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Geochemical anomaly separation by multifractal modeling in Kahang (Gor Gor) porphyry system, Central Iran

Peyman Afzal [a,*], Ahmad Khakzad [b], Parviz Moarefvand [c], N. Rashidnejad Omran [d], Bijan Esfandiari [e], Younes Fadakar Alghalandis [f]

[a] Science and Research Branch, Islamic Azad University, Department of Geology, Tehran, Iran
[b] North Tehran Branch, Islamic Azad University, Department of Geology, Tehran, Iran
[c] Amirkabir University of Technology, Mining and Metallurgy Faculty, Tehran, Iran
[d] Tarbiat Modares University, Department of Geology, Tehran, Iran
[e] South Tehran Branch, Islamic Azad University, Department of Mining Engineering, Tehran, Iran
[f] School of Earth Sciences, University of Queensland, Brisbane, Australia

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ABSTRACT

Geochemical anomaly separation using the concentration–area (C–A) method at Kahang (Gor Gor) porphyry system in Central Iran is studied in this work. Lithogeochemical data sets were used in this geochemical survey which was conducted for the exploration for Cu mineralization in dioritic and andesitic units at Kahang Cu–Mo porphyry system. Similar surveys were also carried out for Mo and Au exploration in these rock units. The obtained results have been interpreted using rather extensive set of information available for each mineralized area, consists of detailed geological mapping, structural interpretation and alteration data. Anomalous threshold values for the mineralized zone were computed and compared with the statistical methods based on the data obtained from chemical analysis of samples for the lithological units. Several anomalies at a local scale were identified for Cu (224 ppm), Mo (63 ppm), and Au (31 ppb), and the obtained results suggests existence of local Cu anomalies whose magnitude generally is above 1000 ppm. The correlation between these threshold values and ore grades is clearly interpreted in this investigation. Also, the log–log plots show existence of three stages of Cu enrichment, and two enrichment stages for Mo and Au. The third and most important mineralization event is responsible for the presence of Cu at grades above 1995 ppm. The identified anomalies in Kahang porphyry system, and distribution of the rock types, are mainly monzodiorite and andesitic units, do have special correlation with Cu and monzonitic and dioritic rocks, especially monzodioritic type, which is of considerable emphasis. The threshold values obtained for each element are always lower than their mean content in the rocks. The study shows threshold values for Cu is clearly above the mean rock content, being a consequence of the occurrence of anomalous accumulations of phyllic, argillic and propyllitic alterations within the monzonitic and dioritic rocks especially in monzodioritic type. The obtained results were compared with fault distribution patterns which reveal a positive direct correlation between mineralization in anomalous areas and the faults present in the mineralized system.

1. Introduction

Separation of background and anomaly is a fundamental issue in exploration geochemistry. In the past and recent years, traditional statistical methods usually assumed that the concentration of chemical elements in the crust follow a normal or log-normal distribution. A geochemical anomaly as defined is a region where the concentration of a specific element is greater than a certain threshold value by statistical parameters, such as mean, median, mode, and standard deviation (Li et al., 2003). However, the traditional methods consider only the frequency distribution of the elemental concentration, and ignored its spatial variability. Specifically, the information about the spatial correlation is not always available. In addition, these methods are only applicable to cases where geochemical data follows a normal distribution. Nevertheless, the normal distribution does not provide the only possible model of geochemical distribution (Li et al., 2003). Furthermore, the gathered data have to be modified in traditional methods; e.g., by rejection of outliers and normalization of data. Moreover, statistical methods e.g., by histogram analysis or Q–Q plots assuming normality or lognormality and do not consider the shape, extent and magnitude of anomalous areas (Rafiee, 2005). Fractal models can be used for solving these problems. The word "Fractal" was coined by Benoit Mandelbrot (1983) from the Latin word "fractus", meaning broken, which he has applied to objects that were too

* Corresponding author. Department of Geology, Science and Research Branch, Islamic Azad University, Tehran, Iran. Tel.: +98 21 66944526.
E-mail address: peymanafzal@yahoo.com (P. Afzal).

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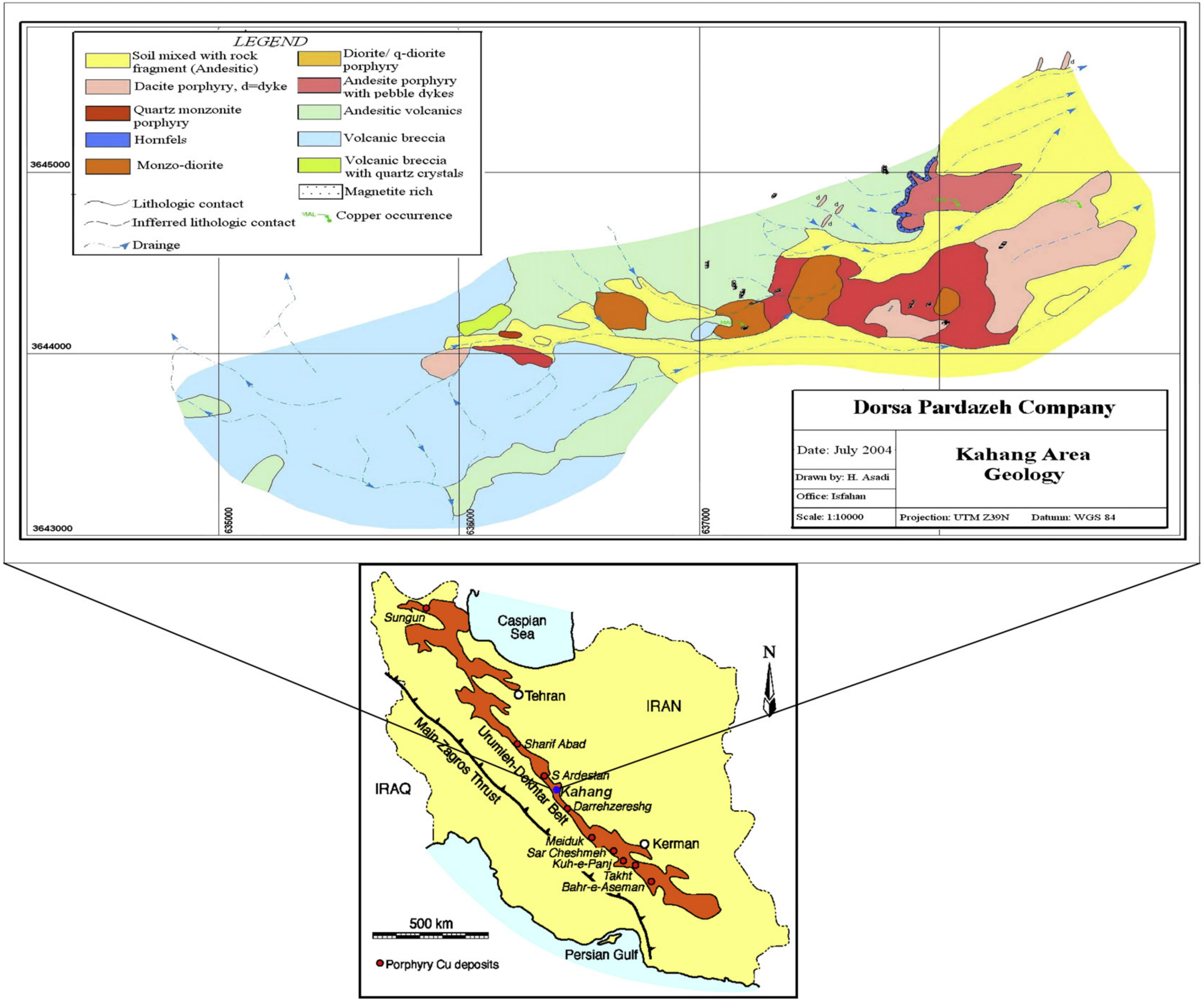

Fig. 1. Geology map of Kahang study area, scale: 1:10,000 within Urumieh-Dokhtar volcanic belt and the known porphyry deposits in the belt.

