Large-magnitude Ring structures as structural precursors for porphyry Cu deposit formation in Kerman copper belt, Iran

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Abstract

Structural analysis of remotely sensed data provides a method of assessing the structural significance of Large-magnitude regional metallogenesis in the Kerman porphyry Cu belt in the southern part of the central Iranian volcanic belt. The role of large-magnitude ring structures in the distribution of hydrothermal alteration zones and porphyry copper deposits in the southern part of the Kerman porphyry copper belt SE Iran is discussed. Ring structures are large circular or elliptical shaped features which are partly recognized on satellite images. In this study, Landsat multispectral images were used to identify the rings and also associated hydrothermal alteration zones. The rudimentary identification stages of the circles were mainly based on their circular characteristics on the images. The present research, utilizes various Landsat Enhanced Thematic Mapper Plus (ETM^+) image-processing techniques, including false color composite images, color composite ratio images, band ratio, and standard principal component (PC) image analysis on six bands and color composite selective PC images in addition to structural analysis, regionally, to discriminate the hydrothermal alteration zones and investigate the distribution of the alteration zones associated with Cu mineralization mostly encompassed within the large ring structures. The associated mineralization in the study area are mainly of porphyry Cu and vein type base metal sulfide deposits. There is a clear structural relationship between the large circles, mineralization and also hydrothermal alteration zones. These circles have encompassed almost entirely of the Cu deposits and prospects in the southern part of the Kerman porphyry copper belt. Formation of the large circular structures do not appear to be related to the external processes but traces of a, geophysically, positive residual anomaly are recognizable on the complete Bouguer anomaly map of the region in which an updoming of the upper mantle is observed. This study contributes to our knowledge for copper exploration in this region, along with, recognizing same large magnitude structural features (ring structures) in regional distribution of hydrothermal alteration zones.

Keywords: Structural Analysis, Ring Structures, Remote Sensing, Cu Deposits, Alteration Zones, Mantle Updoming.

1–Introduction

Most exposed deposits in known porphyry Cu districts have been discovered, and present-day exploration is focused on searching for covered deposits, using structural, tectonic, geochemical and remote sensing methods and so forth. Such strategies require knowledge of geological history on a regional scale and an understanding of porphyry Cu genesis within the broader context of tectono-magmatic arc processes (Richards, 2003). With this frame work, however, the role of tectonism and large magnitude structural forms and processes in controlling the timing and localization of porphyry Cu-forming magma emplacement and perhaps alteration zones has generally been left to other disciplines in the geological sciences. In the present paper, the role of some large-magnitude ring structures in the distribution of the Cu deposits in south Kerman Cu belt has been discussed. Ring structures and associated porphyry Cu mineralization can be of the interesting topics for exploration geologists, albeit, there are few papers that document the relationship (Saul, 1978; Eggers, 1979; Witschard, 1984). This paper presents the results of a study on the relationships between some large circular features, Cu mineralization and also alteration zones, through structural studies and remote sensing techniques, in the Kerman porphyry copper belt. This belt contains extrusive and intrusive rocks of Eocene-Quaternary age, however, maximum magmatic activity is thought to be of Eocene age by many authors (e.g., Stöcklin, 1974; Farhoudi, 1978). Geochemical, tectonic, stratigraphic, and metallogenic evidences all point to an island-arc setting for the CIVB (Shahabpour, 2007).

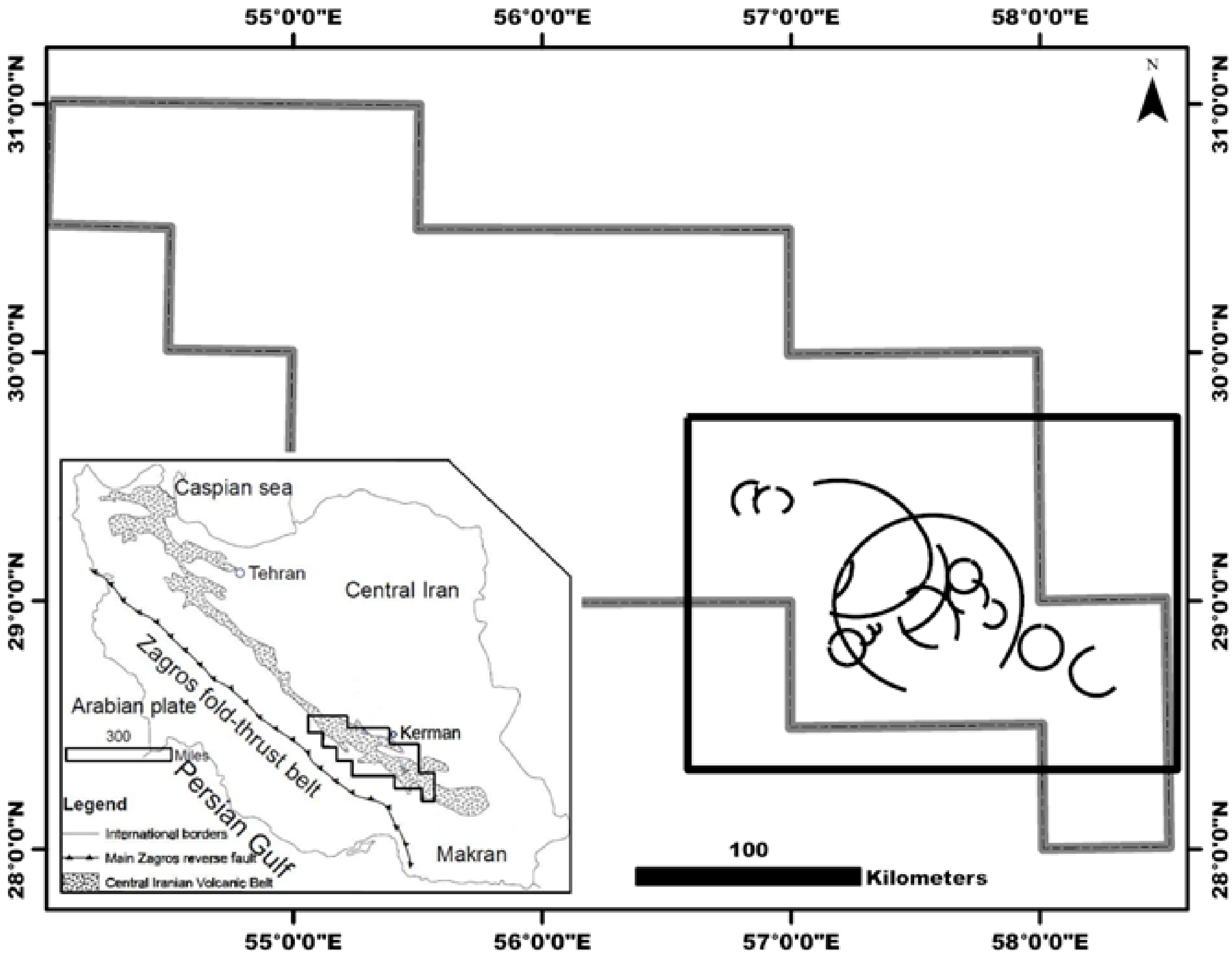

Figure 1) Location of the study area in a northwesterly trending pattern. Inset from Shahabpour and Kramerz (1987).

The investigated area is one of the main copper bearing provinces in the world (Fig. 1). Until now more than 30 deposits and prospects of copper have been explored in this region. Examination of satellite images covering the study area has revealed the presence of a large number of circular features (ring structures) of variable magnitude that seem to play an important structural role in the genesis and localization of copper deposits in this region.

The region is covered by 2 Landsat ETM$^+$ series images, numbers 159-40 and 160-40. Identification of the circles was based mainly on their circular morphology on the images. Extracting the alteration zones using Landsat images (ETM$^+$) carried out to discuss the possible role of the large-magnitude ring structures in the distribution of the hydrothermally alteration zones and Cu mineralization. Landsat imagery has made significant contributions to the advancement of geological mapping in both the known and unmapped areas of the world (Yazdi *et al*. 2013). This study utilizes remote sensing methods in terms of various ETM$^+$ image processing techniques including false color composite images, color composite ratio images, band ratio, and standard principal component (PC) image analysis on six bands and color composite selective PC images to reveal the areas affected by hydrothermal alterations and discuss the possible role of the large-magnitude ring structures in the distribution of the alteration zones. The geologic interpretation is based largely on the investigation of geologic, metallogenic, structural and geophysical maps of the region. With this framework, however, the structures are not, structurally, easy to identify on the satellite images mostly because of tectonic deformation and erosional processes. To avoid any local miscalculating in different stages of the study, all our maps were georeferenced using the Arc GIS (v.9.3).

