM samples collected from the fine particles from quiet water sedimentation or high-energy environment within the sediments provided the best material (BanyYaseen, 2015). The samples studies provided high-energy sediments in the dry arid region climates.

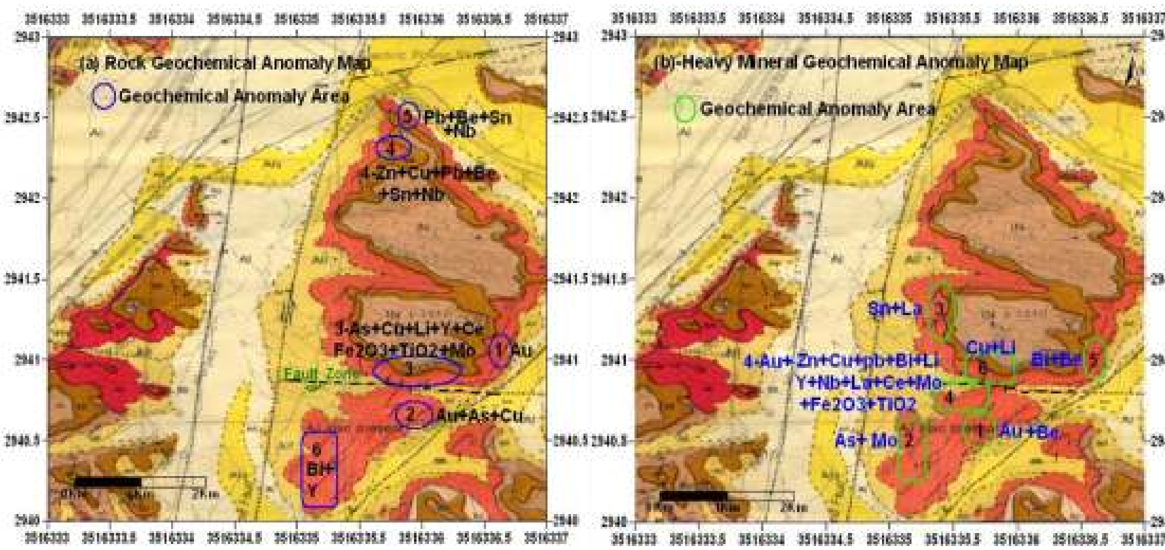
The geochemical analyses for HM data were evaluated to obtain geochemical statistics and maps of the geochemical anomalies for the study elements. The results of the statistical treatment of the HM data is shown in Table 2a and 2b.Two threshold values was the adoption of value (threshold 1 = mean + 2 Stander Diviation (SD) and (threshold 2 = median + 2 SD), respectively; the background values were equal to themean value (Rose *et al*., 1979).The data showed the value of the detection limits, as assumed to be the minimum value of the analyzed element and the statistical parameters were computed on this assumption to draw the maps of geochemical anomalies (Fig. 4). The thresholds 1 and 2 for 45.46 and 51.00 for Fe_2O_3, 17.97 and 14.27 for TiO_2, 19.84 and 17.04 for Au, 60.60 and 51.20 for As, 83.60 and 70.80 for Sn, 696.70 and 544.00 for Zn, 50.60 and 44.20 for Cu, 95.87 and 89.80 for Pb, 35.50 and 39.89 for Bi, 10.30 and 10.42 for Li, 4.50 and 3.60 for Be, 46.5 and 47.5 for Y, 98.98 and 90.1 for Nb, 28.35 and 26.55 for La, 76.4 and 78.6 for Ce, 14.17 and 12. 30 for Mo, respectively (Table 2a).

