

Integration and analysis of airborne geophysics and remote sensing data for exploration of porphyry copper deposits in the Central Iranian Volcanic Belt

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ABSTRACT

The area under study covers an area of 640 km², located in the southern part of Iranian Volcanic-Sedimentary Belt. ETM+ images have been used for alteration mapping. Satellite images can be used for enhancing the areas with hydroxyl and iron oxide minerals. However field checking has shown that this method is not able to enhance all the areas with hydrothermal alteration. At the same time many of the altered areas do not have good signature in the geophysical data. In order to recognize such areas integration of remote sensing and geophysical data can be helpful. The Darrehzar Cu deposit is chosen as a control area. The data analysis and integration of geophysical and remote sensing data is performed by using directed principal components. This technique is found to be useful for the delineation of hydrothermally altered areas with more confidence.

Key words: Data integration, principal components, ETM+, porphyry exploration, raster GIS, Iran

1. INTRODUCTION:

Many of the known porphyry Cu deposits are situated in the Central Iranian Volcanic Belt(Figure 1). This belt has a great potential as far as Tertiary porphyry copper mineralization is concerned. Given the poor soil development, relatively poor vegetation cover but abundant outcrops the arid/semiarid part of the belt is suitable for airborne geophysical survey and remote sensing studies.

Two airborne geophysical surveys were done over the study area. The first airborne geophysical survey (radiometry and magnetometry) over the area was done in 1977 by Prakla-Seismos GMBH on behalf of Atomic Energy Organization of Iran(AEOI). The aim of this survey was exploration for uranium and thorium minerals. The flight line spacing was chosen at 500 meters and nominal terrain clearance was 120 meters. In the second survey a helicopter magnetic/electromagnetic/radiometric survey (HMER) was flown by Geonex Aerodat Incorporated over an area of 7000 km², in Kerman Province(in 1992). The aim of the project was mainly for exploration of porphyry and vein-type mineralization in the Kerman region. The survey was conducted over the area in 200 meters flight spacing and constant height at average elevation of 60 meters for spectrometer, 45 meters for magnetometer and 30 meters for electromagnetic coils. The data then, was processed by various filtering and enhancement techniques for noise removal and

