INTEGRATION OF ASTER AND AIRBORNE GEOPHYSICAL DATA FOR EXPLORATION OF COPPER MINERALIZATION. A CASE STUDY OF SAR CHESHMEH AREA

Hojjatollah Ranjbar[**a], Hadi Shahriari[a] and Mehdi Honarmand[b]
[a] Department of Mining Engineering, Shahid Bahonar University of Kerman, *Jomhoory Eslami Blvd.,* Kerman, Iran
(h.ranjbar@mail.uk.ac.ir , shahriari_h@yahoo.com)
[b] Department of Geology, Faculty of Science, 22nd Baman Blvd., Shahid Bahonar University of Kerman, Kerman, Iran
(honarmand167@yahoo.com)

KEY WORDS: Geophysics, Integration, Exploration, Classification, Fuzzy Logic

ABSTRACT:

Sar Cheshmeh area is located in the Central Iranian Volcanic Belt. Mainly the Eocene volcanic rocks that are intruded by the Oligo-Miocene intrusives cover the area. Copper mineralization in the area is mainly of porphyry type and is associated with extensive hydrothermal alteration. The area has a semi-arid type of climate with abundant rock exposure that makes it suitable for application of remote sensing technique. We have observed that neither ASTER nor airborne geophysical data can delineate all hydrothermally altered areas individually. Bands 5, 7 and 9 of ASTER are integrated with airborne geophysical data, which are K, Th and U counts, and total magnetic intensity. Two well-known copper mineralizations namely Sar Cheshmeh and Darrehzar are chosen as training sets. The integrated data has been classified by using fuzzy method. Ground sampling proved that this method could help hydrothermal alteration mapping in such area with more accuracy.

1. INTRODUCTION

Many of the known porphyry copper deposits are situated in the Central Iranian volcanic Belt(figure 1). This belt has a great potential as far as Tertiary porphyry copper deposits are concerned. Large part of this belt has not been explored in detail for base metals mineralization.

Porphyry type deposits are associated with hydrothermal alterations such as phyllic, argillic, potassic and propylitic. Hydroxyl minerals are abundant in the phyllic, argillic and potassic zones. At the same time an oxide zone is developing over many of the porphyry bodies which are rich in iron oxide minerals. 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 Th mobilization from host rocks and can precipitate with iron in gossan (Dickson et al., 1996). Therefore, radiometry surveys may be used as a tool for exploration of such geological features.. Pitcher et al. (1994) and Ranjbar et al. (2001) have worked on a part of Helicopter Magnetic Eelectromagnetic Radiometric (HMER) data and concluded that the porphyry copper deposits in the Kerman region are showing a distinct magnetic low, relative to the host rocks, a potassium counts high and low resistivity.

Different workers have used ASTER data for geological mapping in recent years(Rowan and Mars, 2001 ; Liu and Mason, 2002, Yoshiki, N., 2002, Rowan et al., 2003). Theoretically, the SWIR bands of ASTER have more capability than the Landsat for recognition of areas with hydrothermal alteration.

Quantitative integration of diverse multi-source geo-information, including geological, geochemical, geophysical and remote sensing data has been attempted by different approaches such as regression analysis(Sinclair and Woodsworth, 1973; Chung and Agterberg, 1980), characteristic analysis (McCammon et al., 1983), canonical correlation analysis (Pan and Harris, 1992), principal components (Ranjbar et al, 2002), Baysian frameworks, weights of evidence (Bonham-Carter et al., 1988), Dempster-shafer belief and plausibility function (An et al., 1994; Tangestani and Moore, 2003), fuzzy sets (An et al., 1991; Chung and Fabbri, 1993; Majumder et al., 1998; Luo and Dimitrakopoulos, 2003) and neural networks (Singer and Kouada, 1996).