Table 2a: Statistical analysis data for the heavy mineral samples

	Fe_2O_3	TiO_2	Au	As	Sn	Zn	Cu	Pb
Unite	wt%		mg/ton	ppm				
Number of values	16	16	22	7	11	15	15	14
Minimum	0.70	0.03	10	2	16	7	8	9
Maximum	56.5	23.6	20	64	79	861	54	137
Mean	11.46	4.10	11.8	16.4	34.8	176.7	22.3	32.07
Median	1.7	0.35	10	7	22	24	16	26
Average	11.46	4.05	11.77	16	34.8	176.7	22.3	32.10
Standard deviation	17.00	6.96	3.52	22.1	24.4	260.6	14.2	31.90
Threshold 1= mean + 2 SD	45.46	17.97	19.84	60.60	83.60	696.70	50.60	95.87
Threshold 2 = median + 2SD	51.00	14.27	17.04	51.20	70.80	544.00	44.20	89.80
	Bi	Li	Be	Y	Nb	La	Ce	Mo
Unite	ppm							
Number of values	9	16	16	16	16	16	16	15
Minimum	2	3	1	4	8	9	25	2
Maximum	27	12	5	51	122	35	87	17
Mean	16.6	7.88	2.9	25.1	36.38	21.3	45.8	8.87
Median	20	8	2	26.5	27.5	19.5	48	7
Average	16.6	7.9	3	25.13	36.38	21.3	45.8	8.86
Standard deviation	9.45	2.42	1.6	10.7	31.3	7.05	15.3	5.3
Threshold 1 = mean + 2 SD	35.50	10.30	4.50	46.5	98.98	28.35	76.4	14.17
Threshold 2 = median + 2SD	39.89	10.42	3.60	47.5	90.1	26.55	78.6	12.30

Table 2b: Correlation matrix of the trace elements for heavy mineral samples

	Au	As	Sn	Zn	Cu	Pb	Bi	Li	Be	Y	Nb	La	Ce	Mo
Au	1.00													
As	0. 08	1.00												
Sn	-0.25	0.88	1.00											
Zn	-0.22	-0.19	0.96	1.00										
Cu	0.89	-0.18	0.88	0.76	1.00									
Pb	-0.10	0.05	-0.41	0.15	0.84	1.00								
Bi	-0.54	0.09	-0.68	0.21	-0.11	-0.07	1.00							
Li	0.53	-0.14	0.63	0.33	0.68	0.50	-0.56	1.00						
Be	0.43	0.34	-0.63	-0.61	-0.48	0.01	-0.06	-0.09	1.00					
Y	-0.15	-0.17	0.55	0.50	0.66	0.77	-0.41	0.85	-0.07	1.00				
Nb	-0.14	-0.10	-0.10	0.96	0.73	0.08	0.23	0.32	-0.36	0.47	1.00			
La	-0.17	-0.19	0.83	0.42	0.65	0.55	0.42	0.89	-0.25	0.91	0.37	1.00		
Ce	0.07	-0.06	0.56	-0.01	-0.01	0.82	-0.44	0.65	0.23	0.79	0.02	0.75	1.00	
Mo	-0.06	0.48	-0.52	0.34	-0.05	-0.20	0.57	-0.67	-0.12	-0.48	0.32	-0.54	-0.53	1.00



(a)(b)

Fig. 5: Geochemical anomalous elements area map for; (a): Rock and; (b): Heavy mineral samples

The Pearson's correlation coefficients for the HM data (Table 2b) showed a positive linear correlations among the concentrations of Au with Cu (r = 0.89) and Li (r = 0.53). High positive correlation of As with Sn (r = 0.88); Sn with Zn (r = 0.98), Cu (r = 0.88), Li (r = 0.63) and La (r = 0.83); Zn with Cu (r = 0.76) and Nb (r = 0.96); Cu with Li (r = 0.68), Nb (r = 0.73), La (r = 0.65) and Y (r = 0.66); Pb with Li (r = 0.5), Y (r = 0.77), La (r = 0.55) and Ce (r = 0.85); Li with Y (r = 0.85), La (r = 0.89) and Ce (r = 0.65); Y with La (r = 0.91) and Ce (r = 0.79); and La with Ce (r = 0.75). Negative linear correlations of the elements of Au for Bi (r = -0.54); Sn for Bi (r = - 0.68) and Be (r = -0.63); Zn for Be (r = -0.61); and Bi for Li (r = -0.56). The good correlation between Au and Cu revealed the main sources for ultration of simple pegmatite and sulfide veins. The Cu is a good pathfinder for Au sources (Taivalkoski*et al*., 2015), but Li sources act as substitutes for the alkaline concentrate in the silicate rocks in granitoidsand pegmatite veins crossing the study area and formlepidolite($K(Li,Al)_{2-3}(AlSi_3O_{10})(O,OH,F)_2$ mineral (Gunter, 1998). The positive correlation between As, Sn, Zn, Cu, Pb and rare earth elements **(**REE) for Y, Nb, La and Ce revealed the weathering of the minerals for the pegmatite and sulfide veins. The REE are concentration in minerals in pegmatite dyke. The REE can be controlled by accessory minerals and by replacement of Ca in minerals such as apatite ($Ca_5(PO_4)_3(OH,F,Cl)$ and titanite ($CaTiSiO_5$). Cesium (Ce) was found to be concentrated in granite pegmatite in micas and potash feldspar. The concentration of Ce in pegmatite liquids may lead to the formation of pollucite mineral ($CeAlSi_2O_6$) (Gunter, 1998).

