

Estimating the Eastern Anomaly Mass of Kahang Cu-Mo Porphyry Deposit Using Ordinary Kriging Method

Hamed Nejad Hosseini Fashkhami*, **Houshang Asadi Harouni**, **Nader Fattahianpour**,
Seyed Hassan Tabatabai

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Abstract

Kahang Cu-Mo porphyry deposit in Isfahan is considered as one of the high potential deposits with the concentration of copper-molybdenum porphyry mineralization in surface and in depth given the severity, type and zonation of alterations as well as evidence of surface mineralization (oxide and leach cap), continuous geochemical anomaly (Cu-Mo ± Au), anomalies of magnetic geophysical index, induced polarization (IP) and resistivity (RS). Moreover, the 3-D modeling of IP / RS indicated the penetration of hydrothermal solutions coinciding with the presence of shear zones in the center of the deposit. In 3D modeling of the magnet, it was found that there is a magnetic mass in the south of the region with high permeability with extension to depth. As there were no calibrations of all the collected specimens, it was decided to use neural network method to estimate the grade in the non-calibrated specimens. For this purpose, a network with 5 inputs including sample spatial coordinates, chalcopyrite values and magnetic permeability were used. This network was run for the number of different neurons in the middle layer and finally the results of the network with 20 neurons in the middle layer were detected with respect to the RMS value for proper grade estimation. After estimating the sample grade, the deposit estimation was done. Initially, the statistical distribution of the data was analyzed and the data were transformed to the normal distribution. Then variography was performed to determine the main directions of anisotropy in the area. After determining the main directions of anisotropy, the optimal block dimensions were determined. In this way, jackknife kriging was used and finally blocks of 10 × 10 × 10 m were selected as optimal dimensions due to the low average relative error. Then using ordinary kriging, the 3-D copper grade estimation in the estimation space was performed. Estimation grade-tonnage diagram was plotted. According to these diagrams, the tonnage of Eastern Kahang deposit per grade cutoff 2500 ppm with ordinary kriging is 3437500 tons and its net copper content is 13750 tons with the same grade. Estimation grade-tonnage diagram was plotted. According to these diagrams, the tonnage of Eastern Kahang deposit per grade cutoff 2540 ppm with ordinary kriging of 3407500 tons and its net copper content is 13630 tons.

Key words: Copper deposit, ordinary kriging method, 3D modeling

Introduction

After detailed exploration and proving the existence of an economic reserve, it is time to estimate the exploitable reserves. One needs to have 3-D information from the deposit to do so. Sampling should be done, which is accomplished by digging windings in a regular or irregular network based on previous studies to obtain 3-D information from the area in question. The new approaches, mostly based on geostatistics, deal with the spatial correlation of the data in the estimation space (variography) and are more accurate. Geostatistical methods like kriging can be very good for estimating storage as it has the lowest variance, but this depends on the condition that the distribution of grade and thickness in the deposit should be structured and there should not be many discontinuities in the area. In such areas where the grade and thickness do not have a structure or there are many discontinuities, other methods are used in combination with the geostatistics (Hassanipak and Sharafuddin, 2001).

Hamed Nejad Hosseini Fashkhami*

Department of mining engineering, Faculty of Mining Exploration, Isfahan University of Technology, Isfahan, Iran.

Houshang Asadi Harouni,

Assistant Professor of Department of mining engineering, Faculty of Mining Exploration, Isfahan University of Technology, Isfahan, Iran.

Nader Fattahianpour, Seyed Hassan Tabatabai

Associate Professor of Department of mining engineering, Faculty of Mining Exploration, Isfahan University of Technology, Isfahan, Iran.

*Email: Hamed.nejadhosseini @ gmail.com

There are different approaches to identify areas and resources. In geochemical exploration, zoning indices are the most valid criterion in determining the initial auras of deposits, deposits erosion level and evaluation of mineralization in depth (Rahimi and Rahimpour, 2005). Kriging is a geostatistical estimation method. This geostatistical estimator is named in honor of one of the pioneers of geostatistical science called D. G. Krig, a South African mining engineer and is a way to estimate the grade of a mineral using the grade of specimens in or out of the sample and is based on logic "weighted moving average" (Hassanipak, 1998). Electric exploration (geophysics) can be used to measure the potentials, currents, and electromagnetic fields naturally present in the earth or are created artificially. The resistivity and IP method are of the electric excavations performed by detecting surface effects resulting from the passage of current in the ground, like other methods (Boni *et al.*, 2007). Metal or electrode IP occurs when metallic materials are present inside the rock. Our metal does not need to be cohesive here. All metal ores or their sulfides like pyrite, pyrrhotine, chalcopyrite, graphite, galena, barnite, magnetite, pyroluzite, cassiterite, ilmenite, and so on, which have a high conductivity, are greatly involved in the formation of electrode IP (Kiberu, 2002; Parasnis, 1979).

Kahang Cu-Mo porphyry deposit is located in Isfahan on the volcanic belt of Urmia-Dokhtar. This index was discovered in 2003 using Landsat Thematic Mapper (TM) satellite data processing and detection of its alteration system. Because of the intensity, type and zoning of the alterations, as well as surface mineralization evidence (oxidized and leach cap zone), continuous geochemical anomaly (Cu-Mo±Au), magnetic geophysical index anomalies, IP and RS are considered as one of the high potential deposits with Cu-Mo porphyry mineralization concentration at the surface and in depth. After zonal exploration, the semi-detailed and the first stage of the detailed exploration should be to an in-depth spatial distribution study was conducted in depth so that a detailed exploration phase could be completed at a later stage according to the results of this estimate.

As in the eastern region of Kahang, the number of excavated specimens is limited and we face a lot of discontinuity and heterogeneity due to 3-D variography, the purpose of the study is to estimate the 3-D storage of this deposit using a conventional kriging method. In this study, while introducing the study area, its geological characteristics are stated. Then using the neural network and obtaining copper grades in new windings is presented. Then the reserve area of the study is estimated by ordinary kriging methods, and finally, the results of the previous chapters are summarized and suggestions are made.

Characteristics of the studied area and exploratory studies

Kahang copper deposit is located in the northeastern corner of Isfahan 1: 250000 topographic sheets, located about 73 km northeast of Isfahan.

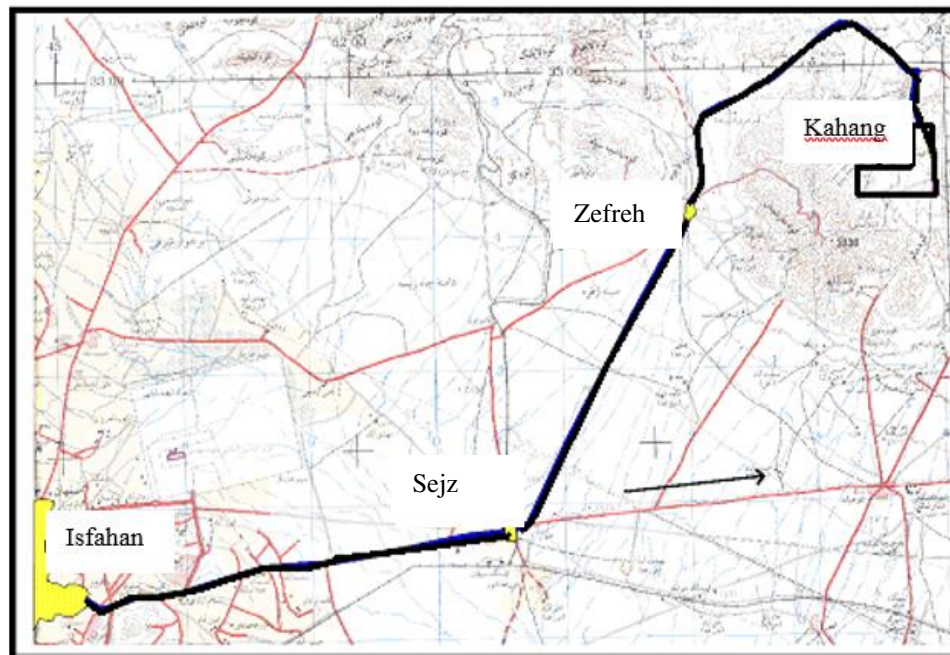
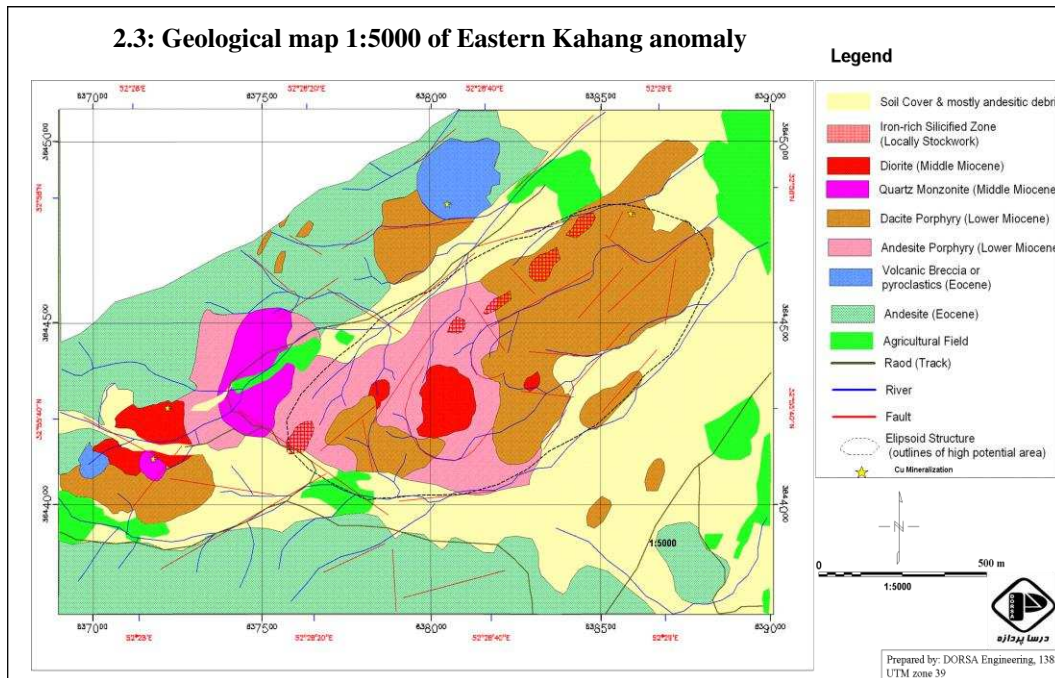