Remote sensing techniques and spatial data analysis through Geographic Information Systems (GIS) have been jointly applied in a mineral exploration context to identify porphyry rich potential areas in the central Iranian volcanic- sedimentary belt. Results confirm the usefulness of this integrated methodological approach as an effective tool to assess mineral potential in the studied region (Ranjbar and Roonwal, 1997; Asadi and Hale, 1999; Tangestani and Moore, 2001, 2003;

[*] Corresponding author

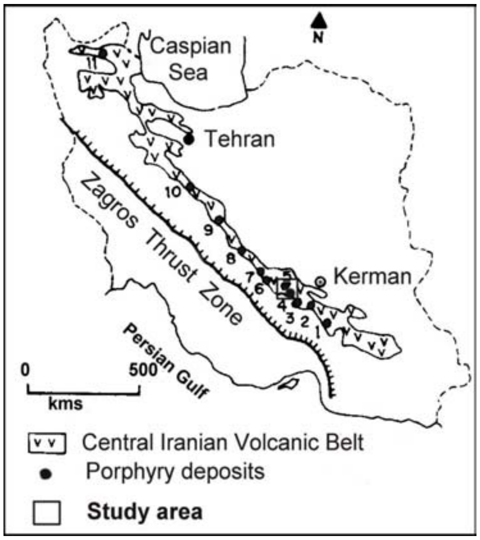

Figure 1: Sketch map showing the position of the Central Iranian Volcanic Belt and porphyry-type Cu deposits sub parallel to the Zagros Thrust Zone(Shahabpour, 1994) 1- Bahreasman, **2-** Takht, 3- Kuhe Panj, 4- Darrehzar, 5- Sar Cheshmeh, 6- Meiduk, 7- Gowde kolvary, 8- Darre Zereshg, 9- South of Ardestan, 10- Sharif Abad, 11- Songun (Shahbpour, 1994).

Ranjbar et al., 2002). The aim of this study is to propose a method for combination and analysis of the airborne geophysical data and ASTER data for exploration of porphyry copper deposits in this belt.

1.1 Fuzzy Set Theory for Mineral Exploration

Satellite images are classified by different methods. In this technique pixels are assigned in groups based on their spectral properties(Lillesand and Kiefer, 1994). The boundary of each group is quite sharp. To do this, several training sites are defined. Each training site is a region that contains a known material(e.g. basaltic rock). One of the main assumption in the traditional classification methods is that the training sites represent pure samples of the classes they represent. But this is rarely the case with the geological materials. But in the fuzzy classification it is assumed that the boundaries are transitional. Fuzzy sets are sets(or classes) without sharp boundaries; that is, the transition between membership and non-membership of a location in the set is gradual (Zadeh, 1965). A Fuzzy set is characterized by a fuzzy membership grade (also called a possibility) that ranges from 0.0 to 1.0, indicating a continuous increase from nonmembership to complete membership. For example, if a pixel is covered by 60% altered and 40% by unaltered rocks , it would be considered to have a fuzzy membership grade of 0.60 in the class of altered and a membership grade of 0.40 in the unaltered class. Wang (1990) has developed a method of classification of remotely sensed data by using the fuzzy logic. The same method is used here to classify remote sensing and geophysical data sets.

Geological information and data interpretations used in mineral exploration are inherently ambiguous. The quantitave precision or expressions like "relatively high" , "high", "fair" , "low", and "relatively low" or "fairly favorable" for the mineral occurance, as well as grey areas between these expressions, is difficult to define.