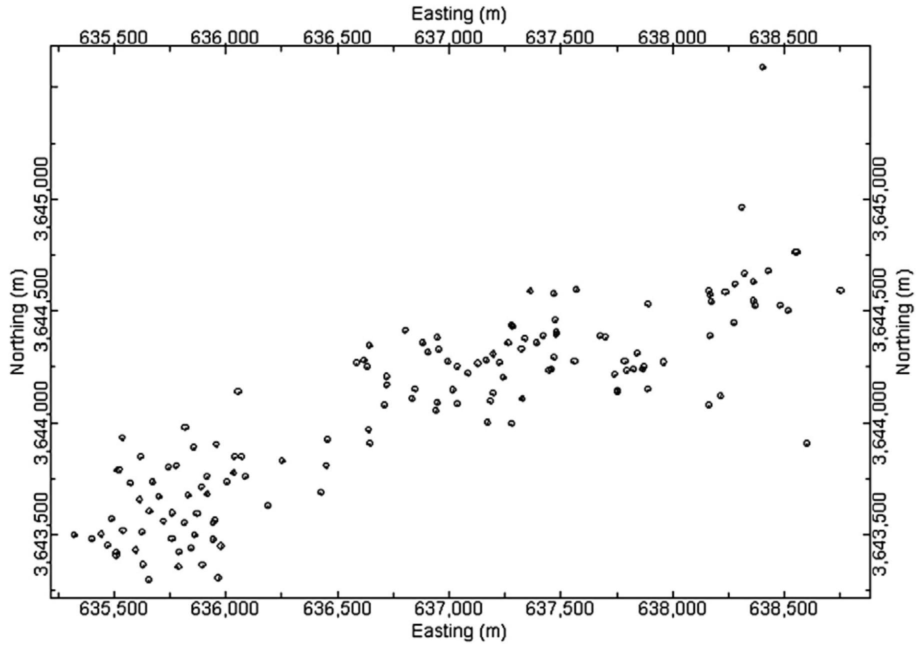

Fig. 2. Lithogeochemical samples' location map of Kahang area.

irregular to be described by ordinary Euclidean geometry (Davis, 2002). Fractal theory has been applied to mineral resources studies since late 1980s. Turcotte (1986) proposed a fractal relationship between average grade and cumulative ore reserves. Meng and Zhao (1991) concluded that somehow a fractal behavior in structures do exists in geological data. Recently, Cheng et al. (1994) proposed a method based on the premise that geochemical distributions are multifractal in nature. This idea and premise provided a scientific tool to demonstrate that an empirical relationship between concentration–area (C–A) does exists, but only few applications have been reported in the literature. Few authors put forward this idea and explain its vast applications (Goncalves et al., 1998; Cheng, 1999; Sim et al., 1999; Wei and Pengda, 2002).

Choosing a particular fractal method for anomaly characterization raises the problem of proving that is it suitable or applicable to be used in any kind of situation? On the other hand, there is no guarantee that the obtained results are meaningful or plausible for the geologic situation at hand and under investigation. None of the known statistical methods used in anomaly separation and geochemical work are independent of the geological knowledge. Therefore this procedure may be the main source of information available to validate any interpretation of the obtained data and the ensuing results.

This paper is organized in five parts. Introduction follows a brief discussion of the "concentration–area" method presented and it will be used in that sense throughout this study. The case study presented here is related to a Cu, Mo and Au exploration work and it covers the relevant concentration–area techniques. Subsequently, a general discussion is argued whereby the anomalous threshold values are correlated to the relevant structural, lithological, and alteration data and this may explain how the obtained results were derived. Also, emphasis is made on how the main conclusions are reached and how they may be drawn and interpreted from this study. The usage of this procedure and how future issues may be dealt with using the suggested methods given in present work in geochemical distribution studies is also presented.

2. The concentration–area method

This method serves to illustrate the relationship correlated between the obtained results with the geological, geochemical and mineralogical information. Its most useful features are the easy implementation and the ability to compute quantitative anomalous thresholds (Goncalves et al., 2001).

Cheng et al. (1994) proposed an element concentration–area (C–A) model, which may be used to define the geochemical background and anomalies. The model has the general form:

$$A(\rho \le \upsilon) \propto \rho^{-a1}; A(\rho \le \upsilon) \propto \rho^{-a2} \quad (1)$$

where $A(\rho)$ denotes the area with concentration values greater than the contour value ρ; υ represents the threshold; and a_1 and a_2 are characteristic exponents. Using fractal theory, Cheng et al. (1994) derived similar power–law relationships and equations in extended form (Cheng et al., 1994). The two approaches which were used to calculate $A(\rho)$ by Cheng et al. (1994) were: (1) The $A(\rho)$ is the area enclosed by contour level q on a geochemical contour map resulting from interpolation of the original data using a weighted moving average method, and (2) $A(\rho)$ are the values obtained by box-counting of original elemental concentration values. By box-counting, one superimposes grid with cells on the study region. The area $A(\rho)$ for a given q is equal to the number of cells multiplied by cell area with concentration values greater than ρ. Average concentration values are used for those boxes containing more than one sample. Area–concentration [$A(\rho)$] with element concentrations greater than ρ usually show a power–law relation (Cheng et al., 1994). The breaks between straight-line segments on this plot and the corresponding values of ρ have been used as cut-offs to separate geochemical values into different components, representing different causal factors, such as lithological differences and geochemical processes. Factors such as

Table 1
Statistical parameters of raw data based on lithogeochemical samples analysis.

Statistical parameter	Cu (ppm)	Mo (ppm)	Au (ppb)
Mean	273.00	26.00	24
Median	100.00	9.70	11
SD	714.95	34.05	39.99
SV	511,158.06	1159.48	1599.97
Maximum	7740.00	219.00	320
Minimum	7.00	0.60	0

SD: standard deviation, SV: sample variance.

mineralizing events, surficial geochemical element concentrations, and surficial weathering are of considerable importance (Lima et al., 2003).

Multifractal theory may be interpreted as a theoretical framework that explains the power–law relations between areas enclosing concentrations below a given value and the actual concentrations itself. To demonstrate and prove that data distribution has a multifractal nature requires a rather extensive computation. As a real example the case of the well-known and widely used method of moments is cited (Halsey et al., 1986; Evertz and Mandelbrot, 1992). This method has several limitation and accuracy problems, especially when the boundary effects on irregular geometrical data sets are