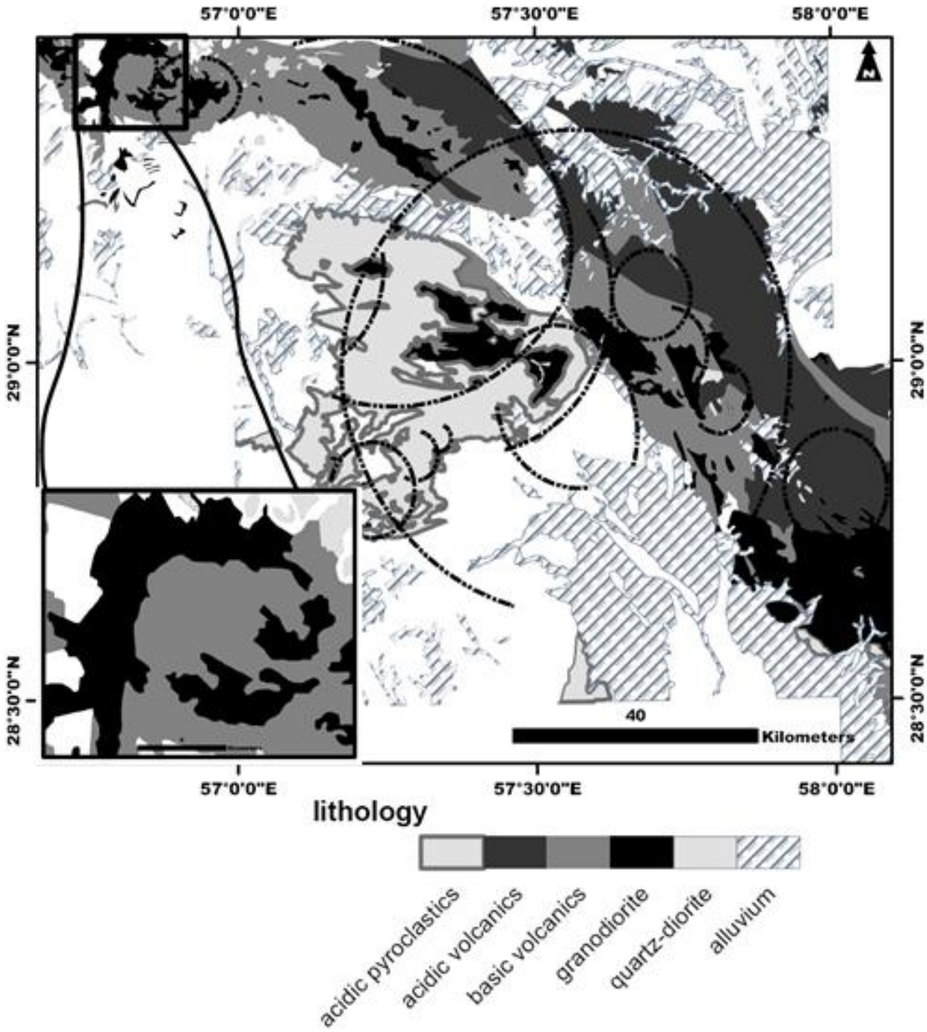

Figure 2) Simplified geological map for the study area showing the distribution of different geological units. A circular outline of acidic volcanics and granitoides partly definable. A little number of the circular features are identified by circularity in lithology (bottom left box).

2– Regional geology

Many authors investigated the studied area (such as, Dimitrijevic, 1973; Berbarian and Yasini, 1983; Berberian, 1983; Hassanzadeh, 1993; Amini, 2002; Shahabpour, 2007; and others). These authors explained that eruption of acidic pyroclastics of Bahre-Aseman complex during early Eocene was the main volcanic activity in the region. This eruption was followed by middle - upper Eocene Razak volcanic complex which consists 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 was invaded by the Oligo-Miocene sea and the 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 Lower Red as well as Upper Red Formations were deposited in a back-arc compressive basin. It is thought that deposition of these sedimentary units has been related to changes in subduction angle of the Neo-Tethys oceanic crust beneath the Iranian microplate. The most important magmatic activity occurred during the Miocene by the intrusion of granitoides consisting mainly of granodiorite and its accompanying shallow intrusions of the Jebale-Barez type and the mainly porphyritic type subvolcanic intrusives of the Kuhe-Panj type. Most of the porphyry copper deposits in the study area are hosted by and genetically related to the recent rock types. Towards the end, the volcanism and plutonism decreased sharply in which small volumes of alkali basalts and foidites represent the youngest magmatic activity. Several large-magnitude ring structures have been recognized in this region show faint correlations with the distribution of different lithological units. Regional geologic map of the area (Fig. 2) indicates that the discussed ring structures are identified mainly in granodiorite and extrusive igneous rocks with acidic to basic composition. Except for a few cases, the large circles are not rigorously detectible on geologic map of the region. Sedimentary units are found throughout the area mainly in the adjacent plains.

3- Ring structures vs porphyry Cu mineralization in the Kerman porphyry copper belt, structural remote sensing

Landsat imagery covering the study area in Kerman porphyry copper belt has revealed some circular features that have not been dealt with previously. Based on the size, number and special features, two types of these structures are well known in south Kerman porphyry Cu belt, as follows:

A: Large-magnitude ring (or ellipsoid) structures: This category of ring structures are generally large, reaching several tens of kilometers in diameter which correspond to regional tectonic trends and are characterized by their small number, the large size and the good to fair feature visibility on Landsat images. Some of these structures reach up to 75 Km in diameter (Fig. 3a).

B: Small circles: This category are characterized by their smaller size (<10 km in diameter), large number and generally fair to poor feature visibility on Landsat images. These forms seem to be surfacial manifestations of intrusive bodies (or stocks) in the study area. This category falls outside the scope of this paper.

Large circles are found in this region and seem to have a recognizable structural (or genetic) control on mineralization. This relationship is more clear when the satellite images are plotted on the metallogenic map of the region (Fig. 3b).

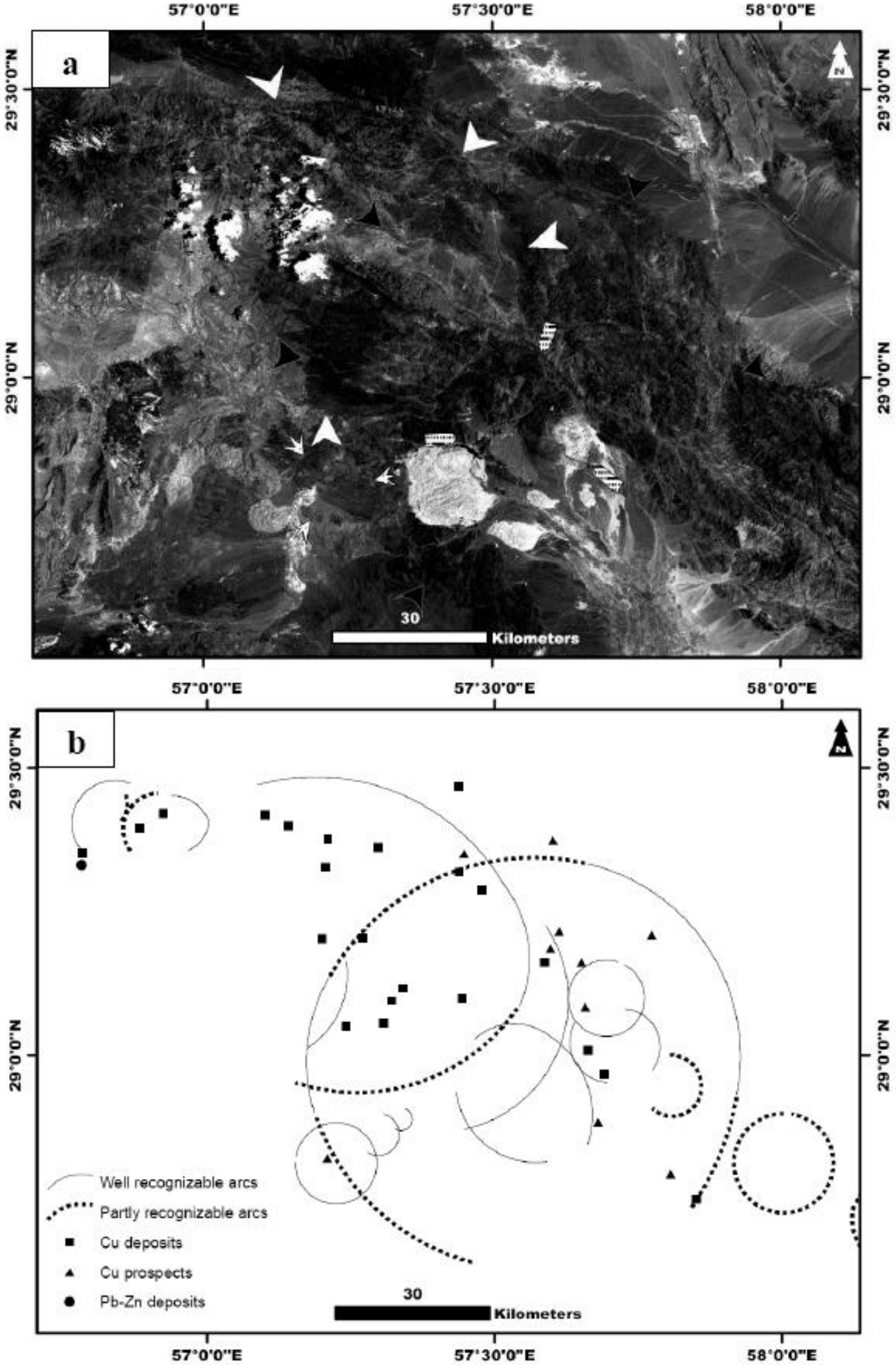

Figure 3a) Traces of some large-magnitude ring structures in south part of the study area on Landsat images. The rims of each large ring structure in this picture (image 159-40 Landsat) are specified by a

particular positioning symbol. b) Rings are drawn for the area of Fig. 3a. The large circles have a structural or genetic role in formation of the Cu deposits. Most of the Cu occurrences have been encompassed by the large circular areas.