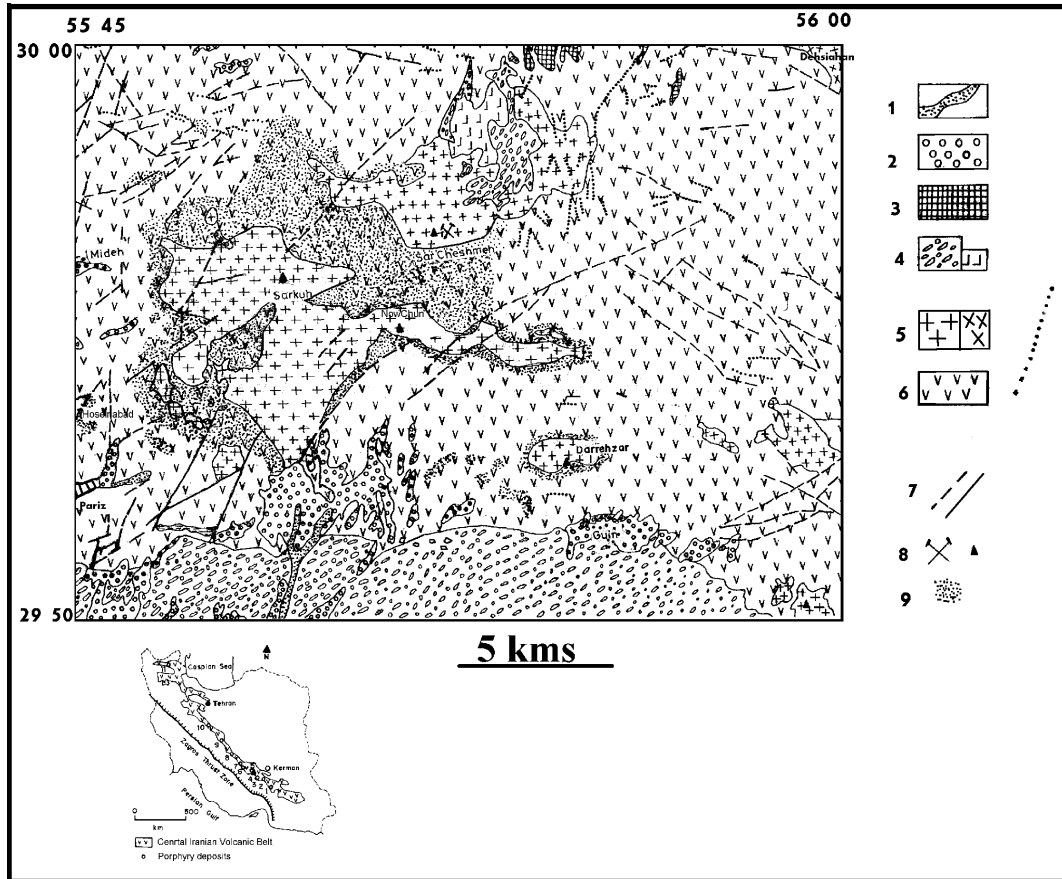


Figure 1 : Sketch map(Inset) showing the position of the Central Iranian Volcanic Belt and porphyry-type Cu deposits sub parallel to the Zagros Thrust Zone(Shahabpour, 1994) 1- Bahreasman, 2- Takht, 3- Kuhe Panj, 4- Darrehzar, 5- Sar Cheshmeh, 6- Meiduk, 7- Gowde kolvary, 8- Darre Zereshg, 9- South of Ardestan, 10- Sharif Abad, 11- Songun. Geological map of Sar Cheshmeh area. 1- Recent alluvium(Quaternary), 2- Younger gravel fan(Quaternary) , 3- Calcareous terraces(Quaternary), 4- Neogene sediments, mostly arenites with pebbles and boulders of volcanic and intrusive rocks. Dacites and dacitic pyroclastics, 5- Oligocene-Miocene Granodiorite, quartz diorite, diorite porphyries and monzonite, dikes, 6- Volcanic-sedimentary complex. Trachyandesites, trachybasalts, basaltic andesites, pyroclastics etc.(Eocene), 7- Fault, 8- Working mine and copper deposit, 9- hydrothermal alteration (After, Dimitrijevic et al., 1971).

data correction(Pitcher et al. 1994). Pitcher et al. (1994) and Ranjbar et al. (2001) have worked on a part of HMER data and concluded that the porphyry copper deposits in the Kerman region are associated with a distinct magnetic low, relative to the host rocks, a potassium high and resistivity low.

The integration of multiple data sets is a necessary step in mineral potential mapping. A major focus in modern exploration programs aims at the search for blind ore bodies. Because of the advent of advance computer technologies, various multivariate techniques have been introduced to interpret and synthesize multiple geo-data sets for target selection (Agterberg, 1989). Principal component analysis is a multivariate analysis which can be used for data which are spatially distributed and have common geographical locations. Statistical analysis of geophysical data has been reported by many authors in the recent years (e.g. Duval, 1977; Pan, 1993; Ranjbar et al., 2001).

The previous studies have shown that the elevated potassium in the sericite zone is often observed around the mineralization areas and also acid sulfate conditions resulting from weathering of near surface sulfides can result in Fe mobilization from host rocks and can precipitate with iron in gossan (Dickson et al., 1996).

The integration of satellite and geophysical data, over the Central Iranian Volcanic Belt, has been reported by many workers (e.g. Ranjbar and Roonwal, 1997, Asadi and Hale, 1999, Tangestani and Moore, 2001 and Ranjbar et al. 2002). The integration of geophysical and satellite data can be done either in vector or raster format. A comprehensive literature review of GIS analysis in raster format is reviewed by DeMers (2002). In this study ETM+ data (Acquisition date, 23/6/2001) has been integrated with airborne geophysical data for proposing a model for further exploration activities in the Central Iranian Volcanic Belt.