Figure 1: Access routes to the old deposit (Asadi Harouni, 2006)

As is seen in the geological and alteration maps prepared at a scale of 1: 5000 (Figure 2), the main rock units in the Eastern deposit of copper porphyry mainly include Andesite, porphyry andesite, porphyry dacite, quartz monzonite, diorite, and andesitic cuttings and quartz iron-oxides veins.

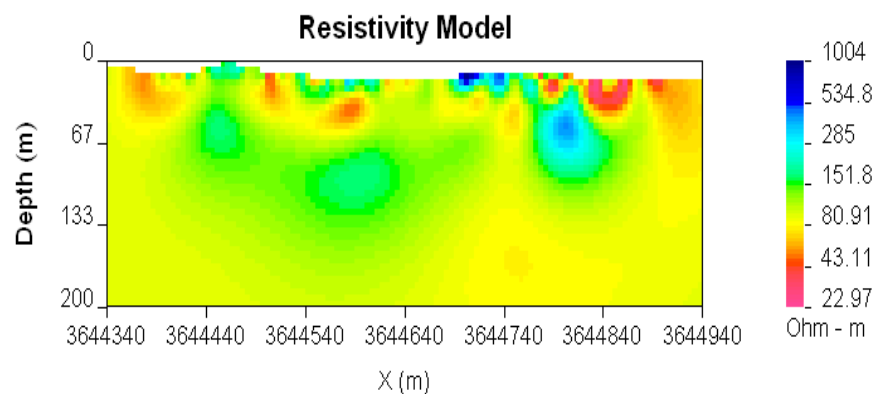


For mineralogy and petrology studies of the Eastern deposit, 16 rock specimens were collected for thin and polished sections and XRF and XRD analyses were selected. Specimens used from extra-mineralization sites were selected. Stone units in the eastern deposit are mainly andesite, andesite shear tuffs (volcanic cuts), andesite porphyry, dacite porphyry, quartz monzonite, diorite, rubble discs, along with silicate gap, quartz- magnetite veins and phyllic, argillic, propylitic, and iron oxides alteration (hematite, goethite, and jarosite), examples of which are given here (Asadi Harouni, 2006).

Field observations and polished cross-sectional studies of about 10 specimens from the Eastern Kahang Cu-Mo porphyry deposit identified the existence of chalcopyrite, pyrite, chalcocite, sphalerite, malachite, pyrolysite, neotocite (copper and manganese oxide), magnetite, gentite, hematite, goethite, jarosite and alunite. The images of polished cross-sections and field observations are shown below (Asadi Harouni, 2006).

Geophysical studies

IP and RS measurements were made by an IPC-9 transmitter made by Scintrex Co., Canada and an IPR-10A receiver made by the same company and other field devices in the time domain. The time to disconnect and connect the current in all of the above images is 2 seconds. Twelve profiles were harvested. Of these profiles, profiles 11 and 12 were in the study area, the sections of which are given along with the following interpretation (Fathipoorpour, 1996).



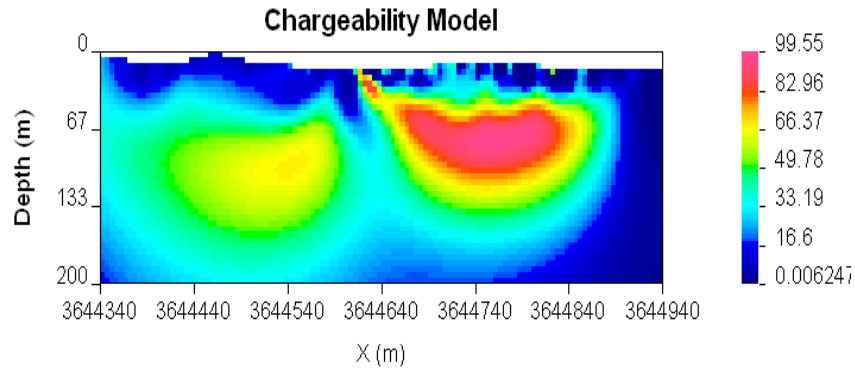


Figure 4: The final reverse model of the actual chargeability of profile 11 (Fathipoorpour, 1996)

The intensity of anomaly of chargeability in the northern branch is more than the southern branch, but the mild depth trend can be seen from north to south (Fathipoorpour, 1996).

Profile 12 is obtained with the same north-south azimuth and length of about 560 meters at 170 meters east of profile 11 and includes 180 measuring points. The results of reverse modeling in accordance with this profile are given in Figures (5) and (6). As can be seen from these sections

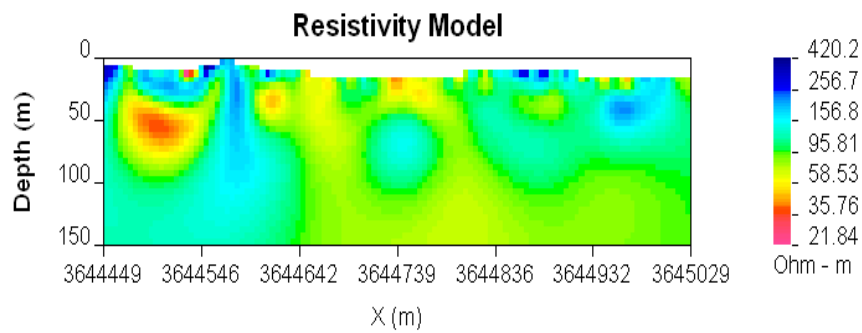


Figure 5: The final reverse model of the actual RS of profile 12 (Fathipoorpour, 1996)

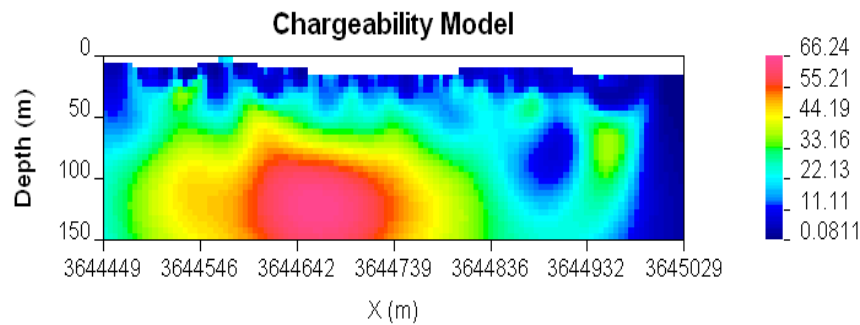


Figure 6: The final reverse model of the actual chargeability profile 12 (Fathipoorpour, 1996)

Magnetometric studies

to examine the possibility of the existence of minerals with associated magnetic (paragenetic) characteristics like pyrrhotite and magnetite and low magnetic properties in comparison with magnetite and pyrrhotite minerals such as limonite and clay minerals and to compare the results of other studies. Magnetic resonance imaging was performed. The harvested network was selected in the form of profiles, the length of which is almost perpendicular to the process of geological formations and structures. The figure below shows the operation of magnetometry data collection in Kahang region (eastern anomaly) (Asadi Harouni, 2006).

