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Geochemical and Statistical Evaluation of Gold Mineralization of AbuSari Area–Northern Sudan

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Abstract

Gold mineralization of the target area is mainly confined to the Meta volcanic, Meta sedimentary rocks of green schist fanciesintruded by granitioid rocks. To reveal secondary dispersion haloes, unconsolidated soil samples were collected along profiles, across the suspected Au-bearing sector. Resultsobtainedfor Au and associated elements (Ag, Co, Pb and Zn), were subjected to statistical analysis to reveal parameters such as background value (Cb), coefficient of correlation, coefficient of variation, geochemical factors, productivities, and coefficient of dispersion. Statistical methods interpretation of the data proved to be effective and complement each other. Geochemical factors and ratios of contents of epithermal elements to hypothermal elements indicate deeper levels of mineralization and weathering, gold dispersion shows erratic behavior. The morphology of secondary dispersion haloes of one element reflects more or less the morphology of the hidden ore bodies.

Keywords

Gold mineralization, Geochemical, Dispersion Halo.

Introduction

This area is situated 7 Km East of the River Nile and the village of Abu Sari, at about 10 Km North of Delgo town. The coordinates are: latitudes 20° 16′ N, and longitudes 30° 35′ E. The Abu Sari mine is accessible from Delgo town traveling north on the main track line to the village of Abu sari and then, 7 Km to the East

The area of study lie in northern state of arid to semi-arid climate, where physical –mechanical weathering and denudation processes dominate.

The area is dominated by middle to late Proterozoic rocks of Arabian Nubian Shield which consist of older gneisses, low grade metamorphic volcano– sedimentary sequences, granitiodintrusions,serpentinizedultratastic rocks and alkaline syenite –granite complexes (Younis.S.M, 2014, Said.A.M, 1994).

The general agreement is that The Arabian Nubian Shield represents the best documented example of late Proterozoic to early Paleozoic crustal growth through process of SW pacific (Bakheit A.K, (1991). This is also seen in Saudi Arabia where the late tectonic theory involving island arc and suture zone , resulting in a deformed and cratonized sequence of mainly Proterozoic volcano-sedimentary rocks. The lithostratigraphic sequence in geochronolagical order from bottom to top: is high grade gneisses, low grade met sediments, serpentenized ultrabasic (ophiolatecomplex) rocks, and younger granitoidal intrusions.The gold -bearing quartz veins are mainly lenses –like, very often showing boudinages giving vertical and lateral change in geometry and composition.The veins generally occur sub parallel to the lithological banding being folded together with the host rocks which have a general north and east strike (Fig.2).

The gold –bearing quartz veins commonly occupy specific structural feature such as minor shear zones fold hinges, and / or fracture network. All the quartz veins are in exo-contact with the regional trend of the volcano – sedimentary sequences and either as highly folded, sheared, and brecciated quartz veins or as weakly folded massive blocky ridges.The quartz veins were hosted in a sequence of chloritic schists, carbonate –mica schist,quartz –mica schist, which is of lower green schist facies, the country rocks were strongly folded, foliated and show a pencil cleavage(Mustafa.Y.S,2014) .

The dip of fold axes is sub vertical to vertical. The lithological banding or bedding is often cut by the pencil cleavage, the contact zone between the massive quartz vein and the adjacent host rocks shows ferruginous alteration.From field observations there are two phases of silica enrichment, the first phase generated big quartz veins or ridges. The second phase gives the druzy crystallized quartz veins of milky color.The druzy quartz veins often show an original