Landsat filtered image (the picture was filtered by Gaussian filter in ENVI software) of the area is shown in Figure 4.

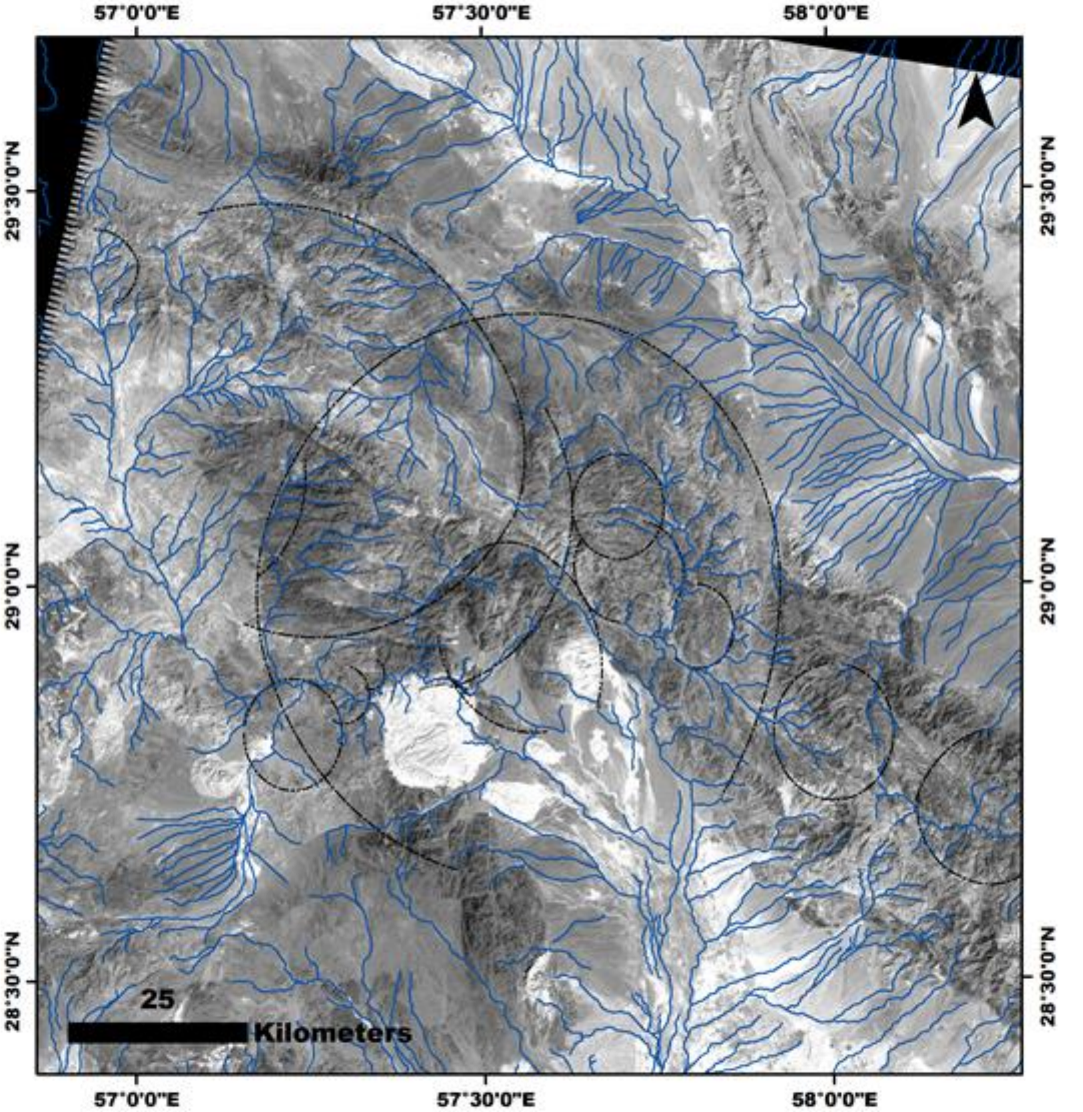

Figure 4) Traces of the large circular features are more detectable using Gaussian type filters. Plotting the drainage map on this image (in Arc GIS 9.3 environment) showed that the ring structures do not show a regular topographic aspect perhaps because of the erosional processes. Ring structures, by contrast, show a clearly circular outline.

Three of the largest circular features are detectable in this picture. River segments of the area are also plotted on this image. According to this map, except for a few cases, the rivers don't follow the rims of the ring structures. This may be due to superficial erosional processes took place in the area. Looking at this map, it can be recognized that the area is, topographically, a bobbed area with circular morphology. The prepared topographic map of the area (Fig. 5) exhibits that the largest circular areas are characterized by the presence of topographic reliefs along parts of their circumferences. It is remarkably clear that the ring structures in this region have morphologically, but not topographically, circular characteristics. Known mineralization in this area includes 33 mappable occurrences or deposits of copper, lead, zinc, molybdenum and rarely silver. The ore occurrences are of porphyry, vein, dissemination and impregnation types. 31 Mineral occurrences are encompassed by the largest circular features and 6 of these occurrences fall on their circumferences. As it is detectable in Figure 3b almost entirely of the Cu occurrences (31/33) have been encompassed by the circular areas and such mineralization has not been occurred towards the south, east and west of the Kerman porphyry copper belt. Such relationship is also clear between the large circles and alteration zones.

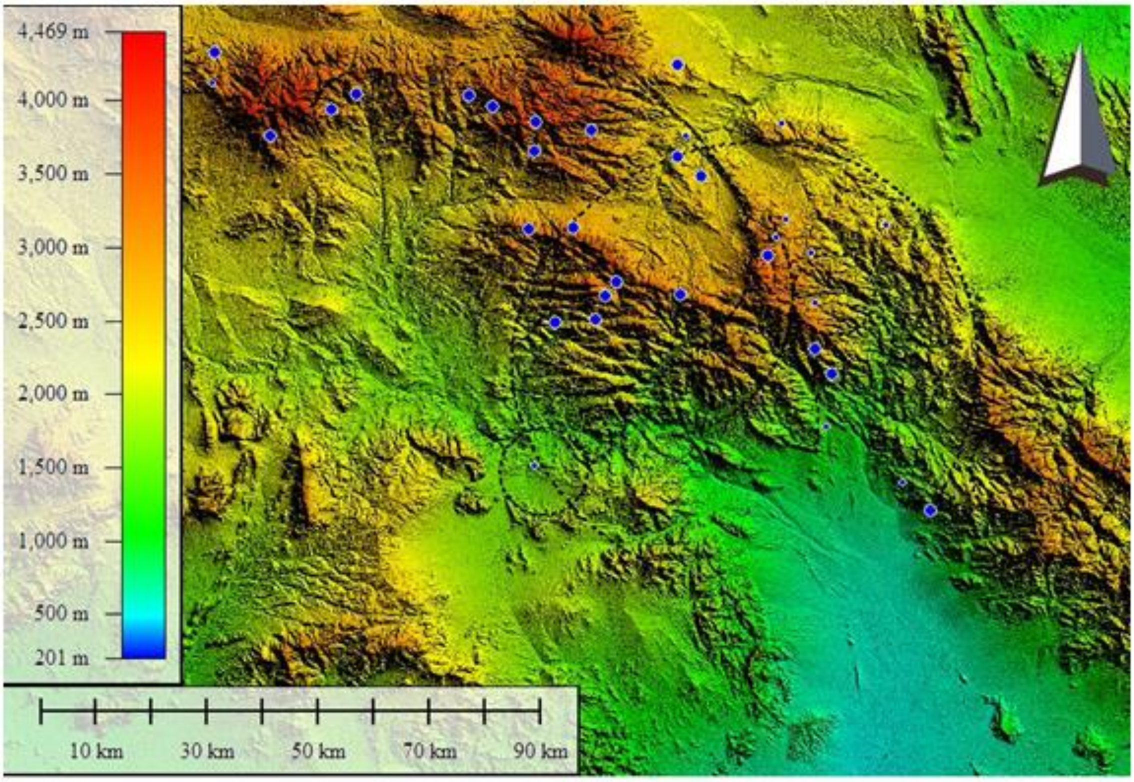

Figure 5) Relief map of the area. The large-magnitude ring structures are identified as circular features encompassed almost entirely of the Cu deposits and prospects.

