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FUZZY ANALYTICAL HIERARCHY PROCESS AND GIS FOR PREDICTIVE CU -AU PORPHYRY IN MOKHTARN 1:100000 SHEET, SOUTHERN KHORASAN, EAST OF IRAN

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ABSTRACT

Mineral exploration generally starts on small scale (small areas) and, then progresses to large scale (small area). There are many methods for achieving this goal. To achieve this goal one of these methods is Fuzzy analytical hierarchy process (Fuzzy AHP) that is the most popular multi-criteria decision-making techniques. In the Mokhtaran sheet for predictive Cu -Au porphyry this method was used. Combining this way with geographic information systems GIS is effective approach for predictive Mineral prospectively mapping (MPM) for Cu -Au porphyry. For preparing MPM, the criteria were geological data (host rocks, heat rocks, alteration), tectonic (Fault), geochemical data (stream geochemical).

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These criteria were weighted based on Fuzzy AHP, Then the produced weight is multiplied in the evidence layer. The final prospectively map was prepared with fuzzy γ=0.9 operator. For evolution this method. The known mineral deposits placed on the final map. The location of these deposits confirmed this method.

Keywords: Fuzzy analytical; Predictive cu -au porphyry.

1. INTRODUCTION

Mineral exploration is difficult process for discovering new mineral deposits in a region. Mineral prospectively mapping (MPM) is used as a tool to delineate target areas that most likely Contain mineral deposits of a particular type (Bonham-Carter, 1994; Carranza, 2008; Yousefi and Carranza, 2015c). To achieve this goal, multiple data sets, or layers (e.g., geological, geophysical, geochemical, and remote sensing data) must be prepared, analyzed and integrated. For integration of layers are performed using geographic information system (GIS) applications.

Various methods have been developed for (MPM). In general, these methods can be classified into two main groups: Knowledge-and data-driven. In data-driven techniques, the known mineral deposits in a region of interest are used as “training points” to recognize and establish spatial relationships of deposits with particular exploration Evidential features (Feltrin, 2008); therefore, these techniques are proper in well-explored areas. Example of data driven is weights-of-evidence. When exploration data have limitation and are not considered the knowledge-driven methods are used. And this method is based on expert opinions. The most common knowledge data methods for preparing MPM are Boolean logic, index overlay, fuzzy analytical hierarchy process and fuzzy logic (Bonham-Carter, 1994; Moon, 1998; Carranza and Hale 2001; Cheng and Agterberg, 1999; Porwal et al., 2004; Carranza et al., 2008).

In this article, it will be reported the results of mapping for Copper and Gold porphyry potential in the 1:100000 Mokhtaran sheet by combining GIS with AHP fuzzy.

2. THE LOCATION OF STUDY AREA

The study area, with a surface of 2500 km2 covering Mokhtaran district on 1:100,000 scale quadrangle maps, is located in the western part of the Southern Khorasan Province, East of Iran. And its location in geographic system base on WGS1984 is 59º 00' 00"- 59º 30' 00" longitude and 32º 00' 00"-32º 30' 00" latitude. Figure 1 shows the situation of this sheet in the map of Iran.

Fig.1. The location of Mokhtaran sheet in southern

3. METHODS

Preparing Exploration Layers:

Preparing mineral prospectively mapping (MPM) will be based on the data integrating that have been shown in figure 2. For achieving this goal these layers should be prepared.

Geochemical layer:

Geochemical of stream sediment samples

To identify a promising area in the Mokhtaran 1:100000 sheet, a drainage geochemical survey was carried out and 787 geochemical samples were taken. Figure2 shows the stream sediment samples location in the study area.

The minus 80-mesh fraction of the stream sediments was analyzed for 18 elements including Au, W, Mo, Zn, Pb, Ag, Cr, Ni, Cu, As, Sb, Co, Ba , Sr ,Hg , Mn, In this investigation was used the concentration–area method for separating anomaly from the background. Among the geochemical data related to this area Cu, As, Sb, Pb, Zn, Mo and Au which are the main elements in the exploration of Cu and Au porphyry deposits have been evaluated and statistical populations were specified for these elements by using the C-A fractal method. In this layer for each element based on it's statically population (back. ground, possible anomaly, Probable anomalies, certain anomalies) were given score. These scores have been shown in table 1 and figure 3.