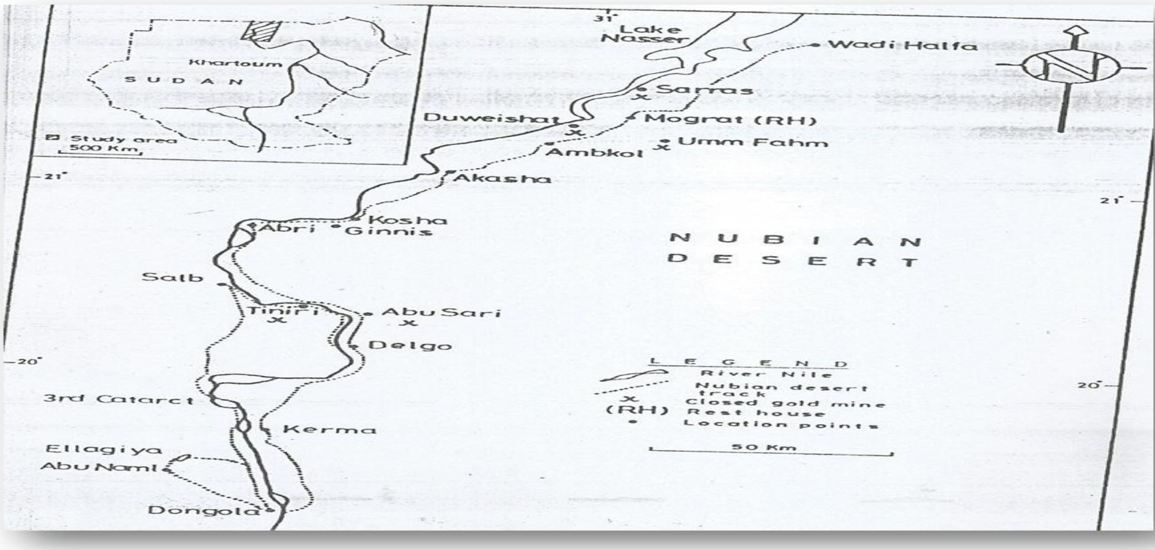

Figure 1 Location of the Gold Mining Areas in the Nubian Desert.

coarse euhedral crystalinity and they are believed to post mineralization.

The gold bearing quartz veins are bluish-gray in color. The auriferous ore sheets consist of veins, lenses, pods and quartz stringers. Gold in oxidation zone are partly included in quartz and/or Fe-hydroxides, partly as free grains in pores and fissure.Pyrite is the most common sulfide and form crystals which reaches 2 cm in size which generally suffer strong fracturing. Arsenophyrite is present in many veins.

The quartz veins occur in carbonate-rich pyritiferous mica schist; with small bands and mylonitic lithologic contacts sub-parallel to the mylonitic layering. Druzy quartz trend is controlled by foliation. The auriferous quartz veins are easily distinguished from vein, like structures related to older and younger events or geologic formation.Some quartz veinsare hosted by chloritic, schists of metavolcanic parent rocks; carbonates, rich and pyriteferous mica schist. The veins are generally in order of tens of decimeters to four meters wide.

The maximum length of discontinuous quartz veins is about 2000meters. The strike of these veins vary between 250°-340°, dipping subvertically to the north.

Method of Interpretation of the Result

Interpretation of result of chemical and mineralogical analysis of stream sediments samples was expected to revealsecondary drainage dispersion patterns of gold mineralization area of sampled drainage system.

Interpretation of analytical result of residual soil sampling along profile is expected to reveal, in its turn, secondary dispersion haloes while results of composite chip samples, whether along profile or haphazardly collected are expected to characterize primary aureoles of the gold-bearing ore bodies.

In this study an attempt has made to quantify geochemical criteria expected to be revealed as a result of orientation studies outlined above.

These criteria are to be used to prospect for and to explore gold mineralized ore to be used to prospect for and to explore gold mineralized ore bodies which are either outcropping on surface but with unseen mineralization , buried by unconsolidated and consolidated younger deposits or blind ore bodies.

Since the study is only orientation, already-known gold bearing bodies, exposed on the surface, were chosen for this experimental work. The target locality chosen as mentioned above is Abu Sari.

The following geochemical parameters and geostatistical factors are considered.

Geostatistical parameters; zoning is a geochemical criteria which when quantified can give an important clue in detailed prospecting and exploration. This quantification can be expressed in terms of coefficient of correlation (r) and geochemical factor (V), (Khalil, 1993).

Coefficient of correlation (r); the formula used to define coefficient of correlation for two chemical elements are a follows:

$r = \sum (\log x_i - \log x^-) . (\log y_i - \log y^-) / \sqrt{(\log x_i - \log x)^2 . (\log y_i - \log y)^2}$ (2)

Where: x_i and y_i are the content of the two respective chemical elements at the locality, where I is the sampling point.

Coefficient of correlation can either be: very reliable (where r equals or more than 0.75). Reliable, where r ranges from 0.74 to 0.65 or satisfactory when it ranges from 0.64 to 0.55.

