Identifying Hydrothermal Alteration: Geochemical Particulars based on Lithogeochemical Data from the Kahang Cu Porphyry Deposit, Central Iran

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Abstract

Kahang Cu Porphyry deposit is situated in the central part of a major Iranian magmatic belt, Urumieh-Dokhtar, in central Iran. There are several sub-volcanic stocks (e.g., porphyric granitoids rocks, quartz monzonite, diorite and monzodiorite-monzogranite) within Eocene volcanic and pyroclastic rocks consisting of basaltic, trachy-andesite and dacitic rocks. Hydrothermal alterations at the Kahang deposit have an extended range and exhibit a concentric zoning pattern including potassic, phyllic, argillic and propylitic from the center to the margin. The aim of this study was to identify geochemical particulars by geochemical applications in 184 rock samples in these potassic, phyllic and argillic alteration zones. The results of this study show that there are high values of K, Mg and Cu in the potassic zone (located in the central part), main Mo anomalous parts and high Cu values can be found in the phyllic zone (eastern part), and high values of Au, Ti and Al are concentrated in the argillic zone (western part) . Overall, the Kahang deposit hosts Cu, Mo and Au mineralization in these three zones.

Keywords: *Hydrothermal Alteration, Lithogeochemical Data, Cu Porphyry Deposit, Kahang, Iran.*

1. Introduction

Identifying hydrothermal alterations, specifically potassic and phyllic, and their geochemical characteristics is important in porphyry deposits, because they host major mineralization zones [1-5]. In porphyry types of mineralization, the main parts of Cu, Mo and Au mineralization occur in potassic, phyllic and moderate argillic zones; however, Au concentration is high in advanced argillic alteration zones [6-8]. Customized methods to determine alterations are based on the existence of minerals such as potassium feldespar (Kf), biotite and magnetite in the potassic alteration zone, quartz, pyrite and sericite in the phyllic zone and alunite in the advanced argillic zone [9-12]. The potassic zone hosts K for Na exchange mineral reactions and is typically represented by the replacement of albitic plagioclase by microcline and/or orthoclase. Therefore, phyllic alteration is evident by quartz-sericite-pyrite assemblage and minor minerals including Kf, kaolinite, calcite, biotite, rutile and apatite [13-16].

The intermediate argillic zone is defined by the presence of montmorillonite, illite, chlorite, and kaolinite group clay minerals. Advanced argillic alteration is formed due to the interaction of host rocks with strong acidic fluids. This alteration is characterized by dickite, kaolinite, pyrophyllite, barite, alunite and diaspore. Moreover, this zone exists in the inner zones of the hydrothermal base and precious metal-bearing veins, and most typically in the high-sulfur epithermal systems [16, 17].

The recognition of geochemical characteristics of different alteration zones is another method of alteration zone identification. Moreover, Mg values are depleted in the phyllic zone, but K, Cu and Mo values are enriched [9,18,19,20]. Argillic alterations, especially advanced alternations, are important for Au deposition. In addition, major alkaline elements such as K and Mg are depleted, but Au, Ti and Al values are enriched in argillic alteration zones [21].

In this paper, the geochemical behaviour of elements has been considered in the potassic, phyllic and argillic alteration zones based on lithogeochemical data in the Kahang Cu Porphyry deposit. Enrichment and depletion of K, Mg, Cu, Mo, Au, Al and Ti lithogeochemical values in related alteration zones

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within this deposit have been calculated and analyzed by the classical statistics method. Mean and median variation of the elements and elemental distributions were delineated in the alteration zones. Moreover, regression between the elements was determined in the Kahang deposit alteration zones.

Kahang Cu Porphyry deposit was first prospected by remote sensing, surface geophysical and geochemical studies [22,23]. This deposit contains more than 100 million tons of sulfide ore with an average grade of 0.6% Cu and 70 ppm Mo, based on general exploration and diamond drilling (78 boreholes).

2. Geological Setting

Kahang Cu Porphyry deposit is located approximately 73 km from Isfahan, located in central Iran. This deposit is situated in the central part of the Cenozoic Urumieh-Dokhtar magmatic belt, which extends 2000 km and is 150 km wide, from the NW to SE Iran (Fig. 1: [24-26]). This magmatic belt has been interpreted to be a subduction related Andean-type magmatic arc that has been active from the late Jurassic era to present [27,28]. The rock units of this belt are composed of voluminous tholeiitic, calcalkaline, and K-rich alkaline intrusive and extrusive rocks with associated pyroclastic and volcanoclastic successions along the active margin of the Iranian plates [28-30]. The belt hosts the main Iranian porphyry deposits, such as Sarcheshmeh, Sungun, Meiduk and Darehzar [23,31-33].

The Kahang deposit, with lithologies consisting of Eocene volcanic–pyroclastic rocks, was intruded by porphyric granitoids rocks, quartz monzonite, monzodiorite-monzogranite to dioritic in composition, and Oligo-Miocene in age (Fig. 1). The Eocene rock units consist of andesite, trachyte, trachy-andesite, silicic breccias and tuffs. The main geologic structures of the area are a NW–SE and NE–SW-trending fault system [23]. The extrusive rocks, including tuffs, breccias and lavas, are dacitic to andesitic in composition. Magmatic events in the Kahang area can be interpreted as followings [23].

1. Explosive eruptions 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 sub-volcanics and intrusive rocks with compositions of dicitic, andesitic, monzonitic and dioritic nature.

3. Mineralization Particulars of the Kahang Deposit

The Kahang is a Cu (Mo-Au) porphyry deposit. Mineralization at Kahang are hosted mainly by Eocene sub-volcanic rocks, especially porphyric quartz diorites, monzodiorite-monzogranite and dacitic rocks.

Ore minerals are dominated by chalcopyrite, pyrite, bornite and lesser amounts of chalcocite, covelite and malachite and disseminated Cu minerals (i.e., chalcocite, covelite, chalcopyrite and malachite, native Au have accumulated in silicic veins and veinlets. Native Au particles are found in chalcopyrite in the eastern part, and Fe-ores (i.e., hematite, magnetite, goethite and jarosite) have been identified in the oxidized zone.

Hydrothermal alteration in the Kahang deposit is pervasive, occurring in an area greater than 10 km^2.

Detailed alteration mapping shows four major types of hydrothermal alterations in the Kahang deposit: potassic, phyllic, argillic and propylitic. The argillic alteration zone (in the eastern part of the deposit) consisting of intermediate and high extensive alunite bearing nature (especially in the western and central parts of the deposit) presents a silicified epithermal system over the upper most part of the deposit. The potassic alteration zone is located in the central part of the deposit with neoformed biotite and Kf veinlets. Phyllic alteration has developed in the eastern part of the deposit and contains high amounts of quartz, sericite, and albite with a argillic matrix. The phyllic alteration (quartz + sericite) has an extended range on acidic to intermediate subvolcanic domes. The propylitic alteration zone marks the outer limit of the hydrothermal system and is dominated by chlorite, epidote and albite.