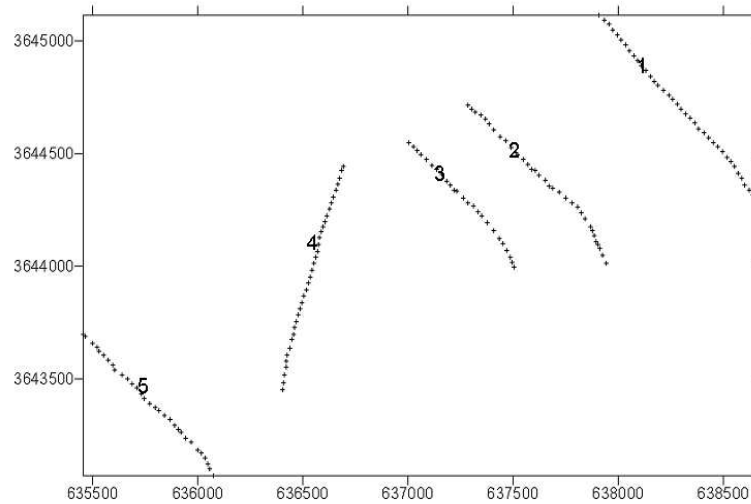


Figure 7: Magnetic harvesting profiles in Kahang deposit (profiles 1, 2 and 3 are located in the eastern part) (Asadi Harouni, 2006)

Geochemical studies

In the geochemical study of the entire alteration system of Kahang deposit, 377 lithochemical specimens (185 rock specimens and 192 soil specimens) were collected as systematically as possible. First, the basic statistical studies were performed on the data and then, according to basic statistical studies like threshold and correlation of elements, single-element copper and molybdenum anomaly maps and Cu-Mo composite aura map were prepared as is seen in Figure (8) (Asadi Harouni, 2006).

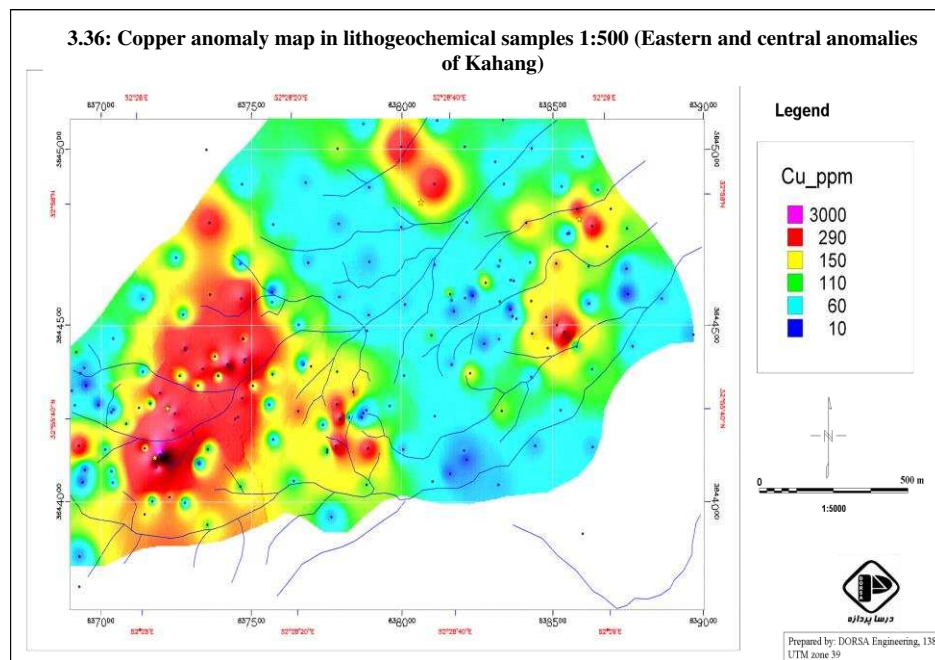


Figure 8: Copper anomaly map at a scale of 1: 5000 (Asadi Harouni, 2006)

In this study, Landsat TM and Esther satellite data were used to determine the alterations and Quick Bird (with an accuracy of up to 66 cm) satellite data to determine the structures and stone units in the range of alteration subsequently (Asadi Harouni, 2006).

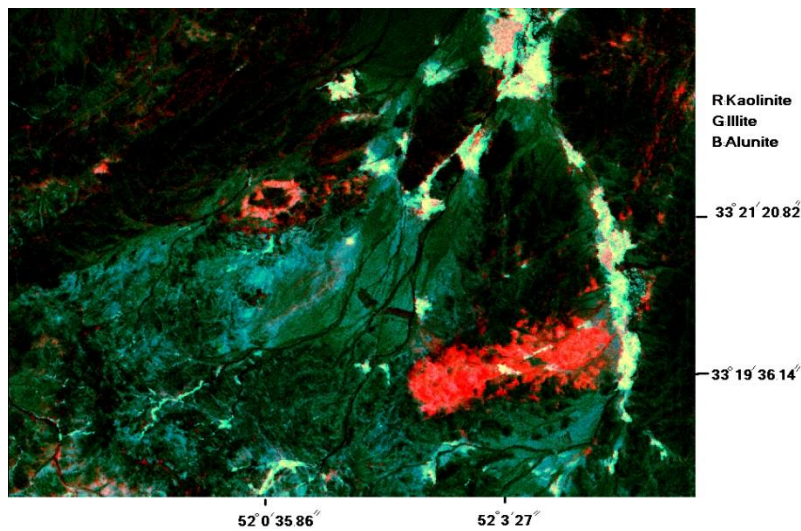


Figure 9: Alteration map obtained from Esther satellite data using red Crosta method (Asadi Harouni, 2006)

Designing and digging of the winding was done from the margin to the inside of the permeation-porphyry system (Asadi Harouni, 2006). Then 3-D geological modeling was done according to the logging data obtained from the excavation around Kahang and using Rockwork2008 software. The type of lithology was determined in each winding two meters by two meters. The following figure shows the model:

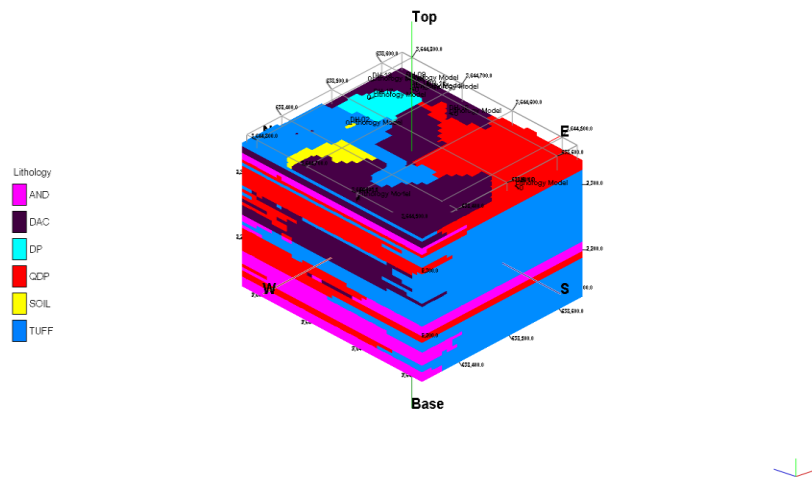


Figure 10: 3-D geological model of the Eastern Kahang deposit

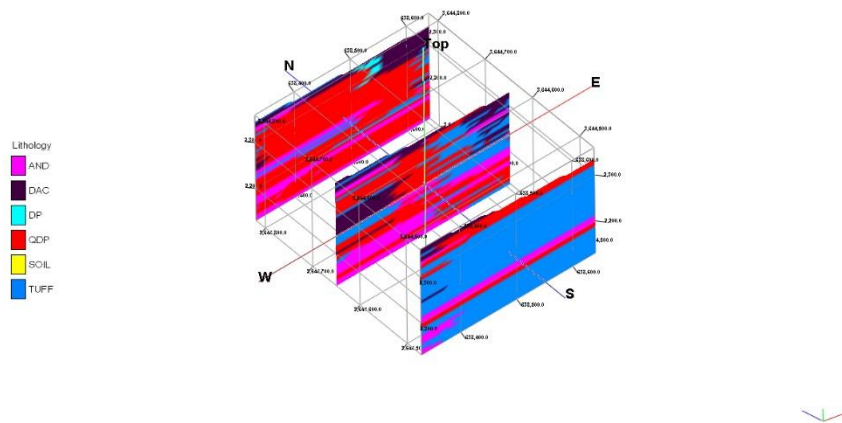


Figure 11: East-West sections of 3-D geological model

According to the above model and the east-west sections, it looks that the predominant stone in this area is porphyritic quartz-diorite. Overall, one can state that the main host stone in Kahang is porphyritic quartz-diorite.