In prospecting for gold in the Sudan only very reliable factor are commended to consider since gold is very erratic in its geochemical distribution.

Geochemical Factor (υ); this is a ratio between element contents. Such a ratio summarizes the geochemical landscape of a mineralized zone. It can also help in determination of weathering level and mineralization horizon of a hydrothermally mineralized ore body.

Such ratio should reflect a geochemical meaning i.e. content of element of epithermal zone (low temperature) to those of hypothermal zone (high temperature).

The ratio are expressed as the content of ore chemical element to that of the accompanying elements e.g. Au/Ag or the ratio of a multiple of two or more contents of chemical elements of contrasting geochemical behavior i.e. the contents of chemical elements which usually dominate in low temperature conditions to those which dominate in high temperature conditions in the process of hydrothermal mineralization i.e. epithermal to hypothermal.

Coefficient of Mobility (Dispersion); Coefficient of dispersion (δ)is the capacity of migration or geochemical mobility of chemical element in certain supergene environment and it is expressed mathematically as follows:

$$\delta = \mathrm{M/Cmax.}\ \sqrt{2\pi}$$

C_{max} = the maximum element content in central apex of the profile of linear productivity (M) that crosses the point of maximum element content (epicenter). Cx Coefficient of mobility (dispersion) can also be computed graphically. This coefficient helps to suggest the horizontal sampling interval along profiles.

Univariate Analysis;the Univariate method is used to calculate the following parameters:
Maximum, minimum and range of element content. These values are the highest and lowest variables, encountered among the difference between the limiting of data set. Variance (s^2): the sample variance is a measure of dispersion and has application in checking the homogeneity of value in any particular set of data. The samples variance is calculated for grouped data as:

$S^2= \sum f_i (x_i - x^-)^2 /n-1$

Where:f_i is the frequency of the interval, x^- = the content of the element, n = number of samples.

Standard deviation (s): is the square root of the variance s^2 and is referd to as dispersion measure in treatment of geochemical data.

Coefficient of variation (C V); the coefficient of variation is considered as a measure of a relative variability which takes into account both mean and standard deviation i.e.

C.V= (s/x^- . 100%)

Values of coefficient of variation above 2 or 2.5 are usually for substance in trace content values, less than these indicates that the element is concentrated I the data amount greater than expected for these trace elements in general. Any values exceeding 0.5 means that treated data is governed by normal low of distribution, less than value means the data is derived from different distribution (long normal).

Multivariate Analysis;Multivariate statistical analysis has been considered to treat the data of the three studied areas. The aim of the study is to demonstrate the applicability of multivariate analysis in delineating know tar-metal mineralization as well as to define other additional target area. The method has been carried out making use of the computer software.

Discussion of the Result

The target area, fall within desert, semi-desert terrain where temperature contrast represents the main agents of weathering. Supergene dispersionand accumulation of elements within the geochemical landscape has been governed by the geological,geomorphological, and climatic factors .Superficial deposits are derived directly from primary hosts rocks with their primary enclosed mineralization. Area of local anomalous gold content (concentration), recorded as local small placer deposits, and could be a results of more than one cycle of dispersion. A combination of these processes and their inter-relation at or near the surface, since mineralization times in Precambrian, governs trace elements dispersion and migration.

The first stage ofweathering started with changing of rocks from massif into clastic state forming coarse and fine grained detrital material.Eluvium which is a Destini gratedmaterial of weathering accumulate in situ, with fine-grained material being transported mostly by wind action.

Geochemical parameters, describe quantitatively the behavior of trace chemicalelementsin certain geochemical landscape. The distribution of chemical elements in certain geochemical environment is governed by geological processes, such as primary mineralization, secondary dispersion or secondary concentration.These geochemical parameters when subjected to conventional geostatistical analysis can be defined and used as prospecting and exploration criteria. The parameters considered in this study are: Background value (C b), coefficient of correlation (r), coefficient of variation of elements (C.V), geochemical factor (υ), coefficient of dispersion (mobility) (δ) and productivity (P) and geochemical reserve (QH).

The main objective of this study is to interpret the results revealed, so as to define quantitatively parameters which may be used as prospecting and exploration criteria to search for gold concentration in arid-semi arid climatic conditions. These results are discussed below as revealed in the studied area.