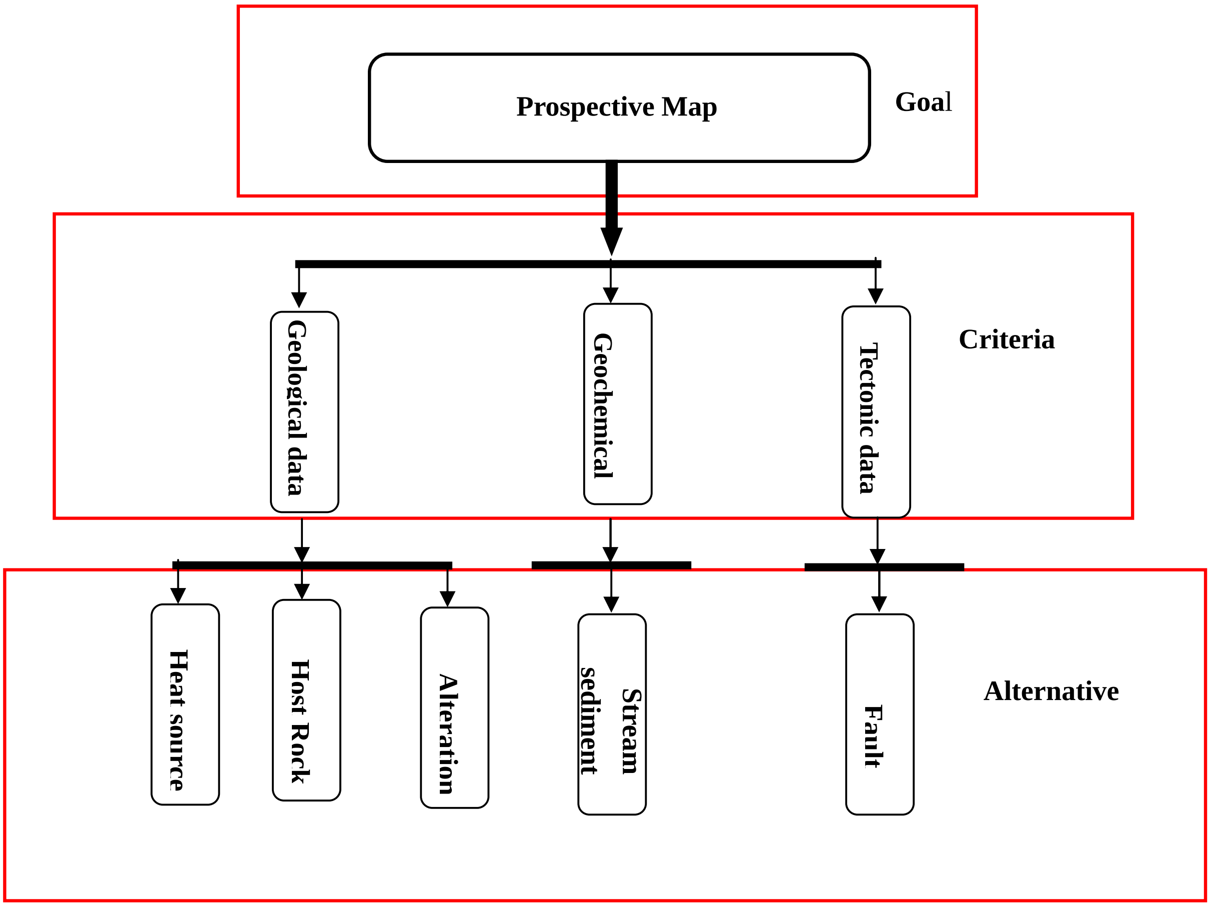

Fig.2. Hierarchy used for prospectively mapping. This hierarchy includes goal, criteria, and alternative. The goal is predictive Cu -Au porphyry in Mokhtarn 1:100000 Sheet