Geochemical studies

The best factor in unambiguous analysis of identifying mineralization zones is to identify them by geochemical characteristics. Zoning indices are "dimensionless" quantities (Rahimi and Rahimpour, 2005).

Geochemical-based statistical studies are done to determine how different elements are distributed in the study. In Eastern Kahang deposit, the distribution of most of the available elements follows the parametric logarithmic distribution. Below are examples of data histograms in soil and winding specimens.

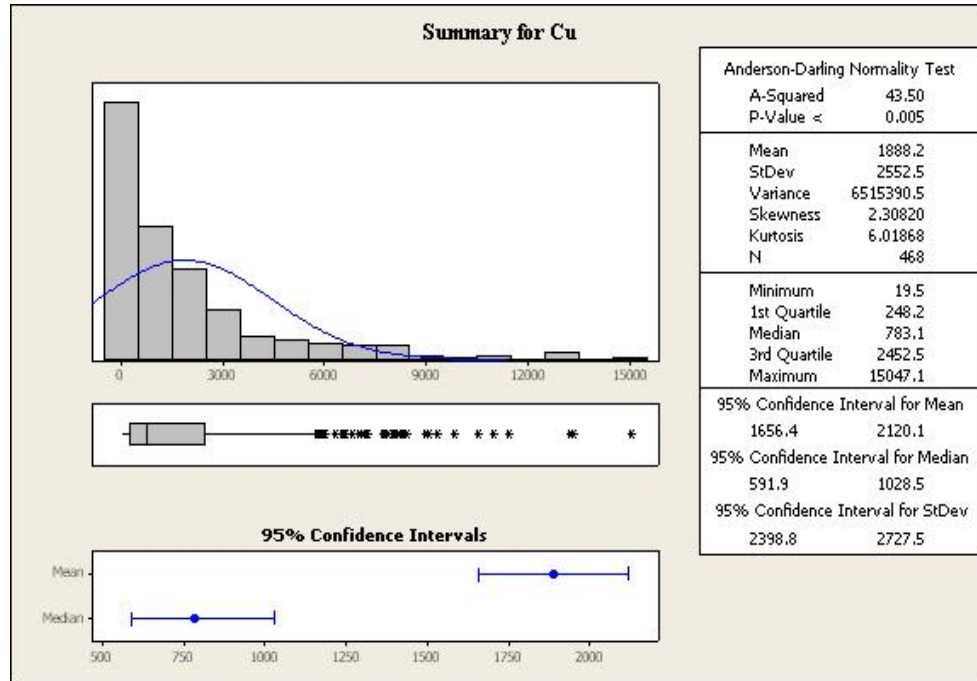


Figure 12: Copper grade histogram in winding in ppm

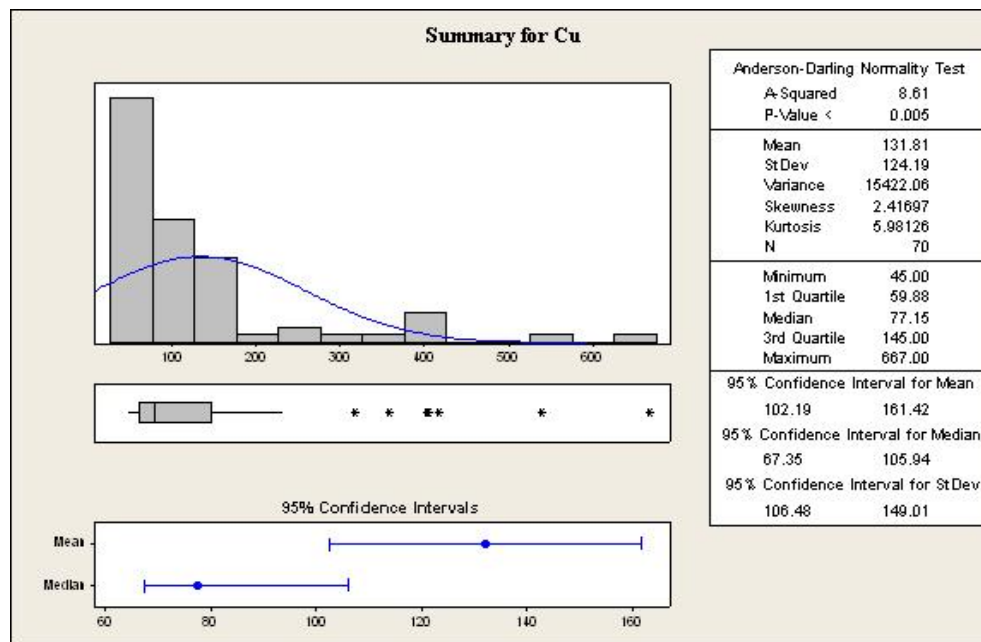


Figure 13: Copper grade histogram in soil specimens in ppm

In Easter Kahang deposit, the distribution of most of the available elements follows the parametric logarithmic distribution. To make a composite, we divided each of the windings into vertical directions and considered the average value of the sample as the standard of each horizon. In this way, we divided the 9th and 11th windings from surface to depth into 50, 68, 80 and 100 meter composites and divided 2nd winding into 30, 45 and 60 meter composites. Some of these divisions are as follows:

Table 1: 60-meter composites in winding 2

Horizon	Cu	Pb	Mo	Zn	Mn	Ag	As	Be	Bi	Co
Level	541.867	74.700	12.250	176.900	834.800	0.403	4.033	1.777	0.590	28.977
Horizon 1	576.333	47.133	2.267	50.500	386.267	0.467	3.633	1.810	0.620	14.500
Horizon 2	2051.667	136.300	18.153	223.933	929.933	1.090	4.367	2.017	0.245	5.700

Table 2: 68-meter composites in winding 9

Horizon	Cu	Mo	Pb	Ag	As	Ba	Co	Mn	Zn
Level	1031	12	196	1	13	359	15	2249	664
Horizon 1	3814	65	291	4	8	352	7	1067	585
Horizon 2	1286	21	116	2	11	189	19	1417	391
Horizon 3	1527	50	112	1	4	350	11	566	194
Horizon 4	843	10	56	1	4	329	10	443	145

The average obtained for each horizon must be normalized to calculate the zoning index. In doing so, the maximum average concentration of each reagent element on different horizons must be multiplied by a factor of 10 to be equal to the largest number in the above tables in terms of the number of digits, and then the remaining values belonging to the same reagent element must be multiplied by the same factor. Then one can calculate the value of the zoning index for each of the elements using the normalized average concentration values and obtain the zoning series of the elements. The normalized values for the above tables are given below.

Table 3: Normalized values of Table 1

Horizon	Cu	Pb	Mo	Zn	Mn	Ag	As	Be	Bi	Co
Level	0.020	0.027	0.044	0.064	0.302	0.015	0.146	0.064	0.213	0.105
Horizon 1	0.030	0.025	0.012	0.026	0.201	0.024	0.189	0.094	0.323	0.076
Horizon 2	0.075	0.050	0.067	0.082	0.341	0.040	0.160	0.074	0.090	0.021

Table 4: Normalized values of Table 2

Horizon	Cu	Mo	Pb	Ag	As	Ba	Co	Mn	Zn
Level	0.049	0.055	0.094	0.065	0.064	0.172	0.073	0.108	0.319
Horizon 1	0.131	0.222	0.100	0.136	0.029	0.121	0.024	0.037	0.200
Horizon 2	0.078	0.125	0.071	0.110	0.064	0.115	0.114	0.086	0.237
Horizon 3	0.092	0.303	0.067	0.085	0.022	0.211	0.069	0.034	0.117
Horizon 4	0.088	0.099	0.059	0.072	0.043	0.343	0.100	0.046	0.150

Now, by having normalized values on different horizons, one can calculate the zoning series. For instance, for the three elements Ba, Be, and Co, which have the highest accumulation on the surface horizon, we will have:

$$G_{Ba} = ((0.346/0.302) + (0.346/0.240) + (0.346/0.204) + (0.346/0.165))/4 = 1.595$$

$$G_{Be} = ((0.148/0.123) + (0.148/0.069) + (0.148/0.067) + (0.148/0.042))/4 = 2.270$$

$$G_{Co} = ((0.130/0.100) + (0.130/0.043) + (0.130/0.034) + (0.130/0.021))/4 = 3.584$$

As is seen, $G_{Ba} < G_{Be} < G_{Co}$. Thus, barium and beryllium are placed in barium and beryllium series zoning after cobalt, or in other words, cobalt has a higher frequency at the surface (it is more at surface) than the other two elements.

