

Modelling of mineral potentials of gold and base metals using GIS in Mahneshan area, Iran

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Abstract

The paper describes a mineral potential mapping of gold and other base metals in Mahneshan area, Iran, using geographical information system (GIS), in which, the method of weights of evidence is used to combine spatial data obtained from different sources to make prediction for mineral potential. This is a quantitative tool for mineral resource mapping that can be used to delineate and predict favorable areas for further exploration by using the characteristics of known and similar mineral deposits. In accord with the descriptive model for gold and other base metal deposits, the spatial distribution of 20 known mineral occurrences was used. In addition, digital evidential maps were used in this study. The maps include maps of lithological units, faults and first derivative of total aeromagnetic data, remotely-sensing data of alteration and also geochemical evidential maps produced on the basis of the results of chemical analyses of samples taken from the stream sediments in the area, and analysed for Cu, Pb, Zn, Sb, As, Ag, Au, Ba and Hg elements. The binary maps were produced and then combined with the model of weights of evidence using 20 known mineral occurrences to obtain a final map of the favorable areas for further exploration of gold and other base metals in the study area. The final map is a predictive GIS model of the mineral deposits in the area. An interesting matter about the final predictive GIS model is that the faults are mainly located in favorable areas which possesses the most probability of mineralisation. Therefore, the faults in these areas have priority for further exploration of gold and others base metals.

Keywords: *Geographical information system (GIS), weights of evidence, mineral potential modelling, binary, mineral occurrences, geology, fault, alteration, stream sediments, aeromagnetic data.*

Introduction

The study area with a surface of 2472 km² is located in the 1:100000 scale geological quadrangle map of Mahneshan. This area is located in Zanzan Province in northwest of Iran. The aim of this study was to develop a preliminary model to predict the locations of undiscovered gold and base metals deposits based on previous works using the weights of evidence analysis in GIS.

Geological background and mineralisation

In quadrangle map of Mahneshan (Fig 1), the outcrop of different kinds of plutonic, volcanic, sedimentary and metamorphic rocks is seen. The lithological units in this area have the ages of the Precambrian to Recent. The geological formations mostly comprise volcanic and sedimentary rocks, that extended in all the area. Precambrian metamorphic and intrusive rocks have mainly outcrops in the west, east, central and southeast of the study area (Lotfi & Kiani, 2001). Granite and gneiss bodies occur in contact of limestone and marble unit (pc¹²) in the west of the study area. There are silica veins which consist of galena and sphalerite in the known mineral occurrences of Pc¹² unit. In the southeast of the study area, k₁, k₂ and k₂^m units have been incurred the contact metamorphism as a result of the heat and hydrothermal fluids of intrusive bodies (G₂) and thus, hornfels and skarn sections are formed (Sadeghi & Fanoodi, 2000). In this area, magnetite, andradite, hydrogrossular, hedenbergite and diopside are accompanied by chalcopyrite and malachite (Lotfi & Fanoodi, 2000). The 1:100000 geological quadrangle map of Mahneshan is a part of the 1:250000 geological map of Takab area. Anguran is the largest lead and zinc mine in Takab area. Zarshuran and Agh-Darreh are two important gold deposits in the area. There are also a number of less significant As, Sb, Cu, Pb, Zn and Au ore indications. One of the most important mine in Mahneshan area is Pashtook lead, zinc and copper abandoned mine, which occurs in the marble parts of carbonate hosted rock. Another important mine in this area is antimony mine, in which stibnite veins occur in the fractured and faulted zone in the altered granite hosted rocks. Other mines in this area are the magnetite, barite, copper, borate, coal, feldspar, kaolinite and gypsum mines. There are also several Cu, Pb, Zn, Sb and Au ore indications in Mahneshan area (Lotfi & Fanoodi, 2000). In this study, spatial distribution of the known mineral occurrences was used for predicting the favorable areas for further exploration.