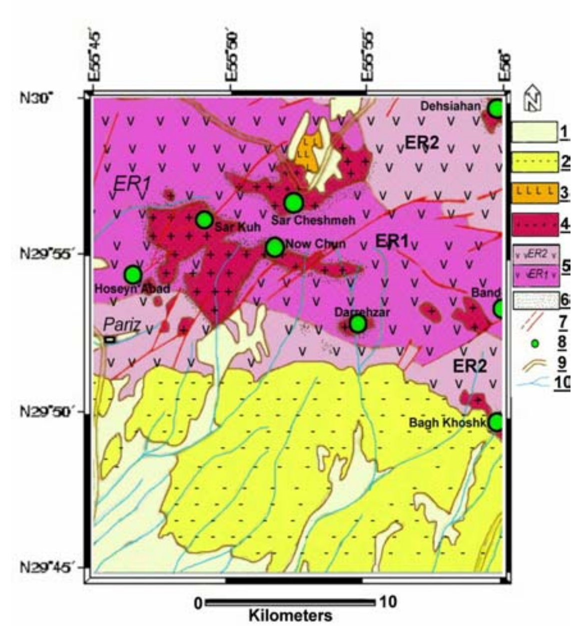

Figure 2: Geological map of Sar Cheshmeh area. 1- Recent alluvium(Quaternary), 2- Younger gravel fan(Quaternary) , 3- Calcareous terraces(Quaternary), 4- Neogene sediments, mostly arenites with pebbles and boulders of volcanic and intrusive rocks. Dacites and dacitic pyroclastics, 5- Oligocene-Miocene 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).

Fuzzy set theory provides a mathematical framework to represent the linguistic and data ambiguities frequently encountered in mineral exploration, geological information analysis and interpretation. The theory formally associates any statement with a quantifiable measure indicating the degree of possibility of the statement (Luo and Dimitrakopoulos, 2003).

The fuzzy set theory was first systematically formulated by Zadeh(1965). A fuzzy set of A is a set of ordered pairs:

$$A = \{(x, \mu_A(x) | x \in X\} \quad (1)$$

Where $\mu_A(x\ )_A$ is termed the membership function or membership grade of x in A (Zadeh, 1965). $\mu_A(x)$ maps X to membership space M. When M contains only the two points 0 and 1. The range of $\mu_A(x\ )$ is [0,1], where zero expresses non-membership and one expresses full membership.

1.2 Study Area and Data

The geophysical data (radiometry and magnetometry) used for this study is collected in 1977 by Prakla-Seismos GMBH on behalf of Atomic Energy Organization of Iran(AEOI). The aim of this survey was the exploration for uranium and thorium minerals. An alkali Magnetometer and a radiometer have been used on an airplane with flight line spacing chosen at 500 meters and nominal terrain clearance of 120 meters. The data was in the form of 1:50 000 scale geophysical contour map. The geophysical data were converted into digital form by using onscreen digitization of contour lines. Airborne gamma ray spectrometer data collected by the Atomic Energy Organization of Iran, gridded to a pixel resolution of 30 meters, is used to create digital images that show the spatial distributions of gamma ray spectrometer data i.e. equivalent Uranium (eU), equivalent Thorium (eTh), and Potassium (%K). Data interpretation is traditionally made visually from hardcopy of pseudo-coloured single-channel (figure 3).

In this study ASTER images (date of acquisition, Summer of 2001) have been analysed and integrated with airborne geophysical data for proposing a model for further exploration activities in the Central Iranian Volcanic Belt. ASTER bands 5,7 and 9 are used here. These bands show absorbtions and reflections over altered areas, Figures 4 and 5 show ASTER bands over an altered areas. The altered areas appear in bright pixels in band 7, while they appear in dark pixels in band 9.

Sar Cheshmeh area is situated within the southern part of the Central Iranian Volcanic-Sedimentary complex, southwest 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 (Dimitrijevic, 1973) .

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. 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 Lower Eocene volcanic rocks and the Quaternary alluvial deposits and gravel fans, respectively. Some well known copper deposits are situated in the volcanic sedimentary belt (Figure 2).

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 volcaniclastics, 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, giving 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. Phyllic alteration persists below the oxidation zone, as is evident from a limited number of samples collected from creeks. Potassic alteration is not seen at surface, possibly as a result of an intense phyllic overprint or surface related weathering.