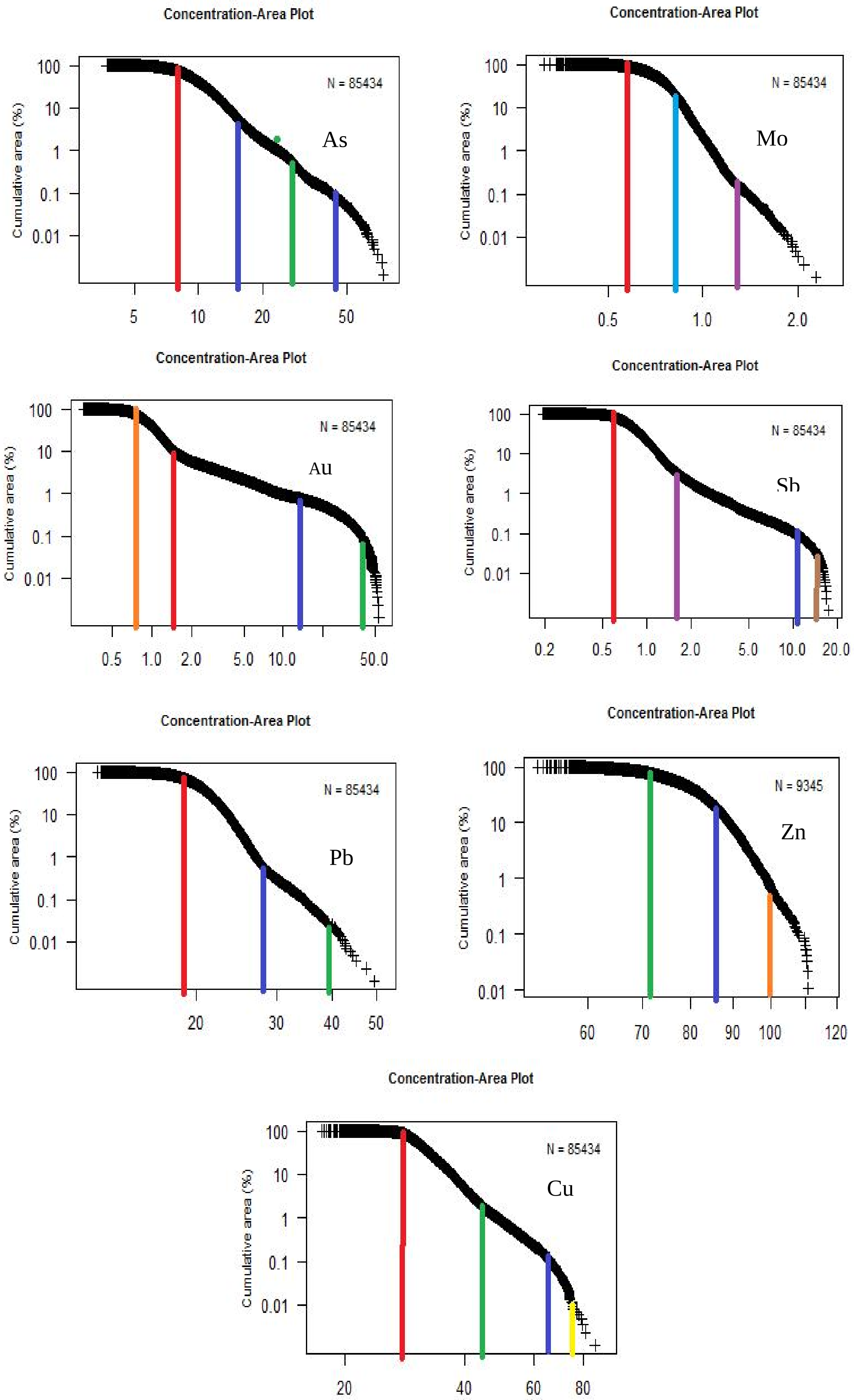

Fig.3. Log–Log plots (C–A method) for Cu, As, Au, Pb, Sb and Zn. The vertical axis represents Cumulative cell areas A, with elemental concentration values in horizontal axis. axis is the actual value (ρ)

