

Original Research Paper

Geochemical and Petrology Properties of Zafarghand Index and Kahang Deposit of Porphyry Copper-Molybdenum

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Abstract: The probability of the occurrence of porphyry copper ore associated with subduction zone of the Neo-Tethys ocean and volcanic arc of Iran (Urumieh-Dokhtar) justifies the necessity of exploration and prospection of this type of ore in Iran. Zafarghand index and Kahang deposit of porphyry copper-molybdenum located in Isfahan province, center of Iran using Satellite data interpretations were discovered in the years of 2010 and 2003, respectively. Geological studies have indicated the presence of argillic and propylitic alteration halos associated with porphyry copper systems. The 250 rock samples were systematically collected at a sampling distance of 100 m and in the center of the porphyry system by a distance of 50 m in Zafarghand. Also, 377 samples of lithogeochemicals (185 rock samples and 192 soil samples) were extracted systematically from Kahang deposit. The study of geochemical data of rock and soil samples showed similarity of these two types of mineralization with other mineralization of porphyry copper-molybdenum elsewhere in the world. Finally, the comparison of geochemical anomalies copper with rock units and alteration zones showed that atmospheric waters had washed out the copper in some of these zones and probably the supergene zone was formed in depth as porphyry copper-molybdenum deposit.

Keywords: Porphyry Copper Alteration, Copper-Molybdenum Porphyry, Geochemistry Anomaly, Zafarghand, Kahang

Introduction

Porphyry copper-molybdenum deposits have been known for the first time in the early decade of the twentieth century in North America. Since then, this term has been used for a wide range of dispersed sulfide deposits associated with intrusive bodies formed in orogeny belt. The composition of intrusive rocks from the porphyry copper-molybdenum deposit varies from acid to medium rocks. The most common combination of intrusive rocks is quartz-monzonite composition, however various compounds from syenite to diorite have also been seen (Karimpour *et al.*, 2005). Generally, porphyry copper mineralization were made in the vicinity of granitic Miocene rocks in the central Iran's volcanic arc (Aliani *et al.*, 2009). Magmatic

activities and mineralization correlations in this arc are also related to the Zagros zone (Derakhshani and Abdolzadeh, 2009). Ever-increasing demand of the metals on the one hand and the reduction of the feasible and superficial sources of these elements on the other hand have caused the deeper reserves of these metals to be considered. The importance of porphyry type deposits as world sources of copper-molybdenum and valuable metals such as gold, silver, selenium, tellurium and rhenium, can justify the importance of exploration of this type of ore deposits (Kudrin *et al.*, 1986). Prior studies associated with geological aspects in Kahang deposit were conducted; for instances in (Afzal *et al.*, 2012; 2010), they studied various mineralization zones especially supergene enrichment and hypogene zones in Kahang deposit, based on analyzing

the subsurface data using a proposed power spectrum-volume (P-V) fractal method. Yasrebi *et al.* (2012) various geological models of the eastern part of Kahang Cu-Mo porphyry deposit were studied. The all alteration and zonation were separated by 3D models of lithology and the alteration model further illustrates that there is an extensive phyllic alteration associated with the shallower potassic alteration to the west approaching the surface (Komeili *et al.*, 2016). Yasrebi *et al.* (2013) identified the major mineralized zones including supergene enrichment and hypogene enrichment in the Kahang porphyry deposit.

In this study, not only the geological properties but also the geochemical properties such as study of geochemical anomalies of elements, determination of threshold values to separate anomalies from background using detachable statistics methods based on the probability distribution function and calculating correlation between chemical elements in order to clustering them have been investigated. Eventually the anomaly maps of single and composite halos of copper and molybdenum were depicted to assign the enrichment zones in both Zafarghand index and Kahang deposit.

The Introduction of Urumieh-Dokhtar Volcanic Arc

The Urumieh-Dokhtar volcanic arc were formed by the subduction of the Neo-Tethys oceanic plate and subsequently the Arabic plate below Iran during the middle Miocene and its rocks are generally intermediate volcanic rocks and their pyroclastics. As shown in Fig. 1, this arc is along the strip with length of 1700 km and with a width of roughly 40 to 80 km which is parallel to the metamorphosed zones of Sanandaj-Sirjan and Zagros thrust and it has been stretched with a trend of northwest to southeast (Darvishzadeh, 1991). The thickness of crust in this zone is 45 to 50 km and is known as largest belt of copper in Iran. Because of the major copper deposits such as Sungun, Sarcheshmeh, Miduk and Darehzar are located in it. Creating this zone is mainly based on magmatic activities in Cenozoic and especially in the Neogen- Pleistocene. The location of both Zafarghand index and Kahang deposit of porphyry copper-molybdenum along with other porphyry copper deposits are shown in Fig. 1.



Fig. 1: Location of Urumieh-Dokhtar volcanic arc and Zafarghand index and Kahang deposit (Asadi Haroni, 2010; 2003)

Geology and Petrology of Zafarghand Index and Kahang Deposit of Porphyry Copper-Molybdenum

Geographic Location and Geology of Zafarghand Index and Kahang Deposit

Zafarghand index is located of 89 km NE of Isfahan center, 22 km S of Ardestan city and 6 km W of Zafarghand village on the Urumieh-Dokhtar volcanic arc. The Kahang deposit is also located at 73 km NE of Isfahan center and on Urumieh-Dokhtar volcanic arc. Tectonic point of view there has been located at the intersection of the Urumieh-Dokhtar volcanic arc and the some part of the Doruneh fault with the NE-SW trend.

The mentioned index and deposit are located at the edge of the central Iranian zone and the Urumieh-Dokhtar volcanic arc, so the presence of copper or other elements are potential. The lithology units of this index are mainly dacite porphyry, andesite, basalt, locally diorite and alluvial. The major of these rock units were affected by highly altered hydrothermal solutions and the alteration zones were created from the center of the porphyry system to the margins, respectively, include phyllic, argillic, propylitic and also potassic alterations could be seen in some parts of the area. Fe-hydroxides (i.e.; hematite, goethite) are observed in most places associated with central alterations. quartz-stockworks and veins and quartz-magnetite gouge in joints and fractures are found in many points related to copper mineralization (malachite and azurite) (Fig. 2).

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Petrology of Zafarghand Index and Kahang Deposit

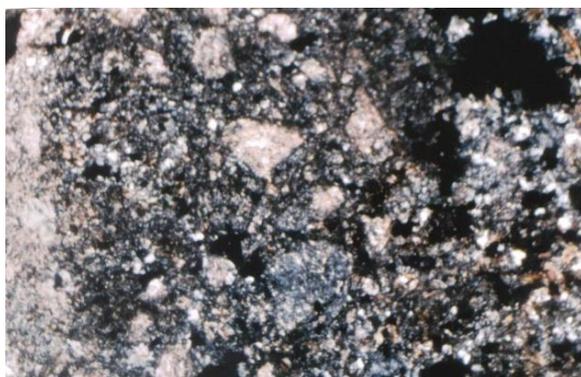
The main rock units in Zafarghand porphyry copper index are mainly andesite, Dacite porphyry, Rhyodacit, quartz diorite and diorite, with quartz-magnetite veins and phyllic (quartz-sericite), argillic (quartz-clay minerals), propylitic (Chlorite-epidote) alterations and

various types of Fe-oxide (hematite) and Fe-hydroxides (Jarosite and goethite). Alterations from the center of the porphyry system to the margins, respectively, include phyllic or quartz-sericite (mainly in the center of the southern and northern porphyry systems), quartz-magnetite stockworks (mainly in southern porphyry system), argillic (quartz-kaolinite) and propylitic alteration (epidote, chlorite in margins). Fe-hydroxides (i.e.; hematite, goethite) are observed in most places in relation to phyllic and argillic alterations.