The geochemical anomaly map for the HM samples of Fe_2O_3, TiO_2, Au, As, Sn, Zn, Cu, Pb, Bi, Li, Be, Y, Nb, La, Ce and Mo are shown in Fig. 4. Six geochemical anomaly areas are documented in Fig. 5b. The anomalous areas were concentrated within the stream crossing the sulfide veins, quartz veins and pegmatite dyke. The anomaly area 1 include Au + Be and anomaly area 2 included As + Mo, these anomalies occurred in the Humrat granite and contained numerous simple pegmatite and sulfide veins. The anomalous area 3 had Sn + La mineral, reflecting the presence of cassiterite (SnO_2) minerals in the host rock. Anomaly 4 is associated with Au + Zn + Cu + Pb + Bi + Li + Y + Nb + La + Ce + Mo + Fe_2O_3 + TiO_2; these minerals reflected the ultration of the sulfide veins with highly iron oxide, pegmatite dyke and the anomaly area located in the fault zone with highly ultration zone. Anomaly area 5 was associated with Bi + Be, reflecting the presence of beryl ($Be_3Al_2(Si_6O_{18})$ and bismuth minerals in grantite rocks and pegmatites(Perkins, 2002). These results revealed the association of metals in alteration with the host rocks and accumulation within the sediment deposits. Anomaly 6 included Cu + Li minerals, reflecting the presence of pegmatite and sulfide veins along the fault zone cross in the study area.

CONCLUSION

Geochemical investigations were performed by two geochemical methods of the rock and <1 mm HM-grain size samples were used for the geochemical exploration of the study area. The sampling technique proved to be extremely sensitive as an exploration tool for the discovery of small-scale mineralization in areas with well-developed drainage, like in the WadiAl Marsad area. The identification of the alteration zone and mineralized rocks reflected the floated samples in the streams and it was found to be critical in categorizing the details of the geochemical results (Hseyun, 2007). The following is the conclusion of the present study:

- The rock and HM sampling was effective in delineating six geochemical anomaly areas Fig. 5.
- Two geochemical anomalies delineated for Au-overlapping for rock and heavy mineral (anomaly 1 for rock overlap anomaly 5 for HM and anomaly 2 for rock overlap anomaly 1 for HM),
- Au anomaly overlapping for As, Cu, Bi and Be.
- The anomaly 3 for rock overlap and anomaly 4 for HM were located at the two side of the fault zone in the study area, which was affected by the fault zone to produce crashed and ultration zone with high oxidization for the left side represented by rock geochemical anomaly 3 and the right side represented by anomaly 4 for HMs.
- The geochemical signatures of Au and As in the Wadi Al Marsad appeared to be hydrothermal alterations, sulfide veins and pegmatite dykes, respectively.
- Effective HM sampling and delineated Au geochemical anomaly of area 1 specificities with the rock geochemical anomaly of area 2 did not appear negate of Au in the studied samples.
- The geochemical signatures of Au and associated elements in the study area are agree for the geology (within calc-alkaline granitic rocks for Araba complex) and geochemical result in WadiRumman area (BanyYaseen, 2015) by appear the anomaly area located in hydrothermal alterations, quartz veins and pegmatite dykes, respectively.
- This study expected to gold mineralization for granitic rocks for as documented for Wadi Abu Khushayba area (Al-Hwaiti*et al*., 2010).

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