4. Geochemical Sampling and Statistical Analysis

Lithogeochemical samples as rock chips were collected from 184 points of the Kahang Cu porphyry deposit (Fig. 2). The samples were analyzed by the inductively coupled plasma mass spectrometry (ICP-MS) method in ACM E laboratories, Vancouver, Canada, based on Group 1T-MS (Ultratrace by ICP-MS). ICP-MS analysis of 4-acid digestion on a 0.25 g split giving a total to near total values for all elements. The digestion is only partial for some Cr and Ba minerals and some oxides of Al, Fe, Hf, Mn, Sn, Ta, Zr [34]. Values for K, Mg, Al, Ti, Cu, Mo, Ti and Au were calculated for statistical analysis, including mean, median, and frequency distribution by histogram, range and standard deviation (Fig. 3 and Table 1). Statistical studies for these lithogeochemical data show that their mean values equal 1.88%, 30.2 ppb, 323 ppm, 18.1 ppm, 0.43% , 0.1% and 5.6% for K, Au, Cu, Mo, Mg, Ti and Al, respectively (Fig. 3 and Table. 1). Their median are 6.98%, 91 ppm, 7.7 ppm, 0.33%, 2.06%, 957 ppm and 12 ppb for Al, Cu, Mo, Mg, K, Ti and Au, respectively (Table 1).

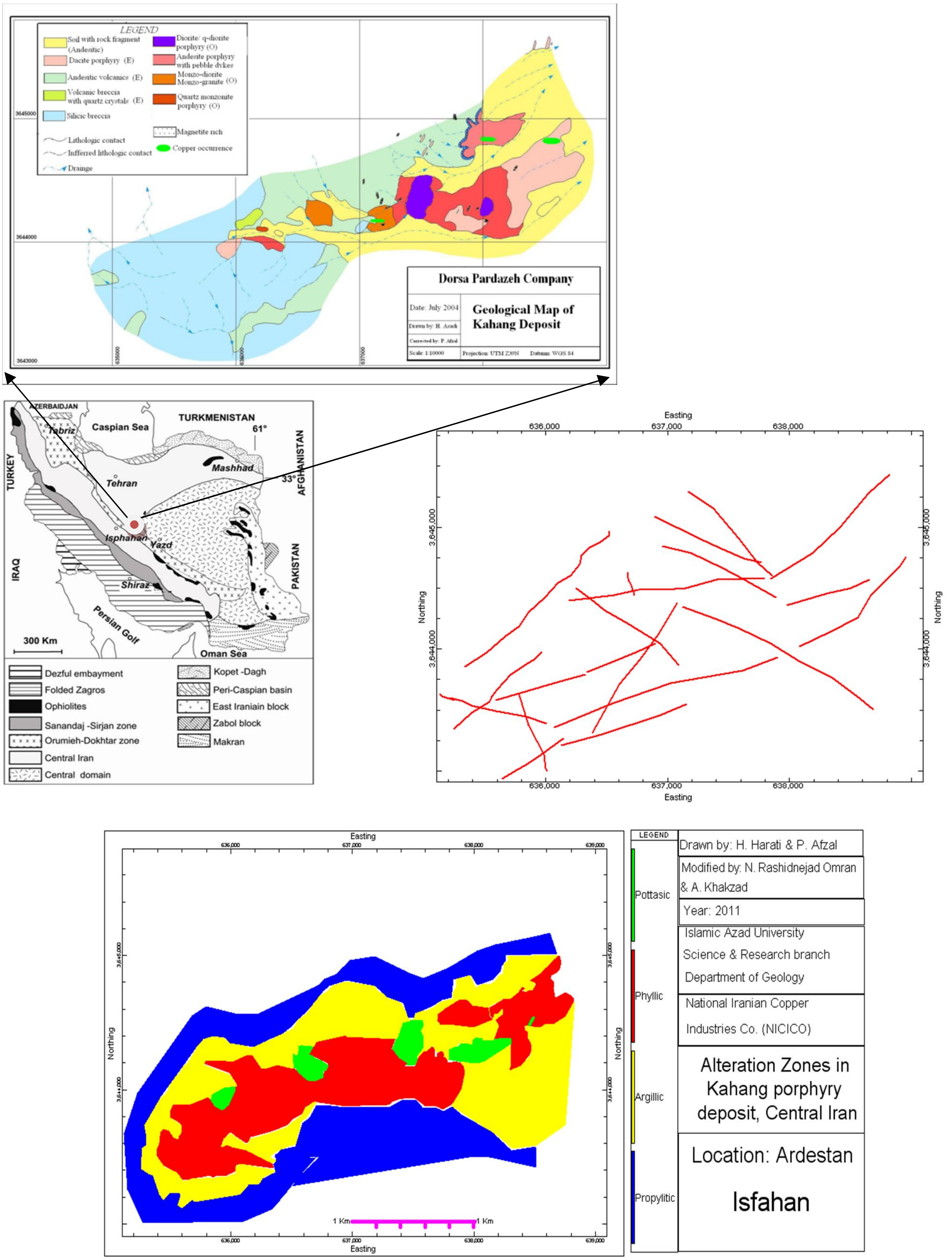


Fig.1. Urumieh-Dokhtar magmatic belt within the Kahang deposit situation, modified based on Alavi [24], and its geological, faults and alternation maps (E: Eocene and O: Oligo-Miocene, respectively)

