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Structural Controls on Cu Metallogenesis in the Dehaj Area, Kerman Porphyry Copper Belt, Iran: A Remote Sensing Perspective

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Abstract

Structural analysis of remotely sensed data provides a method of assessing the structural significance of regional metallogenesis in the Dehaj area as the northwestern part of the Kerman porphyry Cu belt. This belt is consisted of dominant Eocene volcanics and the Dehaj type subvolcanic intrusives. In the study area, geologically, Cu-mineralization is hosted by the Kuh-e-Panj type subvolcanic intrusives. Photogeological analysis of the Landsat imagery reveals a pattern of mainly NW-SE oriented linear structures which were apparently generated in response to crustal thickening and lineament reactivations during the generation of a huge stratovolcanoes. A comparison of lineament map generated from Landsat ETM^+ image indicates that the locations of some of the deposits, magmatic and hydrothermal centers are at/or close to the intersections of linear structures. This study deals also with the irrefutable genetic links between some small circular features and copper mineralization that has not been previously examined. It is proposed that the circular features are superficial expressions of intruded stocks or bodies in subvolcanic levels without remarkable volcanic equivalents. Of particular matter in this framework is the possible genetic/age relationship between the linear structures and the circular features. These small circular features are thought, in some cases, as having been formed due to development of the local extensional points near the intersection of the linear structures in a regional, tectonically, compressive environment. Regionally, plotting the residual anomaly and bouguer anomaly maps of the region provides, geophysically, a lucid explanation as to how the small circles came into existence.

Keywords: Structural analysis, Cu mineralization, Linear structures, Small circular features, Bouguer anomaly.

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Introduction

Most exposed deposits in known porphyry Cu districts have been discovered [35], and some present days studies are focused on searching for covered deposits, through indirect tectonic and structural methods and geological information. The tectono-structural forms controlling the genesis and localization of the mineral deposits are widely discussed in scientific geological literature, perhaps, since the time of Billingsley and Lock [8]. With this background, the study of the structural forms controlling the localization of porphyry deposits has been the focus of attention of various investigators. With this frame work, however, the role of tectonism and some structural forms known to circular features in controlling the timing and the localization of the porphyry Cu-forming magma emplacement, has generally been left to other disciplines in the geological sciences. Circular features and associated porphyry Cu mineralization can be of the interesting topics for exploration geologists, albeit, there are few papers that document the relationship between the circular features, curvilinear features and mineralization [eg., 11, 13]. This paper presents the results of a study on the relationships between some small circular features and observed Cu mineralization in the area of one of the world important porphyry copper belt located in southeastern part of the central Iranian volcanic belt (CIVB), the Kerman porphyry copper belt. Small circular features are found around some important porphyry Cu deposits (e.g. Meiduk) in the CIVB and seem to have been formed in tectono-geological conditions similar to the Cu deposits observed around them. This criteria can be used to identification of new Cu prospects and, in further detailed studies, deposits in the areas they show remarkable concentration. Such fantastic structural relationship encouraged the authors to discuss the topic. The investigated area in the northwest of the Kerman porphyry copper belt (KPCB) covering a region of approximately 2400 Km^2 is situated between 54˚66‘-55˚22‘ E and 30˚32‘-30˚73‘ N. This region is bounded on the west by the Nain-Baft dextral fault and on the east by

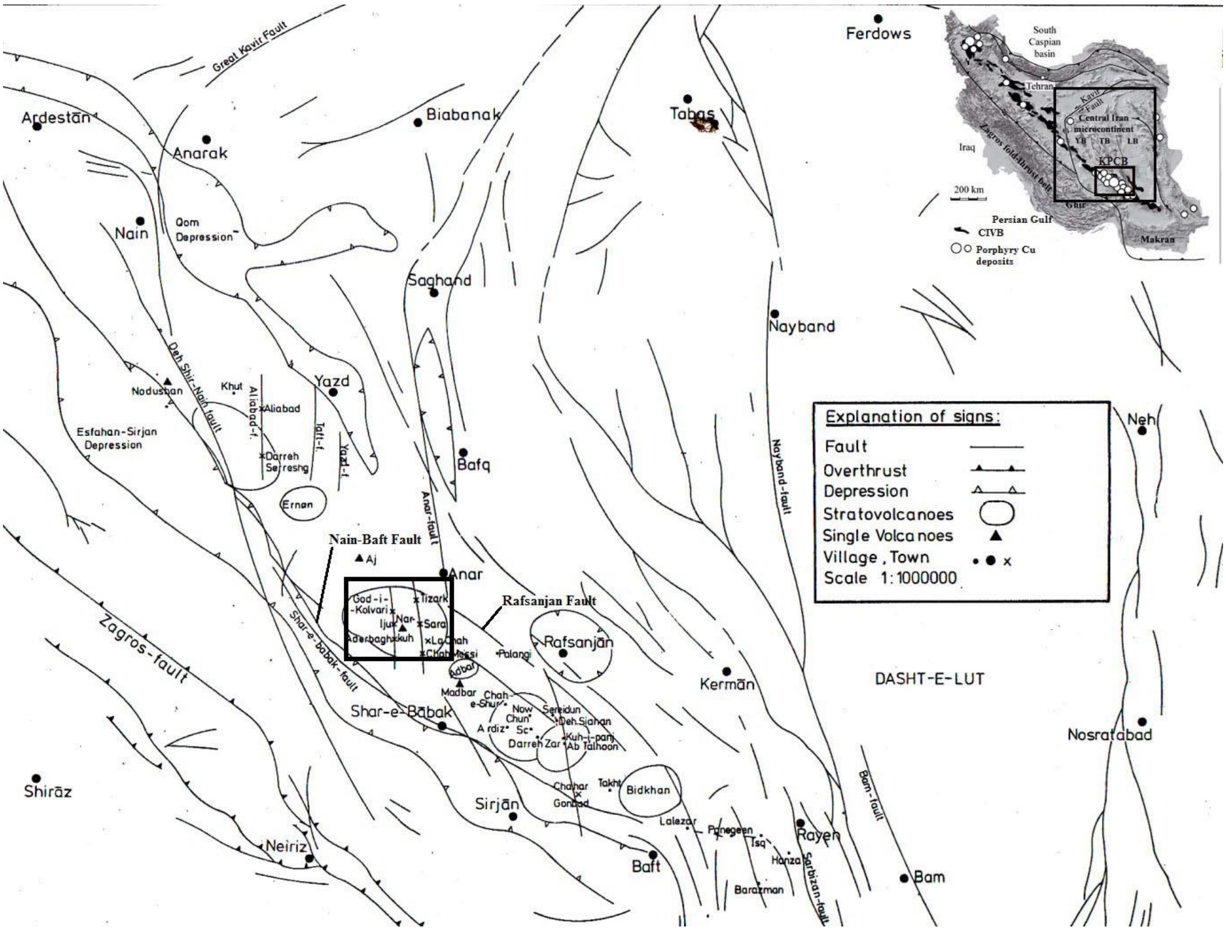

Figure 1. Lineaments derived by satellite imagery for porphyry copper exploration in central Iran (Forster [20]; inset from Shafiei et al [39]).