Hence, the zoning series for Tables (5) to (7) will be as follows:

Table 5: Zoning series

Co	As	Be	Bi	Mo	Cu	Zn	Ag	Pb	Mn
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Table 6: Zoning series

Mn	Zn	Cu	Ag	Pb	As	Co	Mo	Ba
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After obtaining the zoning series, it is time to validate the obtained series. In doing so, the obtained series was compared with the standard porphyry copper series. The standard series of copper porphyry is as follows:

Ba – As – Sb - (Ag, Pb, Zn) – Au – Bi-(Cu, Mo)-(Sn, Co, W, Be)

The Spearman correlation coefficient was used to compare the obtained series with the standard series.

The series obtained from various composites were compared with the standard series of copper porphyry, where only the series from winding 11 were valid and the other series from versions 2 and 9 were invalid. One of the reasons for the invalidity of 2 and 9 series of windings is that the windings have not been dug vertically, or there is probably a fault in the region that has caused the mineralization to move. For instance, when we calculated the 9-meter zoning series instead of the 350-meter total borehole length for its initial 180 m, this series was valid for 60-meter composites listed below:

Table 7: The zoning series obtained from 180 meters of initial winding 9

Mn	Ba	Zn	Ag	Cu	Pb	Mo	Co	As
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Table 8: Comparison of series obtained from 60 m winding composites with standard porphyry copper series

	As	Ba	Zn	Pb	Ag	Cu	Mo	Co
Initial rank	1	2	3	4	5	6	7	8
Comparative rank	2	1	4	4	4	6.5	6.5	8
Difference square	1	1	1	0	1	0.25	0.25	0

Considering the number of specimens and the value of $\sum(\Delta^2) + T_x + T_y$, the series obtained is valid at the at the confidence level of 99%. Thus, there is a possibility of a fault in the area that has caused the mineralization.

The zoning series obtained from winding 11 are valid at the confidence level 99%. Among these, the series obtained from 80-meter composites were considered valid because of having a higher correlation coefficient (82%), which was used to determine the erosion level indices.

Table 9: Comparison of series obtained from 80-meter composites with standard porphyry copper series

	Ba	As	Pb	Sb	Zn	Cu	Ag	Mo	Bi
Initial rank	1	2	3	4	5	6	7	8	9
Comparative rank	1	2	5	3	5	8.5	5	8.5	7
Difference square	0	0	4	1	0	6.25	4	0.25	4

Geophysical sampling in Eastern Kahang

In this study, IP and RS measurements were performed by an IPC-9 transmitter made by Scintrex Canada and an IPR-10A receiver made by the same company and other field devices in the time domain. The time of disconnection and connection of the flow in all the above samplings is considered 2 seconds (Fathipoorpour, 1996). Of these profiles, profiles 11 and 12 have been collected in Eastern Kahang, the results of which are given in Chapter 2. In September 2009, a new profile called 112 was obtained between the two profiles. The position of the harvested profiles can be seen at 1: 1000 topographic map of the area.

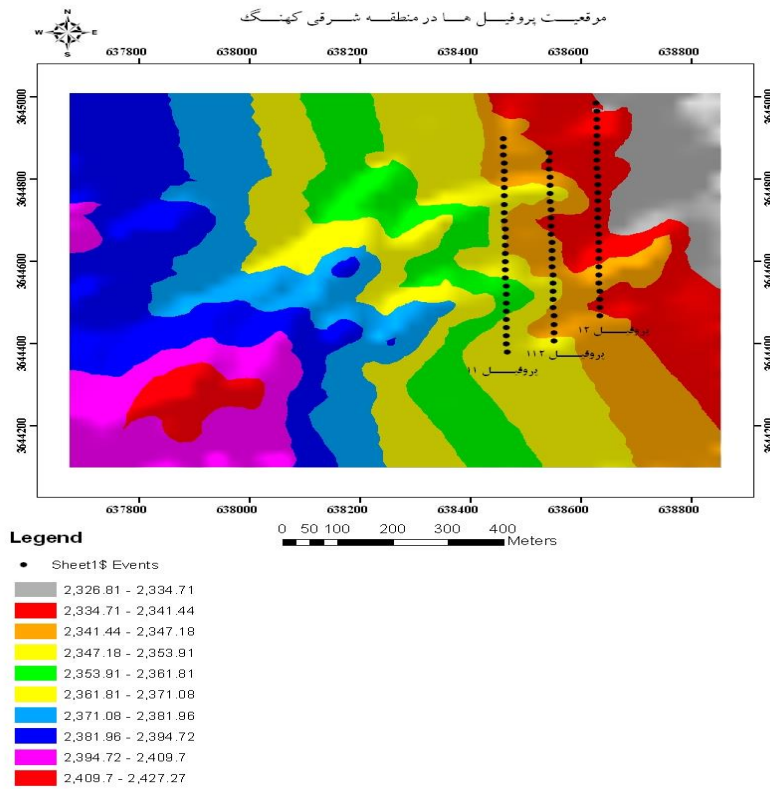


Figure 14: Location of the profiles harvested in Eastern Kahang deposit

3-D modeling of geophysical data

For better understanding of the distribution of chargeability factor, RS and permeability in space, using data obtained from reverse modeling and internalization of this data in three dimensions, a 3-D model of distribution of these factors was plotted. This is done using Rockworks2008 software. The following is a 3-D model of RS, chargeability and permeability.

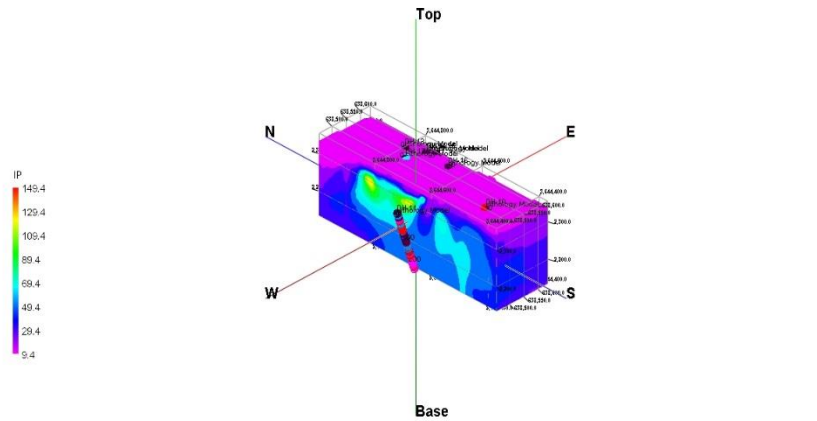


Figure 15: Chargeability 3-D model in Eastern Kahang zone

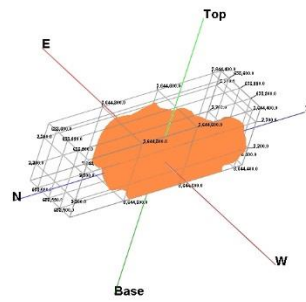


Figure 16: Chargeability 3-D model with a chargeability capacity over 40 mV/V

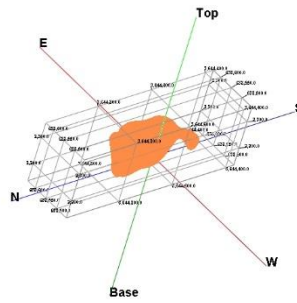


Figure 17: Chargeability 3-D model with a chargeability capacity over 60 mV/V

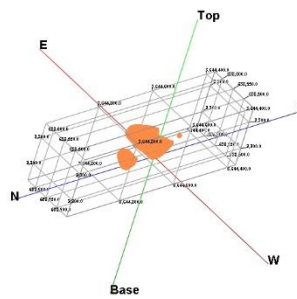


Figure 18: Chargeability 3-D model with a chargeability capacity over 80 mV/V

According to Figure (18), chargeability capacity in the 3-D model is 1.74-149.4 mV/V. As is seen in the figures above, the high chargeability capacity is seen at low depths and in the central region, which can show the penetration of hydrothermal solutions from depth to surface.