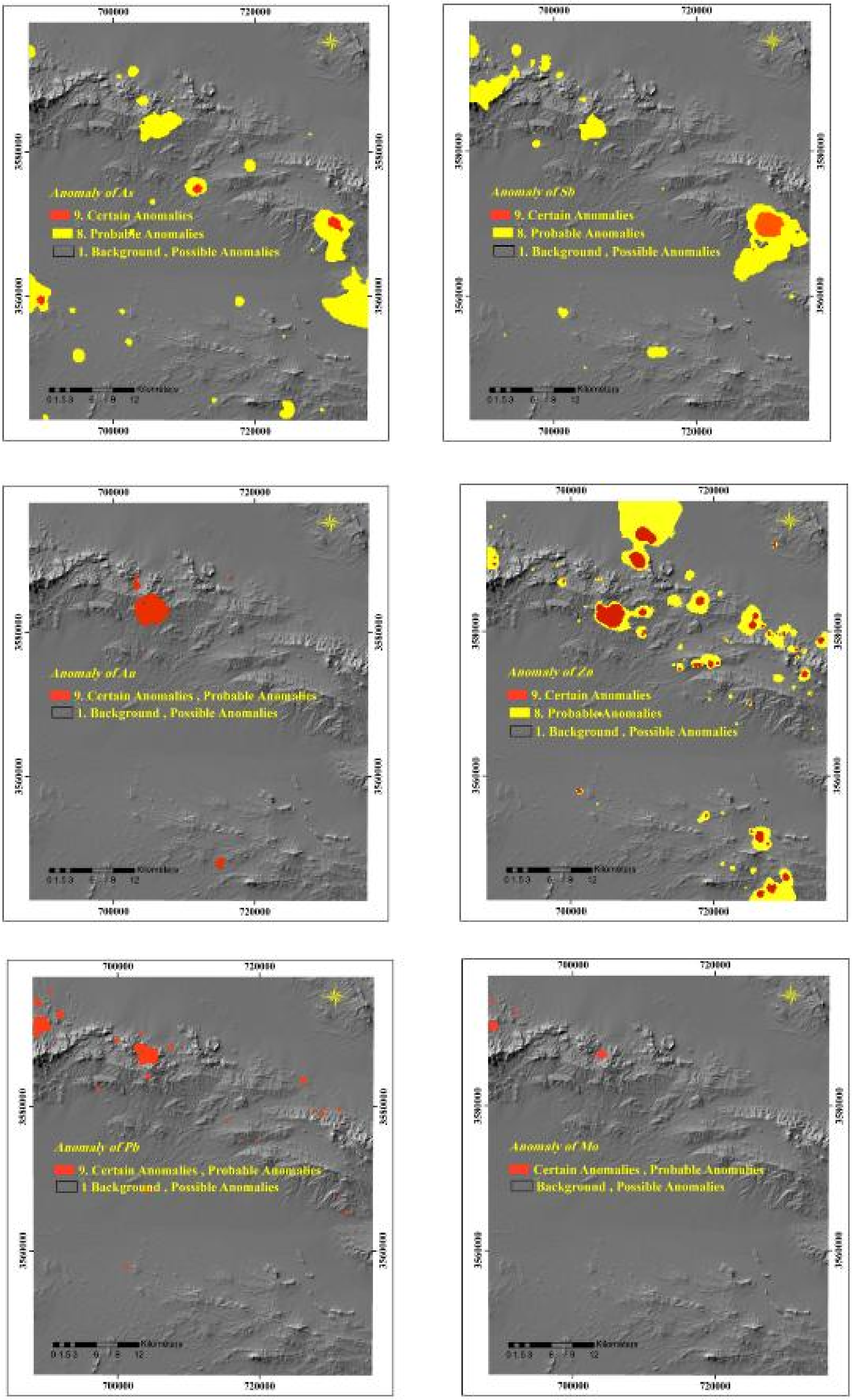

Fig.4. Geochemical anomaly maps of Sb, As, Zn, Pb, Cu and Au based on C–A method

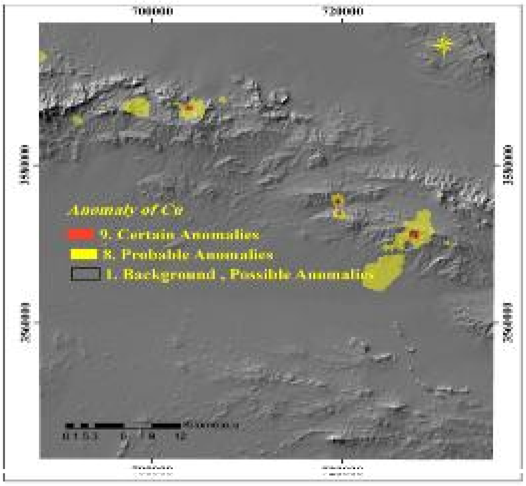

Fig.4. Geochemical anomaly maps of Sb, As, Zn, Pb, Cu and Au based on C–A method

In the cu- Au porphyry type the Geochemical data have zoning. In this type the Cu, Mo, and Au are in core and the Pb and Zn are in rime and Sb and As are distal element. (David et al., 1996).After preparing the anomaly map of fore each element .it should be given weighting to each element base on its importance in genes of this type mineralization. Table 1.

4. GEOLOGICAL LAYER

geology of the study area

In Structural Divisions of Iran, the eastern part of the study area is in western side of Flysch or colored mélange of Zabol–Baluch Zone this zone is located between Lut Block to the west and Helmand (in Afghanistan) to the east. And the western part of this sheet is in the eastern side of the Lut Block. (Aghnabati 2004)

The Flysch Zone is highly deformed and tectonized and consists of thick deep-sea sediments like argillaceous and silicic shales, radiolarite, and pelagic limestone and volcanic rocks such as basalt, spilitic basalt, diabase, andesite, dacite, rhyolite, and subordinate serpentinized ultramafic rocks. The basement is likely composed of an oceanic crust. Most rock units in this zone fall into three main

groups:

– Flyschoid sediments

– Volcanic, volcano sedimentary, and intrusive rocks

– Ophiolitic series

Lut Block extends for about 900 km in a north–south direction. It is bounded in the north by Dorooneh fault and in the south by Jazmourian Depression. In the east, it is separated from Flysch Zone by the Nehbandan fault, whereas the western boundary with Central Iran is Nayband fault and Shotori Mountains. (Aghnabati 2004).

The most part of Mokhtaran sheet is in the lut block. The lutblock is characterized by extensive exposure of volcanic and sub volcanic rocks. The Lut Block is one of the several micro continental blocks interpreted to have drifted from the northern margin of Gondwanaland during the Permian opening of the Neo-Tethys, which was subsequently accreted to the Eurasian continent in the Late Triassic during the closure of the Paleo-Tethys (Golonka 2004). volcanic and subvolcanic rocks over half of the Lut Block with a thickness of 2000 m, and have been formed due to subduction and collision of the Arabian and Asia plates (Berberian et al.,1999; Camp and Griffis 1982; Tirrul et al., 1983). Various types of mineralization are related to tertiary subduction under the Lut Block that led to extensive magmatic activity in this area. this ore deposits are Qaleh Zari IOCG Deposit (Karimpour et al. 2005; Richards et al. 2012), Maherabad porphyry-type Cu–Au (Malekzadeh Shafaroudiet al., 2014) Sheikhabad high-sulfidation and Hanich low sulfidation (Karimpour et al. 2007), Cu porphyry type of Dehsalm (Arjmandzadeh 2011), Kooh-Shah (Abdi et al., 2010), Au epithermal type of Khunik (Samiee, et al, 2011, Karimpour, et al, 2007, Malekzadeh, et al, 2010) and Hired intrusive related gold deposit (Karimpour et al. 2007). From mentioned mineralization Kooh-Shah, Maherabad ,Khunik are located in western part of this sheet .

According to the 1:100,000 geological map the lithology in this sheet classified to three groups:

1) Acidic rocks such as Aplitic Dykes, Granite, which has dispersed, especially in the Eastern part of the study area.

2) Eocene-Paleocene volcanic and sub-volcanic rocks in small stocks and dykes form.

3) Cretaceous ultra-basic, Listvenite and flysh rocks located in Eastern, south and northeast of the study area are determine.

Figures 5a and 5b show the litohlogy that are important in the genesis of porphyry type Cu – Au. And the score of this litohology have been shown in table1.

alteration layer

Remote sensing technology plays a vital role in the initial stages of ore deposits exploration, especially in arid and semi-arid regions. Recognizing hydrothermally altered rocks through remote sensing instruments have been widely and successfully used for the exploration of epithermal gold and porphyry copper deposits. Because of Landset 8 has 5 VNIR bands contain important information regarding absorption features related to transition metals (e.g., Fe2+, Fe 3+) within Fe-oxide minerals. (Hunt, G. R., Salisbury, J. W. 1976). Landset 8 images are used for Fe-oxide minerals and Aster images are used for mapping hydrothermal alteration minerals such as Pyrophyllite, Kaolinite, Illite, Muscovite, Sericite, and carbonate. We used Spectral Angle Mapper (SAM) method for processing Aster and Landset 8 images. Spectral Angle Mapper (SAM) is a physically based spectral classification that uses a n-D angle to match the pixels to reference spectra. (Kruse et al., 1993and shayestehfar et al., 2005).

. Argillic, Phyllic and Propylitic alterations were determined by aid of SWIR bands in aster imagery but iron oxide composites such as Jarosite and hematite were appeared by Landsat 8 imagery. In this study, mineral spectrums of kaolinite for argillic alteration, chlorite and epidote for Propylitic alteration and finally, muscovite and quartz for Philic alteration are used. The final alteration map has been shown in the figure 5c.