the Rafsanjan fault (Fig. 1) and Neogen sedimentary basins. The physiography of the area is dominated by mountainous terrain with peaks nearing 3000 m above the sea level. The areas surrounding are relatively flat areas of sedimentary units. In this study, a combination of remote sensing techniques (on Landsat ETM^+ images) and geological information has been used to define the crustal lineaments as well as some less known circular features in the Dehaj area. The relationship between these structures (lineaments and circular structures) is also discussed. There also is a clear relationship between the lineament density (based on the photolineament map of the area), circular features and Cu mineralization resulted in discussing such relationship in this study. This paper deals strictly with the small magnitude circular features and does not concern some debated large-magnitude ring structures investigated in some regions of the Earth. Tectonic evolution of the region is summarized by Shahabpour [40] and a preliminary study of the ore deposits characteristics in the region is provided by Dimitrijevic [16]. Base metal mineralization occurs throughout the study area. Two principal aims of this study are: (1) interpretation of the relationships between the structural factors and Cu mineralization in the Dehaj area and (2) use of the Landsat multispectral scanner data for detection and suggestion of new areas for Cu exploration in this framework.

Materials and Methods

To handle the problem, several information layers have been used dividing, technically, into two groups including the geological information and the software works. The former comprises regional geology, tectonic setting and metallogeny each of which are used to give the reader an overall view concerning the geotectonic and geo-metallogenic features of the study area. Satellite works carried out included filtering of the Landsat image resulted in finding of some faint linear structures and some small circles whose relationships towards Cu mineralization discussed.

Regional geology

The Dehaj area is a part of the KPCB, and the geological setting of this area (Fig. 2) is similar to the other parts of the KPCB. According to Dimitrijevic [16], Hassanzadeh [23], Amini [4], and Shahabpour [43], among others, eruption of acidic pyroclastics of Bahr-e-Aseman complex during early Eocene was the main volcanic activity in the region. This eruption was followed by the middle-upper Eocene Razak volcanic complex consisting entirely of lower (mainly basic), middle (mainly acidic) and upper (mainly basic) sub complexes that cover a widespread area in the region. Subsequent magmatic activity generated the Oligocene Hezar volcanic complex and associated plutonic rocks with mainly high-K calc- alkaline composition and shoshonitic rocks. Magmatism stopped after the intrusion of the Hezar complex, then the region were invaded by the Oligo-Miocene sea and deposition of Lower Red Formation, Qom limestone Formation and Upper Red Formation occurred. The Oligo-Miocene Qom Formation was deposited in a back-arc extensional basin and the Lower Red as well as the Upper Red Formations were deposited in a back-arc compressive basin [43]. It is thought that the deposition of these sedimentary units has been related to changes in subduction angle of the Neo-Tethys oceanic crust beneath the Iranian microplate [43]. The most important magmatic activity occurred during Miocene by intrusion of the granitoides consisting mainly of granodiorite and its accompanying shallow intrusions of the Jebal-e-Barez type and the mainly porphyritic type subvolcanic intrusives of the Kuh-e-Panj type. Most of the porphyry copper deposits in the study area are hosted by and genetically related to the Kuh-e-Panj type rocks [39]. The most widespread Dehaj type rocks are light-colored dacito-andesites injecting Eocene, Oligocene and Miocene strata. Finally, volcanism and plutonism decreased sharply in which small volumes of alkali basalts and foidites represent the youngest magmatic activity.

Tectonic setting

The Dehaj area is the northwestern part of the KPCB in southeastern part of the CIVB which marks the culmination of Alpine volcano-plutonic activities in south east Iran. Tectonic history of this volcano-plutonic belt is studied and discussed by many authors [eg., 47, 46, 45, 18, 6, 5, 7, 1, 42, 43]. Four types of tectonic settings have been proposed for the CIVB, namely, rift [3], continental arc setting [23], post suturing setting [21] and island arc [43]. A collisional tectonic setting is also proposed for the adakite-like porphyritic granitoides in the CIVB hosting some of the world's largest Cu ore deposits [39]. It appears that the Neogen crustal thickening and arc magmatism are interrelated processes which influenced the porphyry Cu metallogeny [39]. The pre-Miocene structural architecture of the Dehaj basement is dominated by the NW-SE trending volcanic chain between the central Iranian upper plate and the Arabian platform above a subduction zone. Forster [20] cited the location of seven stratovolcanoes localization in central Iran (Fig. 1), all of them are located on the CIVB. Dehaj area is situated on one of the largest stratovolcanoes localization.

Table 1. Inventory of the main mineral deposits and their geological characteristics in the Dehaj area (Compiled from Dimitrijevic [16]; Saric and Mijalkovic [37]; Shafiei et. al [39]).

Deposit	Long/Lat	Deposit type	Age	Host regional lithology	Products (and by-products)
Chah mesi	$55^0,09^{\prime},44^{\prime\prime}$E $30^0,24^{\prime},22^{\prime\prime}$N	Polymetallic		Eocene volcanic-sedimentary complex, Oligo-Miocene intrusive bodies	Cu, Zn, Pb, Au
Meiduk	$55^0,10^{\prime},15^{\prime\prime}$E $30^0,25^{\prime},38^{\prime\prime}$N	Porphyry, Disseminated		Eocene volcanics and pyroclastics intruded by diorite porphyritic bodies	Cu
Sara	$55^0,08^{\prime},32^{\prime\prime}$E $30^0,26^{\prime},50^{\prime\prime}$N	Porphyry, Disseminated		Altered diorite porphyrite surrounded by weakly altered Eocene volcanics and Pyroclastics	Cu, Mo
Serenu	$54^0,59^{\prime},40^{\prime\prime}$E $30^0,29^{\prime},33^{\prime\prime}$N	-		Eocene volcanics and pyroclastics intruded by Oligo-Miocene quartz- diorite porphyrites and Neogen dacites	Cu, Mo
Iju	$54^0,57^{\prime},35^{\prime\prime}$E $30^0,31^{\prime},49^{\prime\prime}$N	Impregnations, Porphyry, Stains and Veinlets		Eocene volcanics and younger diorite porphyrites	Cu
God-e-Kolvary	$54^0,59^{\prime},26^{\prime\prime}$E $30^0,35^{\prime},50^{\prime\prime}$N	Disseminated		Diorite porphyry, granodiorite porphyry and granodiorite	Cu
Kader	$54^0,44^{\prime},37^{\prime\prime}$E $30^0,37^{\prime},10^{\prime\prime}$N	Impregnations, Veins, Veinlets and Supergene		Eocene volcanic-sedimentary complex, Oligo-Miocene quartz diorite porphyries and diorite porphyries	Cu