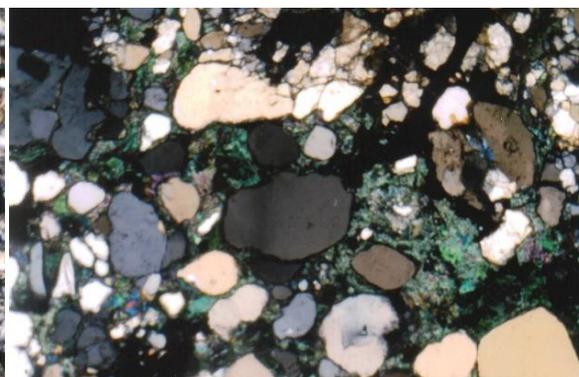
The original matrix of the Rhyodacit as main rock unit is strongly influenced by the phenomenon of sericite and clay and represents the process of the phyllic and argillic alterations, so the original composition of the rock has not been recognized. However it can be assumed that this rock is probably a Rhyodacit, which were affected by the condition of silicification and the silica veins with were formed extensively. After the phenomenon (silicification), the copper (malachite) and also the goethite in between quartz crystals were also composed in vein forms (Fig. 3).



Fig. 2: Quartz and malachite veins in Zafarghand index (Asadi Haroni, 2010)



(a)



(b)

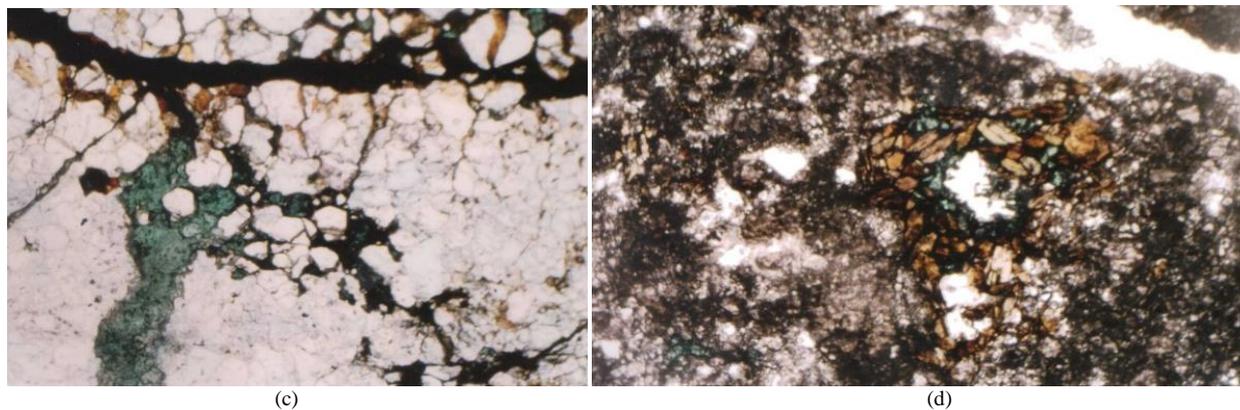


Fig. 3: Microscopic images of (magnified×40 in xpl) (a) malachite forming in quartz crystals of a silica vein in the matrix of the Rhyodacit, (b) the phenomenon of sericite and clay from feldspars in matrix, as the phenocrysts, (c) the formation of secondary Biotite crystals with malachite around the voids in the Rhyodacit, (d) Malachite, goethite and minerals indicate a delay phase in their formation relative to the matrix (Rhyodacit) (Mansouri Esfahani, 2010)

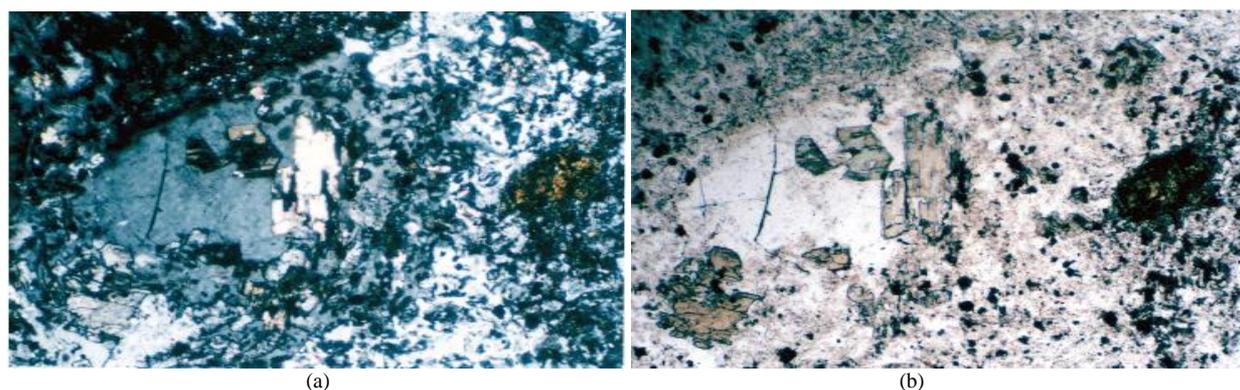


Fig. 4: Microscopic images, (a) amphibole crystals and plagioclase in the matrix of andesite microcrystalline, chloride phenomenon in all sections and epidotization of amphibole in the right side (propylitic alteration) is well observed; (b) hornblende residues undergoing chlorite and epidotization in andesite, which indicates propylitic alteration (Mansouri Esfahani, 2003)

The main rock units in the western deposit of Kahang porphyry copper are mainly andesite, andesite porphyry, dacite porphyry, quartz-monzonite, diorite and breccia andesite with quartz-magnetite veins and phyllic alterations (quartz-sericite), argillic (quartz-clay Minerals), propylitic (epidote, chlorite) and all kinds of Fe-oxide (hematite) and Fe-hydroxides (Jarosite and goethite). The main rock units in the eastern part of Kahang deposit include andesite, andesitic breccia tuff (volcanic breccia), andesite porphyry, dacite Porphyry, quartz-monzonite, diorite, pebble dikes, along with quartz-magnetite veins and silica, phyllic, Argillic, propylitic alterations and Fe-oxide (hematite) and Fe-hydroxides (Jarosite and goethite) (Asadi Haroni, 2007) (Fig. 4). The composition of Miocene stock, ranges from diorite through granodiorite to quartz-monzonite. Field observations and petrographic studies show that the emplacement of the Kahang stock occurred in several

pulses, each associated with its related hydrothermal activity (Afshooni *et al.*, 2013). The primary magnetite grains having irregular boundaries formed in association with phyllic-potassic altered zones (Afshooni *et al.*, 2014). Furthermore, there is evidence of potassic alteration to the west of Kahang. The dacite and rhyodacite volcanic rocks and granitic-granodioritic stocks have been experienced phyllic alteration. Disseminated and stockwork siliceous veins are the major styles of mineralization in this zone. Intermediate argillitic alteration developed on a part of dacitic and rhyodacitic rocks whereas andesite and basaltic-andesite plus related pyroclastic rocks have been subjected to propylitic alteration. Hematite, goethite, jarosite, malachite and azurite are the predominant minerals of supergene zone. Pyrite is the most common hypogene sulfide mineral and chalcopyrite is the predominant Cu- sulfide in the Kahang mineralized area (Komeili *et al.*, 2016).

Geochemical Model of Zafarghand Index and Kahang Deposit of Porphyry Copper-Molybdenum

Geochemical studies are important, especially for ore deposits that enjoy larger halos than the ore deposits by themselves. These halos can be made due to depletion or enrichment of the elements. Investigations of genesis and extent of mineralization zone at surface and depth are also possible with geochemical information. In the common geochemical model of porphyry copper-molybdenum deposits, an anomalous ring of copper-molybdenum in the central part of the anomaly could be found and around it especially at margin of the altered halo, the manganese, silver, zinc, lead, cadmium and bismuth anomalies could be appeared (Hassanipak, 2008). Due to the fact that, some of the elements are less than the detection limit of the device, the data of these elements were removed from the data as outlier values. These elements include Be, Bi, Cd, B, Ga, Te, Hg, Tl, U, W and so on. The process of geochemical modeling are drawing in form of flow chart in Fig. 5. In geochemical studies, the distribution of various elements and compounds in Zafarghand index and Kahang deposit of porphyry copper-molybdenum were determined. The distribution of most existing elements corresponds to the log-normal distribution. For example, in the Zafarghand index, the range of copper element fluctuates from 0.1 ppm to 17002 ppm and the distribution is asymmetric and abnormal, which can be converted using by three-parametric of log-normal distribution ($\text{Log}(\text{Cu}-0.833)$) that could be normalized (Fig. 6 and 7). The probability diagrams of the elements are also drawn in Fig. 8, according to the Kolmogorov–Smirnov test the element has a nearly normal distribution in Zafarghand index and Kahang deposit of porphyry copper-molybdenum.