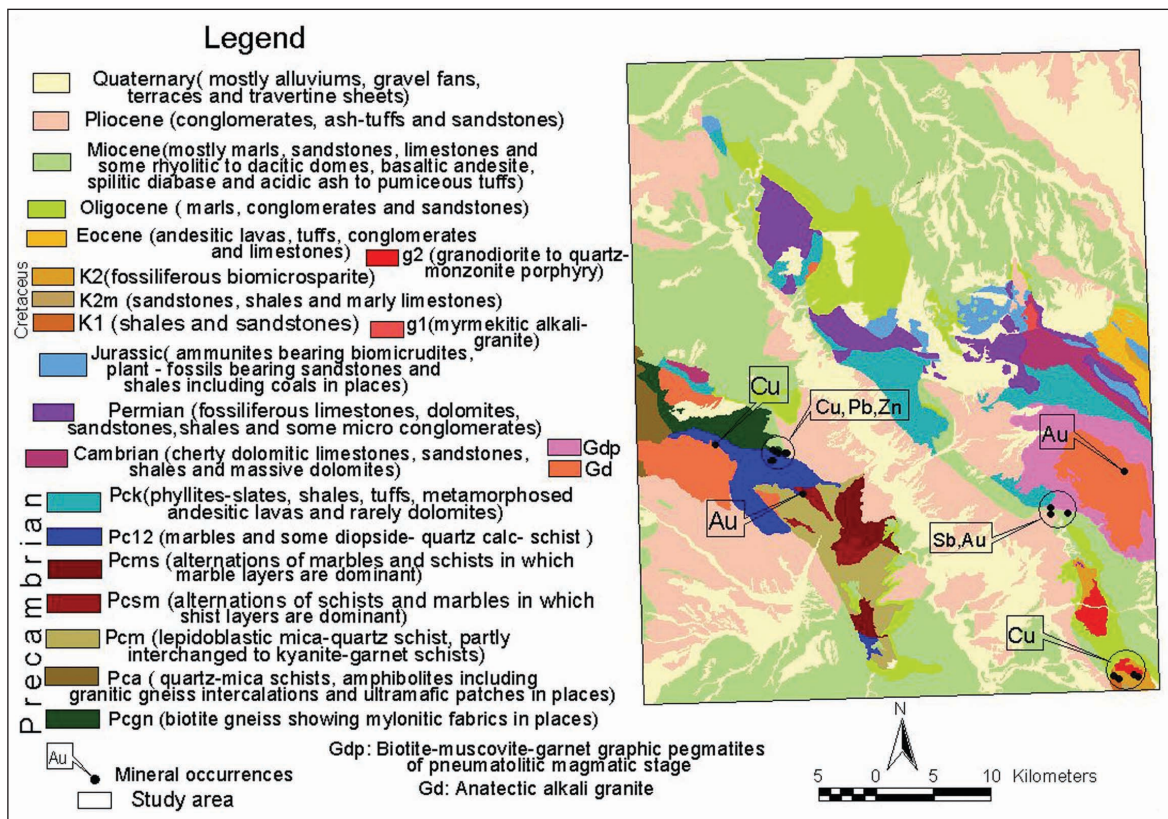


Figure 1. Geological map of the study area

Data sets and data preparation

A digital data base in Mahneshan area was established. The data sets consisted of: 1) 1:100000 scale geological map of Mahneshan (Fig 1) in digital format completed by Geological Survey of Iran (GSI), 2) distribution map of 20 mineral occurrences of Cu, Pb, Zn, Sb, and Au elements (Fig 1) digitised from 1:100000 geological map of Mahneshan and also from distribution map of ore indications obtained from the economic geology studies in the area by GSI, 3) binary map of alteration zones (iron oxide, hydroxyl and argillic zones) interpreted from the selected landsat TM bands by GSI, In which a value of 1 is attributed to the inside alteration pattern and a value of 0 to the outside alteration pattern (Fig 2), 4) first derivative map of total aeromagnetic intensity data interpreted by GSI, and 5) anomaly maps of geochemical exploration based on the results of chemical analyses of samples taken from the stream sediments in the area and analysed for Cu, Pb, Zn, Ag, Ba, Sb, As, and Hg elements. The chemical analysis results of the samples for Au were not used, because of the analysis errors of higher than 10 percent. The first class anomaly maps of the elements were digitised, then these maps are combined. The combined map is a binary map consisted of 2 classes in which inside anomaly pattern has 1 value and outside anomaly pattern has 0 value (Fig 3).