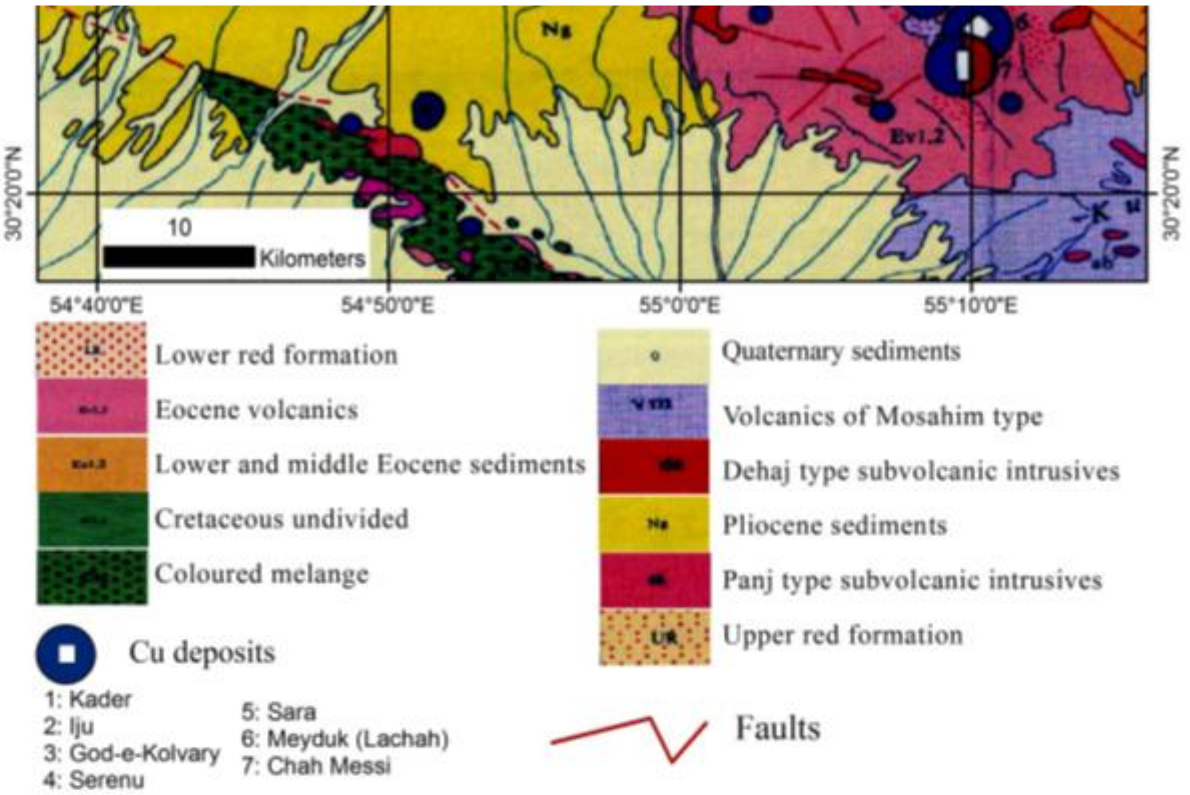

Figure 2. Simplified geological map of the Dehaj area and location of major (porphyry) Cu deposits and prospects (compiled from Dimitrijevic [16]).

Metallogeny

The Cenozoic basement of the Dehaj area hosts several Cu deposits and prospects of mostly porphyry and polymetallic and rarely vein types. Almost the entire of the deposits have been located on a huge stratovolcanoe. An inventory of the location, characteristics and geological environment of important mineral deposits of the Dehaj area is cited in Table. 1.

Satellite imagery

The Dehaj area is covered by 1 Landsat ETM^+ image, number 161-39. Filtering and then preparing the photolineament factor (PF) map was the main processes in satellite imagery. All the imagery processes in this study were achieved in ENVI (4.3) software. The ArcGIS 9.3 software was also used in plotting the prepared images on the preexisting georeferenced metallogenic map of the region. To handle the topic, directional filters were applied on the ETM^+ 8. band of the Landsat image and the lineaments of different trending patterns were revealed. To perform this stage, the lineaments revealed using 45^0, 90^0 and 120^0 directional filters in ENVI software. After preparing the filtered pictures, the pictures were used separately in the Arc. GIS 9.3 software to extract the lineaments.

Interpreted structures of the Dehaj area

Major structural lineaments interpreted from the Landsat image of the area and their special relationship with the mineral deposits are illustrated in this section. The lineaments were used to prepare the photolineament factor map using the PF equation (eq. 1). To present this map, the region was divided into separate cells with appropriate (3 Km in this study) dimensions (Fig. 3. a).

PF=(a/A)+(b/B)+(c/C) [22] (eq. 1)

PF: Photolineament Factor

a: the number of the linear structures in the selected cell size; A: the average number of all lineaments in the entire map; b, the length of the linear structures in the selected cell size; B, the average lengths of all of the lineaments in the entire map; c, the number of the intersections of the lineaments in the selected sell size and C is the average number of the total intersections in the entire map. After computation of the numerical amounts of the proposed cells (Fig. 3. a), the final PF map of the area was prepared (Fig. 3. b). Interpretation of the rose diagram of the lineaments suggests that the main directions of the lineaments are N20-30^0E and less frequently N60-70^0E and N30-40^0W (Fig. 4).

The observable structural relationship between the linear structures and Cu mineralization in the Dehaj area is one of the main problems of interest in this study. This matter is more lucid when the photolineament factor map of the region is plotted on the metallogenic map of the region to the same scale (Fig. 3. b). The depicted photolineaments may consequently be characterized as linear geological boundaries, traces of the internal forces during the generation and development of a large stratovolcanoe and the stocks intruded, and faults (Fig. 5). The lineaments affected the study area may be classified according to their length, number and their relationships with the mineral deposits: (1) main lineaments that are longer (up to upper crustal scale) than the other linear structures and follow the general tectonic pattern of the region in a NW-SE manner (parallel to the subduction zone between the central Iranian hinterland and the Arabian downgoing oceanic slab; Fig. 1). This type of the lineaments seem to either have structural controls on the localization of the stratovolcanoes in the entire KPCB, although some of these lineaments have