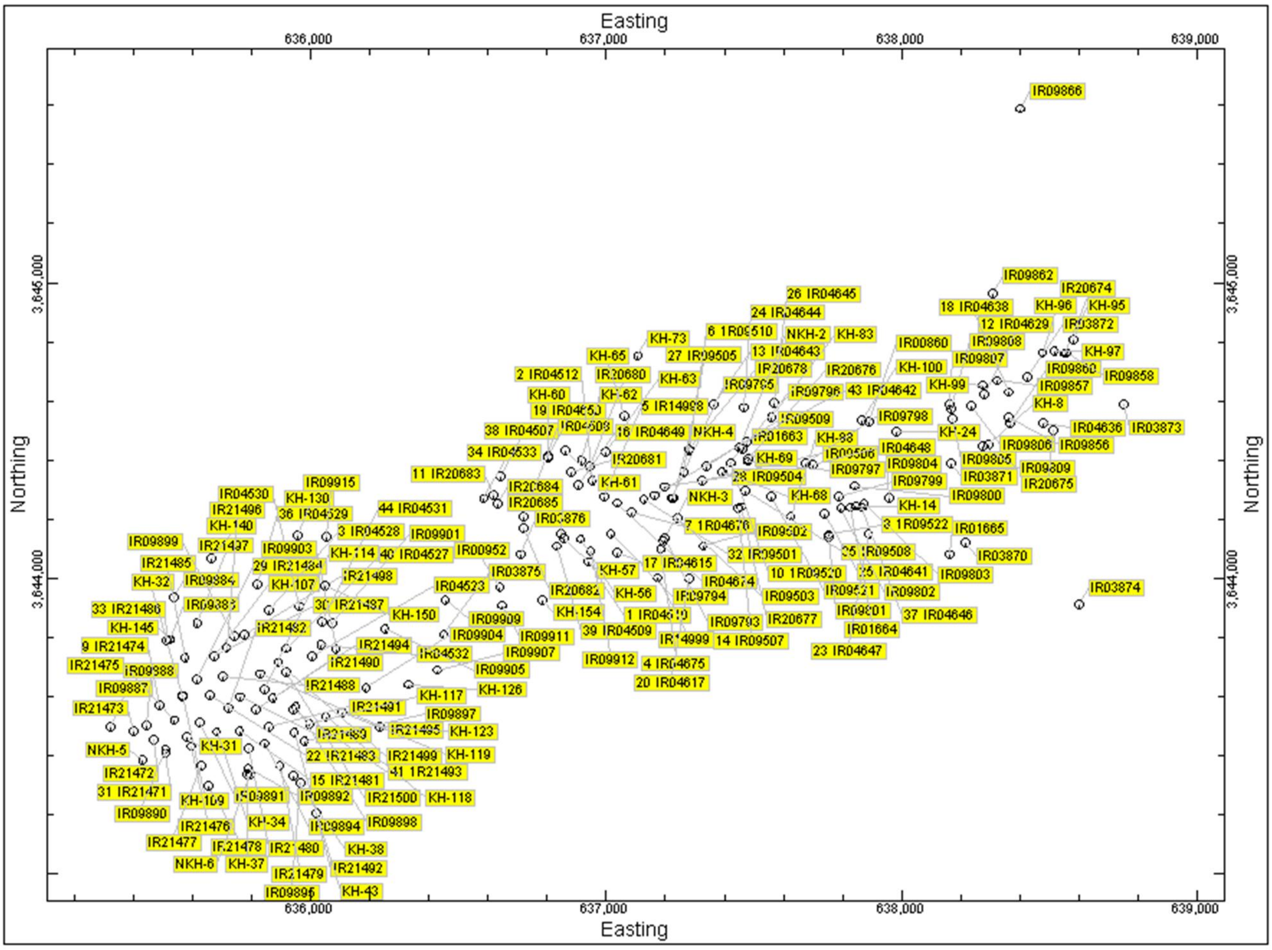


Fig.2. Location map of lithogeochemical samples in the Kahang CU Porphyry deposit.

Table 1. Statistical parameters for K, Mg, Al, Cu, Mo, Au and Ti from lithogeochemical data of the Kahang deposit. SD: standard deviation.

Statistical parameters	K (%)	Mg (%)	Al (%)	Cu (ppm)	Mo (ppm)	Au (ppb)	Ti (ppm)
Accuracy	0.02 %	0.01 %	0.01 %	0.01 ppm	0.05 ppm	0.1 ppm	10 ppm
Sample No.	184	184	184	184	184	184	184
Mean	1.88	0.43	5.60	323	18.10	30.20	1040
Median	2.06	0.33	6.98	91	7.70	12	957
Maximum	4.15	3.55	9.25	8067.52	219	400	6530
Minimum	0.1	0.02	0.34	7	0.30	0	12
Range	4.05	3.53	8.91	8060.52	218.70	400	6518
SD	1.11	0.41	2.98	961.23	31.08	54.18	878.52

Elemental distribution maps were generated by RockWorks 15 software package using the IDS (Inverse Distance Squared) method. IDS is based on the assumption that the nearby values contribute more to the interpolated values than distant observations. In other words, for this method the influence of a known data point is inversely related to the distance from the unknown location that is being estimated. The advantage of IDS is that it is intuitive and efficient. This interpolation works best with evenly distributed points [35].

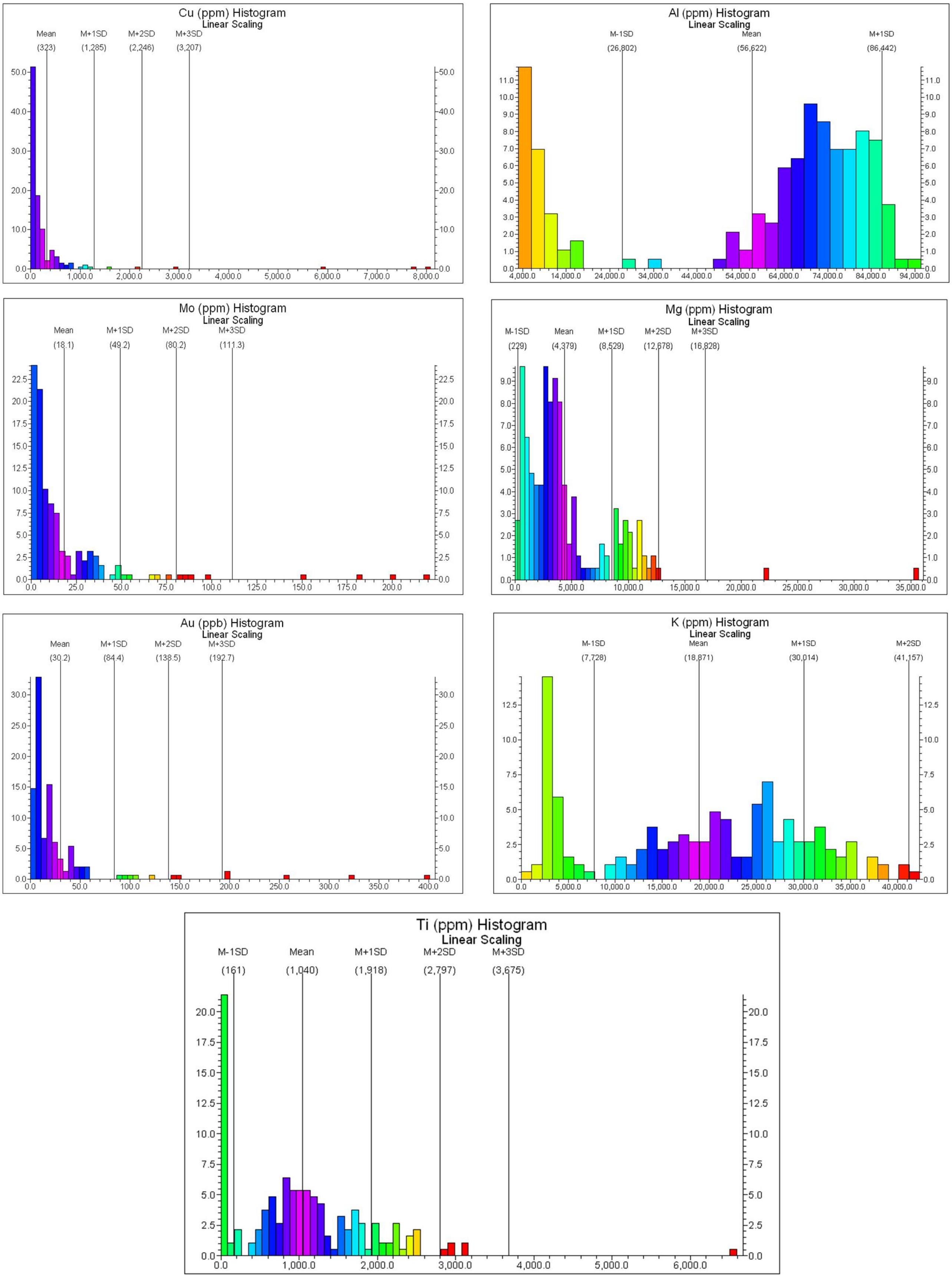


Fig. 3. Cu, Mo, Au, K, Mg, Ti and Al histograms which show multi-modal and L distributions for the elements in different alteration zones of the Kahang deposit.