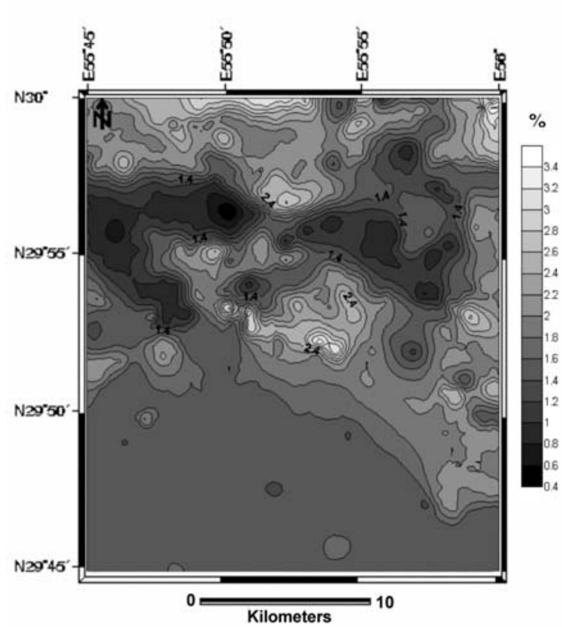

Figure 3: Map shows the potassium radiometry of the Sar Cheshmeh area

The porphyry copper mineralization at Sar Cheshmeh is associated with a granodioritic stock intruded into a folded and faulted, Early Tertiary volcanic–sedimentary series of andesite, tuffs, ignimbrites and agglomerates. A potassic zone is located in the center which has imprints of phyllic alteration. This alteration zone is surrounded by a weak biotite and phyllic zone. A propylitic zone, approximately 1 km thick, surrounds the whole complex and grades into unaltered andesite. The mineralization is occurred in the potassic, biotitized and phyllic zones (waterman and Hamilton, 1975) .

2. DATA ANALYSIS AND DISCUSSION

Field observations have shown that, many altered areas do not show geophysical anomalies but have a strong signature in the satellite data. At the same time there are altered areas which have good presence in the geophysical data but are not seen in the satellite data. For mapping such areas, integration of satellite and geophysical data can be helpful.

2.1 Supervised classification

The supervised fuzzy classification procedure was performed using FUZCLASS, one of the soft classifiers available in IDRISI for windows image processing software. Training data chosen for each informational class was possessing pure signature. The classification allows different levels of pixel membership(0.00 – 1.00) and this is shown by pixel intensity:

$$\mu = \cos 2\alpha \quad (2)$$

Where μ is the sigmoidal membership function, α is defined as

$$(x\text{-point a})/(\text{point b} - \text{point a}) \times \pi/2 \quad (3)$$

When x> point b, μ = 1(IDRISI, 1997).

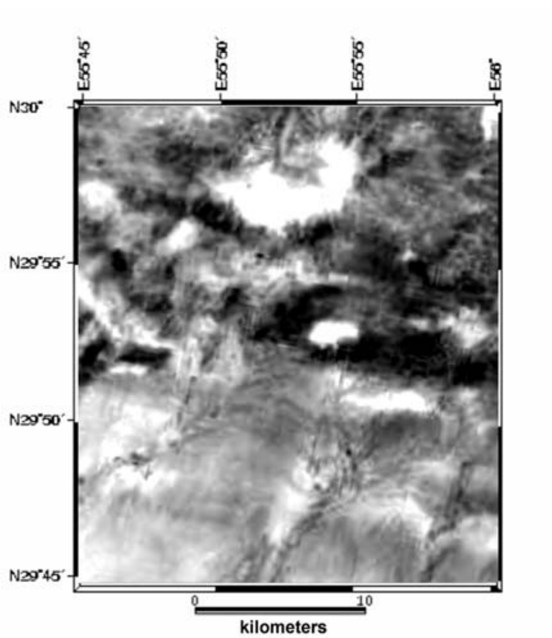

Figure 4: Band 7 of ASTER that shows altered areas in bright pixels.