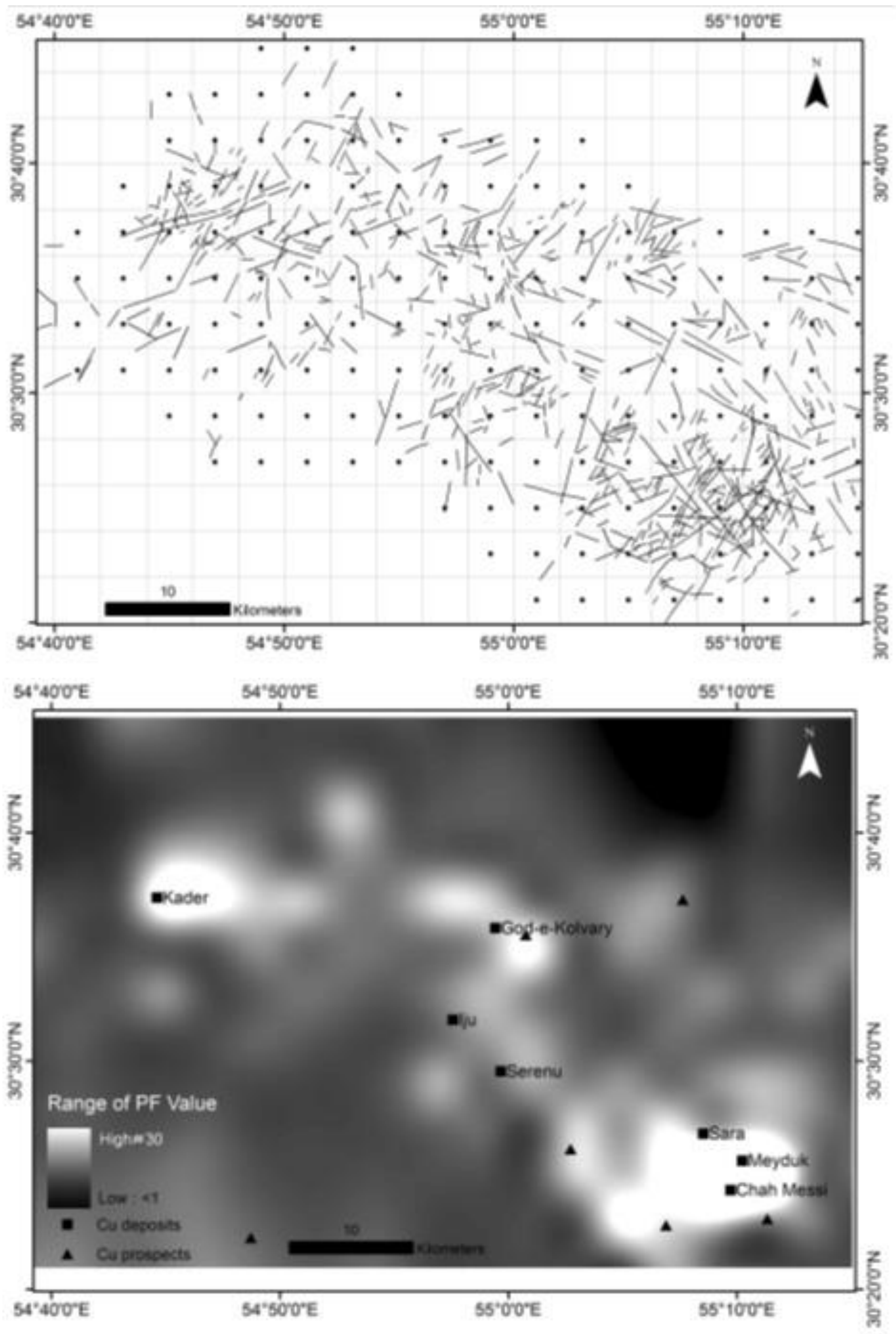

Figure 3. a. The depicted network used in PF amount in preparing the PF map. b. The PF map based on the numerical amounts calculated based upon the PF equation.

direct structural controls and/or relationships with some of the Cu deposits in the Dehaj area (Fig. 6), or be the linear traces of the main tectonic units such as ophiolitic assemblages and; (2) small lineaments that are shorter linear structures (<10 km), all of them are formed above the stratovolcanoes and are discontinuous in length. There is a close relationship between this type of lineaments and distribution of the Cu deposits and prospects in the Dehaj region. There is an undeniable importance of the linear structures to recognize the localization (mineralization) of the Cu deposits in the Dehaj area although much of the small lineaments can be

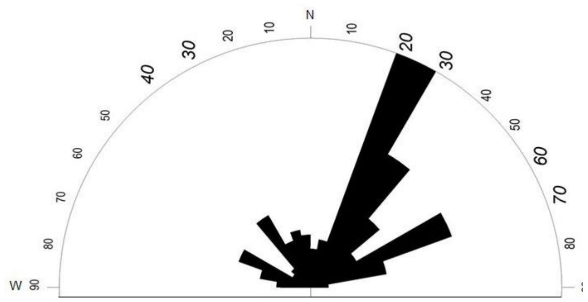

Figure 4. Rose diagram for the lineaments of the study area

proposed as fractures in rock unites. The favorability of the large lineament intersections for focusing magma ascent has frequently been noted in the past [eg., 14, 33, 26]. The Landsat photograph of the same area (Fig. 6) shows also many circular features that have not been previously studied. The circles appear to play an extraordinary control on the Cu mineralization, specially porphyry type Cu deposits. As it is clearly detectable in Fig. 6, the circles are of a similar size, near perfect in outline and are characterized by more frequently in number around the porphyry Cu deposits and the areas with the highest amounts of photolineament factor (Fig. 7). Some of these circles seem to be located at the intersection of the linear structures (Fig. 6 and 8). Some of these circles seem to be mineralized porphyritic Cu bodies or stocks near the surface. Image processing on the ETM$^+$ shows clearly that some of the Cu deposits in this area (Meiduk) are near perfect in outline. Likewise, there is a positive relationship between the density of the circular features and Cu mineralization (Fig. 7).