2. GEOLOGICAL SETTING

Sar Cheshmeh area is situated within the southern part of the Central Iranian Volcanic-Sedimentary complex, southeast of Kerman City. Its geological evolution can be simplified as (a) formation and folding of Early Tertiary Volcanic-Sedimentary rocks, (b) emplacement of Late Tertiary granodiorite, diorite, quartz diorite, monzonite, and tonalite in the Volcanic-Sedimentary complex. Their subsequent faulting, fracturing, alteration and mineralization, both within the porphyry rocks and the associated volcanic rocks, followed by (c) formation of supergene environment and oxidation zone in some of the deposits (Shahabpour, 1982). Hydrothermal alteration involving chlorite, sericite, epidote, carbonate, silica, tourmaline and clay minerals are common. However phyllic, argillic and propylitic alteration are more common in the area (Dimitrijevic, 1973).

The Eocene volcanic-sedimentary rocks consist of andesite, trachyandesite, trachybasalt, agglomerate and tuffs, lava flows and sedimentary rocks. The intrusive rocks are granodiorite, diorite and monzonite. The oldest and youngest exposed rocks are the upper Lower Eocene volcanic rocks and the Quaternary alluvial deposits and gravel fans, respectively. Some well known copper deposits are situated in this area (Figure 1). Darrehzar area is located southeast of the Sar Cheshmeh porphyry Cu deposit. The topography around the deposit is mountainous. Data from detailed geophysical, geochemical and geological survey carried out in 1969 are given by GSI (1973). The deposit was later studied by Maanijou (1994), Ranjbar (1996) and Ranjbar et al. (2001). The Darrehzar porphyry is situated in a diorite-quartz diorite pluton of Oligocene-Miocene age that intrudes an Eocene Volcanic-Sedimentary complex comprised mainly of volcanoclastics, andesite, trachyandesite and sedimentary rocks. The porphyry locally grades into granodiorite. The hydrothermally altered rocks are highly fractured, and supergene alteration has produced extensive limonite and leaching of sulfide, given a characteristic reddish or yellowish color to the altered rocks. A weathered zone is developed a few meters to 80 meters below the surface (GSI, 1973). Propylitic and phyllic alteration are pervasive in the surface rocks with sporadic small areas of argillic alteration (Maanijou, 1993). Potassic alteration is not seen at surface, possibly as a result of an intense phyllic overprint or surface related weathering. Litho-geochemical data has shown that Cu concentration is restricted to the quartz-sericite zone in the area (Ranjbar, 1996).