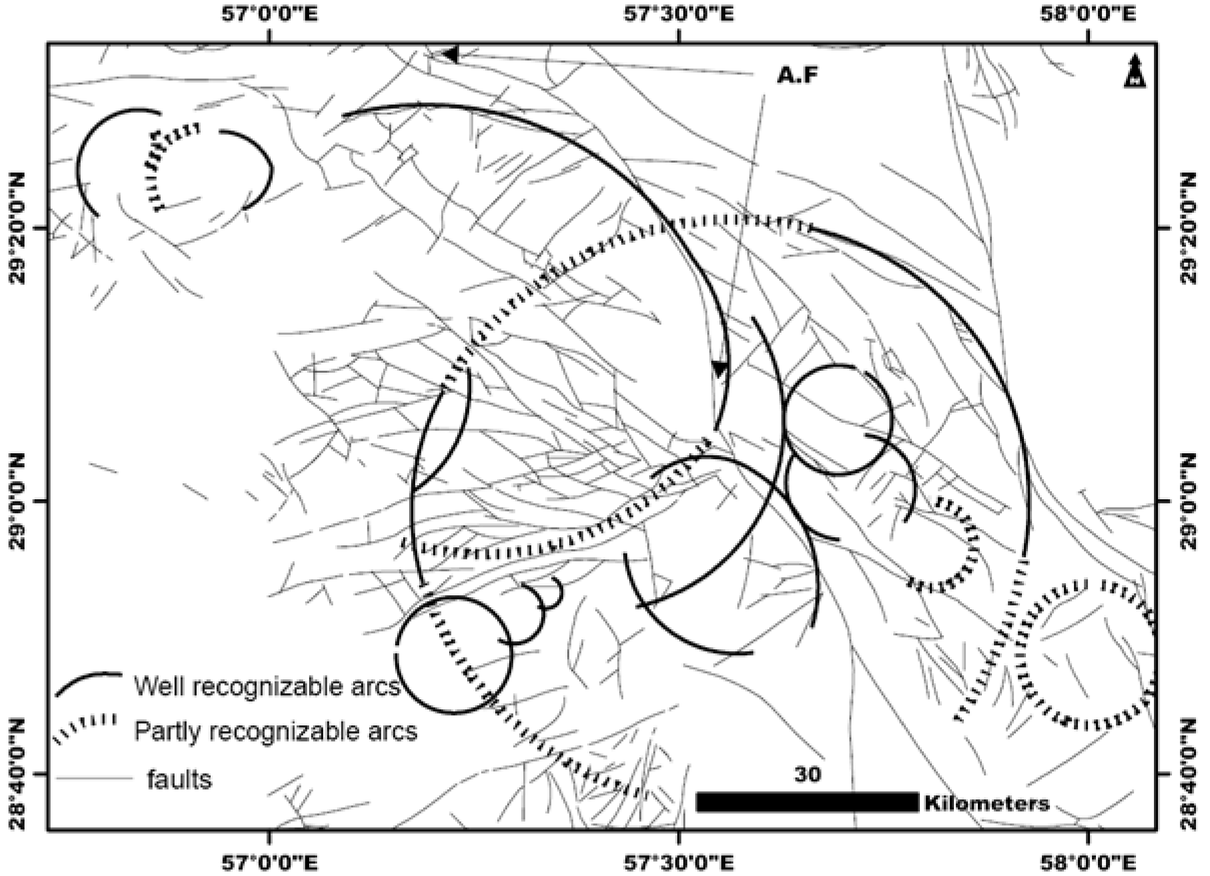

Figure 6) Structural map for the area of Fig. 2. a. Abbreviation: AF:Arcuate Fault.

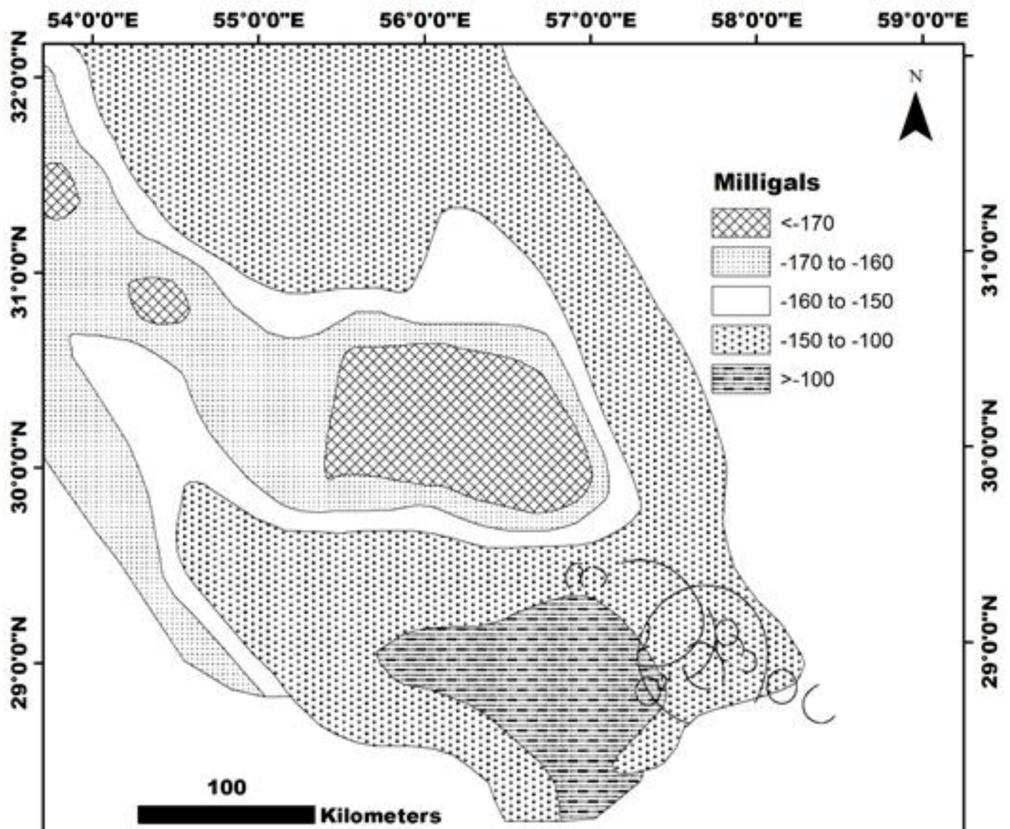

Figure 7) Generalized complete Bouguer map of Kerman and Yazd regions (modified from Dehghani and Makris, 1984). The highest anomaly zone reflects the area of mantle updoming.

It is unmistakably clear that the location of alteration zones have been noticeably affected by the circular areas. Without the presence of the large circles in this area, the circular encompassment of this zones remains unexplainable. Therefore, the large circles seem to have an important structural role in deposition of the copper deposits or prospects as well as distribution of alteration zones in the study area. Based on the structural map of the area (Fig. 6), most of the faults and fractures in this region have been encompassed by the large circular areas and their regional density decreases clearly to outside of the large circular areas. This matter precludes derivation of an external agent (source) for the formation of the large circles. The only explanation of this phenomenon is similar to that of the formation of crustal scale fractures above an updomed internal body which its presence is detectable on bouguer map of the region. That is to say, the occurrence of the large ring structures in this area seems to be really related to internal processes. Besides, one of the ellipsoid structures (a large one) is identified by a partly, but recognizable circular outline of its confining fault along its rims. However, there is no clear evidence of how this fault is related to the ellipsoid. This area shows abundant randomly distributed ring structures of variable size which follow the tectonic trend of the region. Lithological correlation was another tool used in this research to study the ring structures. In general, circular outline in the lithology of the region (Fig. 2) for the basic and acidic igneous units is partly definable, although, this circularity in rock units on Earths crust in the area may be really related to fault controlled displacements. In fact, only the largest structures are partly recognizable on the geologic map of the region. Circularity in the outline of the rock units was used only as a supplementary tool for identification of the ring structures in this area and does not appear to be a significant tool.