The result of scoring this layer has been shown in the table 1.

Tectonic layer:

Fault

Although porphyry deposits are associated with arc volcanism, they are not the typical products in that environment. It is believed that tectonic change acts as a trigger for porphyry formation (Cooke et al. 2005). The density map of fault was prepared. Figure 5d and the e result of scoring this layer has been shown in the table 1.

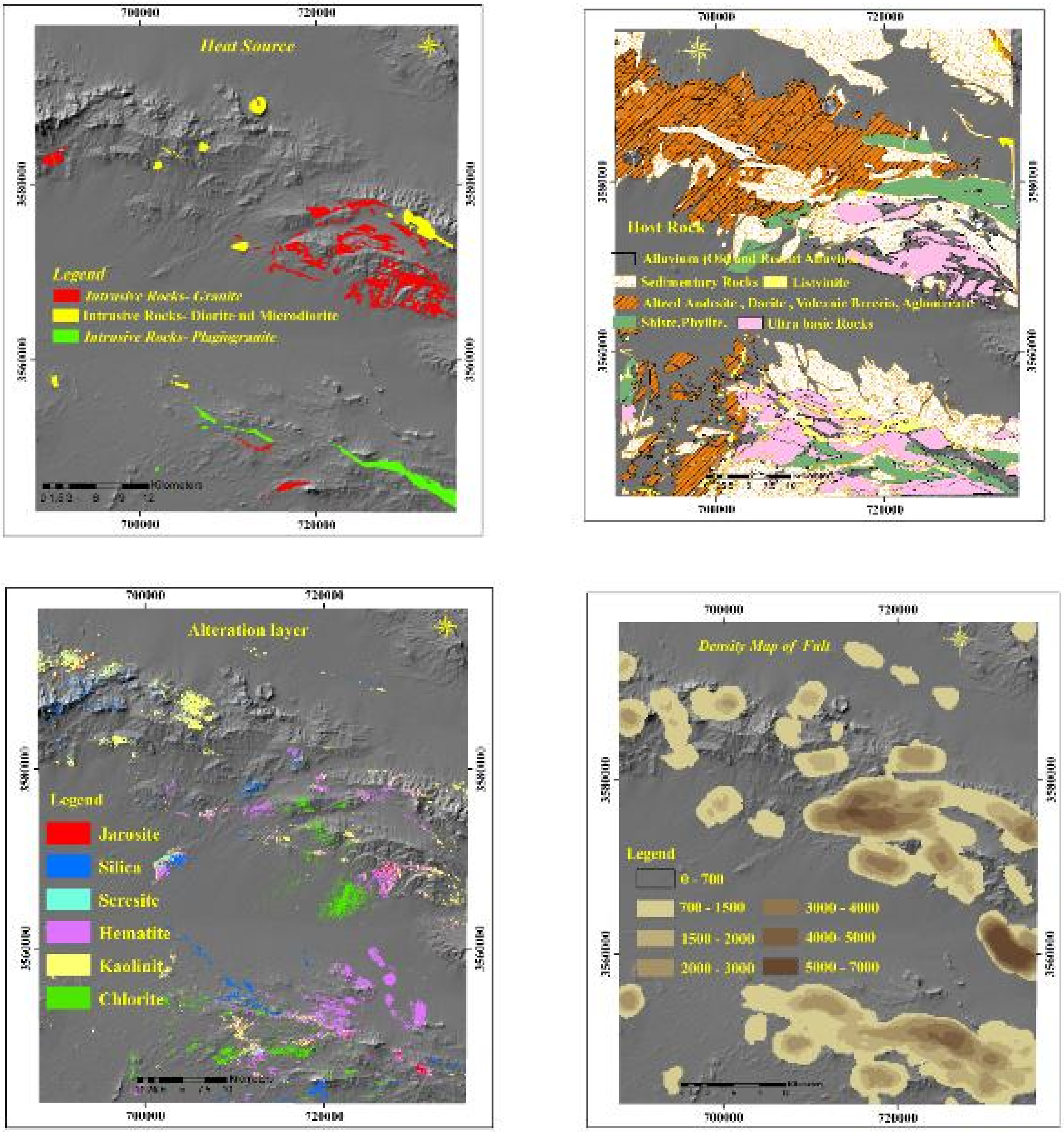

Fig.5. How (a) the location of heat source, (b) the location of host source, (c) alteration layer and (d) density map of fault

Table 1. The Summary of evidence maps, classes and their corresponding weights for Cu-Au porphyry prospectively mapping

Data	Evidenti	Class	Cl
Geological data	Host Rocks	Altered andesit,	9
		Sediment Rocks	5
		Alluvium (Old and Recent	1
		Shiste and Phylite	2
		Ultrabasic Rocks	2
		Listvinit rocks	3
	Heat Rocks	Intrusive Rocks- Geranit	9
		Intrusive Rocks- Diorite	8
		Intrusive Rocks-Plagiogranite	6
	Alteration	Jarosite zone	9
		Kaolinit+-Iron	8
		Kaolinit +silisified zone	6
		Phylic zone	8
		Propylitic zone	9
Geochemical data	Stream sediment	Stream Sediment Anomaly ,	9
		Stream Sediment Anomaly ,	9
		Stream Sediment Anomaly ,	7
		Stream Sediment Anomaly	8
		Stream Sediment Anomaly	8
		Stream Sediment Anomaly ,	8
		Stream Sediment Anomaly ,	8
Tectonic data	Fault	Fault density <700	1
		Fault density =700-1500	6
		Fault density =1500-2000	7
		Fault density =2000	8
		Fault density = 3000	9
		Fault density >3000	1