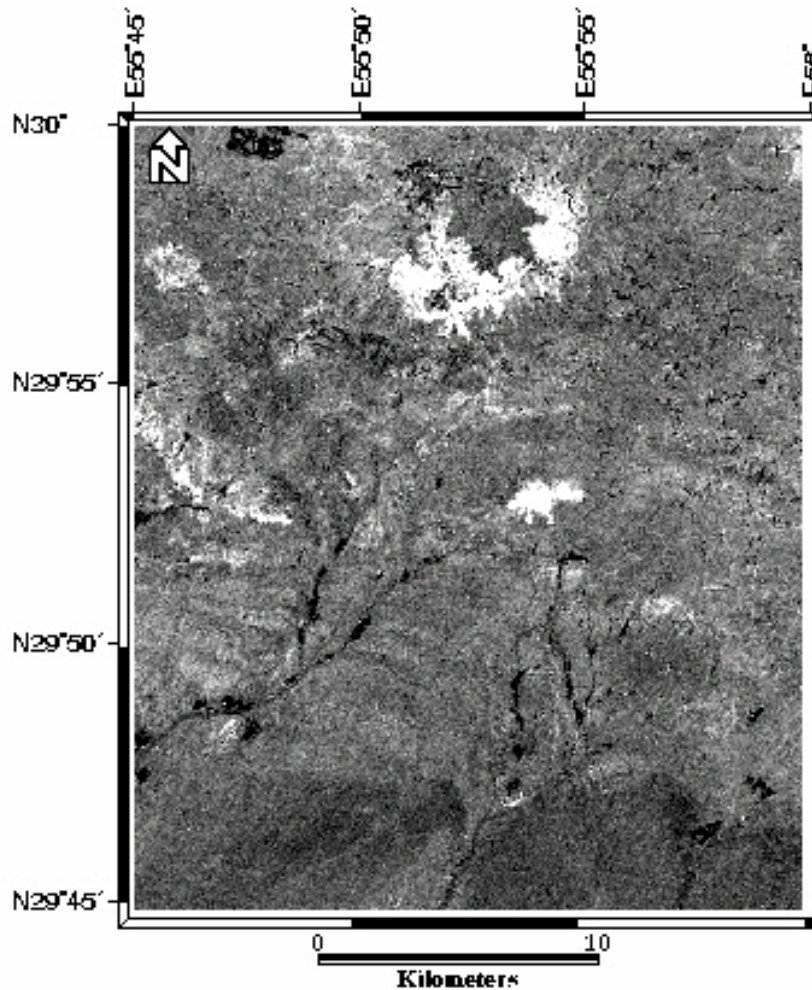


Figure 2: Iron oxide image which is prepared by using Crosta method. The altered areas are shown as bright pixels. Vegetation is depicted in dark pixels.

3. DATA ANALYSIS AND DISCUSSION

Principal component analysis determines the eigenvectors of a variance-covariance or a correlation matrix. The analysis consists of a linear transformation of m original variables to m new variables, where each new variable is a linear combination of the old. The process is performed in a fashion that requires that each new variable account for, successively, as much of the total variance as possible. The use of principal components in exploration has been to separate variable associations into a number of groups of variables that together account for the greater part of the observed variability in the original data (Davis, 1986). This type of analysis is useful when there are number of data layers which can be overlain one over another. With the advent of geographic information system, integrated analysis of spatially distributed data can be done easier. This type of analysis can either be done on satellite images or other geo-data sets.

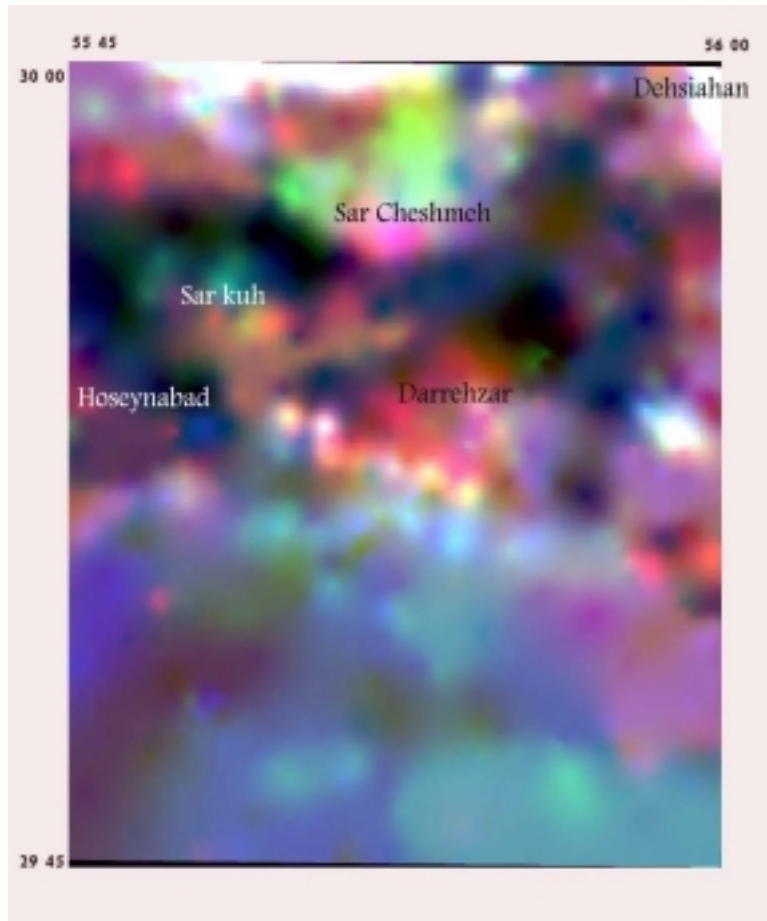


Figure 3: RGB image of K, Th and U counts in red, green and blue respectively. The altered areas are shown by bright pixels.