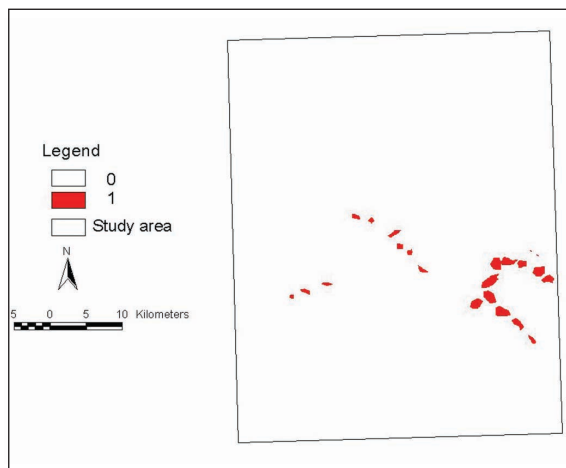


Figure 2. Binary map of alteration zones

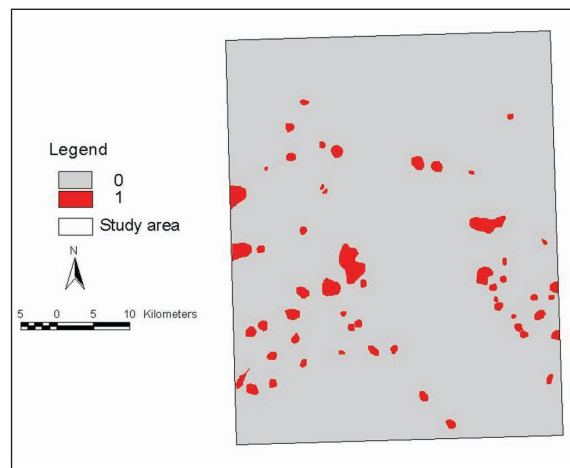


Figure 3. Binary map of geochemical anomalies

Weights of evidence analysis

The process used in the weights of evidence modelling is essentially a quantitative version of the inspection method of overlaying several different map themes to identify areas where mineralisation may be present. In the inspection method, the larger the number and magnitude of appropriate overlapping anomalies in data maps such as geochemistry, geology or others, the greater, the qualitative indication that mineralisation may be present. In the weights of evidence modelling, the importance of theme layers in delineating areas with potential for deposits is determined mathematically by how it compares with the spatial distribution of the known mineral occurrences. When several themes are combined, the areas with the greatest coincidence of weights produce the greatest probability of occurrence of undiscovered mineralisation. The weights of evidence analysis process is consist of digitally comparing the spatial distribution of the known mineral occurrences and evidence themes. The testing produces weights, contrasts and other statistical values (standard deviation of w^+ and w^- , studentized value of c and etc) calculated for each of comparisons. The weights (positive weight w^+ and negative weight w^-) express the degree of spatial association between the known mineral occurrences and the evidence theme. The contrast value is merely the difference between the positive and the negative weight values. The contrast value is the basis for accepting (or rejecting) the evidence themes as predictive themes (Bonham-Carter, 1994; Bonham-Carter, 1995; Bonham-Carter et al., 1998; Boleneus et al., 2001). In this study five binary predictive maps are used as the input maps and the end product is an output map showing the probability of occurrence and associated uncertainty of the probability estimates.

Three maps representing favorable host lithology, first derivative of total aeromagnetic map and structural features are created and used for the weights of evidence analysis. Statistical values calculated to select the optimum classes that have the best spatial correlation with the known mineral occurrences, then 3 binary maps are created. Two maps representing favorable geochemical features and alteration zones prepared as binary maps by the methods explained in section 3. At last the five binary maps are combined to create predictive GIS model.

Analysis of host lithology

The weights of evidence analysis were used to determine the spatial association between the known mineral occurrences and the geological units. The five units of K_1 , K_2 , P_{cgn}, P_{c₁₂} and P_{csm} were selected within the predictive pattern, based on calculated weights and contrast values equal to 2.0 or greater (Table 1). When contrast value is greater than 2, the association is considered extremely predictive (Bonham-Carter, 1998). Based on Table 1, a binary map of geological units was prepared (Fig 4), in which a value of 1 was attributed to inside predictive pattern and a value of 0 to outside predictive pattern.

Analysis of favorable faults

Faults which have spatial association with known mineralisation were digitised from the 1:100000 geological map of Mahneshan area. In addition, some other lineaments were obtained from the interpretation of landsat TM data of the area. The lineaments digitised from the geological map were combined with those obtained from the landsat TM image. The resulting structural domain was rasterised, buffered at distances of 100 m wide bands extending in all directions from each fault to 1000 m and crossed with the raster mineral occurrence point map to estimate the weights of evidence of the domain (Table 2). The optimum buffer, that resulted the maximum value of c was defined at 100 m. Based on the result of weights of evidence analysis, binary map of faults, which is a predictive pattern with a 100 m radius surrounding all faults, was prepared (Fig 5). In this map also a value of 1 was attributed to inside predictive pattern and a value of 0 to outside predictive pattern (Yousefi, 2002).