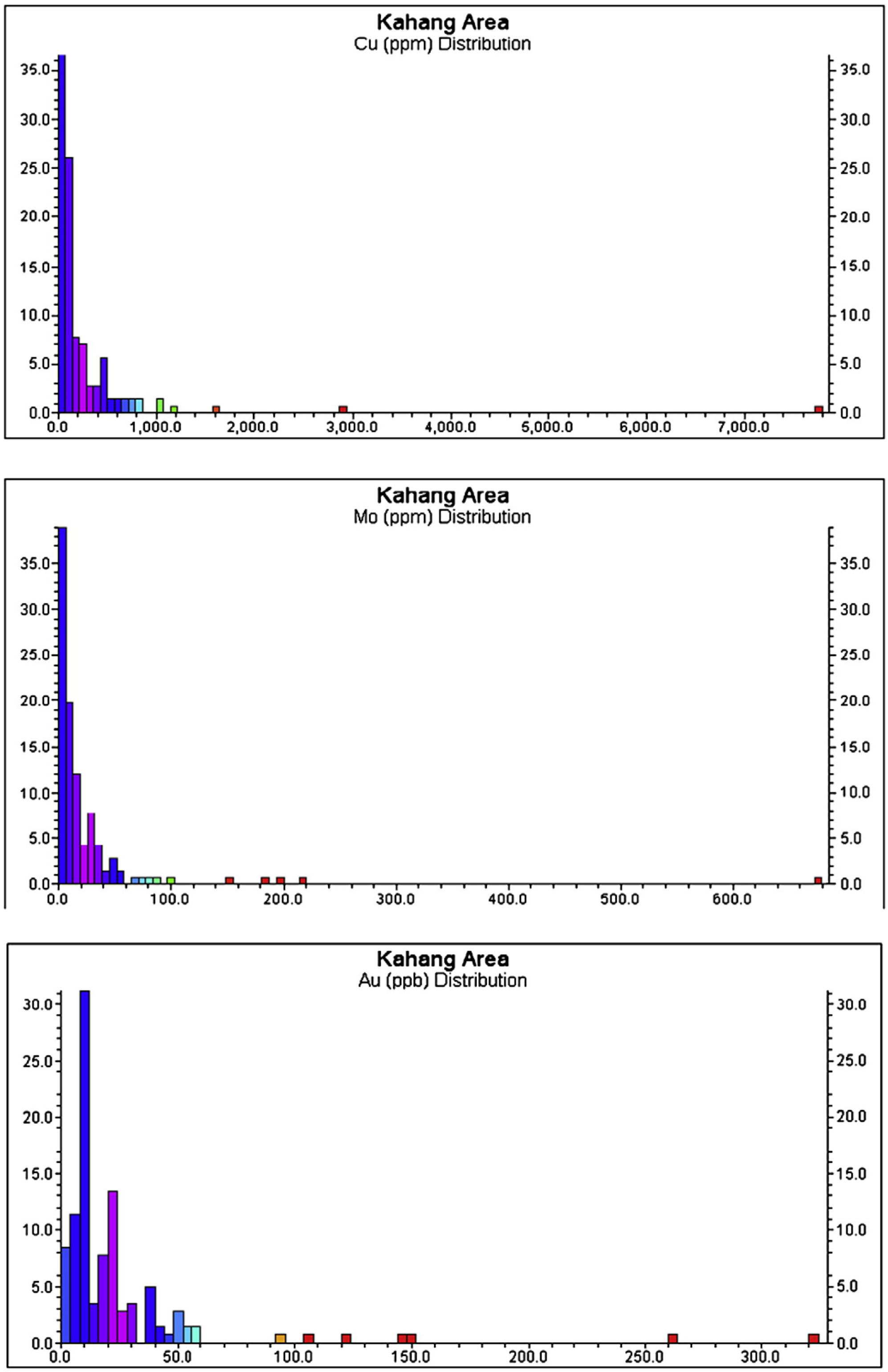

Fig. 3. Cu, Mo and Au histograms.

involved (Agterberg et al., 1996; Goncalves, 2001). The C–A method seems to be equally applicable as well to all cases, which is probably rooted in the fact that geochemical distributions mostly satisfy the properties of a multifractal function. There exists some evidence that geochemical distributions are fractal in nature and behavior, at least empirically according to Bolviken et al. (1992). Some approaches seem to support the idea that geochemical data distributions are multifractal, although this point is far from being proven (Cheng and

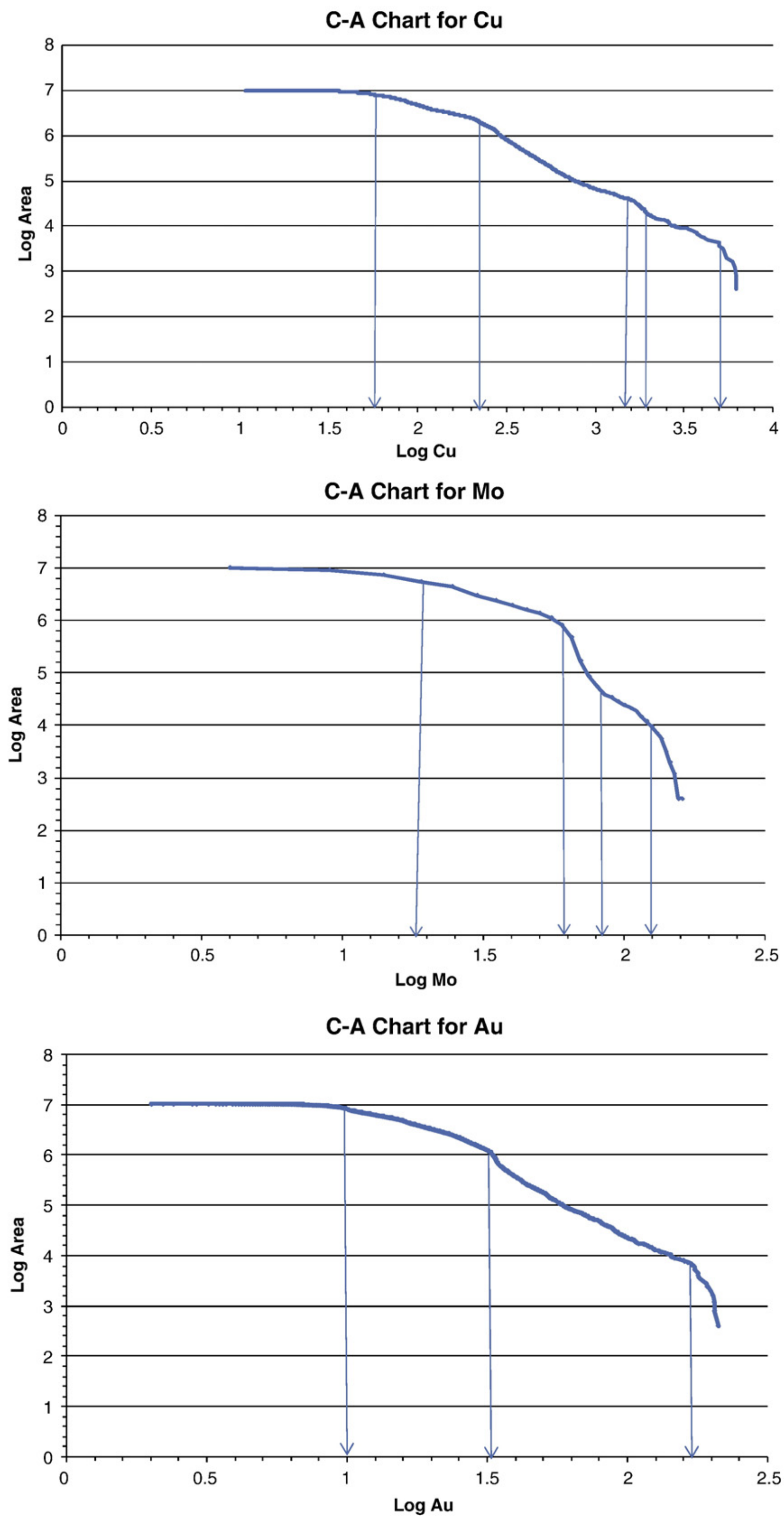

Fig. 4. Log–log plots (C–A method) for Cu, Mo and Au. The vertical axis represents cumulative cell areas $A(\rho)$, with elemental concentration values greater than ρ, and the horizontal axis is the actual value (ρ).

Agterberg, 1996; Turcotte, 1997; Goncalves, 2001). This idea may provide and help the development of an alternative interpretation validation and useful methods to be applied to elemental geochemical distributions analysis.