As shown from Fig. 5, firstly probability distribution function of elements were obtained; moreover, threshold values are calculated to separate anomalies from background using detachable statistics methods based on the probability distribution function and correlation between chemical elements in order to clustering them have been investigated. Eventually the anomaly maps of single and composite halos of copper and molybdenum were depicted to assign the enrichment zones in both Zafarghand index and Kahang deposit.

As could be seen from Fig. 6, all statistic parameters of copper element such as mean, standard deviation, variance, skewness, kurtosis and so on were calculated. It is evident that all of distribution enjoy the positive skewness, however in the normal distribution the skewness should be zero. The data in order to have standard distribution, were converted to three-parametric log-normal (Fig. 7).

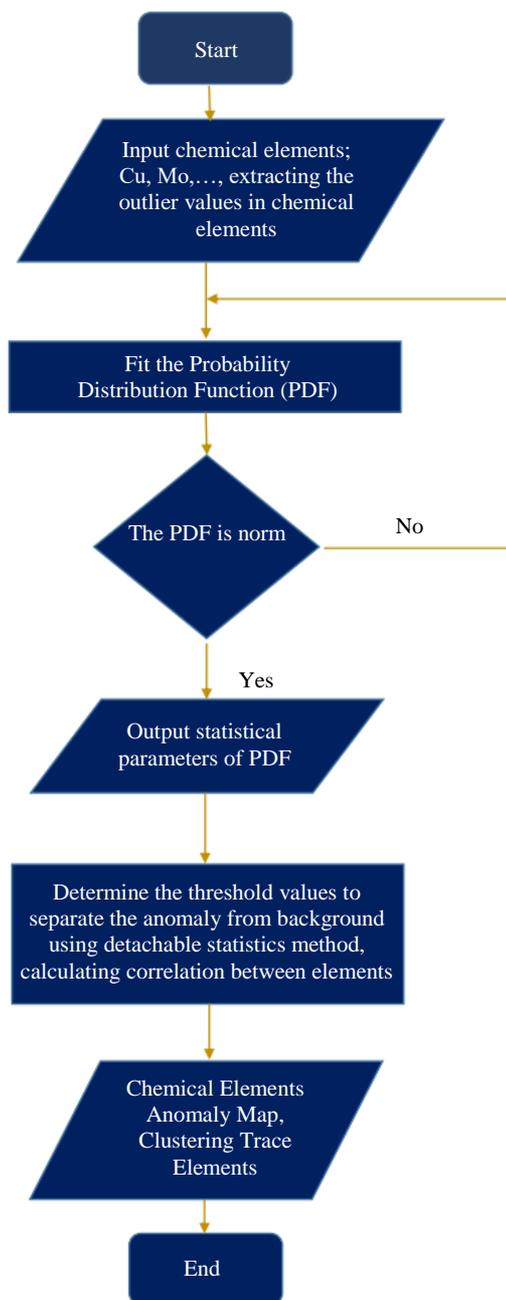


Fig. 5: The process of geochemical modeling in form of flow chart

The three-parametric of log-normal distribution of copper with a nearly zero and three in skewness and kurtosis, respectively, are depicted in Fig. 7. Furthermore, the converted data also should be draw in probability plot and as can be seen from Fig. 8, the data are arranged by nearly straight lines, justifying the normal distributions of copper element in both Zafarghand index and Kahang deposit of porphyry copper-molybdenum.

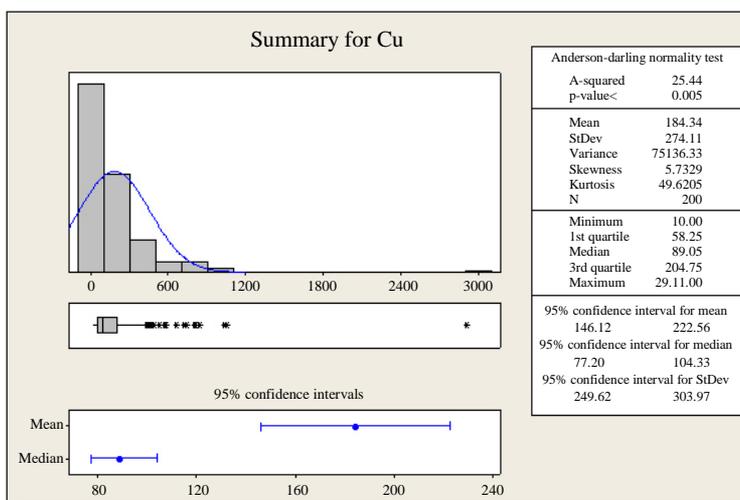
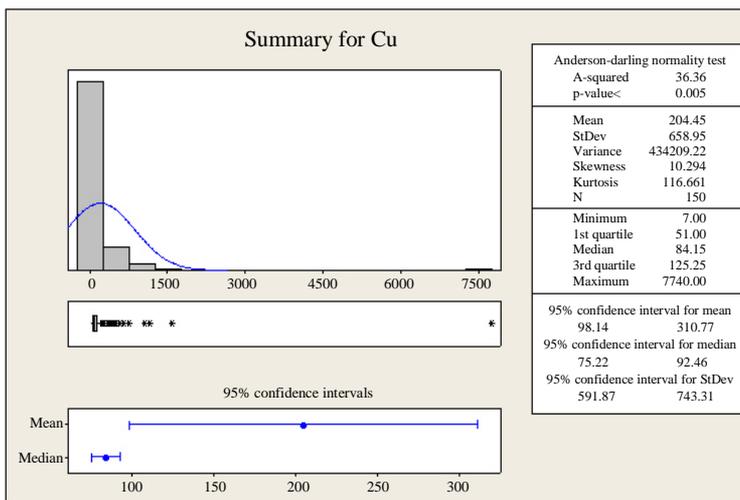
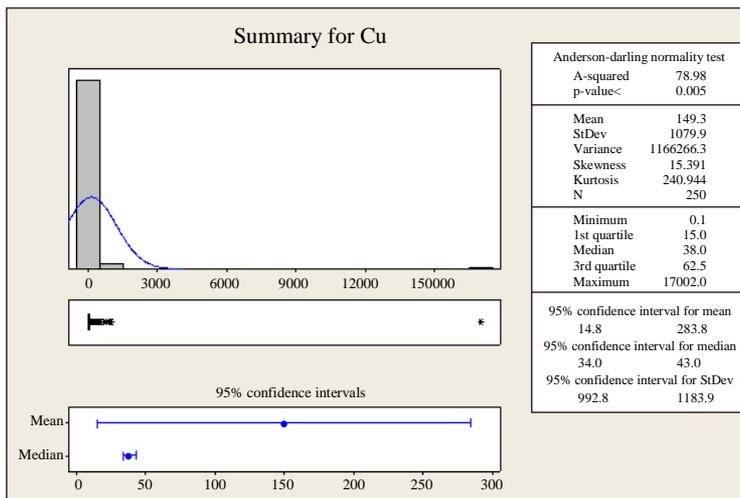


Fig. 6: Distribution diagram of copper element (in ppm); (a) Zafarghand index, (b) western part and (c) eastern part of Kahang deposit