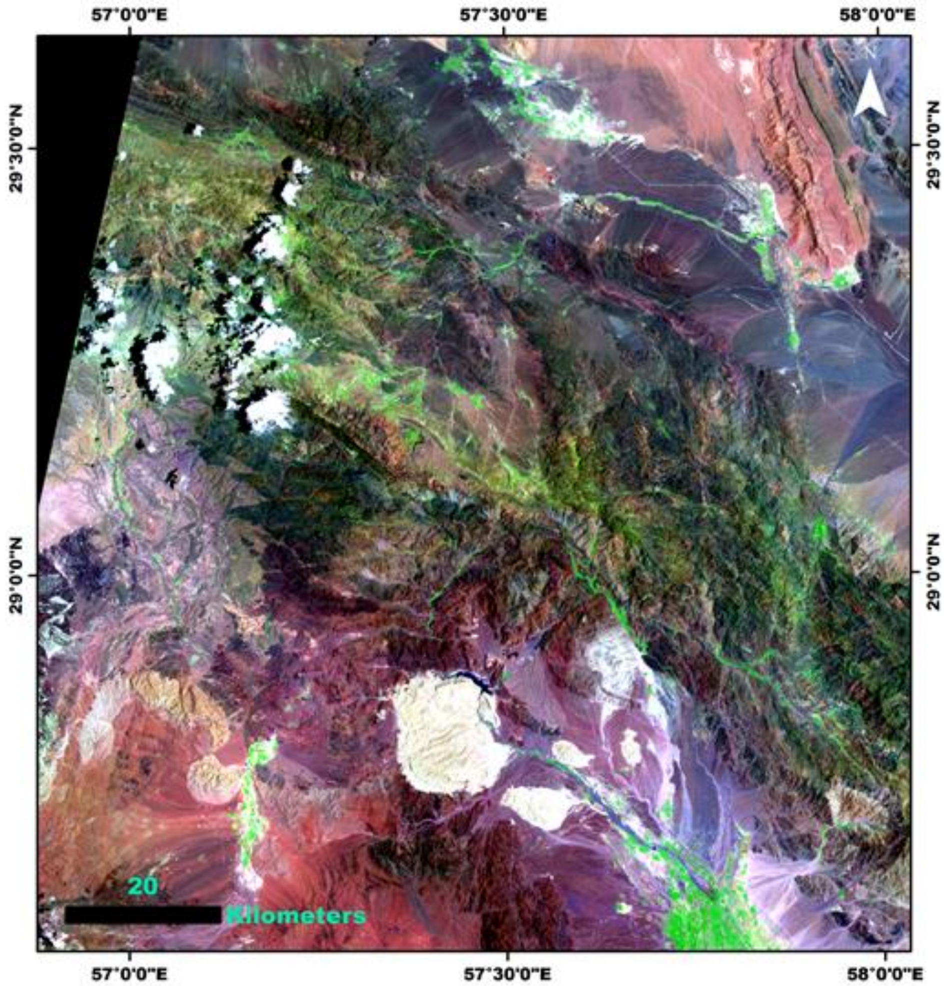

Figure 8) RGB color composite Landsat ETM$^+$ bands 7, 4 and 2. The major lithologies can be observed as differentiated units in this image.

4- Geophysical data

Examination of the complete bouguer (Fig. 7) and residual anomaly maps of Iran suggests the presence of major deep boundaries in this region. Some of the large-magnitude ring structures seem to be formed above a mantle plume. Although, ring structures are formed parallel to the regional tectonic trends and our knowledge of age of the anomaly related dome is very limited, but concentration of the rings and ellipsoids around the edge of the residual anomaly shows that this anomaly have probably played a genetic role in formation of the large rings and ellipsoids. Geophysical data do not provide a logic explanation for occurrences of small circles. Based on tectonic, structural, residual anomaly and crustal thickness maps of the region, initial stages of formation of the large circular areas is related to updoming of a mantle plum. Formation of the large-magnitude circles in some parts of the world is somehow attributed to the updoming of the huge bodies by few authors. It is recognizable, in Kerman Cu belt, that the location of the ring structures coincide with an uplift in the region. Occurrences or dependency of an asthenospheric upwelling on the subduction related environment is well shown (e.g. Richards, 2011; Fig. 4) in which upwelling of an asthenospheric huge body occurs after falling the subducted slab. It is convincing that mantle-plum and subduction processes took place simultaneously, beginning at least from the Mesoarchean (Shchipanskii, 2008) in some parts of the world. Occurrences of a slab break-off beneath the central Iranian volcanic belt in the Kerman porphyry Cu belt is well discussed by a few authors (e.g. Agard *et al*., 2011; Figs. 4 and 5). Breaking off the huge bodies may cause updoming huge domes. The updoming of these diapirlike bodies led to the development of large-scale ring fractures and/or minor collapse in the overlying granites and metasediments. The circular fractures formed by tension above the diapirs, would be the equivalent of the lower half of large-scale caldera-type structures (e.g., Smith and Baily, 1968). Upper mantle magma emplacement will cause extensional domain in crustal levels with fractures (mainly normal faults) providing high permeability pathways for magma ascent and hydrothermal fluids. To some extent, focusing of magma and fluid flow along narrow conduits may be self-organized, because once initial channel ways have developed, they will represent high-permeability pathways and are likely to thermally weaken the wall rocks and promote further fracturing and channeling (Richards, 2011). In this framework, the main role of the updomed bodies, is to prepare a structurally fertile geological environment for localization of the porphyry Cu deposits. Eggers (1979) portrayed that the change from lithostatic to hydrostatic pressure in this fractures would cause ascending hydrothermal fluids to boil, thereby precipitating any sulfide phase. For Kerman copper belt, the mode of formation suggested by Smith and Baily (1968) is logically acceptable in which the updoming of a huge body resulted in formation of, structurally, a fertile environment for formation of Cu deposits and hydrothermal alteration zones.

5- Spectral remote sensing techniques for the study area

Remote sensing can be understood as the science, technology, and art of obtaining information about objects from a distance that takes us well beyond the limits of human capabilities (Aranoff, 2005). This technique, in geological sciences, has been widely applied for mapping of geological units, hydrothermal alteration zones, the rocks affected by different types of metasomatism, fractures, faults, lineaments and so forth. In this study, this technique is applied in both structural (previous sections) and spectral (this section) views. Good exposure of the area makes the remote sensing techniques suitable tool in extraction of hydrothermal alteration zones. ETM^+ images were used in the present study. ETM^+ sensor has the same 7 spectral bands as its predecessor, TM, but has one additional panchromatic band of 15 m resolution and a higher resolution thermal band of 60 m (Wilford and Creasey, 2002). In this study, three different processing techniques were used for detection of probable hydrothermal alteration zones in the study area: 1) color composites; 2) band rationing and 3) Principal Components Analysis (PCA). The large-magnitude ring structures were plotted in all the images obtained in this section to fined a logical relationship between the distribution of the alteration zones and the large-magnitude ring structures.

6- Color composites

Most of the images are displayed in grey scales. Although the human eye is capable of discriminating about 30 grey levels in the black–white range (Drury, 2001), it is much more sensitive to color differences and recognition of color patterns (Ayalew Amera, 2007).

ETM^+ data possesses a great capability for lithological mapping (Ranjbar *et al*, 2004). A false color composite image of Bands 7 (in red), 4 (in green) and 2 (in blue) is generated (Fig. 8). Among different RGB color compositions, 7,4,2 ETM^+ image (in pseudo natural color) proved to be the most useful for separation of different rock types in the study area (Fig. 8). This color composite has widely been applied by several authors (e.g. Ranjbar *et al*, 2004; Yazdi *et al*, 2013 among others) studied the areas containing a diversity of different rock types. This rendition looks like a jazzed up true color rendition - one with more striking colors in which the major lithologies can be differentiated. Another color composition is 5, 4, 1 ETM$^+$ image in which different lithological units are well recognized. The produced image from this band combination (5, 4, 1) is very similar to the image produced by previous (7, 4, 2) band combination.

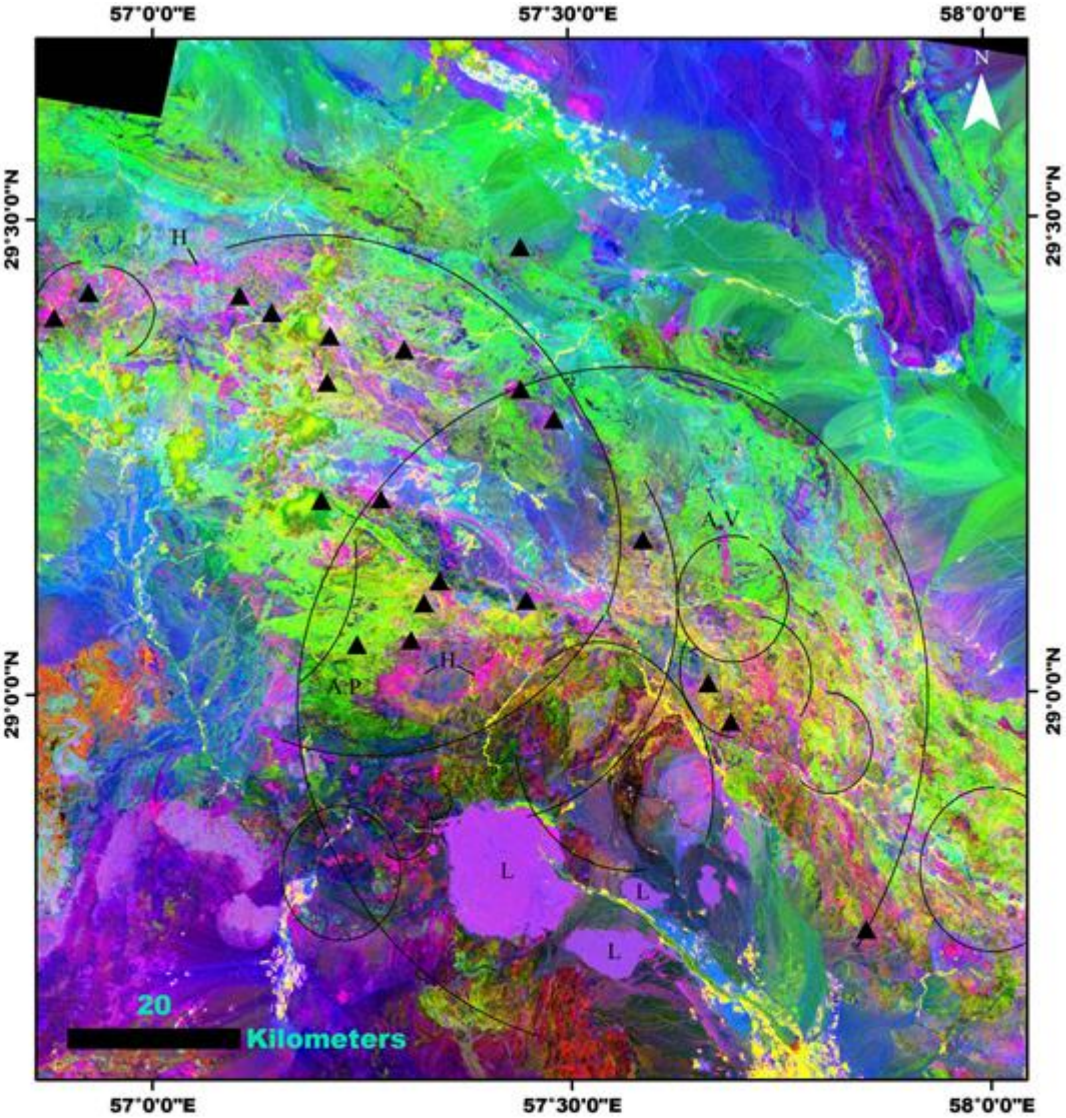

Figure 9) Landsat ETM$^+$ ratio image (bands 5/7, 4/5, and 3/1 in red, green and blue, respectively) for the study area, showing the zone of altered rocks as pink. Triangles are Cu deposits or prospects. Abbreviations: L: limestone; A.V: acidic volcanics; A.P: acidic pyroclastics; H: hydrothermal alteration zones.