5. AHP (ANALYTICAL HIERARCHY PROCESS) METHOD

Assignment of meaningful weights to individual evidential maps is a highly subjective exercise and it may involve a trial-and-error procedure, even in the case when 'real expert' knowledge is available particularly from different experts. The difficulty lies in deciding objectively and simultaneously how much more important or how much less important is one evidential map compared to every other evidential map. This difficulty may be overcome by making pair wise comparisons among the evidential maps in the context of a decision making process known as the analytical hierarchy process (AHP). The concept of the AHP was developed by Saaty (1977, 1980) for pair wise analysis of priorities in multi-criteria decision making. It aims to derive a hierarchy of criteria based on their pair wise relative importance with respect to the objective of a decision making process (e.g., evaluation of the mineral prospectively proposition).the method of deriving criteria weights via the AHP involves pair wise comparisons of criteria according to their relative importance with respect to a proposition. The method adopts a 9-point continuous pair wise rating scale for judging whether Criterion is less important or more important than Criterion Y (Fig. 6)(Carranza EJM ,2008)

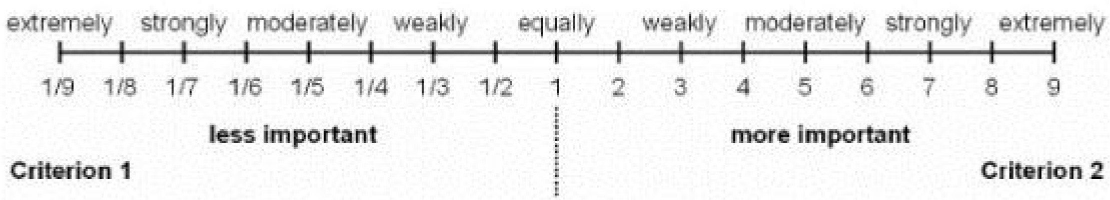

Fig.6. Continuous rating scale for pairwise comparison of relative importance of one criterionversus another criterion with respect to a proposition (adapted from Saaty, 1977)

AHP efficiency criteria are measured by Consistency Relationship (CR) which is estimated according to **Eq. (1)**: CR =CI/RI**.**

CR represents a measure of the error made by the decision maker or an indicator of the degree of consistency or inconsistency (Chen et al. 2010b). It indicates that the matrix judgments were generated randomly (Saaty 1977; Park et al. 2011). The CR depends on the Consistency Index (CI) and Random Index (RI).(table2).

Eq. (2): CI = ƛmax-N/N-1.

Eq2: represents the CI where $ƛ_{max}$ is the largest or principal eigen value of the matrix, and N is the order of the matrix. RI is the average of the resulting consistency index depending on the order of the matrix given by Saaty (1977) shown in Table 2. If the CR < 0.10 then the pairwise comparison matrix is acceptable and the weight values are valid. In the table 3 the CR is 0.03 and 0.06 for criteria and alternatives respectively.

Table 2. Randomi index (RI) (Saaty1980)

Number	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Table 3. Consistency ratio (CR) for pair wise comparison matrix

Criteria			Alternatives		
Geological	Geochemica	Tectonic	Host Rock	Heat	Alteration
DM= 0.03			DM= 0.06		

6. AHP FUZZY

Fuzzy analytic hierarchy process is one of the most popular multi-criteria decision-making techniques that have been introduced by Saaty. This method can be useful when the act of decision making is faced with several options and decision criteria. Although experts use their own mental competencies and capabilities for comparisons, but it should be noted that the traditional analytic hierarchy process may not fully reflect the style of human thinking. In other words, using of fuzzy sets has more compatibility with lingual and sometimes vague human explanations and so it is better to through the use of fuzzy sets (using of fuzzy numbers) we do long term prediction and decision making in the real world. The first study of fuzzy AHP is proposed by Van Laarhoven and Pedrycz (1983), which compared fuzzy ratios described by triangular fuzzy numbers. Buckley (1985) initiated trapezoidal fuzzy numbers to express the decision maker's evaluation on alternatives with respect to each criterion Chang (1996) introduced a new approach for handling fuzzy AHP, with the use of triangular fuzzy numbers for pair-wise comparison scale of fuzzy AHP, and the use of the extent analysis method for the synthetic extent values of the pair-wise comparisons. Fuzzy AHP method is a popular approach for multiple criteria decision-making.

The fuzzy AHP was originally introduced by Chang (1996). Let X = {x1, x2, x3,....., xn} an object set, and G = {g1, g2, g3,....., gn} be a goal set. Then, each object is taken and extent analysis

for each goal is performed, respectively. Therefore, M extent analysis values for each object can be obtained, with the following signs:

$$M_{gi}^{1}, M_{gi}^{2}, M_{gi}^{3}, \dots, M_{gi}^{m}, i = 1,2,\dots,n$$

Where M_{gi}^{m} (j = 1, 2,..., m) are all triangular fuzzy numbers.

Based o n the table4: The Matrix of fuzzy paired comparisons for criteria's was determined and table5 and 6).