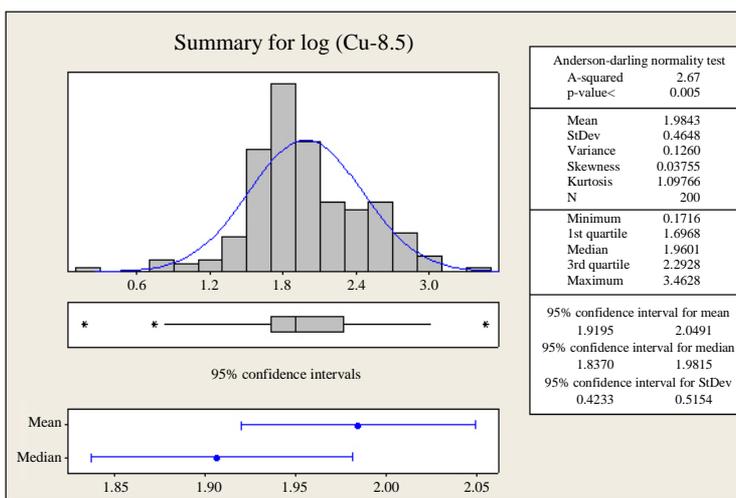
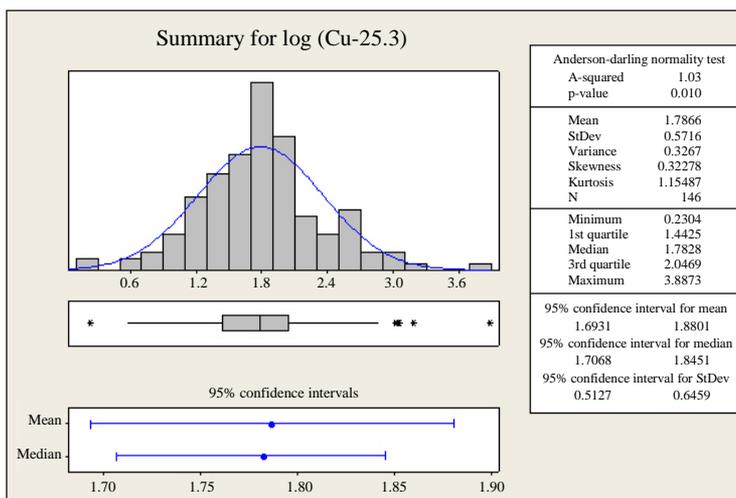
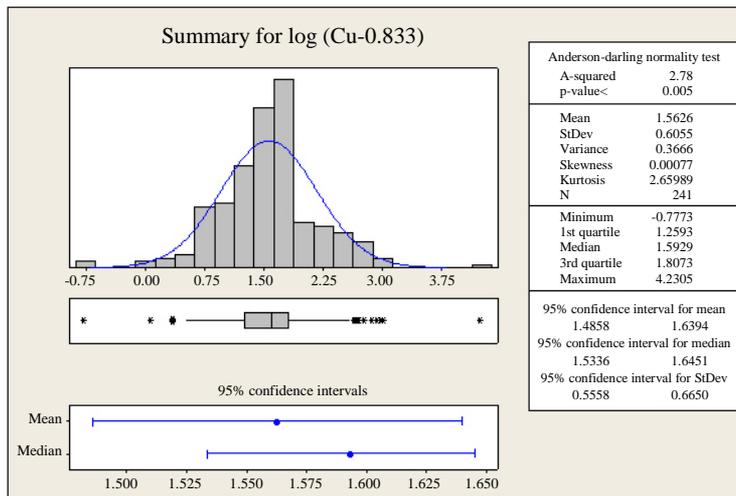
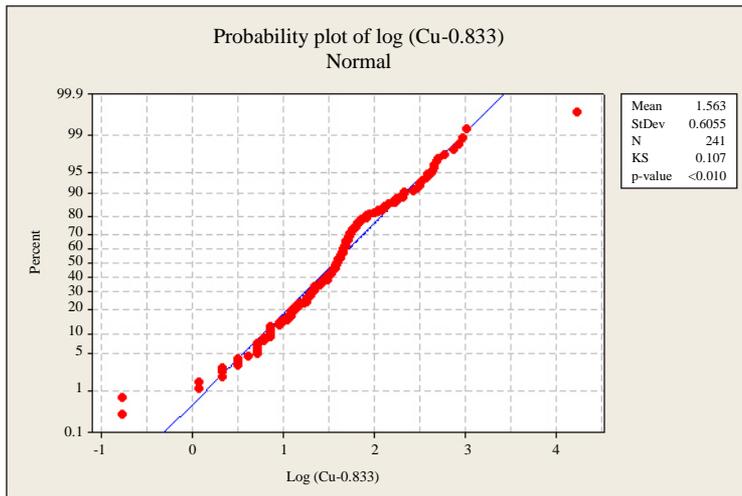
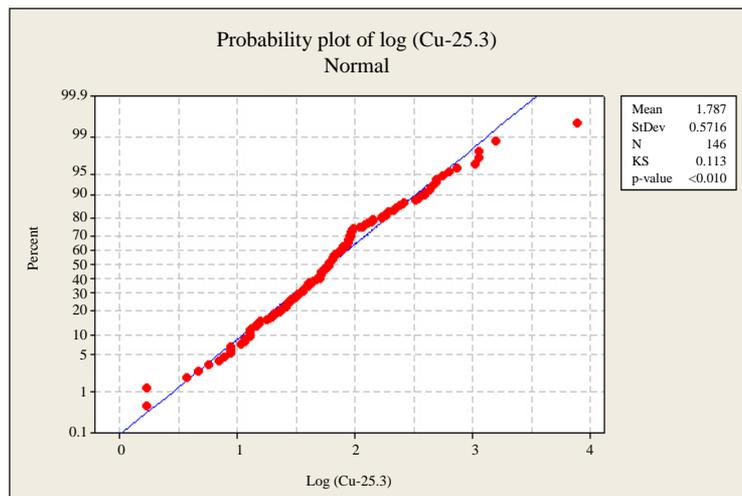


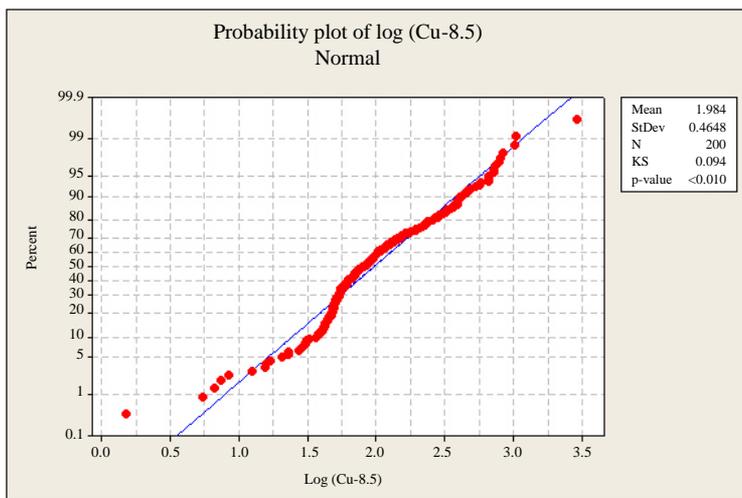
Fig. 7: The three-parametric of log-normal distribution diagram of copper element (in ppm); (a) Zafarghand index, (b) western part and (c) eastern part of Kahang deposit



(a)



(b)



(c)

Fig. 8: The probability diagram of the copper element (in ppm); (a) Zafarghand index, (b) western part and (c) eastern part of Kahang deposit

Determine the Threshold Values to Separate the Anomaly from Background

Detachable statistics are one of the methods based on the distribution function, which can be used to estimate the threshold values (the separation range of the anomaly from the background) (Hassanipak and Sharafodin, 2005). The first step in this method is to find the transformation of the data that approaches the distribution of data as much as possible to the normal distribution, since this method is based on the assumption of the normal distribution of data. Next, the converted data is sorted in terms of their values and should be standardized them to eliminate the scale effects, so that the mean and standard deviation of each element should be zero and one, respectively. The standardized data is called Z. The amount of detachable statistics for each pair are calculated in 3 steps as follows:

1. Calculation of the mean value of two standardized sequential values (m_i):

$$m_i = \frac{Z_{i+1} + Z_i}{2} \tag{1}$$

2. Determination of the detachable value (G_i):

$$G_i = 0.3989 * e^{\left(\frac{-1}{2}m_i^2\right)} * (Z_{i+1} - Z_i) \tag{2}$$

3. In the end the m_i , related to largest amount of detachable statistics is specified and the threshold value could be specified by the following equation:

$$C_a = 10^{(\log \bar{X} + m_i * S_{\log})} \tag{3}$$

The threshold value of copper, molybdenum, lead and zinc elements has been calculated by the above-mentioned method, the results of are given in the Table 1-3 (Safi Khani *et al.*, 2010).

Figure 9 and 10 show maps of single-element halos for copper, manganese in soil and rock samples, in which copper anomalies (threshold values) are separated from background with thicker contour lines.