7- Band rationing

Band ratios are simple and powerful tools for discriminating among mineral types in remote-sensing image data, by enhancing the spectral differences between bands and reducing the effects of topography (Rowan and Mars, 2003; and others) in which bands with high reflectance are divided by bands with high absorption. Among different band ratios, 5/7, 4/5 and 3/1 in red, green, and blue, respectively, was chosen (Fig. 9). In this image the hydrothermal alteration zones are observed as pink and volcanic rocks are also seen as green. The color composite of band ratio 3/4, band 5, and band ratio 5/7 is also an example of ratio images that can be displayed with the original bands (Yazdi *et al*, 2013). The ratio of 3/4 is relatively high for iron oxides; band 5 and band ratio 5/7 are both high for clay minerals (Yazdi *et al*, 2013). Ratios 3/1, 5/7 and 4/3 are in red, green, and blue, respectively (iron oxide image in red, hydroxyl in green, and vegetation cover in blue), and are used as an important index in explorations for distinguishing alteration zones (Yazdi *et al*, 201) (Fig. 10). In general, Landsat ETM+ band-ratios b1-b2, b4-b2, b5-b7, 5/7, and 3/l emphasize alteration, clay and iron minerals that have specific spectral reflectance, and absorption features in these bands (Ghassemi Dehnavi, Sarikhani, and Nagaraju, 2010).

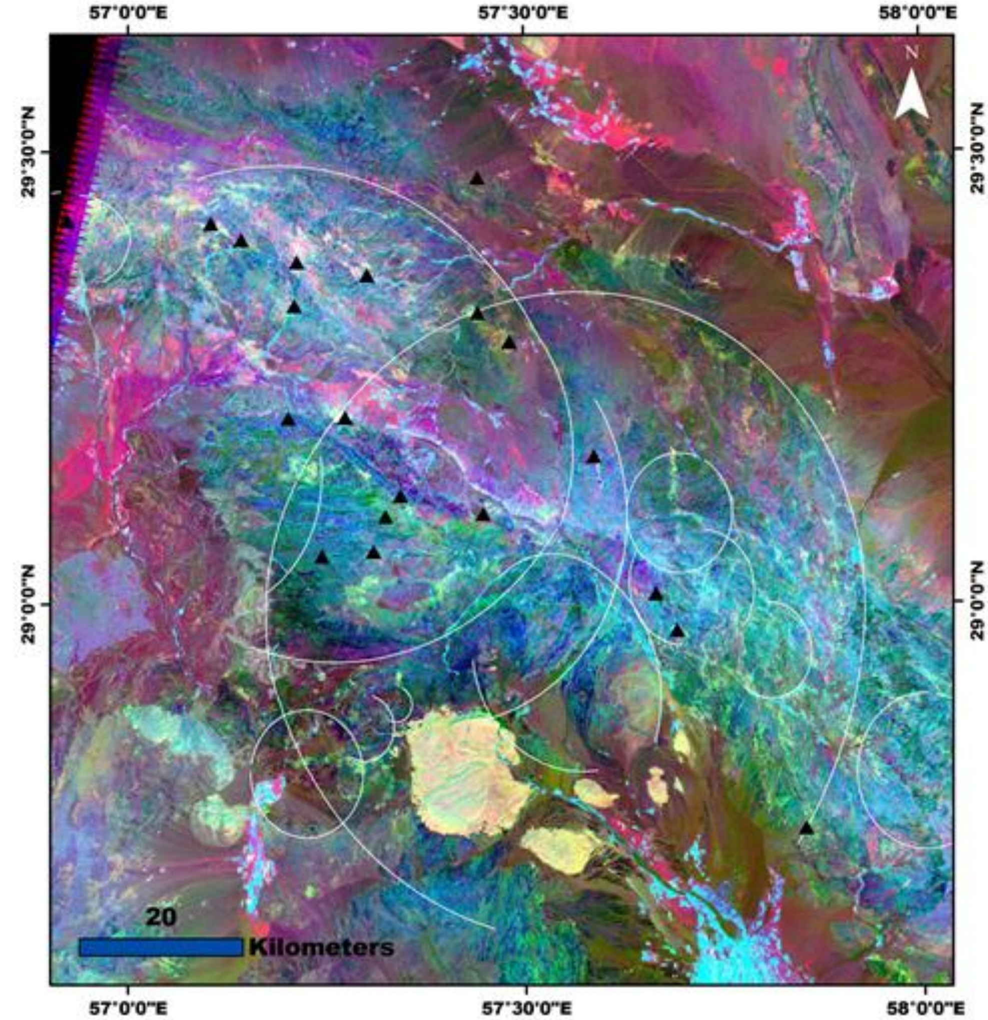

Figure 10) Landsat ETM+ ratio image (bands 3/1, 5/7 and 4/3 in red, green, and blue, respectively) for the study area, showing altered rocks as green. Triangles are Cu deposits or prospects.

8- Principal component analysis (PCA)

PCA is widely used for mapping of alteration in metallogenic provinces (Ranjbar, Honarmand, and Moezifar, 2004). The methodology used herein followed mainly the studies of Crósta and Moore (1989), Ranjbar, Honarmand and Moezifar (2004) among others. The technique, standard PCA on six bands of Landsat, was used for satellite image processing. The principal component transformation described in Table 1 using six ETM+ bands as input Bands (Bands 1, 2, 3, 4, 5 and 7). As it is observed the first principal component does not contain spectral features relevant in this analysis as it is a combination of all bands. This component, in Table 1, contains 90 percent of the variance of six bands. This PC gives information mainly on albedo and topography (Ranjbar *et al*. 2004). Vegetation was enhanced in PC3, as this PC had a higher loading for Band 4 (0.85). Hydroxyl-bearing minerals form the most widespread product of alteration (Ranjbar *et al*, 2004). An abundance of clays and sheet silicates, which contain Al–OH– and Mg–OH– bearing minerals and hydroxides in the alteration zones, implies that absorption bands in the 2.1–2.4 mm range

(Band 7) due to molecular vibrational processes becoming very prominent (Ranjbar *et al*, 2004).

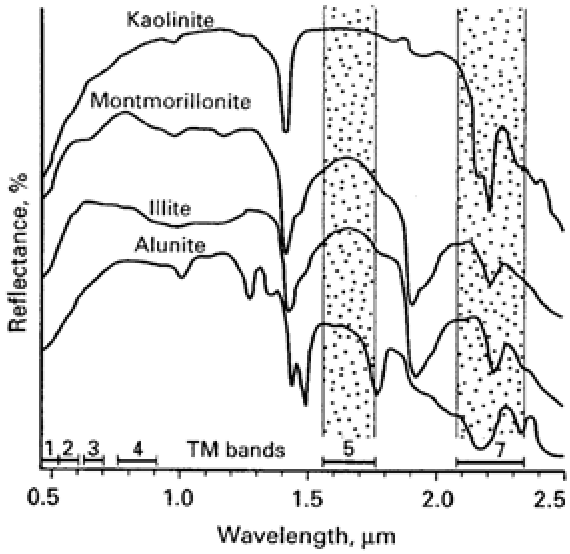

Figure 11) Reflectance spectra of some common clay minerals (after Rowan et al., 1977; Sabins, 1997).

Referring to Figure 11, it will be seen that the clay minerals had absorption in band 7 and reflection in band 5. Therefore one would expect higher loadings of these two bands in PC analysis, but with opposite sign. PC5 has a negative contribution of Band 5 and positive contribution of Band 7. Therefore pixels that map the hydroxyl minerals will be darker in the final hydroxyl image. But in order to show the areas with hydroxyl minerals in bright pixels an inverse of this PC is obtained, simply, through the following equation as applied by several authors (eg. Ranjbar *et al*, 2004).

PC5 = –0.02(Band 1) + 0.12(Band 2) + 0.18(Band 3) – 0.32(Band4) + 0.61(Band 5) – 0.69(Band7).