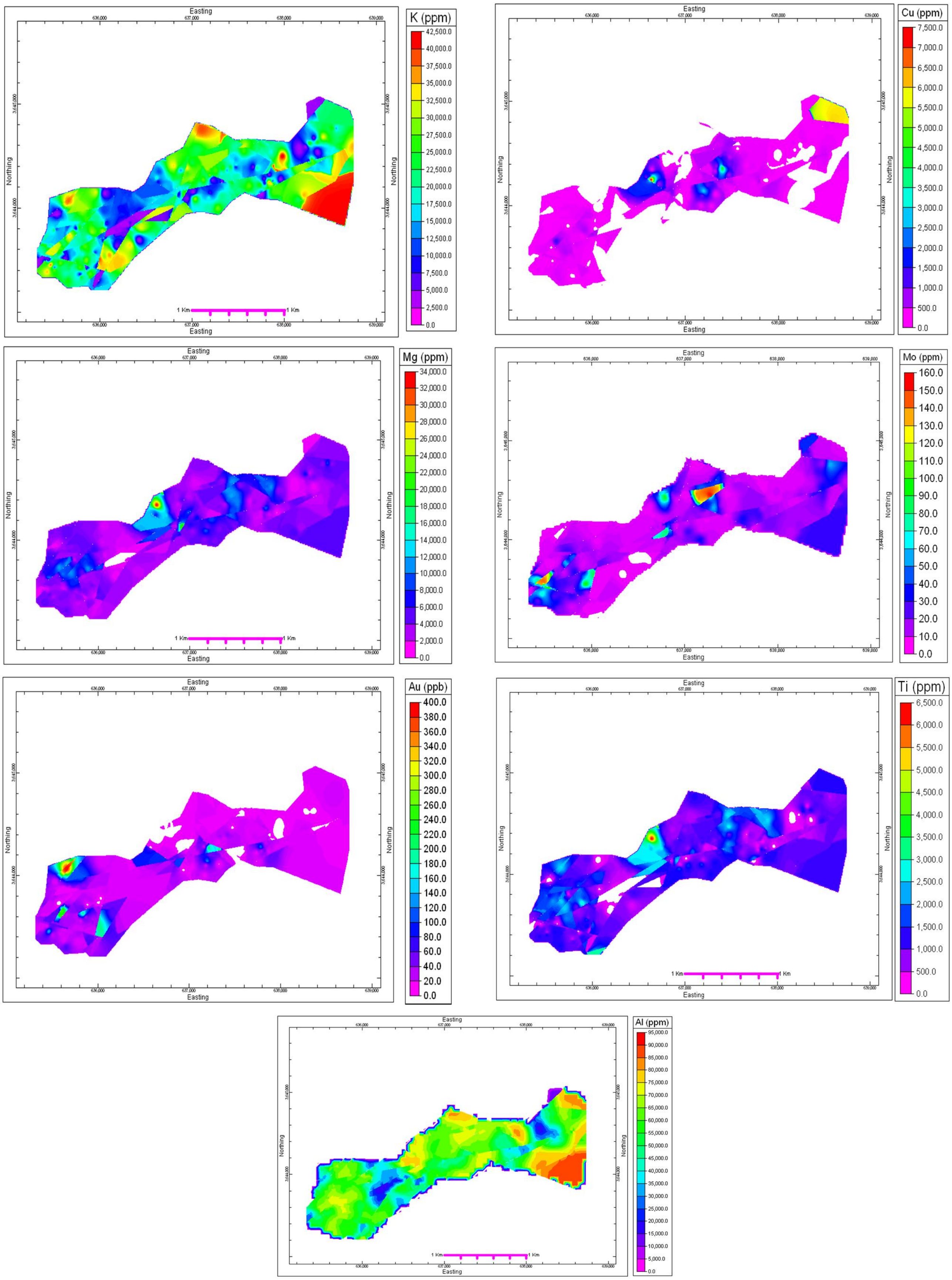


Fig.4. K, Mg, Cu, Mo, Au, Ti and Al distribution maps in the Kahang deposit based on lithogeochemical sampling.

5. Discussion and results

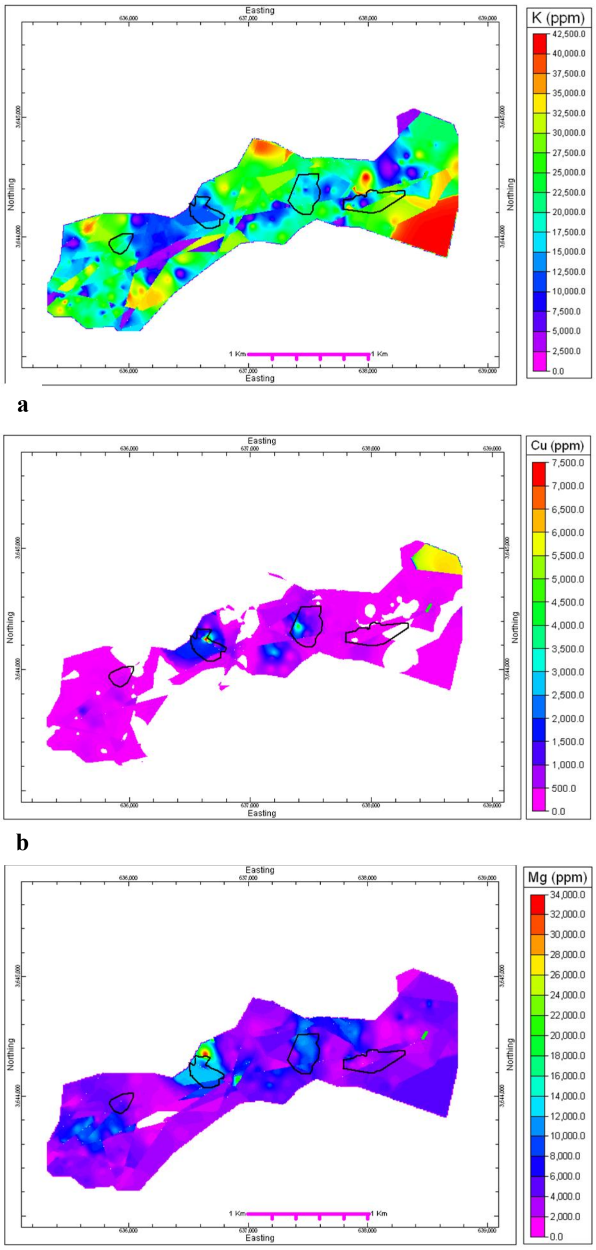
The histograms show that the distribution of elemental values is not normal (Fig. 3). There are three populations for K, including 0 - 0.7%, 1 to 3.5% and higher than 3.7%, based on lithogeochemical data. Au histogram shows two populations, the extended population is between 0 to 60 ppb and the smaller one is higher than 100 ppb, as illustrated in Fig. 3. Mg values in rock distribution show three populations lower than 0.5%, 0.5% to 1.4% and higher than 2.2%, which are mostly between 0 to 0.5%. There are two main populations that exist in Cu histograms and they are between 0 to 0.1% and higher than 0.1%; most being lower than 0.1%. Al distributions have three populations between 0.4 to 1.4% for most of the data and 2.5 to 3.5% and higher than 5% (Fig. 3). Mo histogram shows three populations, including lower than 40 ppm, between 40 and 100 ppm and higher than 150 ppm. Ti distribution has three populations, lower than 200 ppm, between 400 and 2600 ppm, which is evident in most of the samples and is higher than 2800 ppm (Fig. 3). K values are not higher than 3.5% in most parts of the deposit. Additionally, several parts in the SE, NW and central sides of the Kahang deposit have K values higher than 4%. Mg values are lower than 1% in most parts of the Kahang deposit and a small part with high amounts of Mg concentration values, more than 1.2%, is situated in the central parts of the deposit (Fig. 4). Most parts of the Kahang deposit have Au values lower than 50 ppb and a few small parts have high values in the western and central parts of the deposit (Fig. 4). Cu high values, more than 0.4%, exist in the central parts of the Kahang deposit (Fig. 4). Al distribution shows that most parts of the deposit have values between 2.5 and 6% and high amounts of this element is located in the western and SE parts of the deposit (Fig. 4). Ti distribution is similar to Au distribution with high values of Ti in the central and western parts of the deposit (Fig. 4).