Table 1: Threshold value copper, molybdenum, lead and zinc elements in Zafarghand index

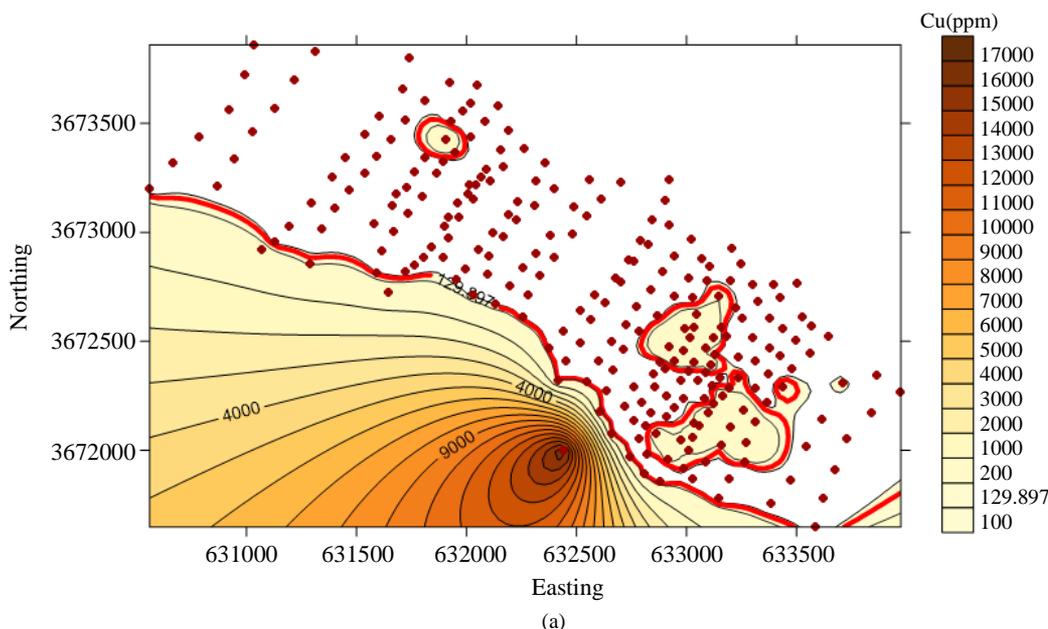
Element	Threshold value (ppm)	m_i
Cu	129.89	0.90538
Mo	11.557	0.02113
Pb	77.460	0.94633
Zn	161.27	0.62971

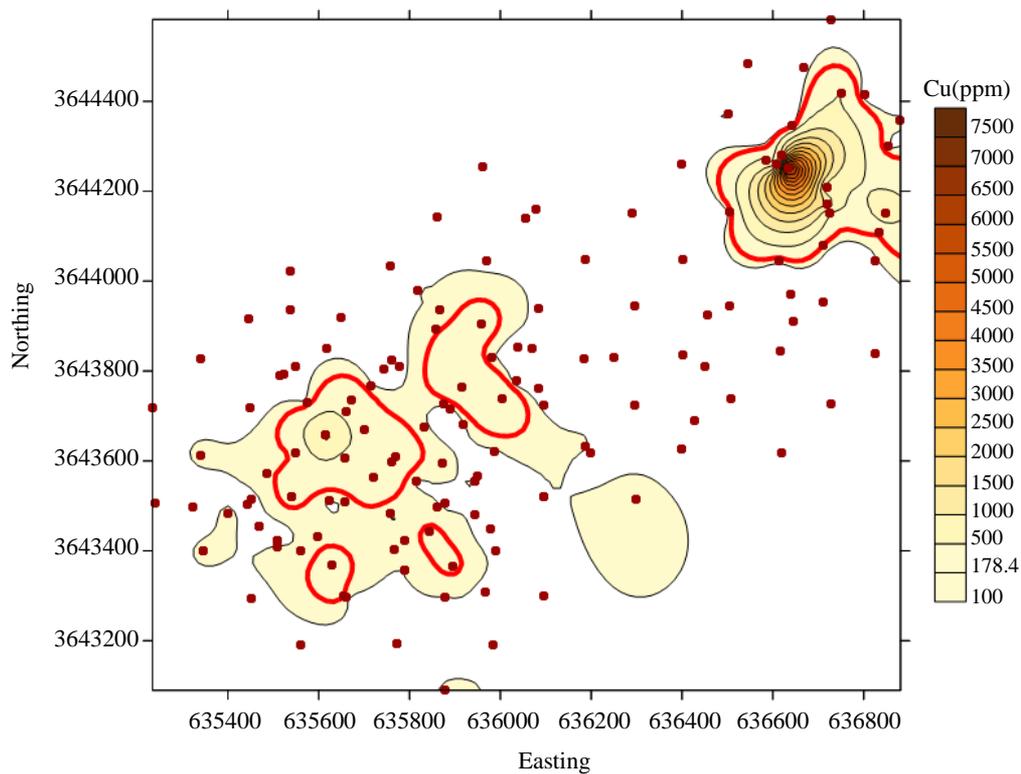
Table 2: Threshold value copper, molybdenum, lead and zinc elements in western part of Kahang deposit

Element	threshold value (ppm)	m_i
Cu	178.400	0.69188
Mo	10.118	82.61900
Pb	114.000	1.04075
Zn	141.950	0.43611

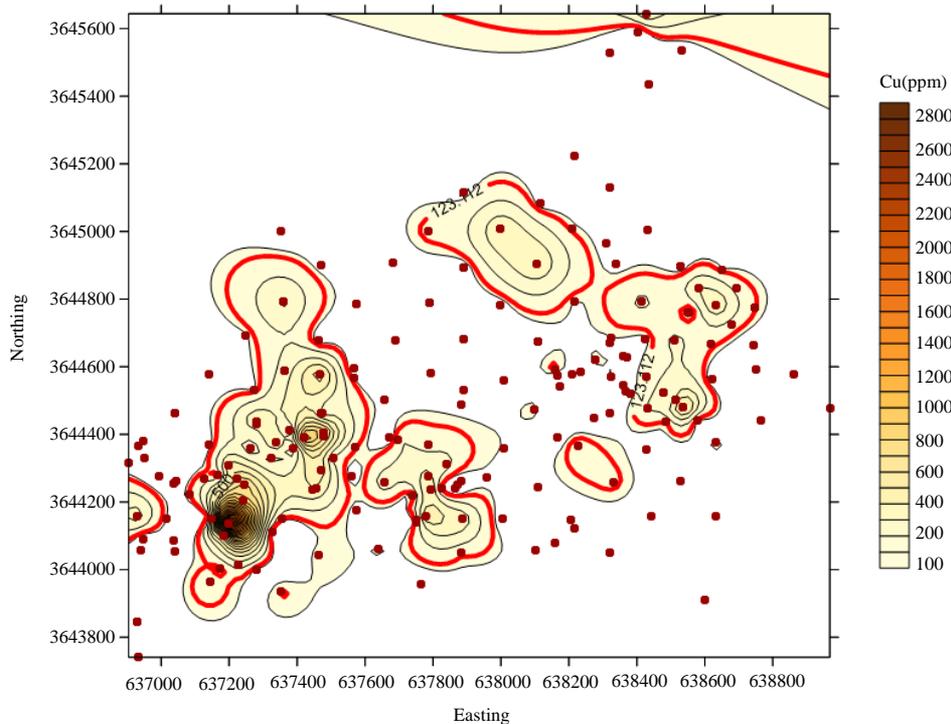
Table 3: Threshold value copper, molybdenum, lead and zinc elements in eastern part of Kahang deposit

Element	threshold value (ppm)	m_i
Cu	123.112	0.16121
Mo	21.000	1.49779
Pb	64.514	0.84069
Zn	248.000	1.34269





(b)