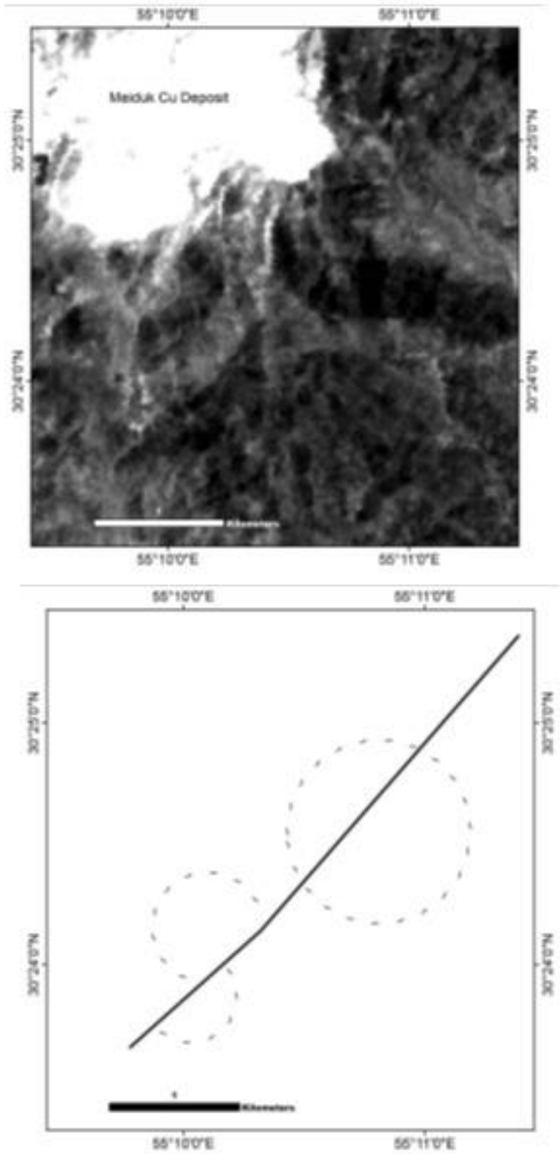

Figure 5. a. Part of the Landsat image showing the relationship among the small linear structure and the fault. It is observable that the fault has separated the two hemispheres of the bottom circle but, surprisingly, the other two circles in the middle and the up-right parts of the picture show no evidence of displacement or rupturing. b. Schematic view of the Landsat image in Fig. 5. a.

Results and Discussion

The study of the geological structures and more specifically the linear structures, has been carried out for a number of decades [eg., 30, 48]. With this framework, however, the idea of the presence of a relationship between the linear structures and mineralization has been an interested topic for most geologists [eg., 25, 26, 27, 29, 32, 34, 19, 14]. According to Kutina [26] there is, genetically, a relationship between the crustal scale linear structures and mantle induced subcrustal convective cells. Holdsworth et al [24] and Chernicoff et al [14] also proposed that these deep, trans-lithospheric ancient discontinuities represent planes of crustal weakness that may be periodically reactivated and intruded during subsequent tectono-magmatic events. But, the O'Leary et al [31] definition of the lineament as "*a mappable, simple or composite linear feature of a surface, whose parts are aligned in a rectilinear or slightly curvilinear relationship which differs distinctly from the patterns of adjacent features and presumably reflects a subsurface phenomenon*" is logically more applicable in which the scale (or magnitude) parameter of a linear structure is skipped. On the other hand, the lineaments are not

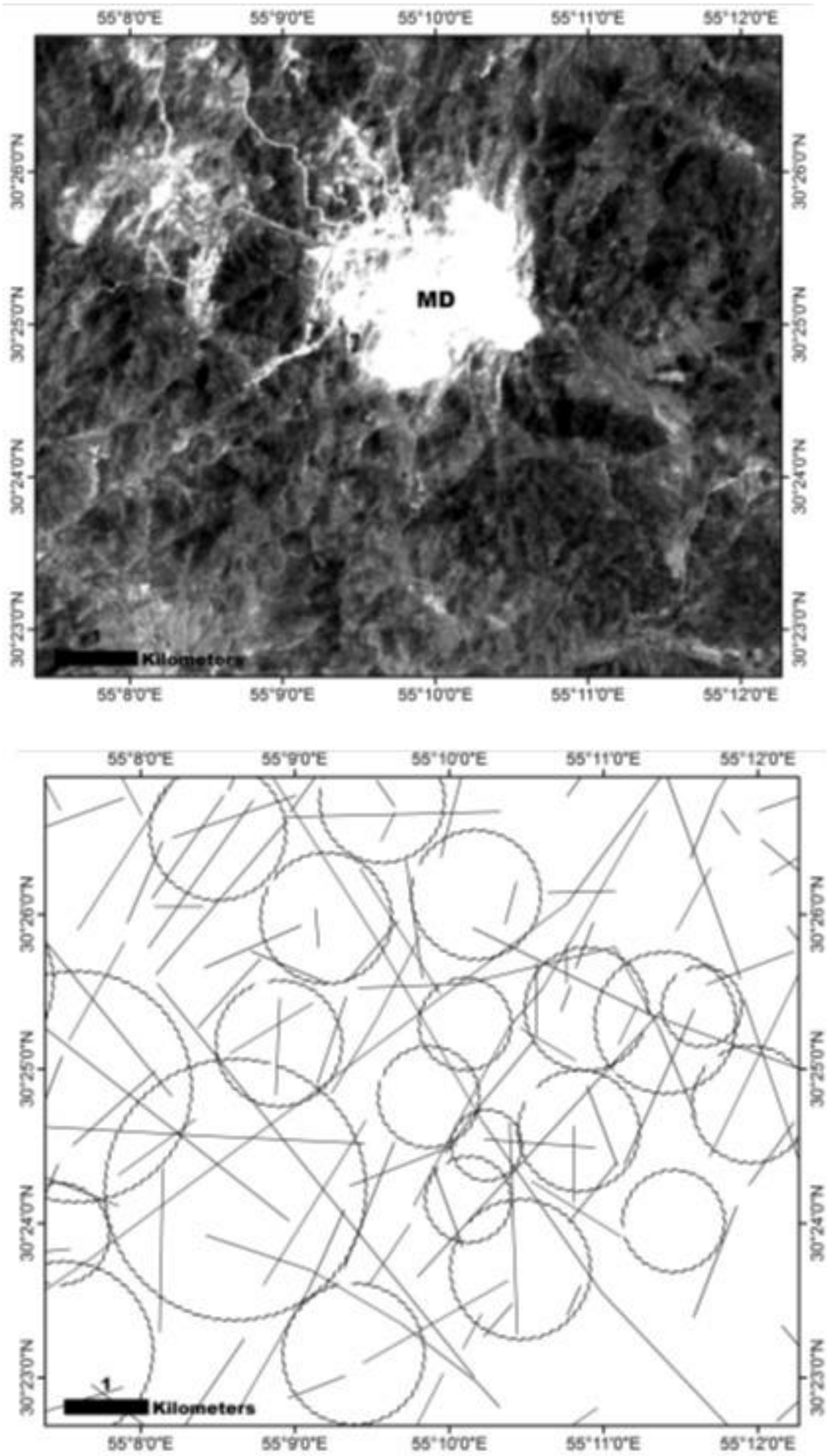

Figure 6. b. Faint, but defined, traces of some small circular features in the study area around Meiduk porphyry Cu deposit. Traces of some larger circles are found in a NW-SE trending

defined strictly to the crustal scale linear structures (lineaments in Fig. 1) and some of the linear structures are so small that no crustal scale mechanism is needed to their formation (lineaments in Fig. 3). Shahabpour [41] classified the lineaments into three (main, intermediate and small lineaments) classes.