5.1. Comparison between elemental distributions and hydrothermal alteration

K, Mg, Cu, Mo, Au, Ti and Al distributions are compared and correlated in different hydrothermal alteration zones in the Kahang Cu Porphyry deposit, based on relationships between the elements and related hydrothermal alteration.

6.1.1. Potassic alteration zone

The alteration zone covered with monzonitc rocks consist of quartz monzonite, monzodiorite and monzogranite within mineral assemblages (e.g., KF, secondary biotite, quartz veins and veinlets, magnetite, albite and chlorite). Sulfidic ores including chalcocite, bornite, chalcopyrite and pyrite are associated minerals chiefly in the central parts of the deposit. Based on Meyer and Hemley [9], K and Mg values are higher in the potassic zone in comparison with other hydrothermal alteration zones. The detected potassic alteration zone in the central part of the Kahang deposit correlate with K values between 1% and 3%, as illustrated in Figure 5. Moreover, the mean of K in this alteration zone is near to the mean of K in all geochemical data (Table 2). On the other hand, K values in the SE part of the deposit are high because there are dacitic rocks which have high values of K and are not related to alteration. Mg values in rock units of this alteration zone are between 1% and 2.5% (Fig. 5 and Table 2).



a

b

c

Fig. 5. Correlation between potassic alteration locations (black polygons) and K (a), Mg (b) and Cu (c) distributions in the Kahang deposit.

Rose [18] and [20] proposed that Cu values are higher in potassic alteration zones. Also, the correlation between the potassic zone and Cu values show that Cu mean derived via lithogeochemical data is higher than the 0.3% Cu value in the potassic alteration zone (Table 2).

6.1.2. Phyllic alteration zone

Quartz, muscovite, cericite, illite, jarosite, tourmaline, calcite and goetite are abundant in the phyllic alteration zone. Ore minerals including chalcopyrite, molybdenite and pyrite have accumulated in this alteration zone; however, the alteration exists in dactic, dioritic and andesitic rocks. In the phyllic alteration zone, alkaline elements, especially Mg decrease but Cu and Mo increase in the sulfidic phase [6; 9; 16; 19; 20]. Mg distribution in the phyllic zone correlates with the first population of Mg, which is lower than 0.5% (Fig. 3). Phyllic alteration zone as is shown in the Mg distribution map (Fig. 6) shows lower than 1% distribution in most parts of the phyllic alteration zone (Table 3). Also, Cu lithogeochemical values of the phyllic zone are between 0.3 and 0.5% and there are several anomalous parts higher than the 0.5% Cu, as depicted in Fig. 6 and Table 3. Mo high grades correlate with the phyllic alteration zone (Fig. 6), which is the last population in the Mo histogram, as illustrated in Fig. 3. Furthermore, phyllic alteration hosts the main part of mineralization for Mo, based on Fig. 6 and Table 3 and the zone is correlated by the accumulation of Cu and Mo sulfidic mineralization.

6.1.3. Argillic alteration zone

Mineral assemblages in argillic alteration consist of kaolinite, quartz, muscovite, illite and albite and alunite, occurring in advanced argillic. However, quartz veins and veinlets are abudant and contain native Au, especially in the western part of the deposit. The argillic alteration zone hosts silicic and hydrothermal breccias and dacitic rocks especially in western part of the deposit. One identification factor of the argillic alteration zone is decreased alkaline elements [9; 20; 21]. Al is increased in the argillic zone (Fig. 7). Most parts of this alteration zone content Al in the second and third population of its proportional histogram (Fig. 3). Furthermore, Al values are high in rock samples higher than 5% in most parts of this alteration zone (Fig. 7). Al statistical parameters in this alteration zone reveal that it hosts the highest values of Al (Table 4). Al high values exist in the western, central and SE parts of the deposit (Fig. 7). Au values are higher than 300 ppb in the western parts of the Kahang deposit (Fig. 7). Additionally, based on Au distribution in rock units (Fig. 7 and Table 5), Au values in the argillic alteration zone are higher than 300 ppb in the western part. It shows that there is Au enrichment in the argillic zone, especially the upper most part of this zone. Ti values are higher than 2500 ppm in most parts of the argillic zone (Fig. 7). High values of Au and Ti exist in this alteration and their means in the argillic zone are higher than their means in the total lithogeochemical samples. Au and Ti high intensity anomalies are associated with the advanced argillic alteration zone and silicified epithermal system in the western and NW parts of the Kahang deposit.