Table 4. TFN Values (Tolga et. al., 2005)

Statement	FN
Absolute	(7/2, 4, 9/2)
Very strong	(5/2, 3, 7/2)
Fairly strong	(3/2, 2, 5/2)
Weak	(2/3, 1, 3/2)
Equal	(1, 1, 1)

Table 5. Matrix of fuzzy paired comparisons for geological criteria

Criteria	Heat source	Alteration	Host rock
Heat	(1,1,1)	(1,1.5,2)	(1.5,2,2.5)
Alteration	(o.5,0.667,1)	(1,1,1)	(1,1.5,2)
Host rock	(0.4,0.5,0.66)	(0.5,0.667,1)	(1,1,1)

Table 6. Matrix of fuzzy paired comparisons for goal

	Geological data	Geochemical data	Tectonic
Geological	(1,1,1)	(0.5,1.,1.5)	(2.5, 3, 3.5)
Geochemical	(,0.667,1,2)	(1,1,1)	(0.5,1.1.5)
Tectonic	(0.286,0.333,0.4)	(0.667,1,2)	(1,1,1)

After the matrix of paired comparisons the relative and final weights must be calculated that researchers have suggested various methods for that. One of them is Extent Analysis Method by Chang, which we use in this research.

In the fallowing equation the i_s is a triangular number that is calculated as fallowed.

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1}$$

S_i for any criteria (table 5) has been calculated : The result is as follows

S_1 (Geological Criteria) = (0.288, 0.484, 0.739)

S_2 (Geochemical Criteria) = (0.156, 0.290, 0.554)

S_3 (Tectonic Criteria) = (0.140, 0.226, 0.419)

S_i for any alternative (table 6) has been calculated : The result of as follows

S_1 (Heat Source Alternative) = (0.288, 0.484, 0.696)

S2 (Alteration Alternative) = (0.205, 0.322, 0.506)

S_3 (Tectonic Alternative) = (0.156, 0.220, 0.338)

If M1= (L1, M1, U1), M2= (L2, M2, U2), the degree of possibility of m1>m2 is defined as

$$V(M_2 \geq M_1) = \sup_{y \geq x} [\min(\mu_{M_2}(y))]$$

Where d is the ordinate of the highest intersection point Between µM1 و µM2

(see figure6) When M_1= (L_1, M_1, U_1), M_2= (L_2, M2, U2), the ordinate of D is given by eq.

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d)$$

$$= \begin{cases} 1 & if\, m_2 \geq m_1 \\ 0 & if\, l_1 \geq u_2 \\ l_1 - u_2 / (m_2 - u_2) - (m_1 - l_1) & \end{cases}$$

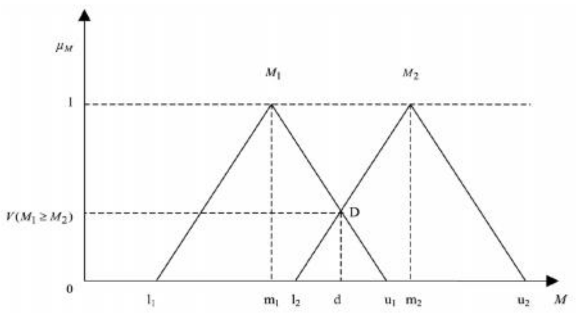

Fig.6'. D is the ordinate of the highest intersection point between µM1, µM2

The degree possibility for a convex fuzzy number to be greater than k convex fuzzy number s M_1 (i=1, 2, k) can be defined by

$$V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1), (M \geq M_2), \ldots, (M \geq M_k)]$$
$$= \min V(M \geq M_i), \; i = 1, 2, \ldots, k$$

The results of V value for alternatives in the table 5 include:

V (s1>S2)=1 (vs1>s3)=1, V(s2>=S2)=0.6 (vs2>s3)=1,V (s3>S1)=0.17 , V(s3>s2)=0.56

The results of V value for table 6 include:

V(s1>=S2)=1 (vs1>s3)=1, V(s2>=S2)=0.58 (vs2>s3)=1,V(s3>S1)=0.34 , V(s3>s2)=0.80

Then the Wight vector is given by, k ≠ i , k = 1, 2,... , n d(Ai) = min V (Si ≥ Sk),

$$W'(x_i) = Min\{V(S_i \geq S_k)\}, \quad ,k = 1,2,\ldots,n. \quad k \neq i$$

$$W'(x_i) = [W'(c_1), W'(c_2), \ldots, W'(c_n)]^T \qquad W_i = \frac{w'_1}{\sum w'_i}$$

The result of the weight for and evident has been shown in the table7:

Table 7. the final weight for any evident

Criterion	Weight	Alternative	Weight
Geological data	0.522	Host Rocks	0.097
		Heat Rocks	0.558
		Alteration	0.345
Geochemical data	0.302	Stream sediment	-
Tectonic data	0.176	Fault	

7. INTEGRATION OF EVIDENTIAL LAYERS

The MPM were generated by integrating 3 evident layers. The weights of each evidence layer calculated by fuzzy AHP method. Then the produced weight is multiplied in the evidence layer .One of the key procedures in the implementation of the fuzzy AHP modeling is the selection of fuzzy operators. Knox-Robinson (2000) pointed out that fuzzy γ operator is useful and realistic, which focuses on balancing the "decreasive" and "increasive" effects of fuzzy algebraic product and fuzzy algebraic sum operators therefore the final prospective map was generated by integrating of weighted map by fuzzy Gamma operator.Figure 7.