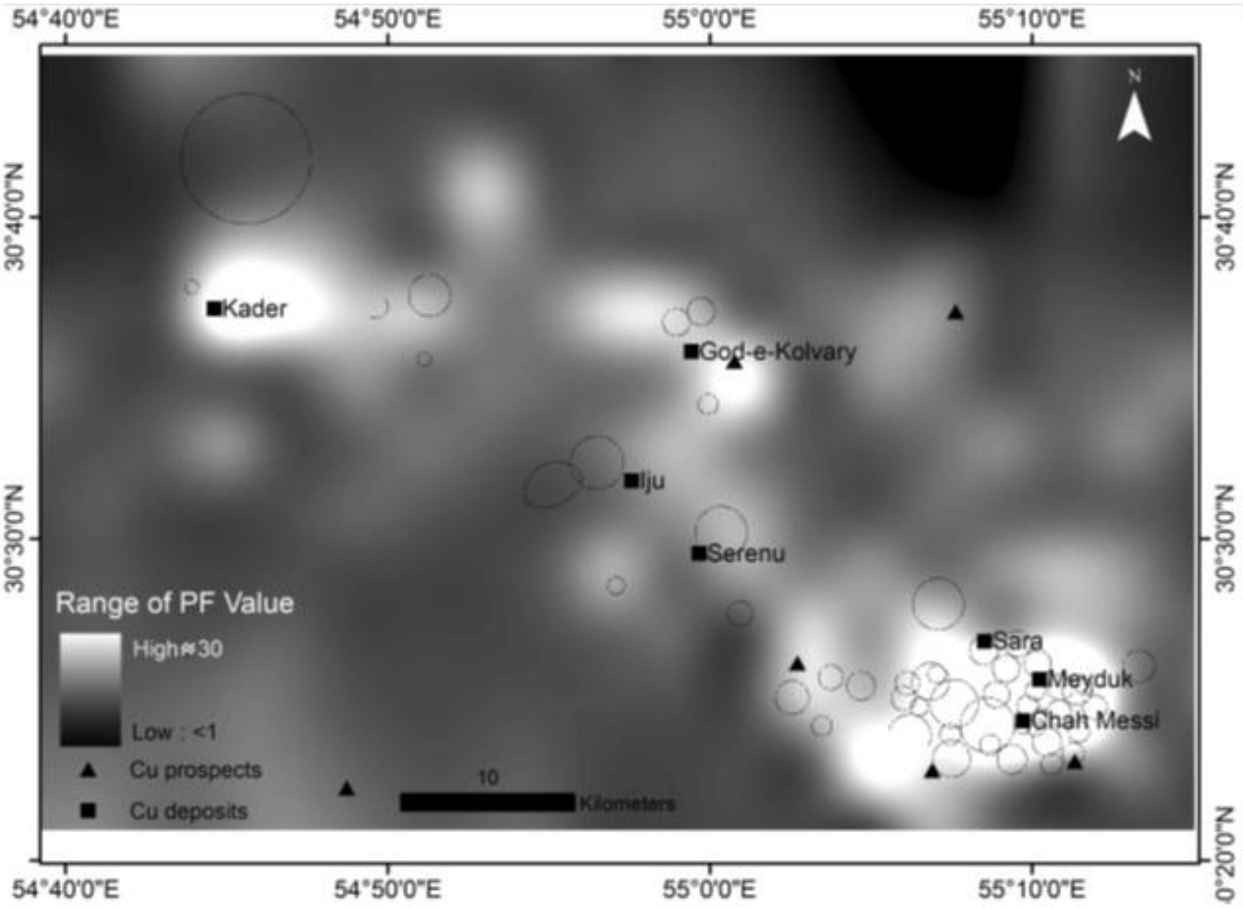

Figure 7. The small circles are mostly found around the porphyry Cu deposits and the areas with the highest amounts of photolineament factor.

Likewise, genetic consanguinity between the porphyry Cu deposits and stratovolcanoes areas is one of the interesting topics in economic geology [eg., 44]. Sillito [44] gave some useful information concerning the importance of the stratovolcanoes localizations in Cu genesis and exploration in some parts of the world like southern America. Available data concerning the porphyry Cu deposits in Iran indicate that most of the deposits are formed in relation to or on the Cenozoic stratovolcanoes in the Central Iranian Volcanic Belt (CIVB). Remarkable limitation of the Cu deposits in KPCB is logically related to the generation and distribution of some huge stratovolcanoes in this region. The study area in the northwest of the KPCB is situated in a stratovolcanoe which is formed above a subduction related tectonic setting. Generation and development of the stratovolcanoes localizations in the KPCB was done after the subduction of the Neo-Tethys oceanic crust beneath the central Iranian microplate. Formation of most of the small linear structures in this region seems to be related to the generation and development of these huge volcano-magmatic centers. The reason for this deduction is that almost all of the small linear structures on the stratovolcanoes have different directions and do not follow a unique trend in the study area, furthermore, their special localization (or their intersections) with respect to the circular features is detectable. Therefore, the formation of most of the small lineaments in the study area doesn't seem to need a subcrustal provenance, although the region is also affected by some crustal scale linear structures. High limitation of the Cu deposits and prospects in and around the areas with the highest amounts of photolineament factor shows clearly, and instrumentally, the importance of the linear structures in Cu exploration in this region. Therefore, recognition of the areas with the highest amounts of this factor can be proposed as an important method in Cu exploration in the Dehaj area. Large magnitude circular features (not discussed in this paper) are another type of structures that their structural importance in metallogenesis is discussed

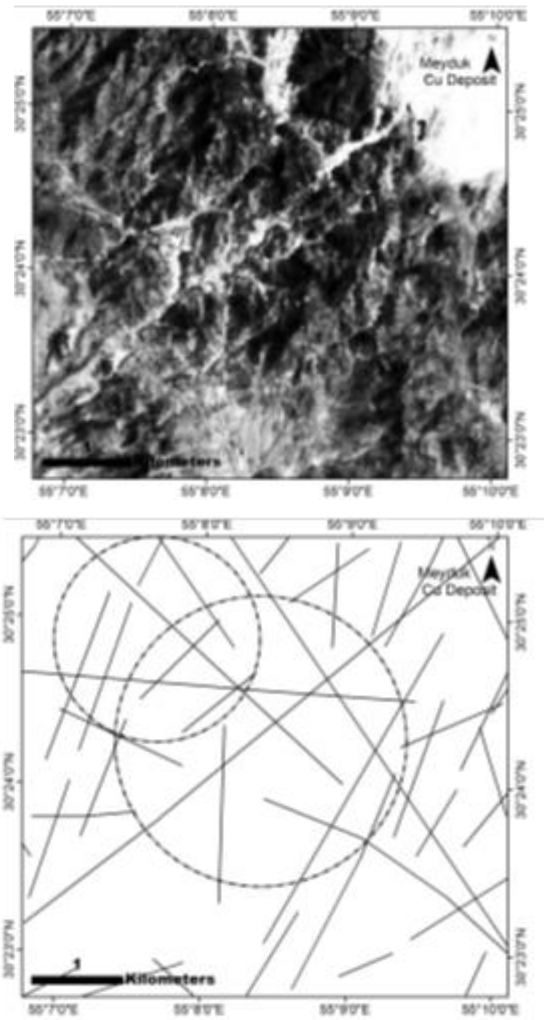

Figure 8. a. The recognition of the genetic and age relationship between the linear structures and the circular features can, to some extent, be more complicated. b. Schematic view of the Fig. 8. a.