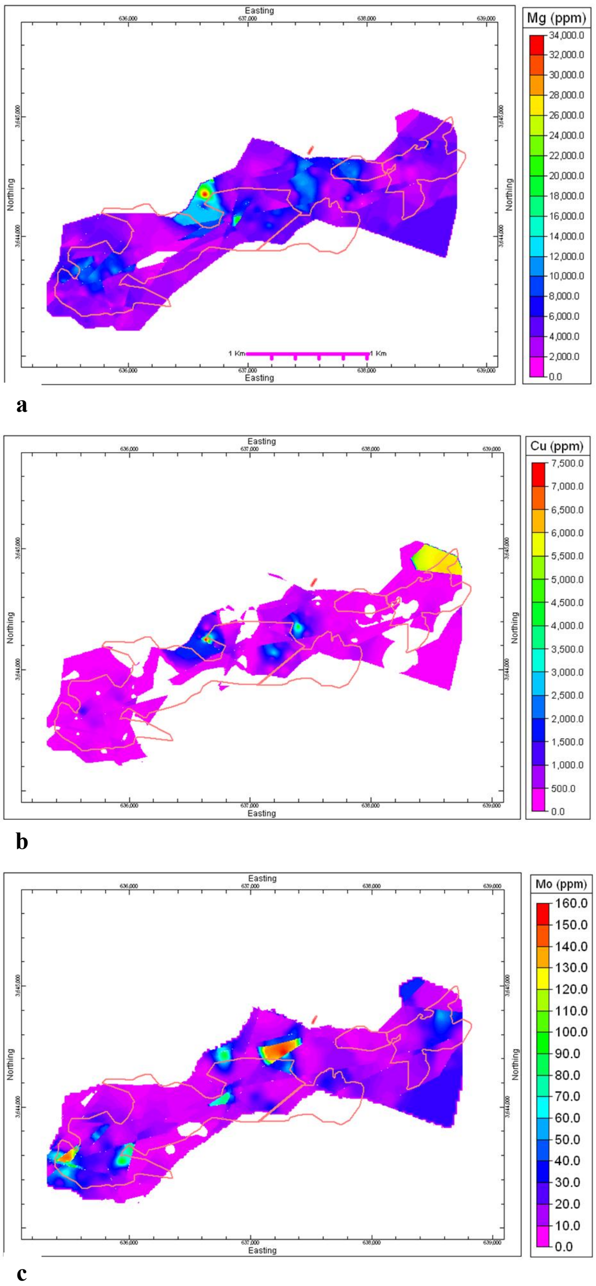


Fig. 6. Correlation between phyllic alteration locations (red polygons) and Mg (a), Cu (b) and Mo (c) distributions in the Kahang deposit.

Table 2. Statistical parameters for K, Mg, Cu, Mo, Au, Al and Ti from lithogeochemical data in the potassic alteration zone of the Kahang deposit. SD: standard deviation

Statistical parameters	**K (%)**	**Mg (%)**	**Cu (ppm)**	**Mo (ppm)**	**Au (ppb)**	**Al (%)**	**Ti (ppm)**
Accuracy	0.02 %	0.01 %	0.01 ppm	0.05 ppm	0.1 ppm	0.01 %	10 ppm
Sample No.	28	28	28	28	28	28	28
Mean	1.97	1.32	3146.27	12.8	47.36	4.75	1340
Maximum	3.30	2.71	8067.52	43	100	7.31	2996
Minimum	0.80	0.05	500	0.4	0	1.66	15
Range	2.50	2.66	7567.52	42.6	100	6.35	2981
SD	1.39	0.87	1085.64	18.71	34.8	2.64	627.35

Table 3. Statistical parameters for K, Mg, Cu, Mo, Au, Al and Ti from lithogeochemical data in the phyllic alteration zone of the Kahang deposit. SD: standard deviation

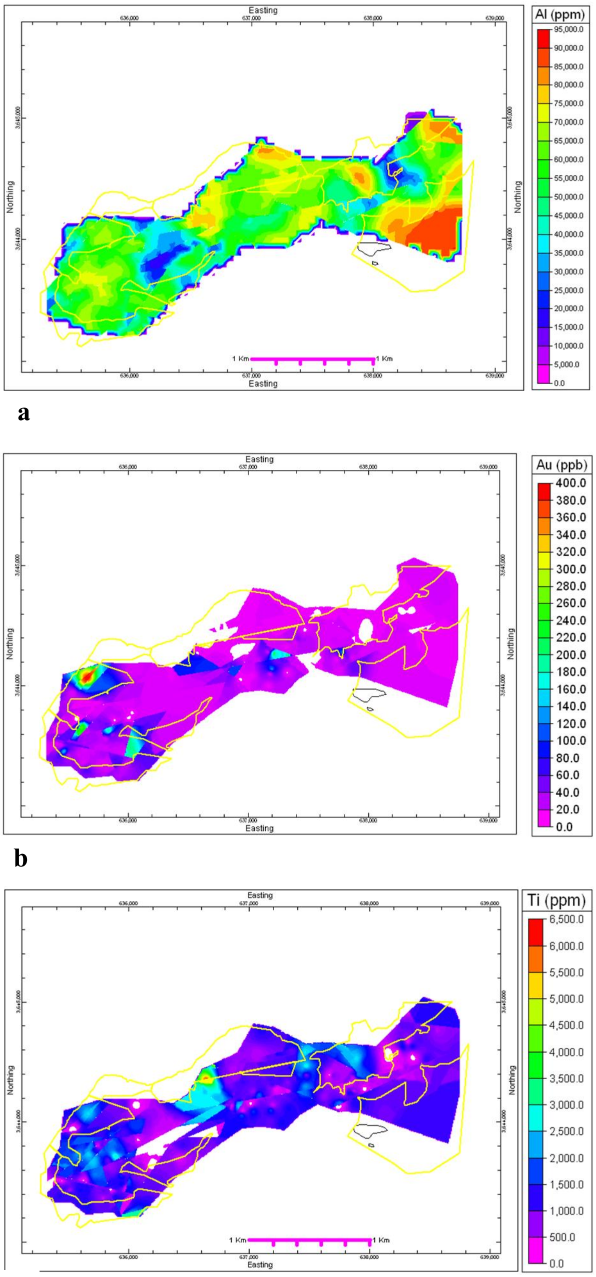
Statistical parameters	**Mg (%)**	**Cu (ppm)**	**Mo (ppm)**	**K (%)**	**Au (ppb)**	**Al (%)**	**Ti (ppm)**
Accuracy	0.01 %	0.01 ppm	0.05 ppm	0.02 %	0.1 ppm	0.01 %	10 ppm
Sample No.	124	124	124	124	124	124	124
Mean	0.87	2153.26	28.11	1.25	20.6	4.21	1720
Maximum	2.25	6037.05	219	2.86	75	8.13	3512
Minimum	0.05	7	0.30	0.5	0	1.60	37
Range	2.20	6030.05	218.70	2.36	75	6.53	3475
SD	0.36	843.91	29.15	1.15	27.4	2.48	349.68

Table 4. Statistical parameters for K, Mg, Cu, Mo, Au, Al and Ti from lithogeochemical data in the argillic alteration zone of the Kahang deposit. SD: standard deviation.