3. Geological setting of the Kahang porphyry system

The Kahang (Gor Gor) area of about 18 km^2 is situated about 73 km NE of Isfahan in Central Iran. This area is located in main Iranian

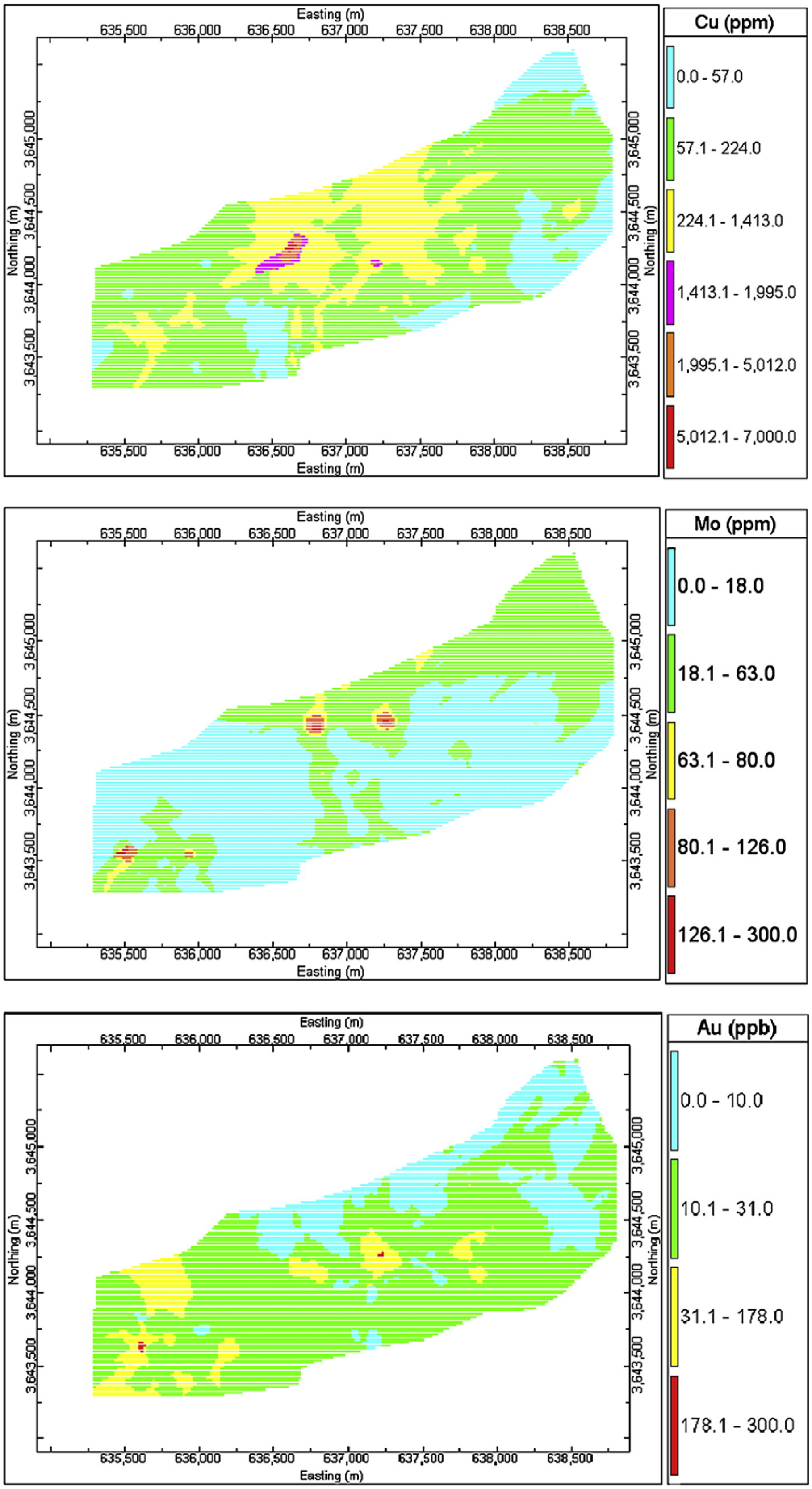

Fig. 5. Cu, Mo and Au geochemical population distribution maps based on C–A method.

Cenozoic magmatic belt named Urumieh-Dokhtar, which is one of the subdivisions of Zagros orogenies (Alavi, 1994). This belt extends from NW to SE Iran. The host all of the Iranian large porphyry copper deposits such as Sarcheshmeh, Sungun, Meiduk and Darehzar shown in Fig. 1 is located on this belt (Shahabpour, 1994). Kahang mineralized area includes a Cu–Mo porphyry system and was

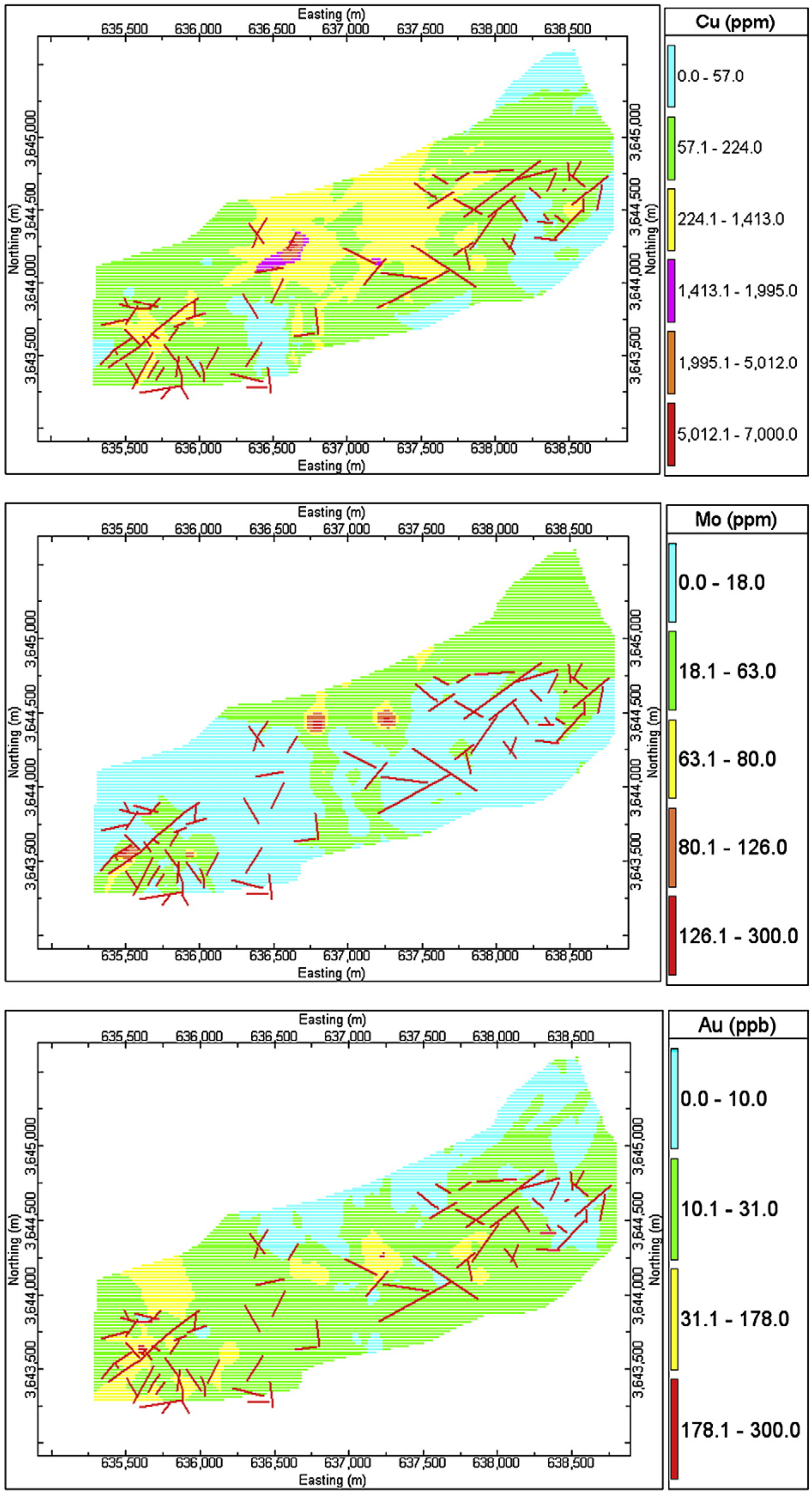

Fig. 6. Cu, Mo and Au geochemical population distribution maps based on C–A method imposed on fault location maps (red lines).