Analysis of remote sensing data

The principal component analysis is widely used for alteration mapping in metallogenic provinces (Kaufman, 1988; Crosta and Moore, 1989; Loughlin, 1991; Benett, et al, 1993 and Rutz-Armenta and Prol-Ledesma, 1998). Three techniques have been suggested for analyzing satellite images. These three techniques are the standard PCA on six bands of Landsat, selective PCA on two bands (e.g. band 7 and 5 for detection of hydrous minerals) and developed selective PCA or Crosta technique on four or six bands. The ETM+ data is analysed and we found that Crosta method on six bands is useful for enhancing the hydrothermally altered areas. Figure 2 shows the areas with iron oxide bearing minerals (Ranjbar et al., 2002).

Although Crosta method is very useful for hydroxyl mapping; nevertheless, there are some areas which are altered but are not enhanced by this technique. Such an area is located in the northern part of the Sar Cheshmeh mine. At the same time there are altered areas which have a good signature in satellite data but they do not have a good signature in the geophysical data (e.g. Hoseynabad deposit in Figure 3). For mapping such areas integration of satellite and geophysical data can be helpful.

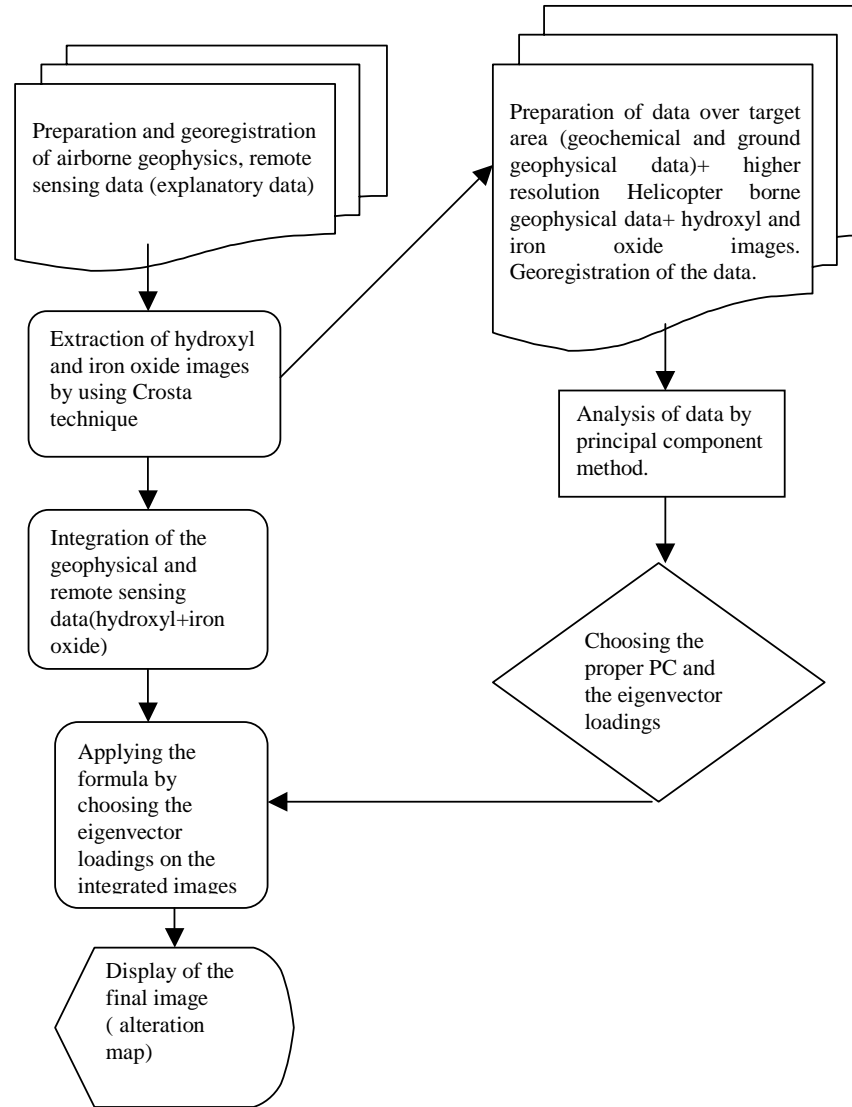


Figure 4: The flow chart that shows the steps for preparation of alteration image.