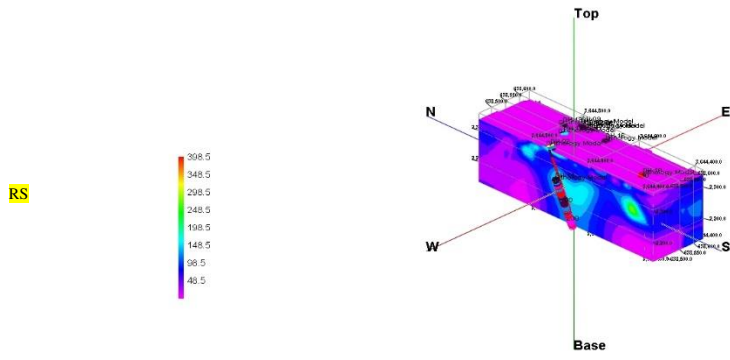


Figure 19: 3-D model of RS of Kahang Eastern zone

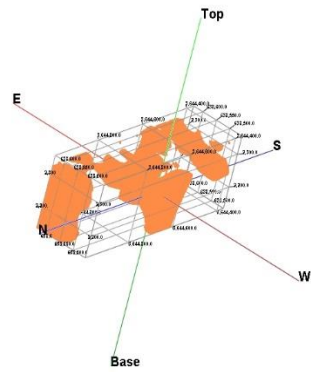


Figure 20: 3-D model of RS with a resistivity above 120 ohms

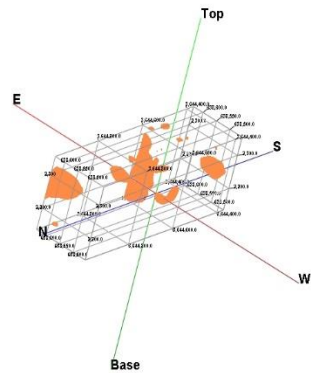


Figure 21: 3-D model of RS with a resistivity above 170 ohms

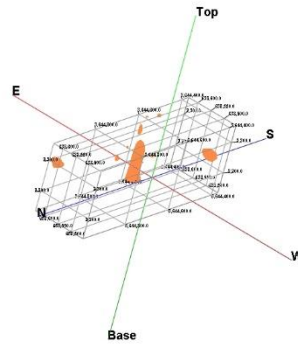


Figure 22: 3-D model of RS with a resistivity above 220 ohms

The range of RS changes is 17.96-398.5 ohms-meters. According to the above models, one can state that the high difference in the central region is consistent with the high chargeability in this region too, and shows the penetration of hydrothermal solutions along with silica vessels and the shear zone is in this area. However, there is a high degree of RS in the southern and northern parts, which is not in line with the chargeability models.

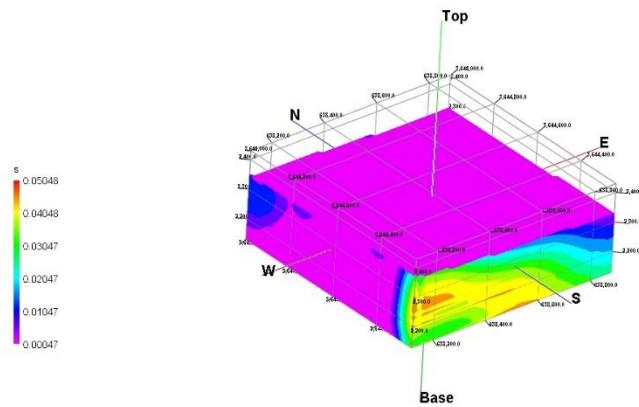


Figure 23: 3-D model of permeability in Eastern Kahang zone

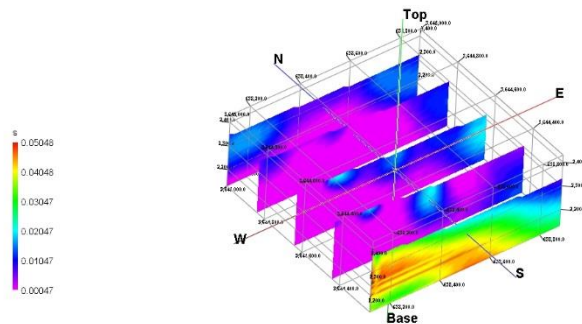


Figure 24: Sections obtained from 3-D permeability model

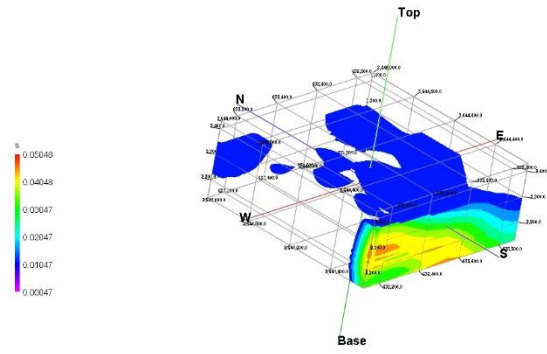


Figure 25: 3-D model of permeability above 0.01

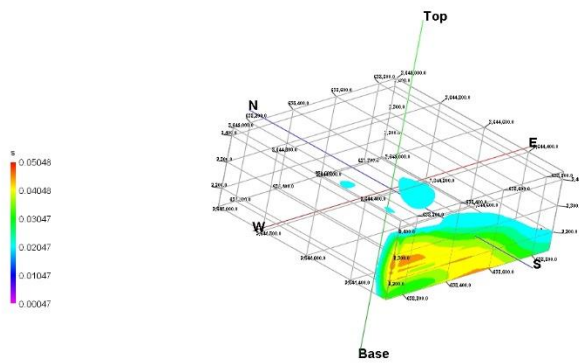


Figure 26: 3-D permeability model above 0.02

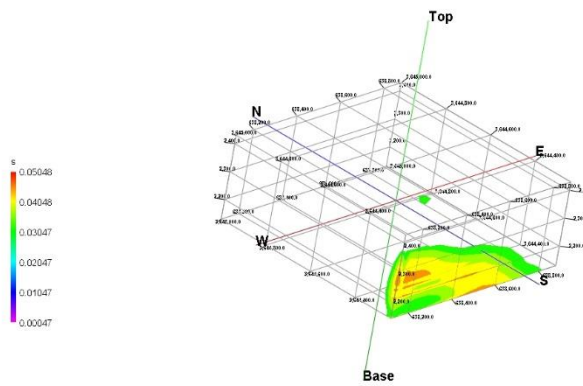


Figure 27: 3-D permeability model above 0.03

Based on the above sections and figures, it seems that the main trunk of the magnetic mass stretches from the south of the region to the north, so that permeability in the south of the region is high and as we move towards the north, this value decreases. Moreover, it seems that the magnetic mass in the south of the region has a depth expansion of more than 200 meters.

Estimation of copper grade using neural network method

One must first do some pre-processing on the data to get the proper answers from the neural network. In doing so, we must first plot the total histogram of the copper data. According to the chart, we are dealing with two different populations. The first was related to scattered copper and porphyry, and the second the penetrating veins that showed the high grade of copper. This population actually shows the penetration of hydrothermal solutions into the rock. Thus, we separated the criteria for this community from the porphyry copper community and did not use them in the neural network. After doing so, the remaining data for the neural network was 353 copper grade data including copper grade specimens of windings 2, 9, 11, and 22 specimens analyzed were from the new windings. Below is a histogram of the primary data and data used in the neural network.