Background value (C b) is calculated from the probability cumulative curves were used to calculate background values for the elements Au, Ag, Cu, Pb and Zn.Gold background value is 5.5ppm, and only 8% of the number of samples revealed anomalous values.Univariate analysis of gold range is 19.98. The formula: CA= ε^3 . Cb, is also applied to calculate Cb and CA. Other statistical factors are shown on table. (2).

Coefficient of correlation (r)

In Abu Sari area only Zn correlation positively with Au, (r = 0.47) and also Zn shows satisfactory correlation with Cu (r =0.51). Ag and Cu showpositive correlation (r =0.52) and negative correlation with Au. This indicate that Au is either of different phases of mineralization with both Ag and Cu or mobile elements have been leached since starting age of digenesis, Table (3).

Table 1 Chemical analysis of Abu Sari residual soil samples.

Sample No	Au	Ag	Zn	Cu	Pb	Pb.Zn / Au.Cu	Au/Ag
A_1	N.D	12	501	40	38	-	
A_2	0.5	15	760	145	49	512.2	0.03
A_3	N.D	9	211	184	38	-	
A_4	N.D	9	275	92	39	-	
A_5	0.4	10	1056	21	59	85583.8	0.04
A_6	0.8	9	978	55	65	1444.7	0.08
A_7	N.D	10	278	349	64	-	
A_8	N.D	13	220	113	43	-	
A_9	N.D	13	42	40	573	3	-
A_{10}	1.2	5	491	57	30	215.3	0.24
A_{11}	N.D	11	202	218	57	-	
A_{12}	0.4	12	695	104	48	801.8	0.04
A_{13}	0.2	8	185	338	55	15.5	0.02
A_{14}	N.D	9	303	84	66	-	
A_{15}	N.D	9	204	151	66	-	
A_{16}	1.5	10	280	122	76	116.2	0.15
A_{17}	N.D	18	224	438	56	-	
A_{18}	20.2	9	274	185	41	2.74	2.22
A_{19}	6.4	8	198	39	46	6.8	0.8
A_{20}	8.5	8	210	157	60	9.4	1.06
A_{21}	1.4	7	206	29.6	49	228.6	0.2
A_{22}	2.1	8	122	116	53	26.5	0.26
A_{23}	5.34	8	145	79	51	17.5	0.66
A_{24}	13.26	7	171	165	70	41.5	1.89
A_{25}	2.2	8	68	193	193	30.8	0.27

Table 2 Statistical geochemical parameters of Abu Sari area, values in ppm.

	Au	Ag	Cu	Pb	Zn
Mean	2.57	9.8	162	57.5	499.9
Maximum	20.18	18	57.5	193	4240
Minimum	0.2	5	21	3	68
Range	20.18-0.2	18-5	573=21	1933	4240-68
Variance	23.69	7.83	17868.9	1023	10522751
Standard deviation	4.8	2.8	133.7	31.8	1026.04
Coefficient of variation%	206%	29%	82%	56%	20.5%
Threshold	12.35	15.4	429.7	121.46	2551.98
Number of sample	25	25	25	25	25

The Coefficient of variation (v of lead, zinc, copper, silver, and gold are 56%, 20.5%, 29%, and 206% respectively. The variation of elements in the area also differs and reflects non-uniform distribution.

The Geochemical factor (v) The ratio of epithermal (low temperature) to the hypothermal (high temperature) elements in the target area summarized the geochemical landscape of these mineralized areas. These ratios also helps in determination of mineralization horizon, or weathering level (Geneatt, et. al 1969, said, A, M, 1994) as described below:

The interpretation of the results of geochemical factors Au/Ag in Abu Sari area i.e. higher gold values are expected in deeper horizons and the sampled portion of the secondary aureole has not covered the whole prospective zone as the halo is still open towards the east.

The Pb. Zn/AN. Cu (Table.4) shows higher values, and this ratio systematically decreases towards the east direction; lowest ratio has been recorded at profile NO. V. Fig.2 .This ratio also indicates that the ore body occur at the eastern parts of the mapped area where the aureole shows higher anomalous value as mentioned before. This ratio indicates that weathering has affected deeper level of the mineralized lode.