Table 1) Principle components for six bounds including 1, 2, 3, 4, 5 and 7.

	Band 1	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 7**
PC1	0.25	0.32	0.46	0.36	0.52	0.46
PC2	0.42	0.36	0.43	0.16	-0.56	-0.40
PC3	-0.31	-0.19	-0.08	0.85	0.08	-0.36
PC4	0.62	0.21	-0.71	0.15	0.17	-0.09
PC5	0.02	-0.12	-0.18	0.32	-0.61	0.69
PC6	-0.52	0.82	-0.23	-0.01	-0.08	0.04

The hydroxyl image is shown in Fig. 12. The only disadvantage in using this method is that the carbonate rocks are also enhanced in the resultant image. To solve the problem, the pixels characteristics of the widespread carbonate bearing areas, recognized based on available maps and ground trothing, have been deleted. The areas containing iron oxides, also, can be manifested using PC4 (Fig. 13). One interested matter in using this technique is the application of PC's in making color images. The PCA image in Figure. 14 is the result of 5/7 (clay), PC3 (vegetation), and PC4 (iron oxide) displayed in red, green, and blue, respectively. This color combination was used by Yazdi *et al* (2013). This PCA color image reflects best the distribution of altered rocks and clay minerals.

9- Discussion

Although, there has not been an ongoing interest in the association of large-magnitude ring structures with mainly porphyry type Cu deposits worldwide, there are irrefutable evidence that point the fact that these structures have an important structural role in the deposition of the Cu deposits in some parts of the world like Arizona as stated by Saul (1978). The correlation between the position of epigenetic copper deposits, the distribution of hydrothermal alteration zones and the ring structures is the main problem of interest in this study. Application of remote sensing techniques showed that the localization of hydrothermal alteration zones are also affected by the presence of the large rings. This, logically can be related to the structural roles of the large-magnitude ring structures in providing widespread fertile metallogenic environments within which the hydrothermal alteration zones are developed.

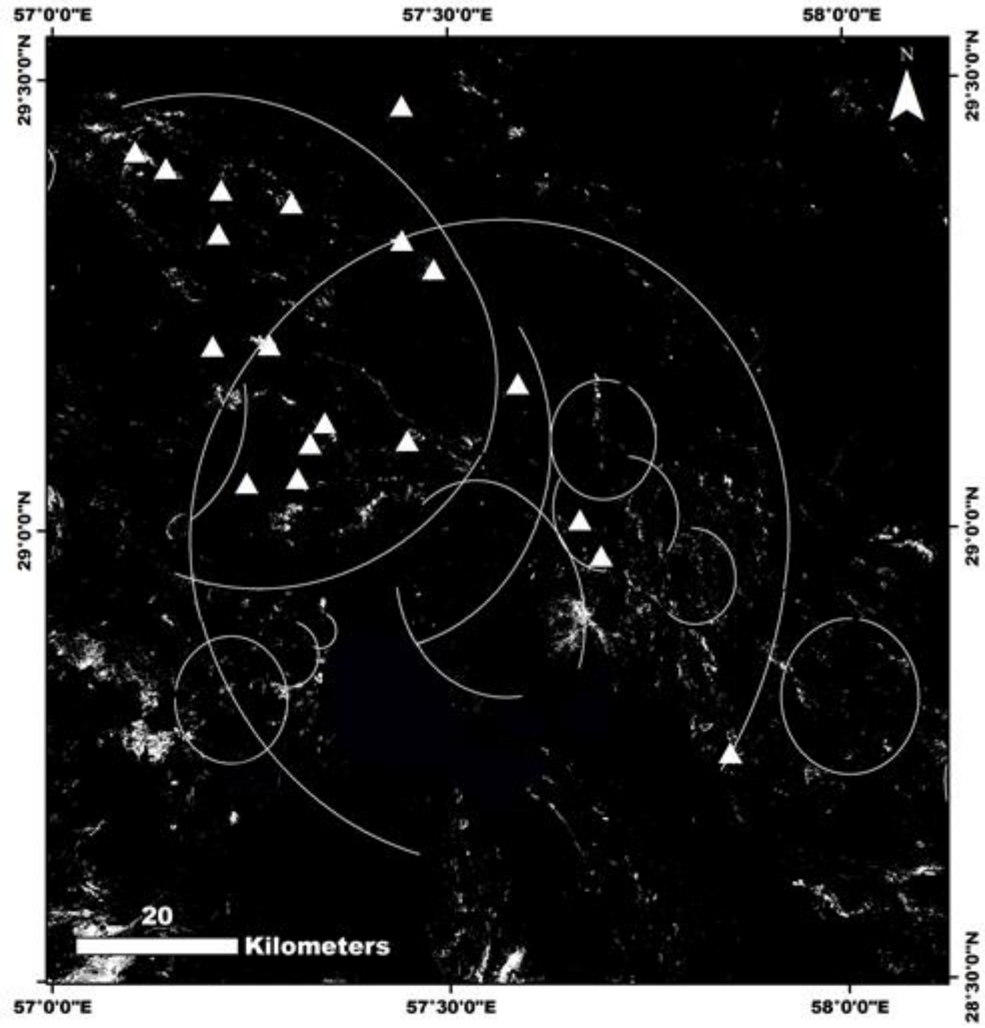

Figure 12) This image is obtained using the eigenvector loadings of PC5. The hydroxyl image shows the altered areas in bright pixels.

Applying the remote sensing techniques including band combinations, band rationing and also PCA analysis for the study area showed that most of the hydrothermal alteration zones are encompassed by large circular areas (ring structures) Although the structural role of the large-magnitude ring structures in the distribution of the Cu deposits and hydrothermal alteration zones poses a scientific importance in this region, but, accumulated data concerning the ring structures indicate that these structures are genetically ambiguous. Saul (1978) proposed a meteorite impact for the mode of formation for the circular structures in Arizona and, although Eggers (1979) opposed an impact origin for the mode of formation of the circles in New Zealand. In his (Eggers, 1979) opinion, for the meteorite impact mechanism to hold, a stable continental shield must be provoked. Geological evidence for the southeast of Iran shows that the area is situated above a subduction zone with Cenozoic in age. The preferred origin of the rings (and ellipsoids) in this region is analogous to that of the rings in North Westland and West Nelson, New Zealand, as described by Eggers (1979). This is supported by the presence of a positive anomaly in the area which reflects the area of a mantle updoming which is manifested in generalized crustal thickness map of the region. In this region, updoming of a mantle plume (which is manifested by geophysical data) resulted in faulting, fracturing and crashing in broad circular areas (Fig. 6). These fractures and faults acted probably as plains of weaknesses for later movements and circulation of hydrothermal solutions and then deposition of Cu deposits and prospects as well as alteration zones.

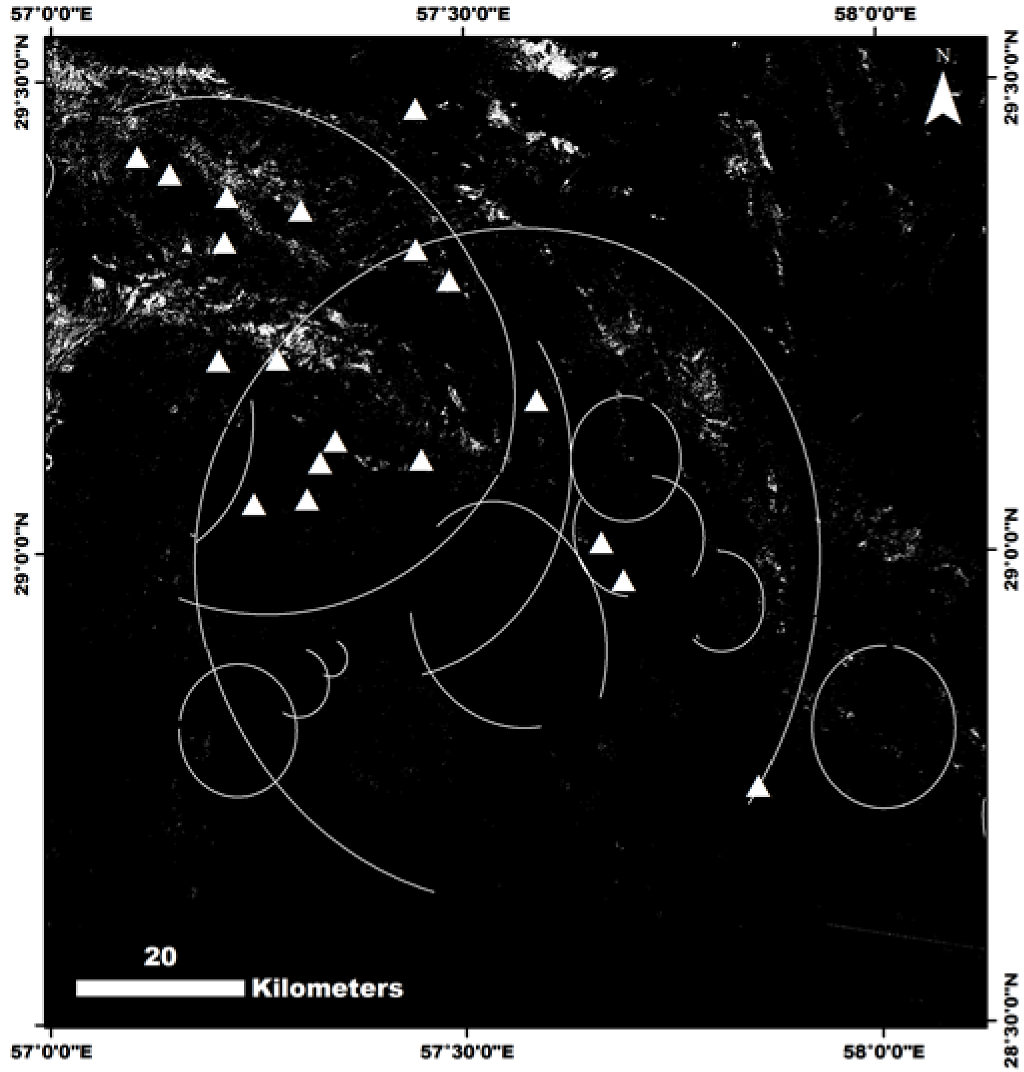

Figure 13) This image is obtained using the eigenvector loadings of PC4 for enhancing iron oxide. The bright pixels are the areas with iron oxide.