Table 2
Element means in different rock types.

Rock type	Monzodiorite	Diorite	Quartz monzonite	Andesite volcanics	Andesite porphyry	Dacite porphyry	Volcanic breccia
Cu (ppm)	1982.88	182.86	401.04	235.54	123.79	111.44	75.54
Mo (ppm)	3.91	14.70	7.23	48.55	26.11	24.50	13.08
Au (ppb)	91.71	16.86	29.81	8.62	22.35	21.74	20.12

Table 3
Element medians in different rock types.

Rock type	Monzodiorite	Diorite	Quartz monzonite	Andesite volcanics	Andesite porphyry	Dacite porphyry	Volcanic breccia
Cu (ppm)	955.00	187.00	355.00	130.00	92.50	86.50	49.00
Mo (ppm)	3.65	8.80	4.00	18.75	12.80	14.50	5.45
Au (ppb)	44.00	18.00	20.00	9.00	10.00	16.00	10.00

discovered in 2005 by remote sensing imaging techniques, geophysical methods and geochemical studies (Tabatabaei and Asadi Haroni, 2006).

The study area is mainly comprised of Eocene volcanic–pyroclastic rocks, which was intruded by quartz monzonite, monzodiorite to dioritic intrusions in Oligo-Miocene rocks (Fig. 1). The extrusive rocks, including tuffs, breccias and lavas are dacitic to andesitic in composition. Magmatic events in Kahang area can be interpreted as follows:

1. Explosive eruptions and ejection of pyroclastics such as tuff and tuff breccia
2. Flows of andesitic to dacitic lavas with porphyry texture from the volcano edifice. It is probable that eruptions of pyroclastic rocks and lavas were repeated periodically.
3. Emplacement of subvolcanics and intrusive rocks with compositions of dicitic, andesitic, monzonitic and dioritic nature, respectively.

On the other hand, these intrusions are roots of acidic to intermediate domes in Kahang area. The main structural features are two faults system trending NE–SW and NW–SE. Locally, their feather type fractures and joints are intense. The main alteration zones of phyllic, argillic and propylitic types were accompanied by the vein to veinlet fillings of quartz, quartz–magnetite and Fe-hydroxides. Mineralization has occurred within intrusives bodies and their surrounding host rocks. The ore minerals, i.e. chalcopyrite, pyrite, malachite, magnetite, limonite, jarosite, goethite, and chalcantite are present and, the latter ones occurred in the zone of quartz stockworks and quartz–sericite alteration. The presence of CuSO4, which is rare in Iranian Cu porphyry systems, may be interpreted as oxidizing conditions. Precise extension and relationships between alteration zones and mineralization, and economical evaluation of the deposit are still being investigated and are under study.

4. Litho geochemistry

A total of 143 collected lithogeochemical samples were analyzed by ICP-MS for elements which relate to Cu mineralization and are of interest, and Mo and Au concentrations were of no significance. Fig. 2 is the location map of the samples. Statistical results show that Cu, Mo and Au mean values are 273, 26 ppm and 24 ppb, respectively presented in Table 1. Their distributions are as shown in Fig. 3 and are not normal. Variation between maximum and minimum for these data shows a wide range. If median is assumed to be equal to threshold values. The obtained statistical results are 100 ppm for Cu, 9.7 ppm for Mo and 11 ppb for Au.

Geochemical maps were generated with IDS (Inverse Distance Squared) method by RockWorks™ v. 2006 software package. This procedure is suggested because it eliminates the undesired smoothing effects caused by the usage of Kriging method. Since the IDS method clarifies the ore grade boundaries and ore concentration values, it is more desirable to use IDS method instead of Kriging which inherently has rather high amounts of truncation errors for the upper and lower boundaries of ore grades. The area was gridded by 20 m×20 m cells. The proposed gridding pattern is put to use because the fundamentals of C–A fractal method is based on the existence of partition function, and the sampled data cannot be utilized effectively; also, since one cannot sample the entire study area, and for evaluation and estimation of any parameter, i.e., ore grade, gridding of the area is inevitably a desired mandate and one cannot do otherwise. The necessary and the needed partition function to be used in fractal methods is based upon assumption of having a cell characterization in the area in order to find and calculate the area which has a certain ore grade. By this method the problem of over sampling will not enter into picture because the C–A fractal method will automatically eliminate any probable grid related problem in division of the area into smaller elements and the original fractal character is preserved (Evertz and Mandelbrot, 1992; Cheng et al., 1994). Concentration–area relations were computed by assigning an area of influence to each sampled point and summing all elemental areas whose concentration lies below a given value. This procedure was repeated for different elemental concentrations. Carrying on this procedure is not cumbersome because there is a regular gridding of 20 m×20 m cells. The evaluated grades in cells were sorted out based on decreasing grades and cumulative areas were calculated for grades. Finally, log–log plots were constructed for Cu, Mo and Au (Fig. 4). Geochemical populations are delineated in these plots of Cu, Mo and Au. On the basis of this procedure, there are 6, 5 and 4 populations for Cu, Mo and Au, respectively as shown in Fig. 4. Cu anomalous threshold is 224 ppm and its high intensity anomaly is 5012 ppm. Also, it is clear that there are three stages of Cu enrichments based on log–log plot as depicted in Fig. 4. The first event for Cu C–A variations occurred at grades below 224 ppm. The second event shows up between grades 224 ppm and 1995 ppm. The final event included major Cu mineralization which occurred and interpreted in grades higher than 1995 ppm. Mo threshold and high intensity anomalies are 63 ppm, and 126 ppm (Fig. 4). Mo log–log plot shows that major Mo enrichment occurred at 63 ppm and higher. Au anomalous threshold is about 31 ppb. There are two enrichment steps interpreted as seen in C–A log–log plot of Au in Fig. 4. Major Au enrichment started from 31 ppb, and, 178 ppb concentration is beginning of high intensity Au anomaly.

Table 4
Element thresholds from C–A method.

Anomaly intensive	Low	High
Cu (ppm)	224	5012
Mo (ppm)	63	126
Au (ppb)	31	178

Each geochemical population in this study was assumed to have various kinds of distributions, and its various components, such as individual chemical elements and their concentrations could be fitted into a straight line on log–log plot. Obviously due to non-uniform behavior of the elements, if plotted on log–log co-ordinates, the plot will have different slopes and various straight-line segments which connects them at them an angle or with breaks on the plot. Breaks between the straight-line segments and the corresponding values of Cu, Mo and Au have been used as cut-offs to reclassify cell values in the IDS interpolated maps and are presented in Fig. 5. Based on these results, elemental grade distribution maps were drawn as Fig. 5. Clearly most of Cu anomalies are located in central parts of the area, especially high intensity Cu anomalies. Few parts of these anomalies were also situated in western and eastern parts of the studied area. Mo anomalies were situated in central and western parts and they are small. Locations of Au anomalies are in western and central parts of the area and the high intensive anomalies are very small located in western and central parts. Based on these maps, potential presence of these elements are located in central and western parts as shown in Fig. 5. Also, several small Cu anomalies are interpreted in eastern part of the area as delineated in Fig. 5.

5. Comparison with geological particulars

Thresholds and cut-off results from C–A method are compared and correlated to specific geological particulars of the region including considering nature of lithological units, faults and alterations. Cu, Mo and Au distributions in the Kahang area, and the faults map are shown in Fig. 6. The anomalous parts clearly indicate the main identified faults especially in western part of the area which is comfortable with existing structural settings and controls as indicated in Fig. 6. Comparison between tectonics confirms forces creating the regional stress field and Cu, Mo and Au anomalies, shows that faults intersect the anomalies situated near those structures as depicted in Fig. 6. On the other hand, faults and elemental anomalies have a proportional relationship. High grade elemental anomalies occurred inside and within the fault zones or located on faults intersection areas (Fig. 6). It could be deduced that fault density has a direct positive correlation with mineralization especially in western parts of the studied area.