Table 3 coefficient of correlation of elements of Abu Sari residual soil samples of quartz vein (deluvial, eluvial).

	Au	Ag	Cu	Pb	Zn
Au	1	-0.23	-0.10	0.05	0.06
Ag		1	0.05	-018	0.24
Cu			1	-0.08	0.50
Pb				1	-0.39
Zn					1

The Coefficient of Dispersion (mobility) (δ) for the elements Au, Ag, Pb, Zn and Cu were calculated to be 7,12,14,12 and 7 meters.

The Productivity The (geochemical) reserves of the elements Au, Ag, Cu, Pb and Zn have been calculated using the relationships: $P = L.\Delta\times\Sigma^{n}_{i=1}$ (CA-nCb),q=P×1×2.5/100=P/40,QH=q.H.1/k (C.F).In Abu Sari area P for gold is calculated to be = 240.60 m^2 %.

q For a layer 1 meter thick = 5.12 Ton per meter.H = 650, K= 1.5.The geochemical reserve (QH) of gold for 50m depth is calculated to be =1413 Ton. Au. Table (4)

Geomorphology of secondary dispersion haloes of gold (Au) of Abu Sari gold mine area have a gentle slope to the west direction towards the river Nile. From the isoconcentratemap .the secondary dispersion haloes have been governed by the morphology of the gold-bearing quartz. Quartz veines show boubinaged structure and the concentration of gold reaches its maximum on the eastern part of the mapped area. Gold shows erratic dispersion, and the high concentration up to 20 ppm, has been recorded in the eastern parts of the mapped area. The isoconcentrate map of gold shows that values are of irregular nature and either high grade mineralization or barren. The erratic dispersion may be due to contamination of old mined dumps around the mined veins. Gold values exhibited a strong lognormal distribution. Nevertheless gold values outlined anomalous zone of approximately of 2.5 sq.km.

For Znthe dispersion of Zn in the area shows a typical hydromorphic distribution pattern, with the highest values near the base of the hill slopes and the aureole follows controlled by the drainage system i.e open haloes along valleys towards the north direction. The element has been partially or totally depleted due to its high coefficient of mobility.

For Cuthe dispersion of Cu in the area show maximum concentration on the quartz–bearing veins, and anomalous concentration down the slopes. This is the result of both elastic and hydromorphic dispersion on the slope. The histogram shows that Cu displays a slightly skewed normal distribution.

Conclusions and Recommendations

- The revealed secondary dispersion of patterns of gold (the main ore element) and the affiliated accompanying elements indicate prolonged and variable conditions of enrichment and improvement of these elements.
- Both forms of secondary gold enrichments, viz. placer concentration and chemical enrichment should not excluded as targets for prospecting even in this desert-semi desert geochemical landscape. Therefore prospecting for gold deposits in such terrains should not be focused only on suspected primary ore bodies but also on those secondary zone, guided by other prospecting criteria such as paleo-burried channels, old terraces, geomorphological features and unconformities.
- From the studied locality it has been found that both primary and secondary mineralized zones are confined to areas where the bed rocks consist of metavolcanic-metasedimentary lithological assemblages of the low-grade greenschist facies. Shear zones and other planes of weaknesses along

structural feature and silicification in form of quartz veins and within endo-exo-contact zones of granitioidal batholiths are also encouraging prospecting criteria.