After the data integration a vector map is generated that contains the signatures of the training areas. As the aim of this study was to delineate the altered and unaltered parts of the area, only two classes are chosen, namely 1)altered and 2) unaltered. The training areas for the unaltered class are chosen based on the field evidences. Darrehzar and Sar Cheshmeh copper deposits, and two other known altered areas were chosen as training areas for the altered class. The geophysical images are integrated with ASTER data and then analysed by using fuzzy classification . By this method the study area is classified into altered and unaltered parts(figure 6). In this image the areas with higher digital numbers have more membership grade that indicates higher alteration grade. At the same time the areas that have less alteration grade are appearing darker in this image. The altered areas are checked in the field. Rock samples have been collected from the area and analysed based on XRD and thin section studies. The collected samples have shown that the areas shown as altered parts in the volcanic areas are sericitized and argillized. There are small areas which are classified as altered in the sedimentary parts of the area. This is due to the fact that the rock fragments accumulated in these parts are derived from the intrusive bodies in the volcanic area.

3. SUMMARY AND CONCLUSION

Neither satellite nor airborne geophysical data are able to map all altered parts in the Sar Cheshmeh area individually. If both the data are integrated together, the altered areas can be mapped with more accuracy. The airborne geophysical data of Sar Cheshmeh area is converted into raster format, combined with ASTER data (bands 5, 7 and 9) and then classified, using Fuzzy classification. Several control points are chosen in the area. The control points are the known mineral deposits within the area. The classified image is divided into altered and unaltered classes. However there is no exact boundary between the altered and unaltered classes. In the resulted image the brighter portions are more altered areas and the darker pixels are unaltered ones. As the satellite and airborne geophysical data are complementary to each other, the combination of these data is very useful for alteration mapping in the Central Iranian volcanic Belt.

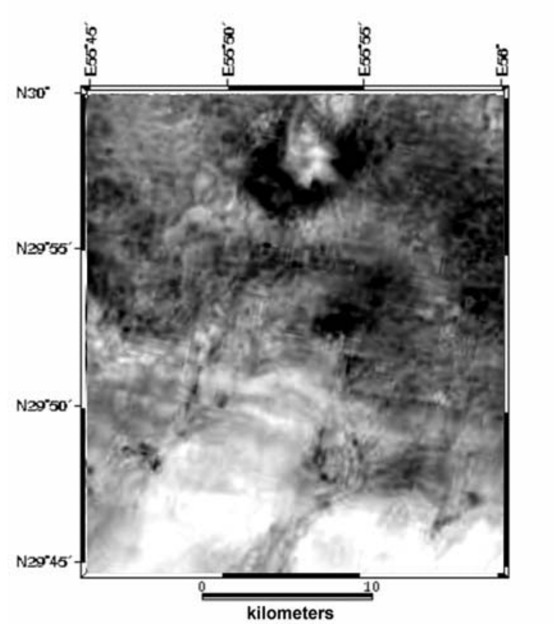

Figure 5: Band 9 of ASTER that shows altered areas in dark pixels.

REFERENCES

An, P., Moon, W. M., and Rencz, A., 1991. Integration of geological, geophysical, and remote sensing data using fuzzy set theory. *Canadian Journal of Exploration Geophysics*, 27, pp. 1-11.

An, P., Moon, W. M., and Bonham-Carter, G. F.,1994., Uncertainty management in integration of exploration data using the belief function. *Nonrenewable Resources*, 3, pp. 60-71.

Asadi, H. H., and Hale, M., 1999, Integrated analysis of aeromagnetic, Landsat TM and mineral occurrence data for epithermal gold exploration in northwest Iran, 13th International Conference on Applied Geologic Remote Sensing, 1-3 March 1999, Vancouver (Canada), p. 8.