Based on the geophysical data and morphological evidences of the study area, the circular features in Earths crust aren't completely seen above the diaper like body in the mantle (as shown in Fig. 7). To explain the topic, we should impress on the mind that the area was a geologically and a tectonically active environment during Cenozoic with a northeastward motion of Arabian plate which culminated in the subduction of Neo-Tethys oceanic crust beneath the central Iranian microplate. This process can be proposed as a powerful agent for displacement of the obducted Iranian continental crust in a northeast direction. Therefore, the not-completely matching circumferences of the circular features with geophysical traces of the internal huge body can be proposed as a legacy of the superficial displacement of the continental crust above a mantle plum. An interesting observation pointing to the certain relationship between the circular areas and the mantle plum is the fact that non of the large circles has been identified on Landsat imagery over the other parts of the CIVB, whereas they might be expected to be formed in other parts of the CIVB if there really wasn't a logic relationship between the presence of the diapirlike bodies and distribution of the large circular areas. According to Saul (1978), Eggers (1979) and Witschard (1984) some of the main types of deposits (porphyry Cu-Mo, sulfides, Fe and polymetallic) are genetically related to the circular structures. Based on their debates, the deposits are on or close to the circumferences of the circles, but, the present study shows that the deposits in the study area have been encompassed by the large circular features.

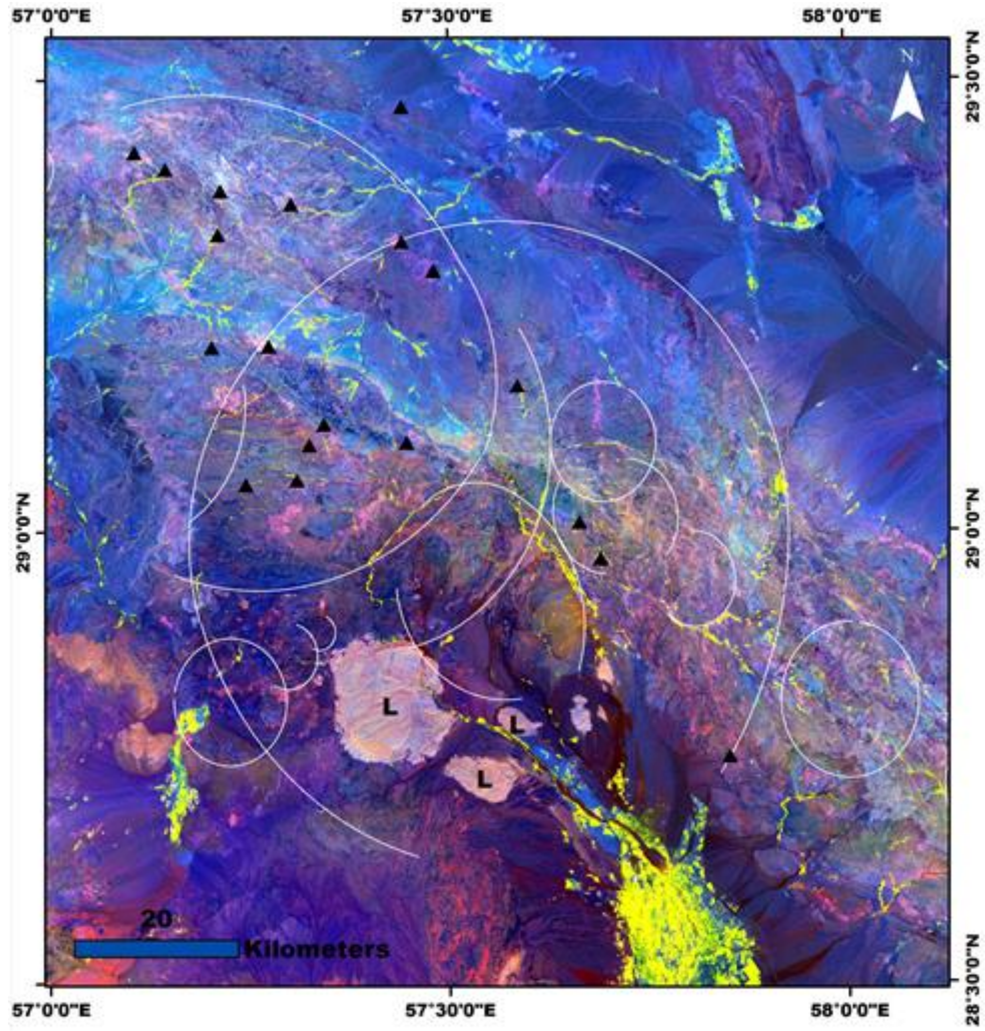

Figure 14) PCA image 5/7, PC3, and PC4 displayed in red, green and blue, respectively, for the study area. The altered areas are pink in color and yellow pixels show the vegetation cover (L: Limestone).

In this area there are about 33 mappable occurrences (deposits or prospects) mainly of porphyry copper. 31 mineral occurrences or deposits are encompassed by the large circular areas. Moreover, the areas affected by hydrothermal alteration activity that are mostly observed within the large circular areas. Therefore, accumulated data concerning the large rings (or ellipsoids) and copper occurrences support the supposition of a structural or genetic link between the large circles and the copper deposits, prospects and also hydrothermal alteration zones. The study of the relationships between the circles, Cu deposits and alteration zones can serve as a useful prospecting guide in the exploration of the deposits related to hydrothermal processes. It should be noted herein that the study of such relationship is useful in early planning stages, on the other hand, by the instrumentally of these structural studies, geographically, the entire area -under the exploration study- will be more scientifically studied and perhaps limited. Therefore, logically, the more limited the exploration area, the more economically the exploration program and the more possibility of the discovery of the covered deposits.

Leaving aside their economic importance, ring structures represent an interesting geological topic for which we still have not a good explanation, although their importance in copper mineralization has not been universally accepted. This problem stems from the fact that they have not been deeply studied, debated and noticed in different geological environments, probably because of our limited knowledge about their essence and irrefutable structural roles in mineralization. We hope that this study could has been used in depicting new views in the field of structural controls on Cu mineralization and also hydrothermal alteration zones in south Kerman porphyry copper belt.

10- Summary and conclusions

The present study is, technically, divided into two parts including the structural remote sensing techniques and the spectral remote sensing techniques. The structural factors comprise the morphology, topography, structural and lithological aspects used in the identification of the large-magnitude ring structures on the Landsat images. The geophysical aspects were also investigated to find a logical provenance for mode of formation of the large-magnitude ring structures. The large rings show a circular outline encompassed most of the Cu deposits and prospects and also alteration zones.

Several spectral remote sensing techniques including band ratios, color compositions and principal component analysis carried out through which several images with specific color compositions were obtained on which the distribution of the hydrothermal alteration zones is mapped. The distribution of the hydrothermal alteration zones coincides clearly with the areas encompassed by some large-magnitude ring structures identified through the structural remote sensing techniques. Three of the maps obtained in this study (Figs. 12, 13 and 14) using the PCA method extracted powerfully the areas affected by hydrothermal alteration zones and also the areas show widespread iron oxide contaminations.

The results obtained through this study can be summarized as follows:

1- The study of satellite images of Kerman porphyry copper belt has revealed several large-magnitude ring structures which correlate with the location of porphyry type copper occurrences and the distribution of hydrothermal alteration zones.
2- The large-magnitude rings are identified mainly by their circular morphology on Landsat images.
3- Most of the copper deposits and prospects, alteration zones and observed faults in the study area are encompassed by the definite large circular areas.
4- A limited number of the large rings are characterized by circular arrangement of their confining faults.
5- Applying several spectral remote sensing techniques showed that the distribution of hydrothermal alteration zones is controlled by the areas were the volcanic bodies outcropped and encompassed with the large ring structures.
6- The large-rings do not show a regular topography manner, although, they show clearly a circular outline.
7- The large rings have been formed above a positive residual anomaly possibly above a mantle plume which is also manifested in crustal thickness and Bouguer anomaly maps of the area.

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