by few authors [eg., 38, 17]. The smaller ones that are discussed herein for the study are also attracted the geologists attention in the other regions found. Presence of these type of structures in some parts of the world is documented and their characteristics are studied. According to Chernicoff, et al. [14] the locations of magmatic and hydrothermal centers can be related to the interpreted structural framework, and are seen to occur near the intersections of major lineament zones. These authors [14] also suggested that such intersection zones, in three dimensions, form trans-lithospheric columns of low strength and high permeability during transpressional or transtensional tectonic strain, and may thereby serve as conduits for magma ascent to the shallow crust. Carranza and Hale [11], mathematically, applied the methods of Bonham-Carter. et al [9] and Bonham-Carter. et al [10] to quantitatively characterize the spatial association between gold occurrence and curvilinear geological features in a mining district in the Philippines. In addition, Carranza and Hale [11] presented an experimental technique to quantitatively characterize the spatial association between mineral occurrences and curvilinear geological features. Chernicoff and Zappettini [13] have also recognized similar sub-circular to elliptical features in south-central Argentina through magnetic signatures. According to these authors, these sub-circular or elliptical features can be grouped into two classes in terms of their diameter, either larger than 15 km or smaller than 5 km. Both groups of features present high magnetic gradient and intensity that increase towards their outer rim. Several circular structures are recently being studied in the Dehaj area [28] and some traces of these structures are cited in this study. Universally, there is no an agreement about the essence of the circular features, however, high frequency of the circles in magmatic areas and circular outline of some of the Cu deposits shows clearly that some of these circular features can be interpreted as mineralized porphyritic bodies or stocks in subvolcanic levels in the Dehaj area.

The relationship between the circular features and the linear structures can be used in identification of the essence of the circles. In most cases, the linear structures have transected the circles but there isn't any traces of displacement (except for the case observed in Fig. 5). Economically, Since the syn-deposition faulting causes the out pouring (as proposed in the past) much of the metal bearing waters and therefore formation of abortive subvolcanic bodies, the entire of the linear structures don't seem to be fault traces in the area. To handle the problem, it is notable that the porphyry deposits and prospects are found in this area, moreover, the deposits are situated in areas with low density of the faults detected on the metallogenic map of the region [37] (Fig. 2), therefore, it can be concluded that most of the linear structures seem to be external expressions of near surface internal structures. This matter is more acceptable when a special relationship between the circular features and density of the linear structures can be recognized. The relationship indicates that most of the lineaments seem to have structural relationship and are formed through movements and crustal reactivations within the generation of a huge stratovolcanoe perhaps during the latest contemporaneous magmatic activities. With this framework, however, proving the regional provenance of the circular features convinced the authors to plot the residual anomaly (Fig. 9) and Bouguer anomaly (Fig. 10)

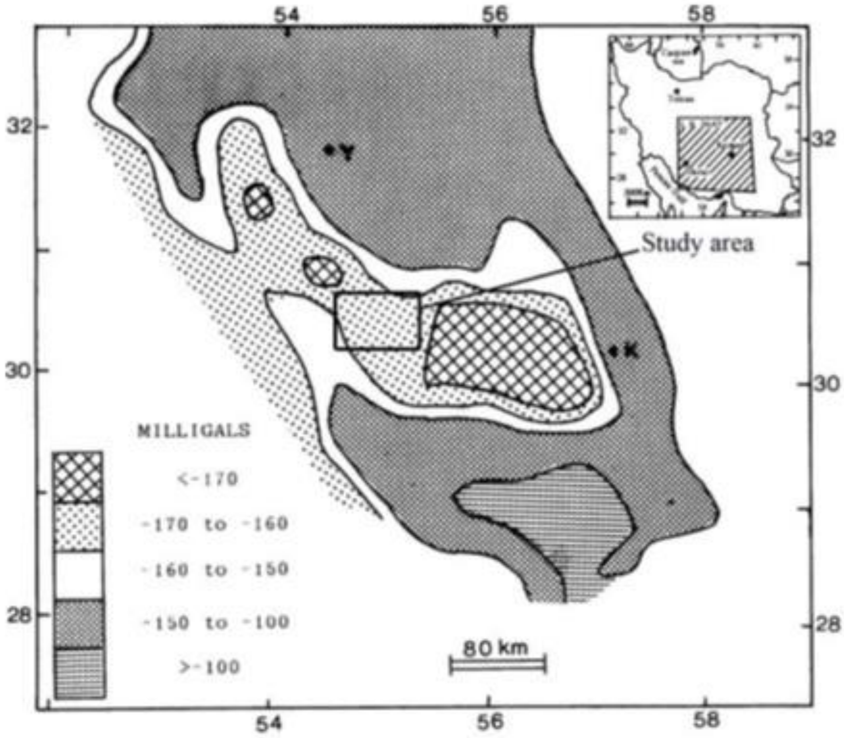

Figure 10. Generalized complete Bouguer map of Kerman and Yazd regions (modified after Dehghani and Makris [15]). In this map, the study area occurs in the inner part of -170 to -160 mgal zone.

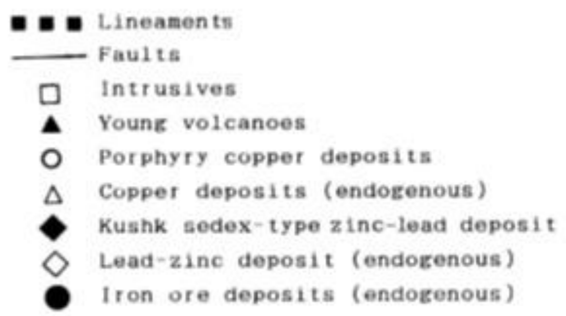

Figure 9. Residual anomaly map of the area (modified after Dehghani and Makris [15]). In this map, the small circles and also the endogenous deposits of Kerman and Yazd regions occurs along the outer or inner boundary of the 0 to -10 mgal zone.

maps of the region to find, geophysically, a lucid explanation to answer the question as to "how the small circles came into the existence"? Examination of the residual anomaly and complete bouguer maps of Iran suggests the presence of major deep boundaries in this region. According to Shahabpour [41] and based on the residual anomaly map of the region (in Fig. 9) nearly half of the endogenous deposits of Kerman and Yazd regions occurs along the outer or inner boundary of the 0 to -10 mgal zone. Therefore, such anomalies, logically, can be proposed to play the genetic role in feeding the crustal levels and occurrence of the Cu deposits in this region. Upward magma injection, originated from this anomaly, through deep conduits to near surface levels and cooling the magma as stocks and perhaps oval-shaped bodies has led to appearing the superficial manifestation of such magmatic bodies or stocks as small circular features (Fig. 11). It should be noted here that some similar structural forms (with circular outline) have been proposed as indicative of the central parts of the volcanic occurrences [12] and collapse of the volcanic structures by few authors [eg., 2]. Such circular forms are also present in the entire KPCB show traces of volcanism. This type of the circles are found throughout the study area but show no sharply concentrations around the porphyry Cu deposits and fall outside the scope of this paper and the term “circular feature”, in this study, has been mainly used for the circles found near the porphyry Cu deposits and prospects, apparently show no direct evidence of volcanism and seem to be related to plutonic activities.