Table 1. Weights of evidence analysis of host lithology

Class	Area(sq.km)	Points	W ⁺	W ⁻	C	S(w ⁺)	S(w ⁻)	S(c)	Stud(c)
K_1	1.1900	1	6.4719	-0.0512	6.5231	2.5026	0.2303	2.5132	2.5955
K_2	10.5200	3	3.8922	-0.1595	4.0516	0.6829	0.2434	0.7249	5.5889
P _{cgn}	25.1700	4	3.1448	-0.2145	3.3593	0.5452	0.2508	0.6001	5.5977
P _{c₁₂}	37.3200	4	2.6913	-0.2095	2.9008	0.5292	0.2508	0.5856	4.9535
P _{csm}	9.1700	1	2.7107	-0.0480	2.7586	1.0594	0.2303	1.0842	2.5444

Table 2. Weights of evidence analysis of favorable faults (Yousefi, 2002)

Class	Area(sq.km)	Points	W ⁺	W ⁻	C	S(w ⁺)	S(w ⁻)	S(c)	Stud(c)
100	352.4200	9	1.1697	-0.4474	1.6170	0.3377	0.3023	0.4532	3.5679
700	90.5200	3	1.4439	-0.1265	1.5704	0.5872	0.2434	0.6357	2.4704
900	87.3500	2	1.0578	-0.0700	1.1278	0.7153	0.2366	0.7535	1.4969
200	165.5100	3	0.8193	-0.0941	0.9134	0.5827	0.2434	0.6315	1.4465
800	95.8900	1	0.2587	-0.0119	0.2726	1.0053	0.2303	1.0313	0.2624
500	146.9000	1	-0.1715	0.0099	-0.1814	1.0034	0.2304	1.0295	-0.1762
>1000	1063.1300	1	-2.1566	0.5145	-2.6711	1.0005	0.2310	1.0268	-2.6015

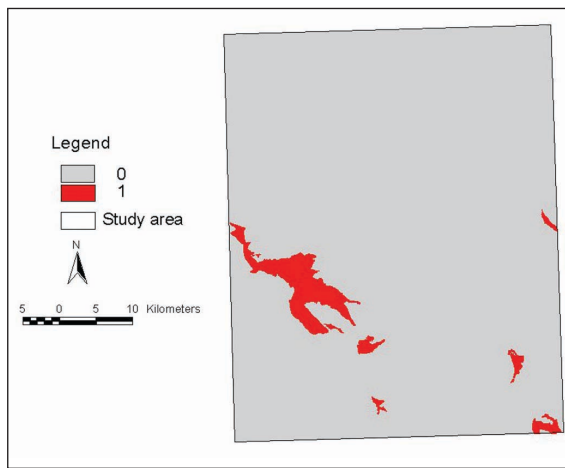


Figure 4. Binary map of geological units

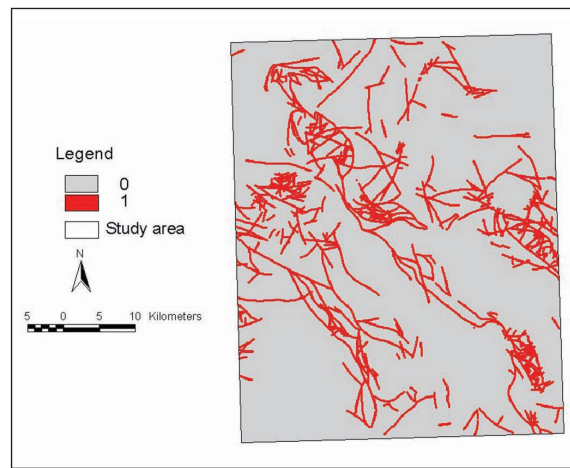


Figure 5. Binary map of faults (Yousefi, 2002)

Analysis of first derivative of total aeromagnetic intensity data

First derivative of total aeromagnetic intensity data was used for illustration of local anomalies. For performing weights of evidence analysis, the map of first derivative was reclassified to 20 classes from 1 to 20. The optimum class consisting of 13, 12 and 8 were selected on the basis of the contrast values greater than 2 (Table 3), and then, a binary map of first derivative of aeromagnetic data, which is a predictive pattern, was prepared (Fig 6). In this map, again inside predictive pattern has a value of 1 and outside predictive pattern has a Value of 0.