- Silica enrichment in Abu Sari areas has been interpreted to be developed in two phases. The first phase resulted in the formation of the large gold-bearing quartz veins. The second phase of silica enrichment gave the druzy cross-cutting quartz lenses of milky whitish color, which are supposed to be post mineralization, and appear to be devoid of gold.
- Abu Sari gold background value is 2.5 ppm, anomalous value is 13 ppm. Only 8% of the analyzed samples.
- Prospecting for gold (primary and secondary) should be confined to areas where the bed rocks of metavolcanic-metasedimentary lithological assemblages of the weaknesses along structural features and silicification in from of quartz veins and veinlets within endo-exo-contact zones of granitoidal batholiths.
- Sampling of the residual soil must cover the whole suspected mineralized zones guided by geomorphological, geological and geochemical criteria and should be collected at 5-10m interval, which the distance given by coefficient of dispersion.Sampling in virgin area of similar geotectonic-geochemical environment should cover drainage pattern by sampling both heavy concentrate of the sandy fraction (+18 mesh) together with clayey fraction (-80 mesh) to reveal secondary drainage dispersion patterns. This shouldlead to bound sectors where secondary dispersion haloes can be defined by soil sampling (-80 fraction) along profile across the geological strike.
- Correlation coefficient of element give reliable reliable results for chip composite samples. The correlation for residual soil samples is not a useful parameter. Chip-composite rock samples be collected for all the exposed ore bodies.
- Geochemical factor is a useful parameter for determination of ore body level as well as weathering level. To make full use of geochemical factor (υ). Sampling should be carried out for different levels and at certain intervals laterally.
- Further detailed prospecting and exploration work should be carried out to consider the morphology of the hidden ore bodies through e.g. isoconcenterate mapping.
- Open secondary dispersion haloes need to be covered by profile soil sampling so as to define the whole prospective mineralized zone,
- Trenches are be dug across the primary ore bodies and the surrounding country rocks down to bed rock.
- Where the drainage pattern washing potential mineralized zone reaches the banks of the Nile.
  The small delta should be dissected by pits along profile (rectangular grid)across the elongated deltas (wash zones) or square grid in triangular and equidimentional deltas.

Table 4 Geochemical reserves of Au, Cu, Pb and Zn of Abu Sari mineralization zone.

Chemical Element	C b	CA	Q	K	H	QH
	%	%	T/m		M	Ton
Au	2.55×10^{-4}	13×10^{-4}	0.32	1.5	650	1413
Ag	9.8×10^{-4}	21×10^{-4}	3.8	1.2	650	1087
Cu	162×10^{-4}	350×10^{-4}	1.4	0.9	650	26793
Pb	57.5×10^{-4}	120×10^{-4}	0.4	0.8	650	223
Zn	500×10^{-4}	2800×10^{-4}	25.5	0.5	650	14040

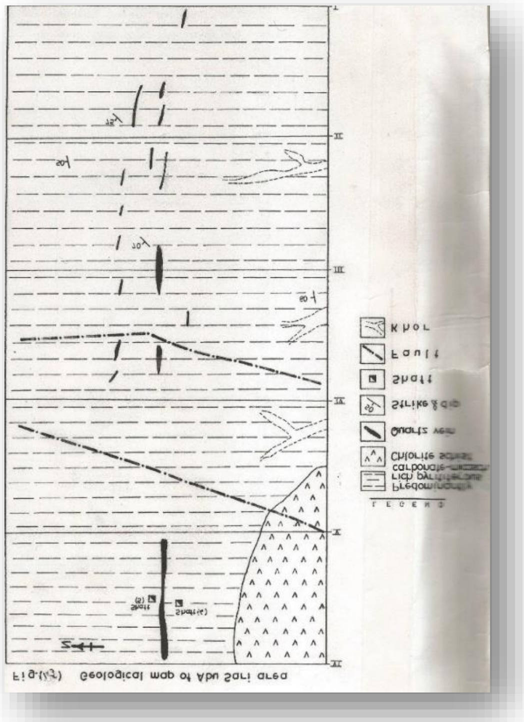

Figure 2 Geological Map of Abu Sari Area.

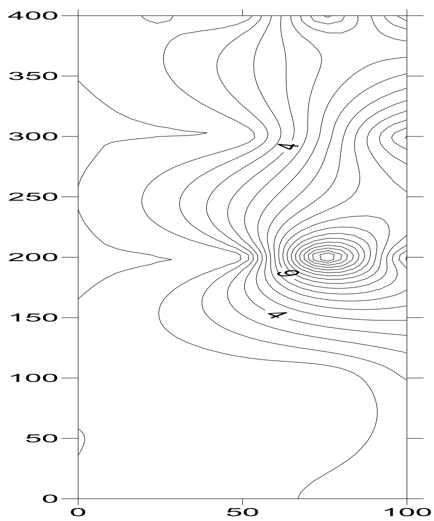

Figure 3 Isoconsentrate Map for Au-Abu Sari Area.