Data integration and analysis

As geophysical data have more ground penetration than the satellite images, both satellite and geophysical data were integrated, in order to map the altered areas. To do this a control area is chosen first. The data is subdivided into target and explanatory variables (Pan, 1993). The geophysical, geochemical and remote sensing data are georeferenced and given a common UTM coordinate system. The explanatory data includes airborne geophysical data (K, Th, U counts and total magnetic intensity) and remote sensing data (hydroxyl and iron oxide images which are generated by Crosta method). The explanatory data covers 1:50000 scale topographic sheet of Sar Cheshmeh with an area of 640 km². The geophysical data for the target area is k, Th, U counts and total magnetic intensity (Helicopter born). Other data for the target area include geochemical (Cu and Mo), ground geophysics (IP and resistivity) and alteration data (phyllitic and propylitic).

The steps taken for the integration and analysis of the data are shown in figure 4. The geophysical data for the target area was imported directly from the source file. The geochemical and alteration data were digitized and then made into raster format. In order to reduce scale difference, all variables were converted into 8-bit integer format. The variables were subjected to statistical analysis (Table 1). Data analysis is performed in two steps. (1) Integration and analysis of the target and explanatory variables in the control area, (2) transformation of explanatory variables by using the eigenvector loadings of the first step.

Table 1: Principal component analysis for the target and explanatory variables over Darrehzar porphyry copper deposit. Eigenvector loadings less than 0.2 are excluded.

	Principal components				
	1	2	3	4	5
Cu	0.33	-	-0.40	0.64	0.37
Mo	0.55	-	-	0.52	-
Resistivity	-0.56	0.31	0.30	-	0.60
I P	0.67	0.20	0.43	-	-
U counts	0.31	0.84	-	-	-
Th counts	0.37	0.79	-0.22	-	-
K counts	0.35	0.57	-0.39	-0.30	-
Total Mag¹	-0.46	0.47	0.57	0.20	-
Phyllic	0.75	-0.40	-	-0.30	0.41
Propylitic	-0.75	0.40	-	0.30	-0.41
Iron oxide	0.87	-	0.30	-	-0.20
Hydroxyl	0.85	-	0.20	-	-0.30
Percentage Of variance	36.3	19.7	9.1	8.6	8.1

¹total magnetics

The first PC highlights the areas with phyllic and argillic alteration. Higher negative loadings of resistivity, magnetic intensity and propylitic zone indicate that the propylitic zone is more resistive and have more magnetite content. Higher loadings of K counts , Th counts , Cu and Mo and hydroxyl, iron oxide are associated with the phyllic alteration zone. The explanatory variables(hydroxyl and iron oxide images, airborne geophysics) were integrated and transformed by using the eigenvector loadings of the first PC using following equation(Figure 5).

$$PC1=0.35(K_{counts})+0.37(Th_{count})+0.31(U_{counts})-0.46(Magnetic_{intensity})+0.87(iron\ oxide)+0.85(hydroxyl)$$

The image shown in figure 5 is highlighting the areas with intense alteration. There are altered areas which are not enhanced with Crosta method(e.g. north of Sar Cheshmeh mine). The reason