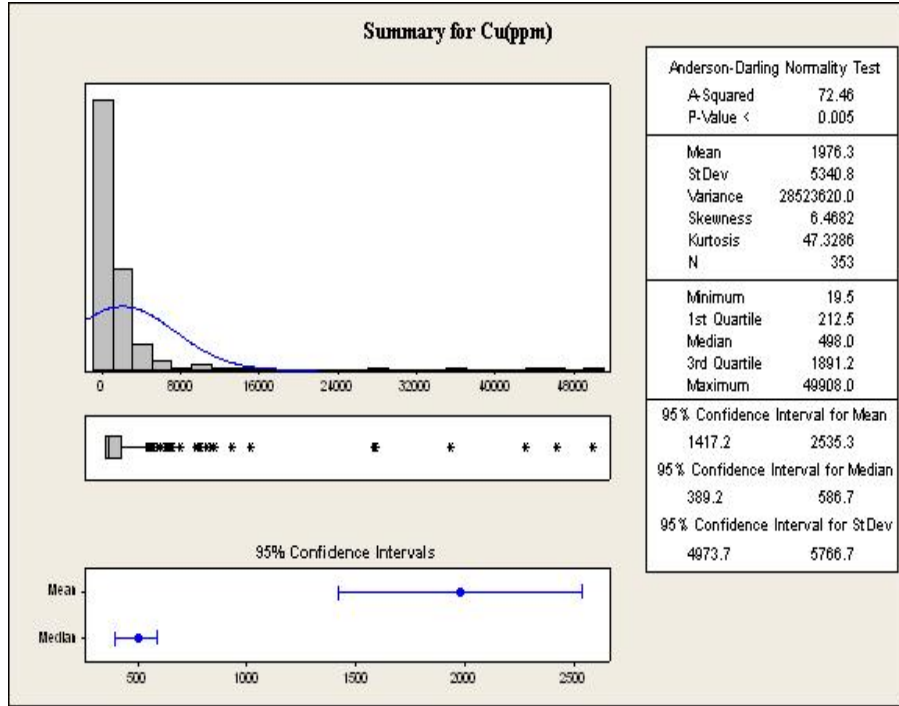


Figure 28: Histogram of primary copper grade data

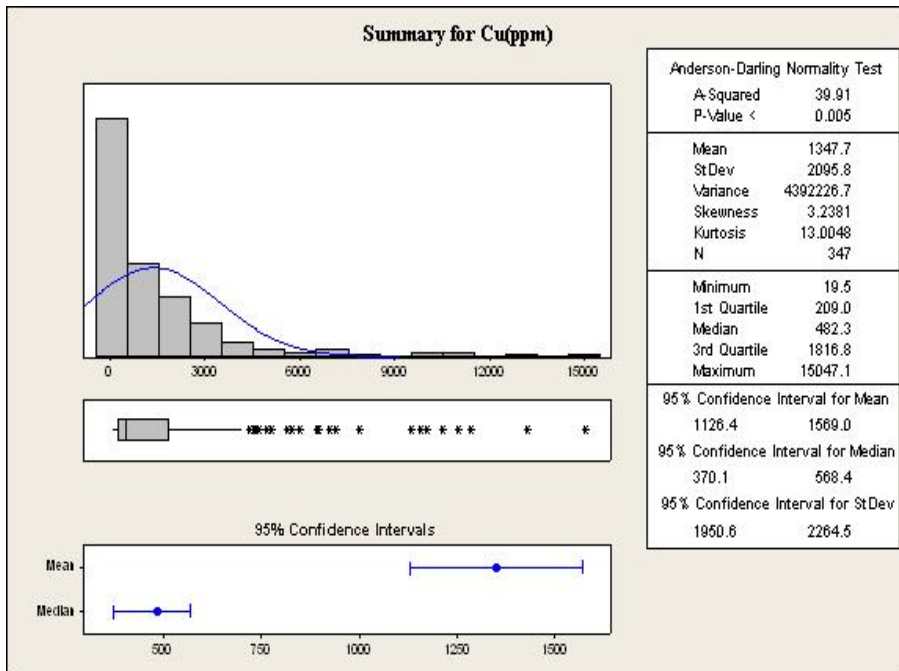


Figure 29: Histogram of copper grade data used in neural network

As Figure (29) shows, the grade of copper data varies from 19.5 ppm to 49908 ppm, which is a very large range of changes. Hence, as copper grades were seen in the veins, it was decided to remove grades above 20,000 ppm from the dataset. Moreover, the data similarity matrix was calculated to remove data that is very similar (their distance from each other is small) from the data, which was ignored given the limited data to run the network.

The neural network used in the study is a neural network with five inputs and one output (copper grade). In this method, the neural network is run randomly for a number of data several times, and finally the average estimate of the various networks is considered as the final estimate. A program written in MATLAB environment has been used to implement this method.

Table 10: Table of relative errors obtained for the analyzed specimens (to be continued on the next page)

borehole	Cu	Cu-m	Difference	Relative errors
KA-DDH13	6906	4405.183	2500.817	0.3621
KA-DDH13	2064	1541.117	522.883	0.253
KA-DDH13	46303	42383.328	3919.672	0.0846
KA-DDH14	4120	2486.636	1633.3631	0.396
KA-DDH14	1162	777.909	384.091	0.331
KA-DDH14	49908	38160.55	11747.45	0.235
KA-DDH14	9529	6276.77	8252.23	0.341
KA-DDH14	1772	1988.663	-216.663	-0.122
KA-DDH15	498	436.448	61.551	0.123
KA-DDH15	373	481.622	-108.623	-0.291
KA-DDH15	1487	1357.777	129.223	0.087
KA-DDH17	25	30.863	-5.836	-0.234
KA-DDH17	2784	1944.493	839.507	0.301
KA-DDH17	27730	11627.92	16102.08	0.581
KA-DDH17	35433	33178.28	2254.72	0.064
KA-DDH17	27582	20536.912	7045.088	0.255
KA-DDH17	3668	2406.302	1261.698	0.343
KA-DDH10	2035	1305.856	729.143	0.358
KA-DDH10	1134	1531.082	-397.082	-0.350
KA-DDH16	242	319.1529	-77.153	-0.318
KA-DDH16	1062	952.265	109.734	0.103
KA-DDH16	432	423.783	8.216	0.019

Kriging

Under ideal conditions, the purpose of analyzing the structure of a region variable in a deposit is to identify its properties of that spot, because at the estimate used by the geostatistical method of point data, these data belong to the V-volume sample placed in its center. Considering the homogenization of each sample and then measuring the desired quantity on it, the variable of the region is called the so-called regulated. In doing so, the results of drilling core analyses for copper grade were used as 8-meter composites. Finally, 195 8-meter composites from 9 windings, whose scattering position is seen in Figure (5-1), were used for geostatistical calculations. The estimated area has $200 \times 310 \times 350$ dimensions. Prior to conducting geostatistical studies, it is necessary to first perform statistical studies on the available data and to determine the statistical descriptive parameters and the method of data distribution, for which Wingslib software was used.

As one of the necessary conditions for geostatistical studies is using normal distribution, the data must be transformed to normal distribution. There are different approaches to transform data to normal distribution, of which three-parameter transformation and Box Cox transformation. The histogram of the transformed data is shown in Figure (5-3).

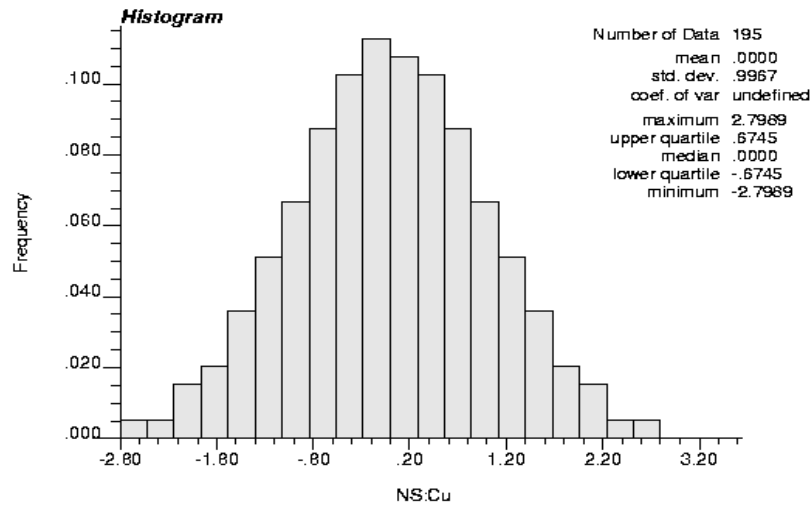


Figure 30: Histogram of data transformed to normal distribution

Variography

The purpose of establishing a variogram function is to be able to recognize the structure of variability, especially relative to distance, and to determine the directions of maximum anisotropy for estimating by kriging method. At first, a non-directional variogram of the area is plotted. This type of variogram is usually used in isotropic deposits or at the beginning of variography to examine the possibility of the presence or absence of a suitable spatial structure. In 3-D space to determine a directional variogram, two angles must be specified for the vector h, including 1) the vector angle h located on the xy plane with a positive direction of the x-axis and 2) the vector angle h with the xy plane from called angles θ and ϕ . To cover all directional variograms, angle θ must vary between zero and 180 and angle ϕ between -90 and +90. In this study, directional variograms with angles of 0, 30, 60, 90, 120 and 150 degrees for angles θ and ϕ were calculated using Wingslib software and optimized by Variowin software.

Table 11: Characteristics of the variograms corresponding to the main directions of anisotropy

Max.	Influence radius	Nugget effect	Slope	Extension	Model	Continuity of variability
1	170	0.64	0	0	Linear	Maximum
0.99	80	0.13	0	60	Spherical	Middle
0.71	37	0.14	60	30	Spherical	Minimum

After variography and determining the main directions of anisotropy, it is time to determine the optimal dimensions for the estimated blocks. As the minimum distance between the windings was 23 meters, the dimensions of the blocks in x and y directions were considered equal to half of this distance - 10 meters.