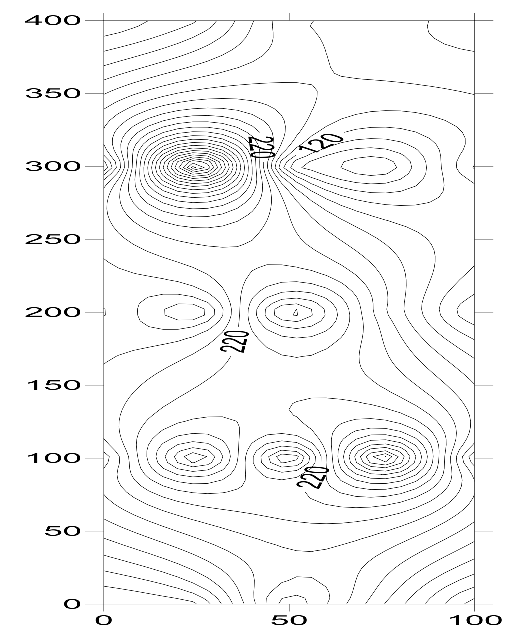

Figure 4 Isoconsentrate Map for Cu-Abu Sari

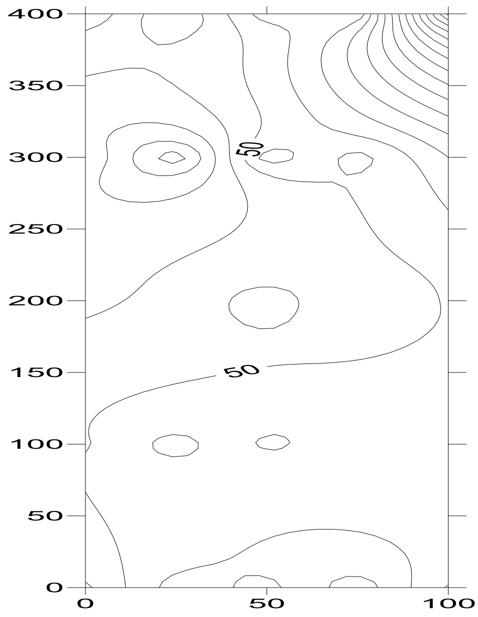

Figure 5 Isoconsentrate Map for Pb-Abu Sari

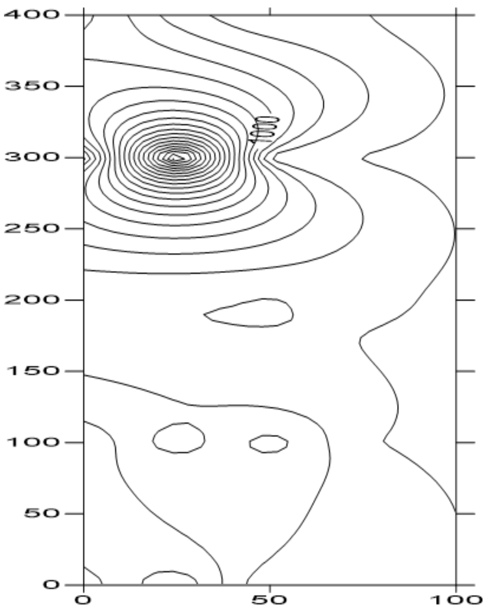

Figure 6 Isoconsentrate Map for Zn-Abu Sari

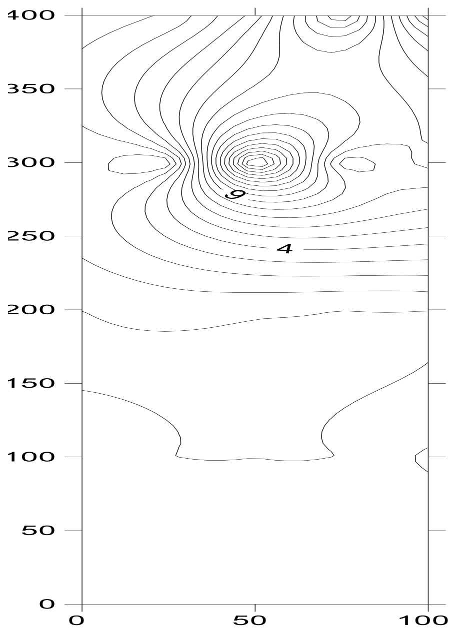

Figure 7 Isoconsentrate Map for Ag-Abu Sari.

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