In this study area, based on results of the analyzed samples, there are seven different rock types. Mean and median values elemental concentrations were calculated for these rock units and are presented in Tables 2 and 3. Cu mean, 1982.88 ppm, in monzodioritic rocks is

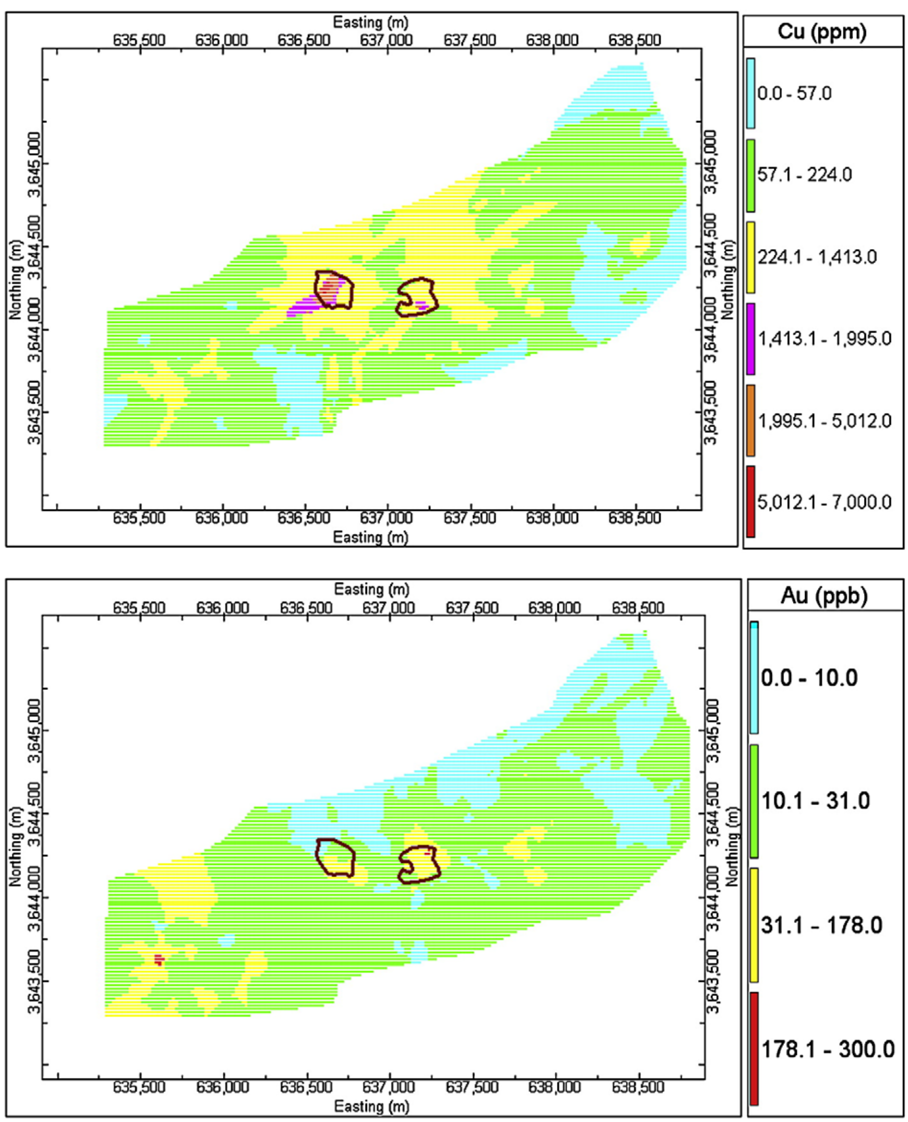

Fig. 7. Relationship between Cu and Au distribution and monzodiorites (polygons).

highest among all rock types as presented in Table 2. Mean Cu concentration in monzodiorites, quartz monzonite and andesitic units is higher than its threshold values obtained from C–A method as given in Table 2. Mo mean is lower than Mo threshold values calculated by the C–A method, but Mo mean value in andesitic units is close to threshold values (Table 2). The Au mean value is higher than its threshold obtained from C–A method at 31 ppb and is higher only in monzodiorites to about 91.71 ppb. Also, the Au mean in quartz monzonite is at 29.81 ppb, close to the threshold value of 31 ppb, as presented in Table 2.

If one assumes that median is equal to threshold values obtained from classical statistics the Cu, Mo and Au thresholds can be calculated in different rock types. Cu median in monzodiorite of 955 ppm, and quartz monzonite of 355 ppm, is higher than Cu threshold from C–A method which is 224 ppm, but it is lower in other rock types as given in Table 3. On the other hand, highest Cu enrichment exists in monzodiorite and Mo median is lower than the threshold from C–A method at a value of 63 ppm in all rock types, but in andesitic units is higher than the others as presented in Table 3. Au median is highest in monzodiorite at 44 ppb, and higher than C–A threshold of 31 ppb in Table 3. These results show that monzodiorites are enriched in Cu and Au, but Mo enrichment exists in andesitic units. Also, these parameters correspond with intrusive bodies' emplacement time in this region. Thresholds of these elements were calculated by C–A fractal method presented in Table 4.

Lithological unit's positions were correlated with elemental distribution maps. There exists a strong relationship between Cu concentration values higher than 5012 ppm and Au higher than 178 ppb in high intensive anomalous parts with monzodiorites based on this correlation given in Fig. 7. It shows that monzodiorites host high intensive Cu enrichment and Au anomalies. In other words, major Cu and Au mineralization occurred concurrent with monzodiorites in final stage of Cu and Au enrichments. But, Mo high intensive anomalous parts (higher than 126 ppm) in central parts of the area are hosted by andesitic units. Andesitic units show very low contents of Cu and Au as their background in northern parts of the area, but these rocks contain low grade anomalies of Cu, i.e., between 224 ppm and 1413 ppm, and Au, i.e., 31 ppb and 178 ppb, in central parts. In western parts of the area volcanic breccias hosts high intensive Mo and Au and low intensity Cu anomalous parts as illustrated in Fig. 8. Also, faults have caused the increase in porosity or void volume in volcanic breccias. Quartz monzonites contain low amounts of Cu, having the maximum values of 1413 ppm and Mo and Au values are about the same as background values, lower than 63 ppm and 31 ppb, respectively. Dioritic units have low amounts of Cu, Mo and Au that they host low intensity Cu anomalous amounts in