Statistical parameters	**Al (%)**	**Au (ppb)**	**Ti (ppm)**	**K (%)**	**Mg (%)**	**Cu (ppm)**	**Mo (ppm)**
Accuracy	0.01 %	0.1 ppm	10 ppm	0.02 %	0.01 %	0.01 ppm	0.05 ppm
Sample No.	32	32	32	32	32	32	32
Mean	6.39	27.26	1097	1.04	0.89	2421.4	14.36
Maximum	9.25	400	6530	2.07	1.7	5983	140.71
Minimum	1.73	0	12	0.84	0.05	8	0.6
Range	7.52	400	6518	1.23	1.65	5975	140.11
SD	3.76	58.69	901.65	0.97	0.48	796.5	16.35

6-2. Determination Correlation Coefficient between Elements in the Alteration Zones

Coefficient correlations between major elements were calculated and their correlation charts were generated (Fig. 8). K and Mg have a positive correlation (+0.29) that shows a direct proportion between both of them in the alteration zone because K and Mg have increased in the potassic alteration zone. However, Al and Ti have a high correlation coefficient (+0.72) in the argillic alteration zone and there is a proper correlation between Au and Ti (0.45) as is shown in Fig. 8. Ti and Au have high densities and residual in the argillic zone, especially in the advanced argillic zone [16]. Cu and Mo have a positive correlation (+0.41) in the phyllic alteration.



a

b

c

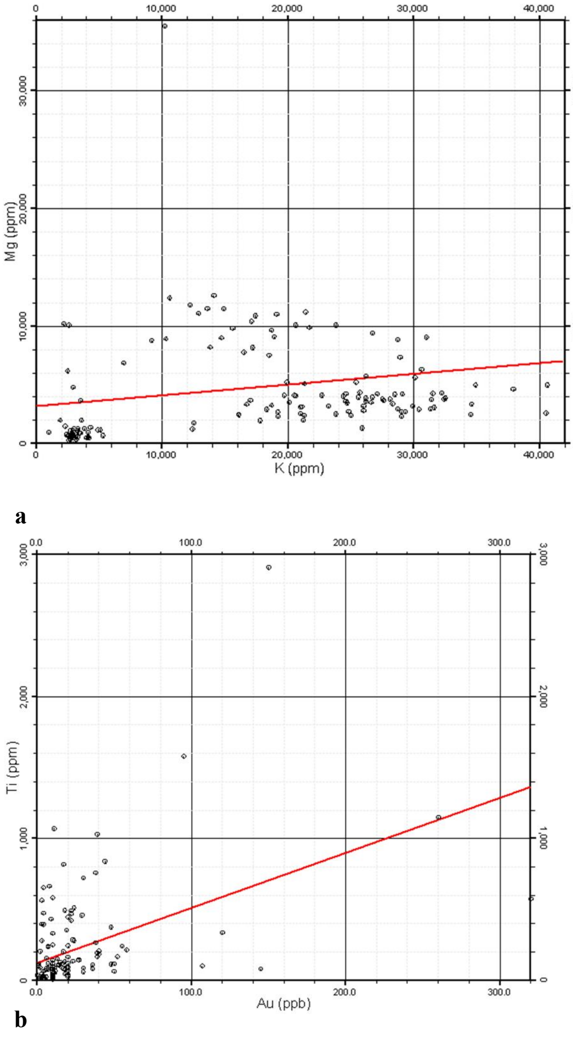
Fig.7. Correlation between the argillic alteration locations (yellow polygons) and Al (a), Au (b) and Ti (c) distributions in the Kahang deposit.

Conclusion

Results of this study have shown that there is a relationship between K, Mg, Al, Cu, Mo, Au and Ti values in the rock units and different alteration zones in the Kahang Cu Porphyry deposit. Moreover, statistical parameters and histograms of these elemental values have shown that there are also high amounts of Ti, Al, K and Mg values. K values are high in the potassic alteration zone, especially in the central part of the deposit within Kf and neoformed biotites. Additionally, K in the SE part of the deposit is high because there are dacitic rocks containing high values of K. The main parts of Cu enrichment are situated in the potassic alteration zone.

Also, several Cu anomalous parts occur in the phyllic alteration zone and this alteration zone has a high grade Mo anoumalous part. On the other hand, main Cu mineralization occurs in the potassic and phyllic zones and Mo mineralization exists in the phyllic zone. Based on geological studies, Mo and Cu sulfidic minerals occur in high values in phyllic zones. Mg value variations show that the potassic alteration zone contents high values of this element, but it has been depleted in the argillic zone.

Al have high values in the argillic zone with a maximum value equal to 7.5% and Al values are higher than 5% in the lithogeochemical map. This map reveals that Al, Au and Ti are enriched in the argillic alteration zone. Moreover, Au and Ti high grade anomalous parts are correlated in the western part of the deposit. Au concentrated parts are associates with the advanced argillic zone in the western part of the deposit, which is evident for argillic alteration high intensity in the western part of the deposit.



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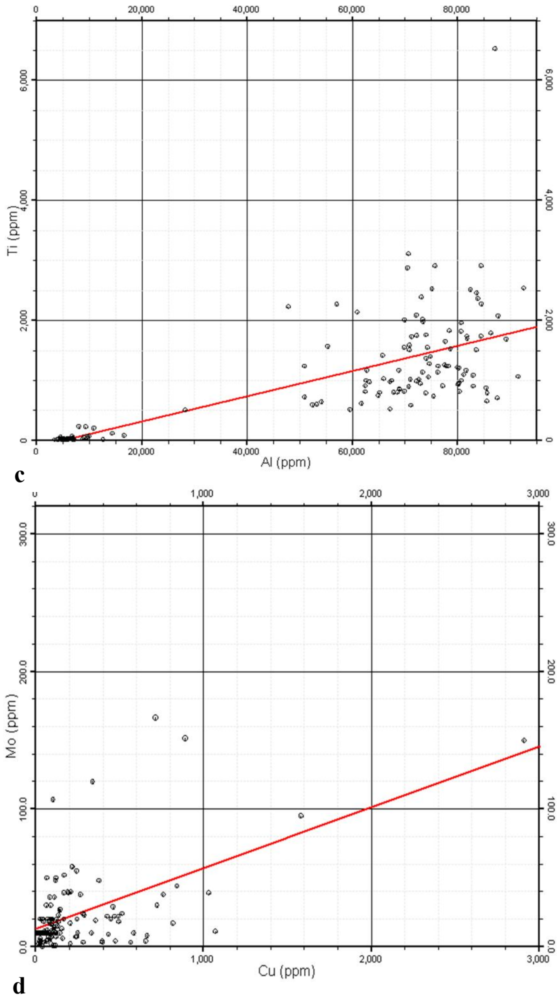

Fig. 8. Correlation charts between (a) K and Mg; (b) Au and Ti; (c) Ti and Al; and (d) Cu and Mo in lithogeochemical samples of the Kahang deposit.

The potassic alteration zone hosts high grade anomalous parts (>0.5%) of Cu in the central part of the deposit and phyllic alteration is associated with main Mo mineralization parts (>100 ppm) in the eastern and western parts of the deposit. Correlation coefficients and charts indicate that there are positive correlations between index elements of alteration zones. Moreover, there are proper correlations for Ti-Au and Al-Ti in argillic, K-Mg in potassic and Cu-Mo in phyllic alteration zones.