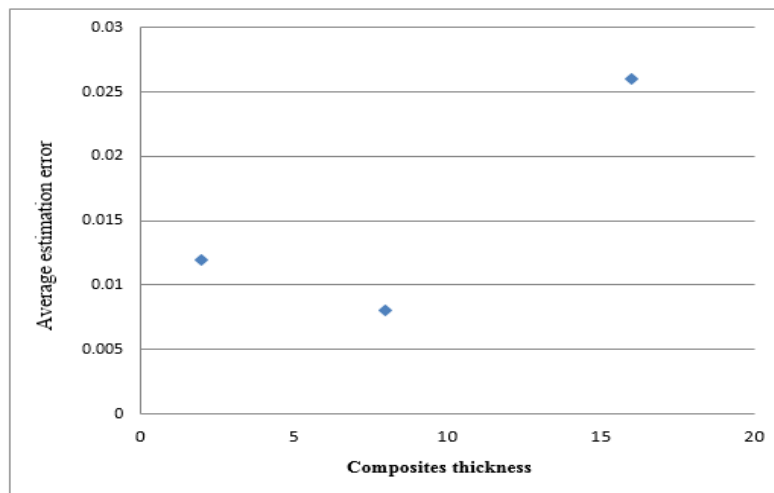


Figure 31: Graph of errors obtained by jackknife kriging method for block dimensions appropriate to composites

Thus, by having the main directions of anisotropy, non-directional variogram and determining the optimal dimensional block dimensions, 3-D estimation of copper grade in the eastern region of Kahang was performed using Kings3d program of Wingslib software. Then the results of grade estimate were transferred to Rockwork 2008 software and a 3-D estimate block model was plotted as follows.

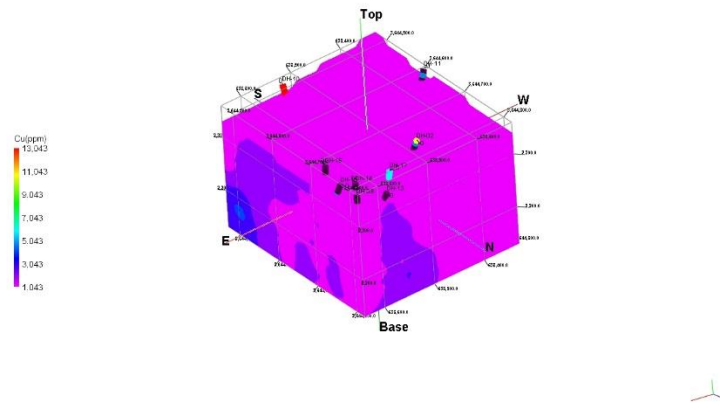


Figure 32: Block model of copper grade estimate in Eastern Kahang deposit

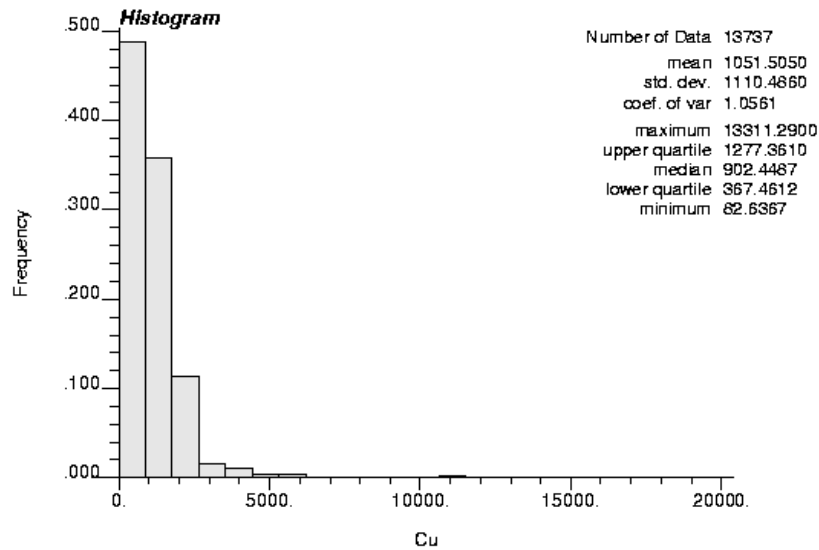


Figure 33: Histogram of the transformed data from grade estimate

Figure (32) showed that the statistical characteristics of the estimation data are very close to the statistical characteristics of the primary data. Here, the distribution is of the L-distribution type too, which means that the lower grades have a high frequency and the high grades have a low frequency.

One must first obtain the volume of the blocks that are higher than the standard grade to calculate the mineral reserves using the estimated blocks. This value is then multiplied by the average volume of rocks in the area, in which case the value obtained can be extracted equal to the tonnage of the ore. If we multiply this value by the average value of the grades above the grade of the limit, the resulting value can be extracted equal to the tonnage of pure mineral. Based on these and considering the limit of 0.25% for copper, ore tonnage and net copper tonnage that can be harvested with this grade are given in the table below.

Table 12: Net tonnage and net copper for 2500 pp

Pure copper (ton)	Average grade (%)	tonnage	Medium rock density	Ore volume (cubic meters)
13750	0.4	3437500	2.5	1375000

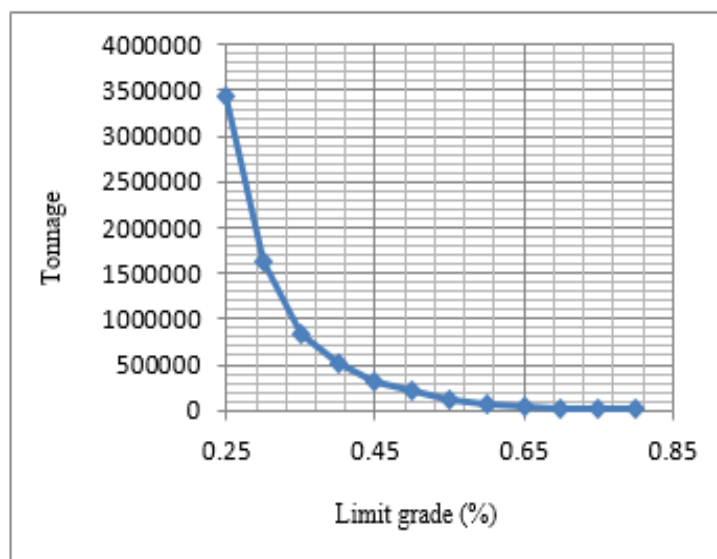


Figure 34: Grade-tonnage diagram of Eastern Kahang deposit (for estimating ordinary kriging)

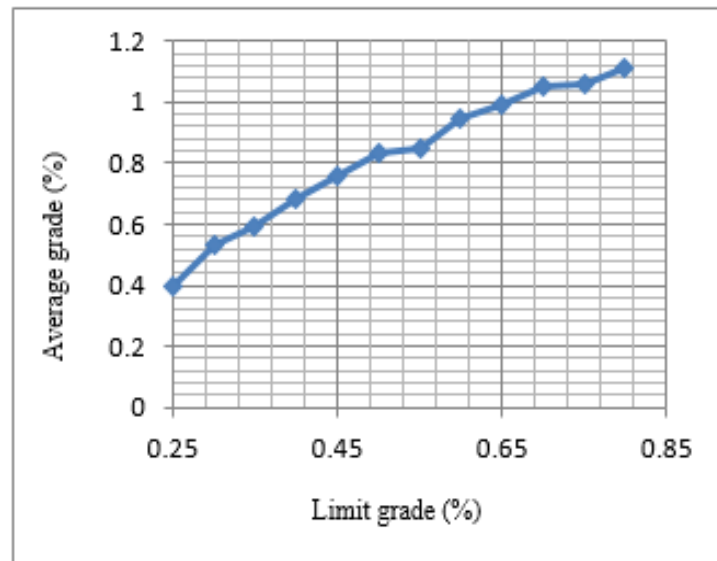


Figure 35: Average-limit grade diagram of Easter Kahang deposit (Estimated with ordinary kriging)

Conclusion

The study used various methods to estimate the 3-D storage of the deposit. In the geochemical discussion, the zoning index method is used to determine the erosion level indices as summing the linear production power of the auras or their mean in the zoning index method that is usually done for a large group of elements reduces the effect of random errors on the initial data. RS, chargeability, and magnetometry studies have been performed in discussion of the geophysics of the region. As according to the previous and new geological studies, cutting and alteration zones are intense in the region, carrying out RS and chargeability studies are necessary to identify shear zones, siliceous veins and to move the hydrothermal solutions. The region's magnetometric studies have been performed to identify the region's magnetic mass and its relationship to copper mineralization. As some of the specimens of exploratory specimens had not been analyzed, the neural network method was used as one of the best methods for identifying nonlinear relationships between variables to determine the standard of these specimens. After determining the grades, the deposit storage was estimated by ordinary kriging method. It is recommended that the uniform geochemical indices obtained should be used for drilling in other Kahang zones. In doing so, one can use the information of the windings drilled in other zones and obtain the desired ratios for them to determine the position of the erosion level for other excavations.

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