Conclusion

The purpose of this study has been to examine the link between the porphyry Cu deposits and the structural factors in the Dehaj area. To do this, the base information about the geology of the area were discussed and then, preparation of the photolineament factor map of the region carried out to examine the relationship between the structures that seem to play an important genetic control on Cu mineralization in the study area. Given the great importance of the circular features, herein in the context of mineralization, as an agent for Cu prospecting, understanding the origin of this type of structures is a critical aspect of ore deposit occurrence. With this framework, however, any structural model concerning the formation of the small circles in the Dehaj area must take into account the following points:

1- Most of the circular features are formed near the well known porphyry copper deposits (Meiduk, Chahmessi, …);

2- There is a clear relationship between the distribution of the circles and the density of the linear structures as is detectable on the PF map of the area;

3- Dimensionally, most of the circles are similar to some (Meiduk) Cu deposits in the area;

4- The circular features are all formed above a large stratovolcanoe;

5- The circles are, tectonically, formed in a post-subduction environment.

So the main part of the answer to the mystery of the small circular features lies in the geological phenomena concerning the formation of the stratovolcanoe from its origin in the past towards its appearance today as well as the internal magmatic sources in formation of the magmatic bodies and stocks manifested on the Bouguer anomaly and residual anomaly maps of the region. Looking at the mentioned points, it can be deducted that most (not compulsively all) of the circular features in this area have the same root or provenance. To handle the topic, a simplified structural model (Fig. 11) is proposed for formation of these circles, in this area, in which the circles are the superficial expressions of the clustered manner intruded bodies stem from an intrusive body originated from a huge magmatic source near the former arc system channeled along compressed preexisting conduits. The small circles are superficial manifestations of the intruded, probably, porphyritic bodies situated in subvolcanic levels, tectonically, in post-subduction environments. These subvolcanic intrusive bodies lack volcanic equivalents perhaps due to their small volumes, their post-subduction setting in which the volcanic activity is more common prior to the intrusive activities and compressional tectonism in the lower crustal levels (as is suggested in the past) and therefore paucity of the conditions needed in formation of a widespread volcanic activity.

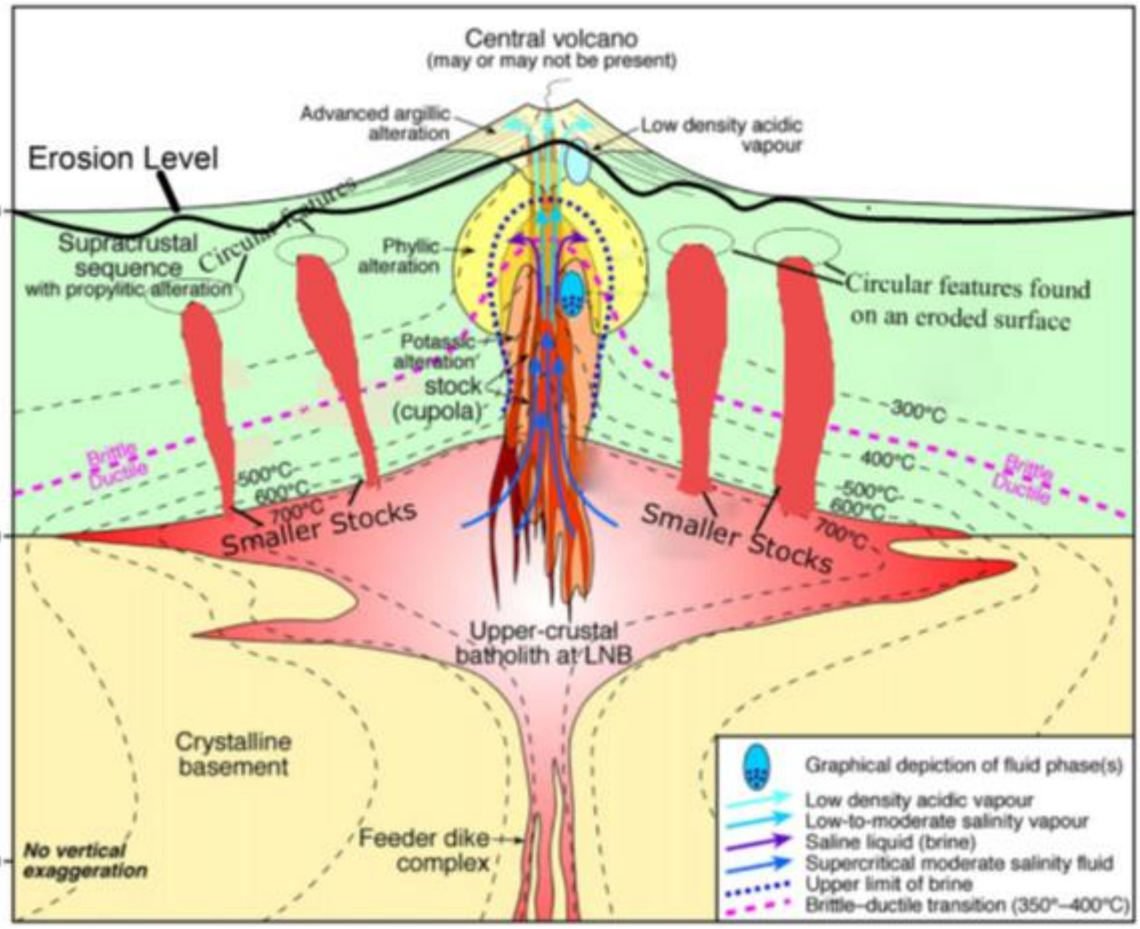

Figure 11. A simplified proposed geological and topographic model indicating the volcano-plutonic activities concerning the formation of the small circular features in continental margins (modified from Richards [36] and its sources).

Some of the linear structures seem to be deep rooted structures controlling the generation of the small circular features and, also, mineralization and some of them are thought to be the surface linear expressions of the intruded bodies in subvolcanic levels emplaced in a post-collisional tectonic setting appeared as small circular features. All data conclude that it is possible that the identification of the relationships between the circular features and mineralization in plate tectonic settings related to the subduction zones in post subduction environments will be applied in future exploration for porphyry type Cu deposits.

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