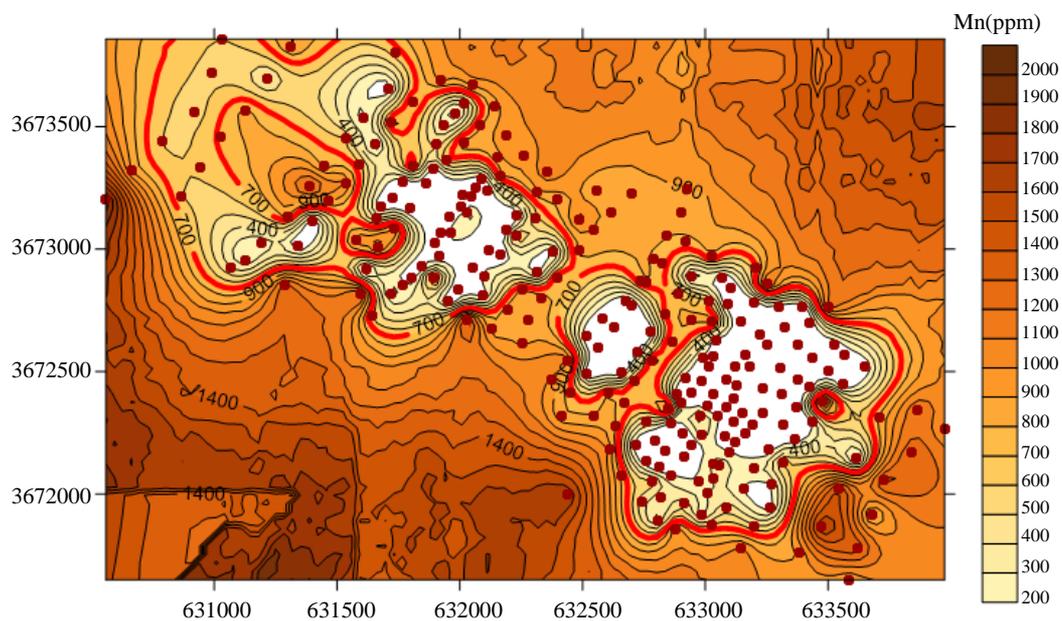


(d)

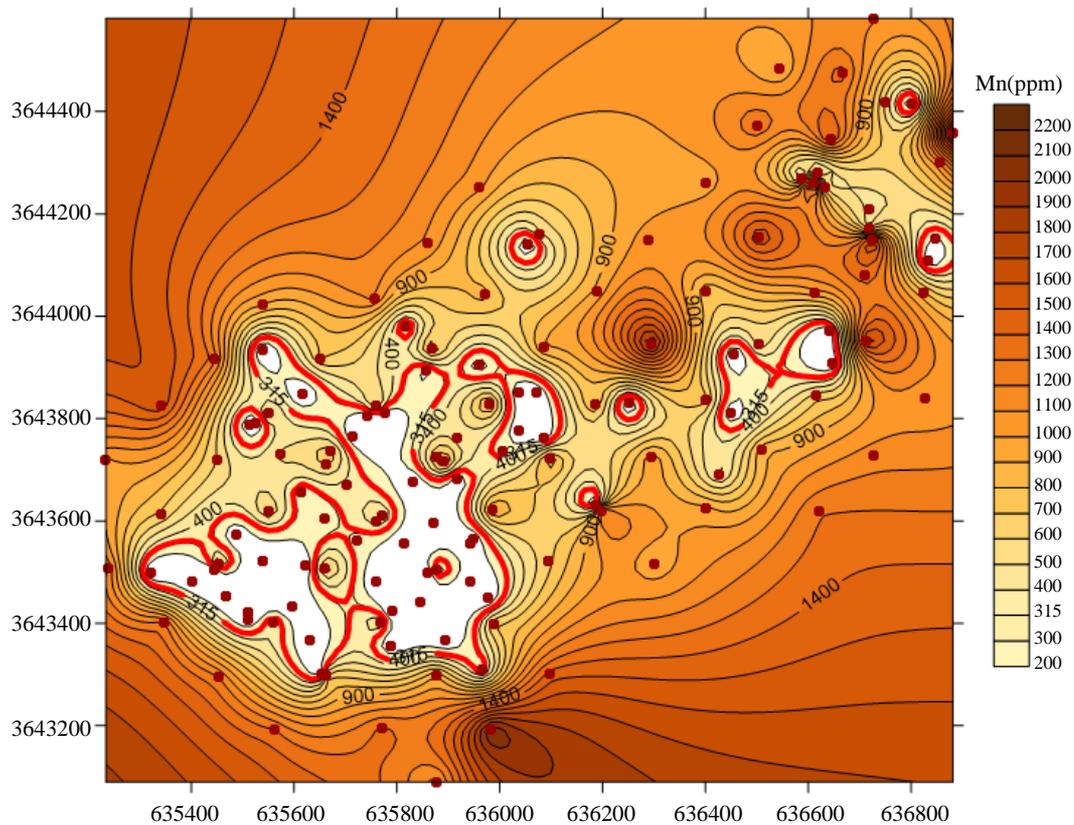
Fig. 9: The copper element anomaly map (in ppm); (a) Zafarghand index, (b) western part and (c) eastern part of Kahang deposit

According to the above maps in Fig. 9 and 10, copper anomalies are existed in elsewhere the manganese's are

depleted. In order to find this reason the correlation between elements should be calculated.



(a)



(b)

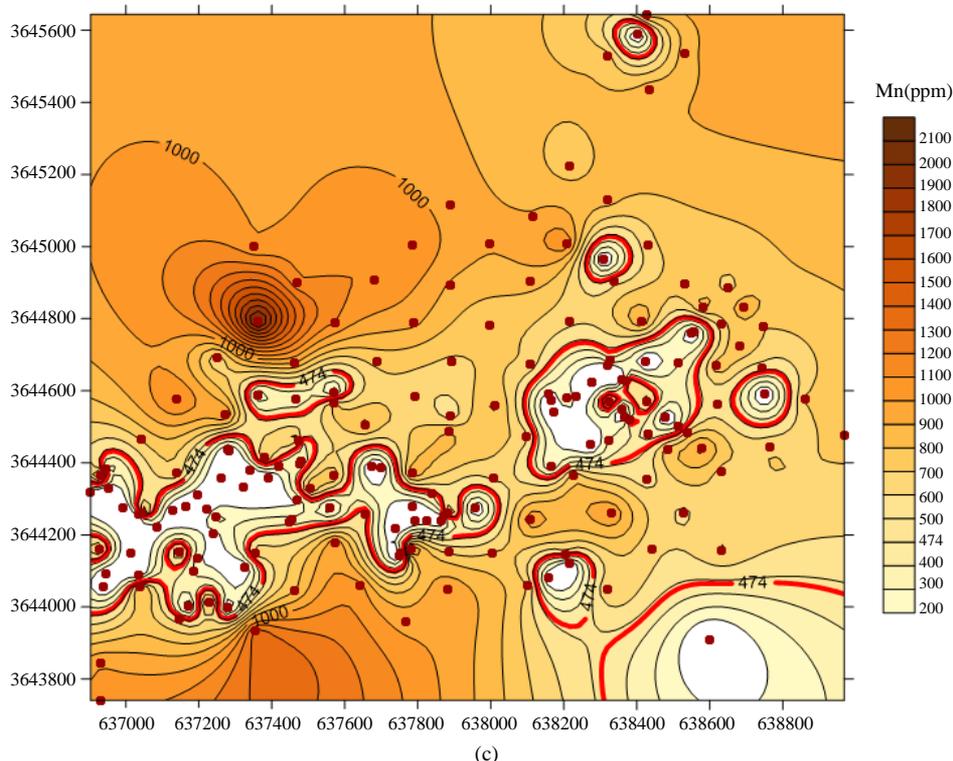


Fig. 10: The manganese element anomaly map (in ppm); (a) Zafarghand index, (b) western part and (c) eastern part of Kahang deposit

Correlation between Elements

Pearson correlation coefficient is used to find the correlation between the elements. Therefore, the main condition of correlation in this method is the normal distribution (i.e., skewness and kurtosis are zero and three, respectively). For this purpose, elements obey the of the three-parameter log-normal distribution (Hassanipak and Sharafodin, 2005; Safi Khani *et al.*, 2010). The Pearson correlation matrix are presented in Equation 4-6 associated with Zafarghand index, western and eastern part of Kahang deposit, respectively:

-	Cu	Mo	Pb	Zn	As	Sb	Mn	Cd
Cu	1.000	0.499	0.115	0.228	0.431	-0.239	-0.167	0.405
Mo	0.499	1.000	0.426	0.254	0.313	-0.263	-0.160	0.495
Pb	0.115	0.426	1.000	0.262	0.397	-0.135	0.352	0.475
Zn	0.228	0.254	0.262	1.000	0.569	0.062	0.547	0.615
As	0.431	0.313	0.397	0.569	1.000	-0.070	0.389	0.836
Sb	-0.239	-0.263	-0.135	0.062	-0.070	1.000	-0.155	-0.505
Mn	-0.167	-0.160	0.352	0.547	0.389	-0.155	1.000	0.449
Cd	0.405	0.495	0.475	0.615	0.836	-0.505	0.449	1.000