Table 3. Weights of evidence analysis of first derivative of aeromagnetic data

Class	Area(sq.km)	Points	W ⁺	W ⁻	C	S(w ⁺)	S(w ⁻)	S(c)	Stud(c)
13	4.1800	1	3.6540	-0.0500	3.7040	1.1465	0.2303	1.1694	3.1674
12	7.7100	1	2.9073	-0.0486	2.9559	1.0719	0.2303	1.0967	2.6960
8	443.8900	13	1.3100	-0.8570	2.1670	0.2815	0.3786	0.4718	4.5930
6	551.6300	5	0.1166	-0.0360	0.1526	0.4493	0.2592	0.5187	0.2942

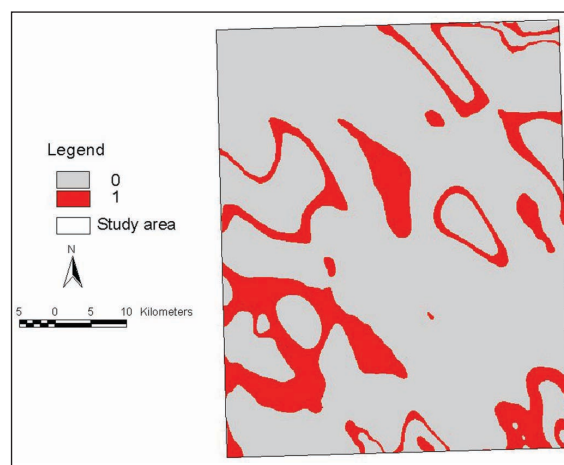


Figure 6. Binary map of first derivative of aeromagnetic data

Integrating patterns for predicting GIS exploration model

The predictive exploration model was generated by summing the evidential patterns of five binary maps (binary maps of lithological units, faults, first derivative of aeromagnetic data, alteration zones and geochemical anomalies) representing the gold and base metals recognition criteria in Mahneshan area. Figure 7 shows a predictive GIS model which has the posterior probability occurrence of ore indication in each unit cell. In Figure 7 the highest probabilities of ore indication existence belong to areas where more recognition criteria exist.

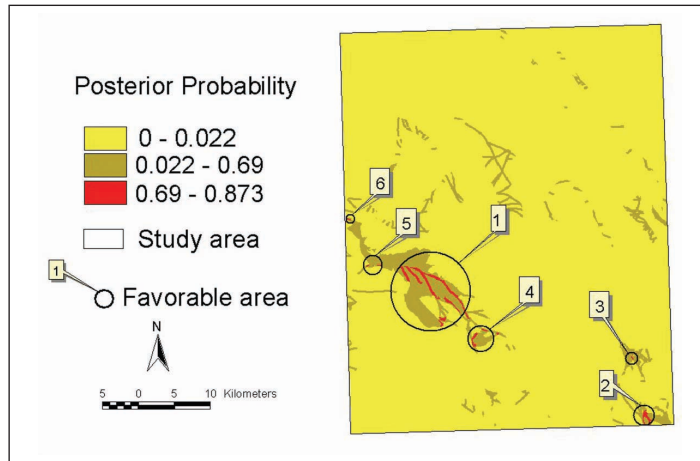


Figure 7. Predictive GIS model

Conclusion

The final predictive GIS model (Fig 7) highlights some favorable areas for further exploration, shown by circles. This model is a preliminary model to predict the location of undiscovered gold and base metals deposits in Mahneshan area. Two important favorable areas are located on PC^{12} unit in the west and on K_1 and K_2 units in the southeastern parts of the study area. The favorable areas are only very small parts of the study area. Notable features in Figure 7 are the faults of the favorable areas which have the highest posterior probability mineralisation values. The faults have not been mentioned as favorable areas in previous exploration works. The mineralisation in the area is controlled by NW- SE trending faults. The faults which are in both areas 1 and 2 have priority for further exploration, specially in area number 1, where the Precambrian metamorphic rocks have outcrop in the area.

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