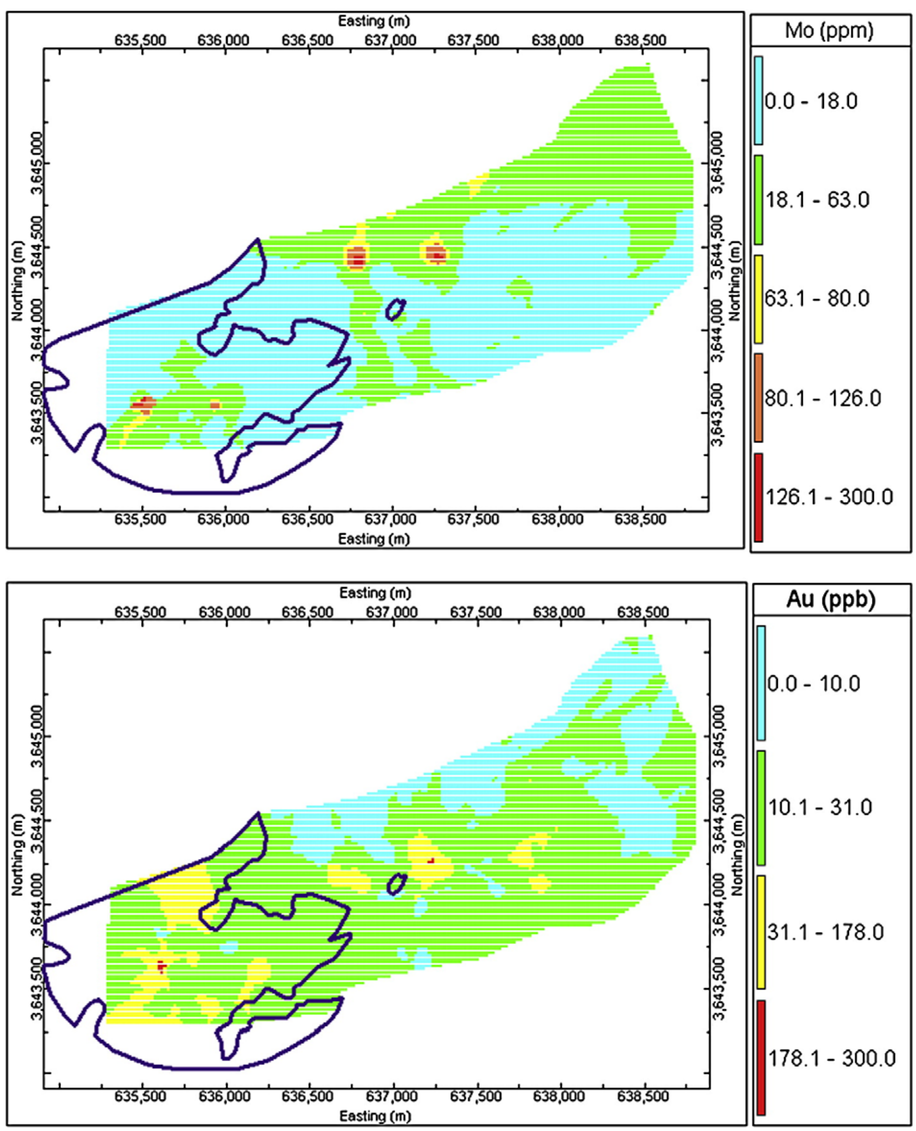

Fig. 8. Relationship between Mo and Au distribution and volcanic breccias (polygons).

eastern part of the study area, lower than 1413 ppm concentration. Dacitic unit present in eastern part of the area is barren and does not host these elements. Its elemental contents are equal to background, but in central and western part, dacitic units show low values of Cu, between 224 ppm and 1413 ppm, and, for Au: between 31 ppb and 178 ppb. Results from C–A method are correlated with elements' median values in rock types. These concentrations show a good relationship with intrusions.

Alterations have a strong positive relationship with Cu, Mo and Au anomalies. All of the anomalous parts are covered by phyllic, argillic and propylitic alterations. Most phyllic alteration is associated with Cu and Mo, especially Cu anomalies as shown in Fig. 9. Cu with concentration at maximum 1413 ppm, Mo, higher than 126 ppm, and Au, higher than 178 ppb, do have anomalies in western parts of the area and are covered by phyllic alterations. Also, phyllic alterations correlate with Cu low intensive anomaly in eastern parts only as shown in Fig. 9. Phyllic alterations are surrounded by high intensive Cu anomaly in central part of the area. Argillic alterations cover parts of eastern and central Cu anomalies, where Cu grade is 2000 ppm and more. The rock type covers for Mo and Au anomalous parts in west of the area are delineated in Fig. 10 and are of the volcanic breccia type. Geological evidences such as covering high intensive elemental anomalies and high amounts of $CuSO_4$ show that argillic alteration has low to medium intensity in Kahang porphyry system. Au anomalies in central and eastern parts have a rather good relationship with argillic alterations (Fig. 10). Propylitic alterations correlated with Cu content of higher than 5000 ppm, Mo concentration higher than 150 ppm, and Au higher than 180 ppb constitutes the high intensive anomalies in central part of Kahang area. This alteration is correlated with the richest Cu anomaly as depicted in Fig. 11. Propylitic alterations cover parts of Cu anomalies in central area (Fig. 11), but, these anomalies are situated outside of most Mo and Au bearing anomalies.

6. Conclusions and future challenges

Study on Kahang Cu–Mo porphyry system reveals the potential use of the C–A method for geochemical anomaly separation as a useful tool for geochemical and mineral exploration. The advantages of this method rely essentially on its simplicity, and easy computational implementation, as well as the possibility to compute a numerical value of concentrations, i.e., the anomalous threshold, which is the most useful criteria for cross examination of information with numerical data from different sources, commonly used in lithogeochemistry.

There exists a very good correlation between the calculated anomalous threshold values and the range of concentrations obtained in the rocks, especially for Cu in the Kahang area. Such correlation is also valid for other elements, but, the range of values is clearly different. These results may also be interpreted differently according to their nature, especially multifractal curves in log–log plots. Cu concentration in the area may be a result of the three steps of enrichment, i.e., mineralization and later dispersions. Major Cu and Au mineralization occurred by the intrusion of Oligo-Miocene monzodiorite bodies in this area. But, for Mo and Au in Kahang area this may be explained by two enrichment steps that the major mineralization occurred in andesitic units.

The occurrence of Cu and Au high enrichments in monzodiorites in central parts of the area has been actually realized in the samples collected from the field. Mo high intensive anomalies were found within andesitic units. Statistical analysis also confirms these results. Elemental anomalies in western parts of the area are associated with volcanic breccias. Dioritic units in eastern parts host Cu in low intensive anomalies. It can be concluded that lower grade mineralization of Cu has occurred in diorites and quartz monzonites. Also, data analysis shows that major Cu and Au enrichment steps are concurrent with that of monzodiorites. The process for Mo enrichment is synchronized with andesitic rocks and their subsequent changes. The studied element anomalies have proper and direct relationships with faults in Kahang area. High intensive element anomalies are mostly situated at fault intersections. These kinds of occurrence are seen especially in west of area with volcanic breccias because faults were pathways for mineralized fluids. Volcanic breccias are the proper host rock for elements to be deposited in them since they have good primary porosity which faulting had increased this parameter. There is a good correlation between phyllic, argillic and propylitic alterations and anomalous concentration, of Cu, Mo and

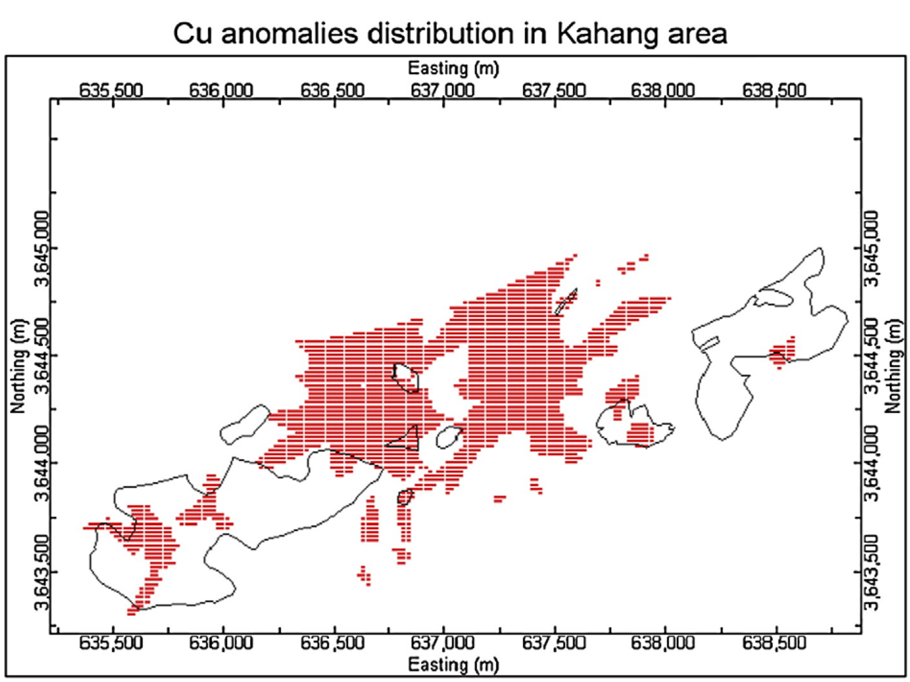

Fig. 9. Relationship between Cu geochemical anomalies and phyllic alterations (black polygons).