(4)

-	Cu	Mo	Pb	Zn	As	Sb	Mn	Cd
Cu	1.000	0.305	-0.009	0.025	0.053	0.346	-0.404	-0.0293
Mo	0.305	1.000	-0.129	-0.516	0.227	0.287	-0.515	-0.188
Pb	-0.009	-0.129	1.000	0.581	0.395	0.639	0.209	0.559
Zn	0.025	-0.516	0.581	1.000	0.009	0.125	0.554	0.523
As	0.053	0.227	0.395	0.009	1.000	0.568	-0.060	0.068
Sb	0.346	0.287	0.639	0.125	0.568	1.000	-0.317	0.184
Mn	-0.404	-0.515	0.209	0.554	-0.060	-0.317	1.000	0.315
Cd	-0.0293	-0.188	0.559	0.523	0.068	0.184	0.315	1.000

(5)

-	Cu	Mo	Pb	Zn	As	Sb	Mn	Cd
Cu	1.000	0.192	0.071	0.228	0.125	-0.253	-0.153	0.226
Mo	0.192	1.000	-0.061	0.122	0.091	-0.080	-0.178	0.234
Pb	0.071	-0.061	1.000	0.304	0.145	-0.082	0.334	0.330
Zn	0.228	0.122	0.304	1.000	0.480	-0.285	0.429	0.795
As	0.125	0.091	0.145	0.480	1.000	-0.111	0.239	0.740
Sb	-0.253	-0.080	-0.082	-0.285	-0.111	1.000	-0.774	-0.024
Mn	-0.153	-0.178	0.334	0.429	0.239	-0.774	1.000	-0.095
Cd	0.226	0.234	0.330	0.795	0.740	-0.024	-0.095	1.000

(6)

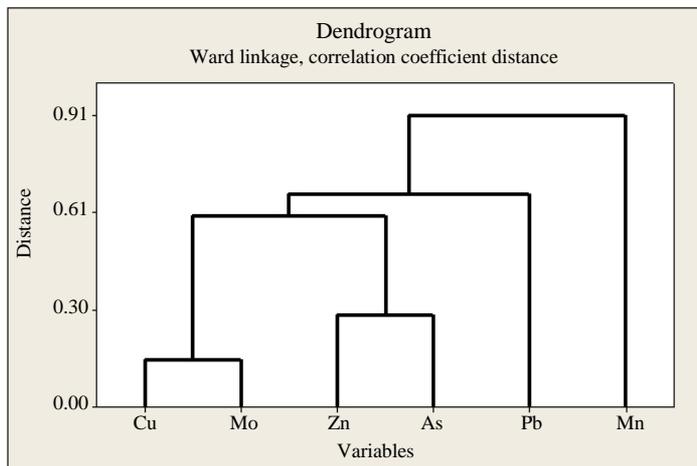
According to Equation 4-6, the copper and molybdenum elements have a positive and fairly high correlation coefficient, while the elements have a negative correlation with manganese, which is a evidence to exist copper-molybdenum deposit by itself.

Clustering Elements

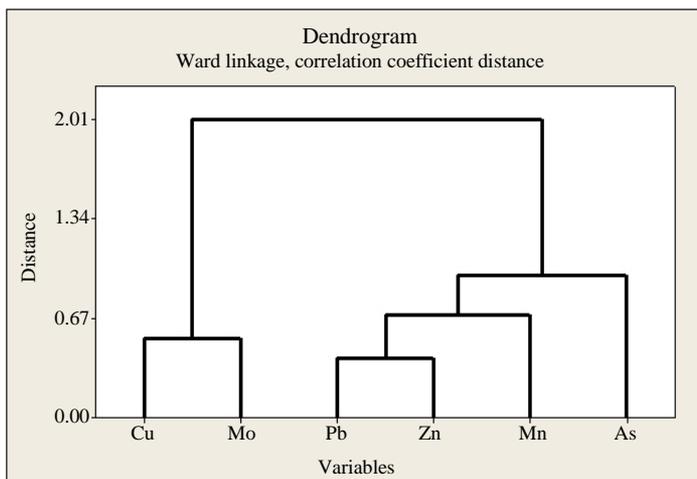
In the Ward's method, the criterion of connecting an object to a cluster or two clusters to each other which are creating the least increase in the summation of squared deviation of average in the desired cluster. The results of this method are suitable for the appearance and maintenance of the construction hierarchy. For this reason, this method has been identified as an appropriate choice in cluster analysis and in this methods, the correlation coefficient has been used as a similarity criterion (Hassanipak and Sharafodin, 2005; Safi Khani *et al.*, 2010). At this stage, it has been tried to use the main elements of the deposit and other above-deposit elements which they enjoy more mobility than copper and

molybdenum. As copper shows good correlation with molybdenum in all Equation 1-3, so in order to confirm

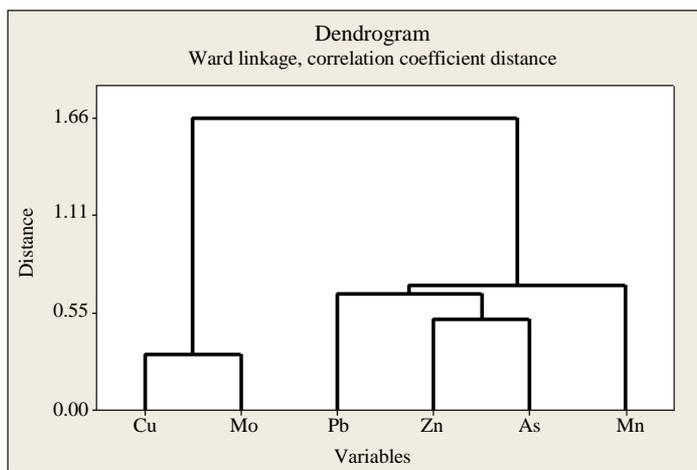
this correlation, cluster analysis was drawn using Pearson's coefficient of correlation (Fig. 10).



(a)



(b)