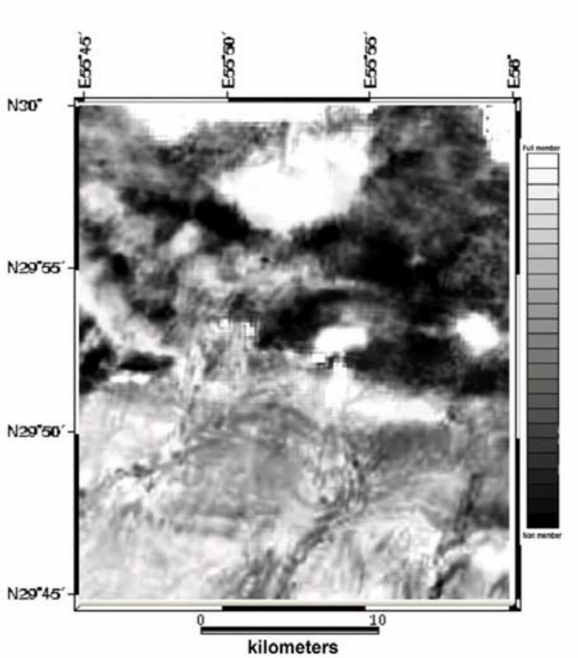

Figure 6: Classified image of the area. The areas with higher alteration are shown with brighter pixels in the volcanic areas.

Bonham-Carter, G. F., Agterberg, F. P., and Wright, D. F., 1988. Integration of geological data sets for gold exploration in Nova Scotia. Photogrammetric Engineering and Remote Sensing, 54: 1585-1592.

Chung, C. F., and Agterberg, F. P., 1980. Regression models for estimating mineral resources from geological map data. Mathematical Geology, 12: 473-488.

Chung, C. F., and Fabbri, A.G., 1993. The representation of geoscience information for data integration. Nonrenewable Resources, 2: 122-139.

Dickson, B. L., Fraser, S. L., Kinsey-Henderson, A., 1996, Interpreting aerial gamma-ray surveys utilizing geomorphological and weathering models, Journal of Geochemical Exploration, 57, 75-88.

Dimitrijevic, M. D., 1973. Geology of Kerman region. Report YU/52, Iran, Geological Survey of Iran, Iran.

Dimitrijevic, M. D., Dimitrijevic, M. N., Vulovic, D., 1971. Geological map of Iran, 1:100 000 series, sheet 7149-Pariz.

Geological Survey of Iran (GSI), 1973. Exploration for ore deposit in Kerman Region. Geological Survey of Iran Report Yu/53, 220p.

IDRISI, 1997. Help system (online) and users manuals for IDRISI for windows 2 Image Processing Software, Clark Labs, Worcester, MA.

Lillesand, T. M. and Kieffer, R. W., 2000, *Remote sensing and image interpretation*, 4th edition, John Wiley and Sons, New York, pp. 585-608.

Liu, Y. G. and Mason, P. J., 2002. Hydrothermal alteration mapping in epithermal gold deposits of Abanicos Trend, Argentina, using ASTER data, www. Ese.ic.ac.uk (accessed April 2004).

Luo, X., and Dimitrakopoulos, R., 2003, Data-driven fuzzy analysis in quantitative mineral resource assessment, Computers and Geosciences, 29, pp. 3-13.

Majumder, T., Bandopadhyay, S. and Mukherjee, R., 1998. Fuzzy logic and its application in mineral exploration. Proceedings of the International Symposium APCOM, Dec. 7-9, Western Australia, pp. 141-143.

McCammon, R. B., Botbol, J., M., Sinding-Larsen, R. and Bowen, R. W., 1983. Characteristic analysis, 1981-final program and a possible discovery. *Mathematical Geology*, 15, pp. 59-83.

Pan. G. C. and Harris, D. P., 1992. Estimating a favourability equation for the integration of geodata and selection of mineral exploration targets. *Mathematical Geology*, 24, pp. 177-202.