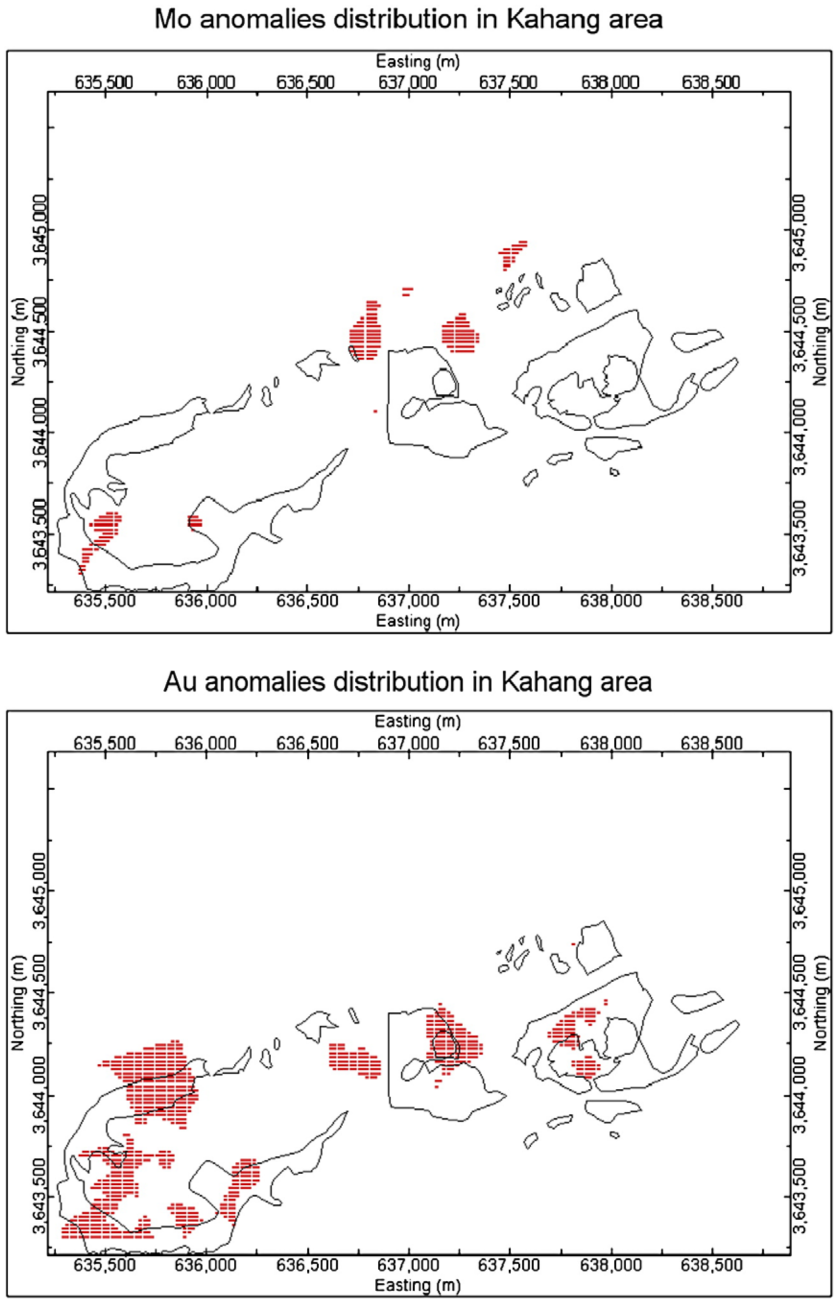

Fig. 10. Relationship between Mo and Au geochemical anomalies and argillic alterations (black polygons).

Au. Low to medium intensive argillic alterations have good relationships with high grade anomalous elemental enrichment parts. It is a logical assumption that Cu enrichment is high and is feasible of high grade potential (0.5% and higher grade) for this element but Mo and Au accumulations do not seem to be economically feasible.

Further, geological evidences include lithological information, alterations and tectonics setting proved that accuracy of the results is obtained from C–A methods. Richest parts of these elements correlated direction to tectonics and many other particulars of these rocks are situated at fault intersections. Cu, Mo and Au enrichment processes are correlated with lithological units and their time table emplacement. Dioritic and monzonitic units especially monzodiorites were last emplacements in this area and these units host high grade Cu and Au anomalies. Mo anomalies in central part of the area are located in andesitic units that show Mo mineralization may have occurred in primary and secondary emplaced volcanic bodies, especially, volcanic andesites. Low Mo grade is proper evidence in this area. Volcanic breccias occurred from primary volcanic intrusion and their hosting of very low grade Cu–Mo and Au mineralization at a background level is seen in their many parts but extensive faulting caused the fluids found to approach for entry to this rock type and high richest anomalous of Mo (higher than 126 ppm) and Au (higher than 178 ppb) within low grade Cu anomalous (between 224 ppm and 1413 ppm) occurred inside or in intersection of faults. It shows that high grade mineralization of these elements is at a later stage and is controlled by tectonics and fluid flows.

Although it may be easier to study geochemical anomalies with the C–A method, multifractal nature of C–A log–log curves could be of essential help to geoscientists for interpreting the stages which an element is enriched. The developments in multifractal theory and their usage could provide a favorable ground for the stochastic simulation of geochemical distributions, and their understanding and interpretations.

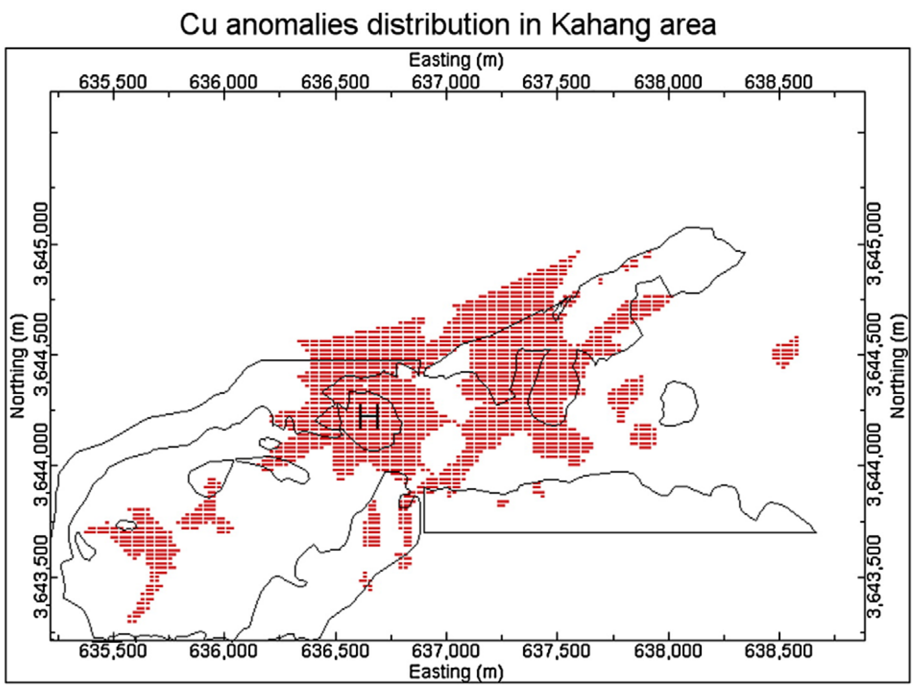

Fig. 11. Relationship between Cu geochemical anomalies and propylitic alterations (black polygons; H: high intensity anomaly).

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