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References

[1] Lowell, J. D., 1968. Geology of the Kalamazoo orebody, San Manuel district, Arizona. Economic Geology 63, 645–654.

[2] Guilbert, J. M. and Park, Jr. C. F., 1997. The geology of ore deposits, Freaman and company, New York, 985 p.

[3] Yilmaz, H., 2003. Exploration at the Kuscayiri Au (Cu) prospect and its implications for porphyry-related mineralization in western Turkey, Journal of Geochemical Exploration 77 (2-3), 133-150.

[4] Garza-González, C., Camprubí, A., González-Partida, E., Arriaga-García G. and Rosique-Naranjo, F., 2006. Hydrothermal alteration and fluid inclusion study of the Lower Cretaceous porphyry Cu–Au deposit of Tiámaro, Michoacán, Mexico, Journal of Geochemical Exploration 89(1-3), 124-128.

[5] Sillitoe, R.H., 2010. Porphyry Copper Systems, Economic Geology105(1), 3-41.

[6] Lowell, J. D., Guilbert, J. M., 1970. Lateral and vertical alteration-mineralization zoning in porphyry ore deposits. Economic Geology 65, 373-408.

[7] Cox, D. P., Singer, D., 1986. Mineral deposits models. U.S. geological survey bulletin, 1693 pp.

[8] Evans, A. M., 1993. Ore geology and industrial minerals: An Introduction, Balckwell Scientific Publications, 390 p.

[9] Meyer, C., and Hemley, J. J., 1967. Wall rock alteration in barnes, H. L. (Ed.) Geochemistry of hydrothermal ore deposits, p. 166-235, Holt, Reinhart and winston, New York.

[10] Seedorff, E., Dilles, J.H., Proffett, J.M., Einaudi, M.T., Zurcher,L., Stavast, W.J.A., Johnson, D.A., Barton, M.D., 2005. Porphyry deposits: characteristics and origin of hypogene features.Economic Geology 100th Anniversary, 251–298.

[11] Panteleyev, A., 2004. Porphyry Cu+/-Mo+/-Au, in Selected British ColumbiaMineral Deposit Profiles, Volume 1 - Metallics and Coal, Lefebure, D.V. and Ray,G.E., Editors, British Columbia Ministry of Energy of Employment andInvestment, Open File 1995-20, pp. 87-92.

[12] Berger, B. R., Ayuso, R. A., Wynn, J. C., Seal, R. R., 2008. Preliminary Model of Porphyry Copper Deposits. USGS, Open-File Report, 1321 pp.

[13] Coope, J.A., 1973. Geochemical prospecting for porphyry copper-type mineralization — A review, Journal of Geochemical Exploration 2(2), 81-102.

[14] Krauskopf, K. B., 1979. Introduction to Geochemistry, McGraw-Hill, 2nd editions, International series, 617 p.

[15] Bowden, P., 1985. The geochemistry and mineralization of alkaline ring complexes in Africa (a review): Journal of African Earth Sciences3, 17–37.

[16] Pirajno, F., 2009. Hydrothermal processes and mineral system: Vol. 1, Springer, 1250 p.

[17] Sillitoe, R.H., 1997. Characteristics and controls of the largest porphyry copper-gold and epithermal gold deposits in the circum-Pacific region, Australian Journal of Earth Science 44, 373-388.

[18] Rose, A. W., 1970. Zonal relations of wall rock alteration and sulfide distribution at porphyry copper deposits, Economic Geology 65, 920-936.

[19] Shaver, S. A., 1986. Elemental dispersion associated with alteration and mineralization at the hall (nevada

moly) quartz monzonite-type porphyry molybdenum deposit, with a section on comparison of dispersion patterns with those from climax-type deposits, Journal of Geochemical Exploration 25 (1-2), 81-98.

[20] Robb, L., 2005. Introduction to Ore-forming processes, Blackwell Science Ltd, 325 p.

[21] Beane, R. E. and Titley, S. R., 1981. Porphyry copper deposits, Part II: Hydrothermal alteration and mineralization, Economic Geology 75, 235-269.

[22] Tabatabaei, S. H., AsadiHaroni, H., 2006, Geochemical characteristics of GorGor Cu-Mo porphyry system, 25thIranian symposium on geosciences, Geological survey of Iran, pp. 60.

[23] Afzal, P., Khakzad, A., Moarefvand, P., Rashidnejad Omran, N., Esfandiari, B., Fadakar Alghalandis, Y., 2010. Geochemical anomaly separation by multifractal modeling in Kahang (Gor Gor) porphyry system, Central Iran, Journal of Geochemical Exploration 104, 34–46.

[24] Alavi, M ,. 1994.Tectonic of Zagros orogenic belt of Iran: new data and interpretations. Tectonophysics 229, 211-238.

[25] Alavi, M., 2004. Regional stratigraphy of the Zagros folded-thrust belt of Iran and its proforeland evolution. American Journal of Science 304, 1-20.

[26] Aghanabati, A., 2004. Geology of Iran. Geological Survey of Iran, 587pp. (in Persian)

[27] Schroder, J.W., 1944. Essaisur la structure de l'Iran. EcologaeGeologicaeHelvetiae 37, 37-81.

[28] Dargahi, S., Arvin, M,. Pan, Y,. Babaei, A,. 2010. Petrogenesis of Post-Collisional A-type granitoid from the Urumieh-Dokhtar magmatic assemblage, Southwestern Kerman, Iran: Constraints on the Arabian-Eurasian continental collision, Lithos 115, 190-204.

[29] Berberian, M., King, G.C.P., 1981. Towards a palaeogeography and tectonic evolution of Iran. Canadian Journal of Earth Sciences 18, 210-265.

[30] Berberian, F., Muir, I.D., Pankhurst, R.J., Berberian, M., 1982. Late Cretaceous and Early Miocene Andean-type plutonic activity in northern Makran and Central Iran. Journal of the Geological Society of London 139, 605-614.

[31] Shahabpour, J., 1994. Post-mineral breccia dyke from the Sar-Cheshmeh porphyry copper deposit, Kerman, Iran. Exploration and Mining Geology 3, 39-43.

[32] Atapour, H., and Aftabi, A., 2007. The geochemistry of gossans associated with Sarcheshmeh porphyry copper deposit, Rafsanjan, Kerman, Iran: Implications for exploration and the environment, Journal of Geochemical Exploration 93 (1), 47-65.

[33] Boomeri, M.,Nakashima, K. and Lentz, D. R., 2009. The Miduk porphyry Cu deposit, Kerman, Iran: A geochemical analysis of the potassic zone including halogen element systematics related to Cu mineralization processes, Journal of Geochemical Exploration 103 (1), 17-19.

[34] Acme Labs schedule of Services & Fees, 2010. Geological Ultratrace 4-Acid Digestion. Page 9, www.acmelab.com

[35] Shepard, D., 1968. A two-dimensional interpolation function for irregularly-spaced data. Proceedings of the 1968 ACM National Conference. pp.517–524. doi:10.1145/800186.810616.