8. DISCUSSION AND CONCLUSION

Exploration strategies for non-renewable resources have been changing rapidly along with the accelerating innovations in computer hardware and information processing technology. In This research was used fuzzy AHP method for exploration of Cu- Au porphyry. For achieving this goal any evidence (geological, geochemical data and tectonic). Was used. The weight of any evidenc (geological, geochemical data and tectonic) was based on the type of Cu- Au porphyry. The final prospectively map was prepared with fuzzy γ=0.9 operator. The final map shows the prospective area for Cu and Au porphyry type. The figure 8and and9 show the rate of favorability in the different parts of Mokhtaran sheet. This diagram (figure8) is base on Fuzzy

AHP prospectively and the percent of the study area. This diagram show 4 zone. The zone 1 has very low favorability and the value of fuzzy AHP prospectively is 0-0.1. Zone 2 has low favorability and AHP prospectively is 0.1 -0.2. Zone 3 is moderate favorability and Fuzzy AHP is 0.2-0.4. Zone 4 is the high favorability and fuzzy AHP is more than 0.4. (Fig. 9). Table 8 show the area of Fuzzy AHP value on the Mokhtaran sheet.The high favorability includes 4.3 % of total volume of map. The high favorability area is in the western, eastern and northern part of the study area. Previous studies of the region have introduced a porphyry and epithermal system in this part of the study area and related ore deposits are Au Khonic, Au-Cu Maherabad and Cu Shadan. In the southern part of map, there are ore deposits such as Chahzaghoo and Hiread and their mineralization is Au (Samiee, etal, 2011, Karimpour, etal, 2007, Malekzadeh, et al, 2010, Shahabi, et. al, 2006). These mentioned ore deposits can be confirmed on this investigation.

Table 8. Area and percent of FUZZYAHP

area (km2)	Fuzzy AHP Value	percent
2136.73	0.00	72.8
320.52	0.1-0.2	10.92
195.52	0.2-0.3	6.66
26.62	0.3-0.4	0.91
70.90	0.4-0.5	2.42
35.18	0.5-0.6	1.20
11.34	0.6-0.7	0.39
8.24	0.7-0.8	0.28
0.11	0.8-0.9	0.003

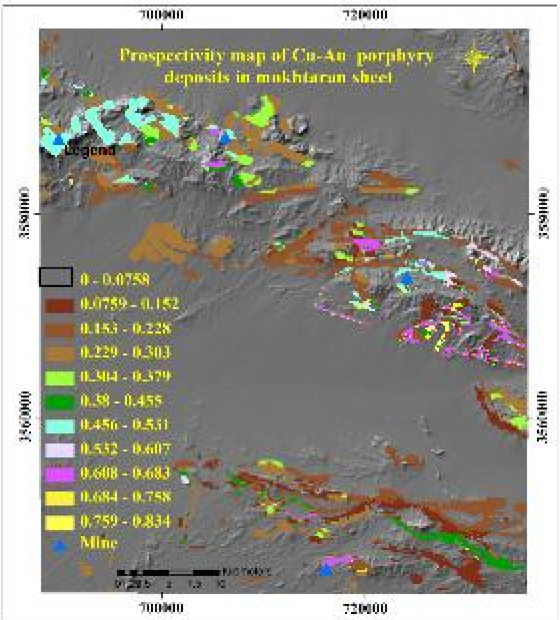

Fig.7. Prospectively map of Cu-Au porphyry deposits in Mokhtaran area generated using fuzzy AHP method

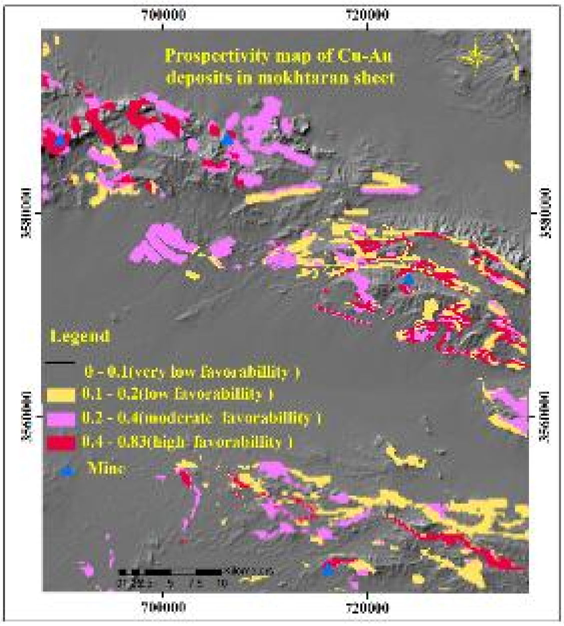

Fig.8. This figure shows the location of low, moderate and high prospectively on Mokhtaran sheet

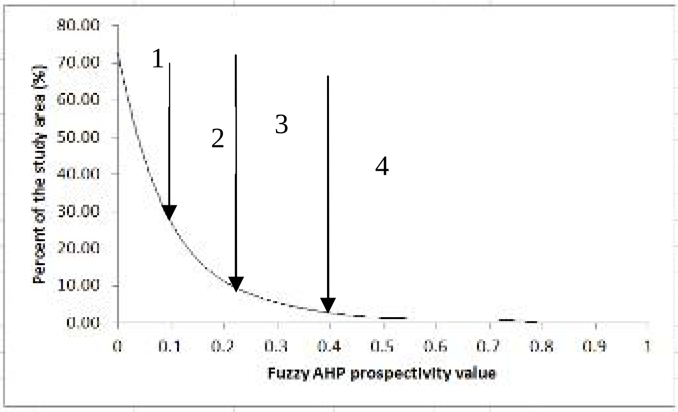

Fig.9. Diagram of Fuzzy AHP prospectively this diagram shows 4 areas, 1: very low favorability, 2: low favorability, 3: Moderate favorability, 4: High favorability

9. ACKNOWLEDGMENTS

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