Pitcher, D. H., Steele, J. P. and Watson, R. K., 1994, The application of airborne geophysical techniques to the delineation of hydrothermal systems in base and precious metal deposit. Northwest Mining Association Conference, Spokane, December, 1994, pp.1-12.

Ranjbar, H. and Roonwal, G. S., 1997, Integrated mineral exploration for porphyry copper mineralization in Pariz area, Kerman, Iran: a case study of the Darrehzar porphyry copper deposit. 4th Biennial SGA meeting, 11-13 August 1997(Finland-SGA), pp. 677-879

Ranjbar, H., Hassanzadeh, H., Torabi, M., Ilaghi, O., 2001, Integration and analysis of airborne geophysical data of the Darrehzar area, Kerman Province, Iran, using principal component analysis, *Journal of Applied Geophysics*, 48, pp. 33-41.

Ranjbar, H., Honarmand, M., Moezifar, Z., Shakoori, M., 2002, Integration and analysis of remote sensing, airborne geophysics and geochemical data of Sar Cheshmeh area, using directed principal component analysis. 9th International Remote Sensing Conference(Agia Pelagia, Greece: SPIE), 23-26 September 2002, pp. 429-437.

Rowan, L. C., and Mars, J. C., 2001. Initial lithologic mapping results using Advanced Space borne Thermal Emission and Reflection Radiometer(ASTER) data, EOS, Transactions American Geophysical Union, Spring Supplement, Abstract U31A-05.

Rowan, L. C., Hook, S. J., Abrams, M. J., Mars, J. C., 2003. Mapping hydrothermally altered rocks at Cuprite. Nevada, using the advanced spaceborne thermal emission and reflection radiometer (Aster), a new satellite-imaging system. *Economic Geology*, 98(5), pp. 1018-1027.

Shahabpour, J., 1994, Post- mineralization breccia dike from the Sar Cheshmeh porphyry copper deposit, Kerman, Iran, *Exploration and Mining Geology*, 3, pp.39-43.

Sinclair, A. J. and Woodsworth, G. J., 1970. Multiple regression as a method of estimating exploration potential in an area near Terrace, B. C. *Economic Geology*, 65, pp. 998-1003.

Singer, D., A., and Kouada, R., 1996. Application of a feedforward neural network in the search for Kuroko deposits in the Hokuroku District, Japan. *Mathematical Geology*, 28, pp. 1017-1023.

Tangestani, M. H., and Moore, F., 2001. Porphyry copper potential mapping using the weights-of-evidence model in a GIS, northern Share-e-Babak, Iran, *Australian Journal of Earth Sciences*, 48, pp. 695-701.

Tangestani, M., H., and Moore, F., 2003. The use of Dempster-Shafer model and GIS in integration of geoscientific data for porphyry copper potential mapping, north of Shahr-e-Babak, Iran, *International Journal of Applied Earth Observation and Geoinformation*, 4, pp. 65-74.

Wang, F. , 1990, Fuzzy supervised classification of remote sensing images, *IEEE Transactions on Geoscience and Remote Sensing*, 28, pp.194-201.

Waterman, G. C., and Hamilton, R. L., 1975. The Sar Cheshmeh porphyry copper deposit, *Economic Geology,* 70, pp. 568-576.

Yoshiki, N., 2002. Rock type mapping with indices defined for multispectral thermal infrared ASTER data: Case studies, Proceedings of Remote Sensing for Environmental Monitoring, GIS Applications, and Geology II, Sep 23-26 2002, Agia Pelagia, Greece, SPIE. v 4886, 2002, pp 123-132.

Zadeh, L. A., 1965, Fuzzy sets, *IEEE transactions on Information and Control*, 8, pp. 338-353.

ACKNOWLEGEMENTS

ASTER data is provided by ERSDAC of JAPAN. National Copper Industries Co.(NICICo) of Iran has provided necessary facilities for field checking and sampling. Geophysical data is provided by Atomic Energy Organization of Iran. Office of Mine and industries of Kerman Province has supported this work.