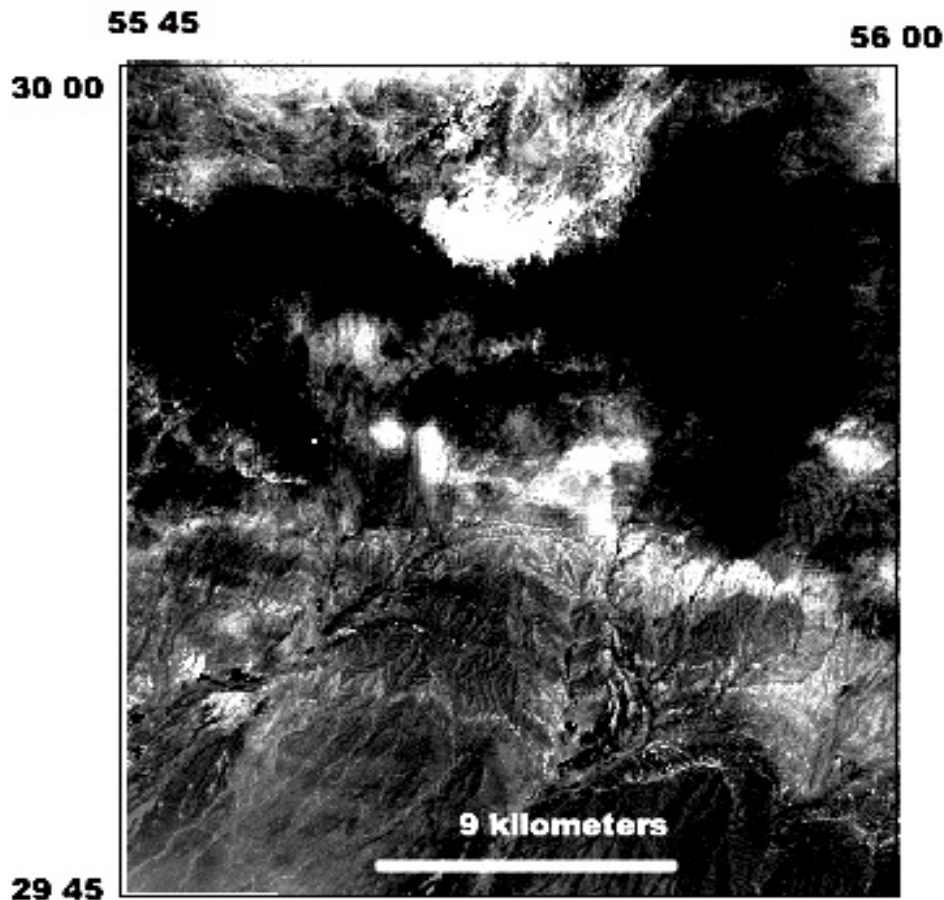


Figure 5: Combination of remote sensing and geophysical data. The altered areas are shown in bright pixels.

may be a thick soil and vegetation cover over this area. At the same time the boundaries of the altered areas are not clear in the airborne geophysical data (e.g. Darrehzar area). After applying the above method this area is also shown as an altered one.

The higher K and Th counts over the altered areas are due to the presence of abundant sericite, clay and K-feldspar minerals. The thin section study from the propylitic zone revealed that the observed higher total magnetic intensity over this zone is mainly due to the presence of abundant magnetite. Similar result has been obtained over the Sar Cheshmeh area, located just north of the Darrehzar area (Ranjbar et al., 2002).

4. SUMMARY AND CONCLUSIONS

Airborne magnetic/radiometric data sets have been integrated with ETM+ data and analyzed using directed principal component analysis (Figure 5). Darrehzar porphyry copper deposit is chosen as a control area for determining the correlation between airborne geophysical data and satellite images, and geochemical /alteration data. The data analysis is performed in two steps. (1) integration and analysis of the

target and explanatory variables in the control area, (2) transformation of explanatory variables by using the eigenvector loadings of explanatory variables from the first step.

This technique is found useful for delineation of hydrothermally altered zones which in turn provides some information about the mineralization type. The combination of satellite images with geophysical data can enhance the alteration zones with more confidence. This technique can reduce the enhancement of the false anomalies (e.g. salt encrustation). Unfortunately the authors do not have permission to publish the results of Helicopter borne geophysical data. As these data have better spatial resolution and collected at lower height, integration of remote sensing and Helicopter born geophysical data results in better alteration mapping.

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