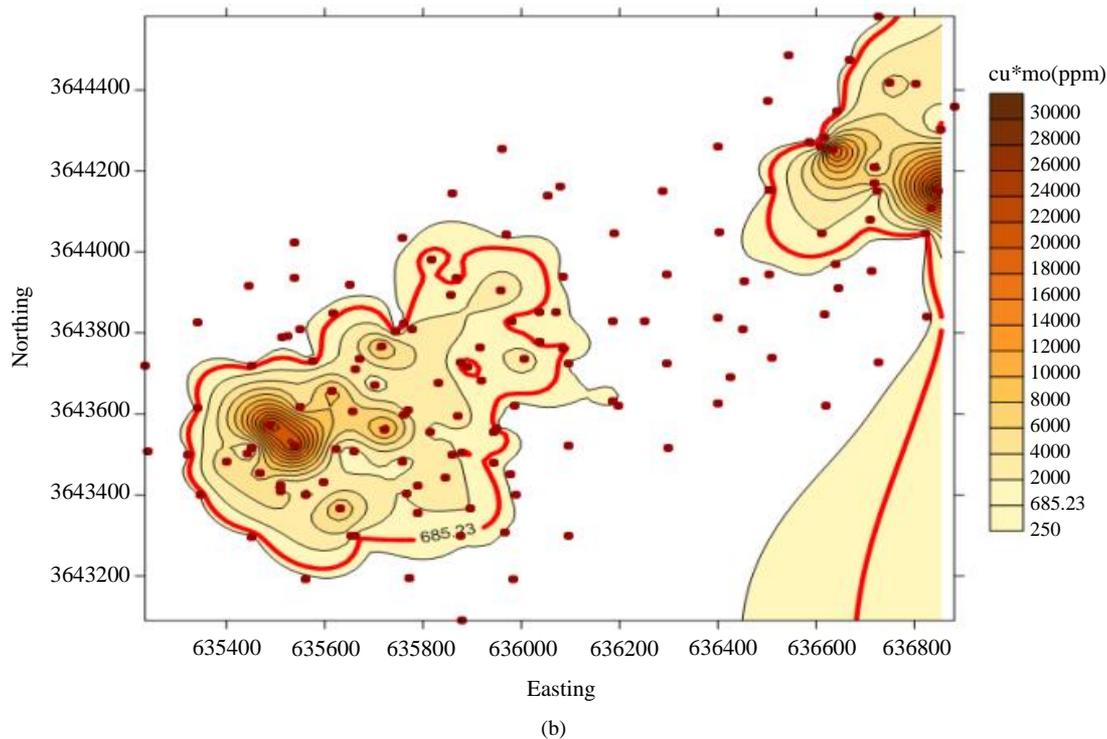
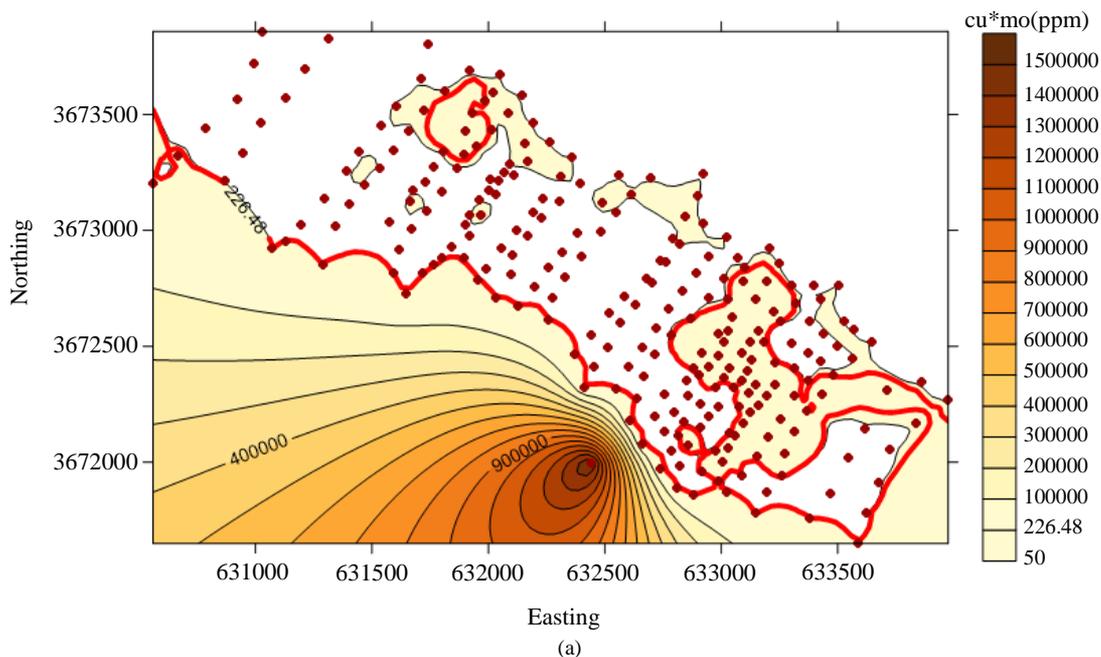
(c)

Fig. 11: The cluster analysis of trace elements in the exploration of copper halos in; (a) Zafarghand index, (b) western part and (c) eastern part of Kahang deposit

As can be seen from Fig. 11, the elements that are presented in the center of mineralization system (i.e.; Cu, Mo) are placed in the same category and the marginal elements of the ore deposit (above deposit), which are more mobile, located in the other categories and this is another evidence for existence the copper-molybdenum porphyry deposit.

Composite Halo

After calculating the correlation coefficient and performing the cluster analysis of the elements, since the copper and molybdenum elements were placed in a cluster, then this correlation could be presented in the form of a composite halo maps.



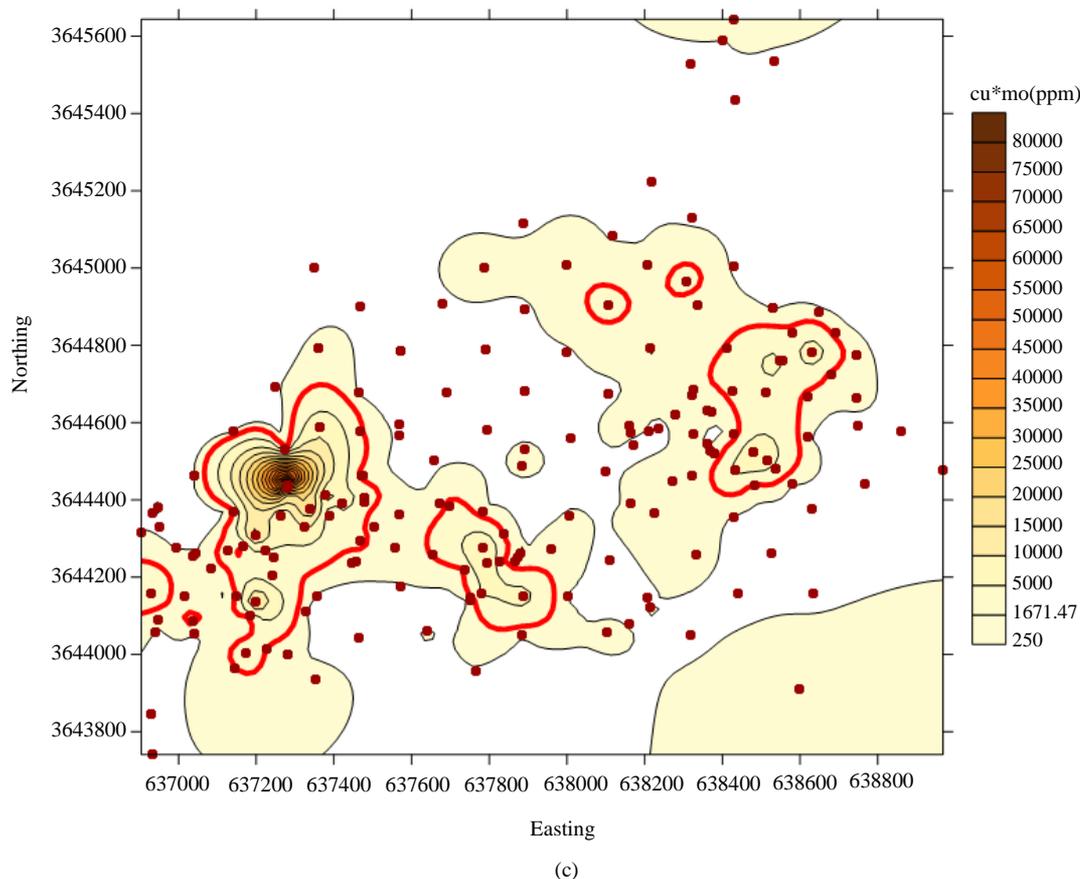


Fig. 12: The anomaly map of composite halo of copper and molybdenum in (in ppm); (a) Zafarghand index, (b) western part and (c) eastern part of Kahang deposit

By the comparison the Fig. 9 and 12, the composite halo of copper and molybdenum elements are extended in nearly same area and it is a verification of the positive correlation of two mentioned elements.

Conclusion

In this study, geological properties along with the geochemical properties such as study of geochemical anomalies of elements, determination of threshold values to separate anomalies from background using detachable statistics methods based on the probability distribution function and calculating correlation between chemical elements in order to clustering them have been investigated. Eventually the anomaly maps of single and composite halo of copper and molybdenum were depicted to assign the enrichment zones in both Zafarghand index and Kahang deposit. The conclusions are summarized as follows:

- Early geological evidence such as the type of rock units, alteration zoning (from the center to the

margins including phyllic, argillic and propylitic alterations) indicates the characteristics of the porphyry copper-molybdenum deposits

- In geochemical studies, considering the presence of copper, molybdenum in a cluster and lead, zinc, manganese and arsenic in other cluster indicates the presence of copper-molybdenum mineralization in the region
- The concentration of copper and molybdenum in the central part and the second cluster elements on the margin of mineralization indicates the porphyry copper-molybdenum mineralization system
- The composite halo of copper and molybdenum elements are a verification of the positive correlation of two mentioned elements

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Author's Contributions

All authors equally contributed in this work.

Ethics

All rights of this study are owned Department of Mining Engineering, Isfahan University of Technology and Dorsa pardazeh company and should be maintained.

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