Investigating the Characteristics of shear zone gold deposit by implementation of discriminant functions on the Probability plot model

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Abstract
One of the most important goals in mineral exploration is the identification of mineralization areas. Since gold is considered as the financial support of countries, this is one of the important requirements in identifying and evaluating these deposits. Therefore, samplings and exploratory studies must be designed to minimize the risk of exploration process. The mineralization of gold in Kurdistan region of Iran, in the Sanandaj-Sirjan zone, has been categorized as a shear zone gold type. In order to optimize separation of gold mineralized anomalous areas, it is necessary to carefully investigate the characteristics of the sub-population. In this research, the discriminant analysis method was implemented on the probability plot modeling results for a more accurate investigation and an improvement in results. Accordingly, the stream sediment samples were used for 21 geochemical variables (Zn, W, V, Ti, Sn, Sb, Pb, Ni, Mo, Mn, Hg, Cu, Cr, Co, Bi, Be, Ba, B, Au, As, Ag). Initially, four sub-population were identified among the data of the gold element by modeling the probability diagram and the approximate background and anomaly limits were estimated analyzing the model.. Then among the raw data, the concentrations of 5, 15 and 30 ppb were selected as the boundaries of the papulations, and the values of 15 and 30 ppb were introduced as the anomaly's thresholds with an area of 38 and 26 km^2, respectively. Subsequently, each of these sub-population were coded. The data was classified using the discriminant analysis- DA method, with three discriminant functions, DF, consisting of 6 variables (Ag, Au, Co, Mn, Mo, V) with the greatest effects on the samples classification. The five variables next to the gold element were identified as the most effective elements in identifying gold anomaly samples that were largely consistent with the gold characteristics of shear zones. Original methods and cross-validations were used in order to validate functions in classifying the population. After this validation the areas were categorized with 87% and 83% of correctness. The results of DFM on probability model can be used to optimize the exploratory operations and classify new exploratory data to the background or anomaly using the six geochemical parameters mentioned above and it can be an effective guide to the subsequent stages of exploratory operations.

Keywords: **Gold element geochemical data, Stream sediments, Probability plot modeling, Discriminant analysis, Anomalies area**

INTRODUCTION
Today, the separation and identification of high-concentration areas from low-concentration gold deposits is of great importance due to very small concentration changes. Various methods are available to separate geochemical anomalies. Probability diagram theory was first proposed by Hazen in 1914 and used to simplify data on a reserve. The range of application of probability diagrams is diverse in the mineral exploration, including its application in geochemical, geophysical, and reserve estimation projects.
Probability diagrams are one of the methods with low volume of calculations and high speed of operation. In this method, the existing trends are separated from the data on which the initial statistical studies have been done considering geochemists' opinions.
Discriminant analysis method has been invented by Fisher in 1936 and developed based on multivariate linear regression. Discriminant analysis is similar to multiple linear regression, except that the dependent variable not only does not have a normal distribution, but also is a qualitative variable with a small number of values. This method is useful when there is one grouping variable (qualitative) and several quantitative independent variables. The researcher's goal is to obtain a relationship that can determine the membership in the grouping variable according to the independent variables. This method is used to identify geochemical anomaly

samples to study the properties of trace elements, separate mineralized rocks from sterile,, model mineralization of gold deposits, explore reserves copper has been used with sedimentary host, and classify the environmental geochemical data.
In this study, it has been tried to use the results of probability diagram as input of discriminant analysis method in classifying geochemical data of gold element in order to investigate the effects of gold mineralization,. We used the capabilities of this integrated method in improving the resolution of background and anomalous samples (subpopulations). Also, based on this method, it is possible to identify the effective elements in detecting anomalous areas of gold. An attempt was made to isolate the underlying sub-populations and the anomaly of this element by modeling the probability diagram of the data obtained from the stream sediments samples. Then, the characteristics of these sub- populations have become more obvious by classifying the mineralization sub-populations obtained from probability diagram modeling, and the results have been improved. Based on this discriminant functions, the new samples can be classified into the categories.

METHODS and FINDINGS

1- Sampling and preparation of samples
Geochemical sampling in an area of about 370 square kilometers of 1:100,000 Saqqez sheet has been done from new sediments and 40-mesh particles. If the samples are dry, 40 mesh is passed through the sieve and the -40 mesh particles of sediment are separated and packed. Otherwise, a sufficient amount of raw sample is taken and then dried at the site using indirect heat. Finally, the -40 mesh particles are separated and packaged. About 100 grams was taken from each geochemical sample, packed, labeled, and then sent to the laboratory for preparation. After pulverization and conversion to -200 mesh in the laboratory, these samples were sent to a laboratory for analysis. The samples were analyzed using the spectrometer diffusion method and atomic absorption in the laboratory of the Geological Survey of Iran (GSI). Due to the availability of a mineralization map from regional and local geochemical exploration for gold, in this article only this element has been used for interpretation. The results of the data analysis did not show any outlier data, but there was a sample with outlier data feature that was replaced after correction.
2- Modeling the probability diagram of the gold element
In order to identify mineralization populations and separate anomalies from the background, it is necessary to model the data with knowledge of the properties and geochemical behaviors of the elements. Probability diagram is one of the plotting techniques that examines the behavior of the studied variable and how it is distributed in population. Each change in linear trend in the probability graph corresponds to a population with a specific mean and standard deviation that is the result of syngenetic and petrogenetic effects. Therefore, any changes in the slope of the line corresponding to the model in the probability diagram indicates different geochemical behaviors in geological environment. If by this modeling, the trend of sub-populations can be distinguished and separated, the boundaries of each sub- population will be determined separately. In studying the geochemical properties of shear zone gold, the Au element is of special importance. Therefore, the probability diagram modeling of gold data in mineralization of Kurdistan shear zone is first discussed. Fig.1 shows a modeled probability diagram of gold data.

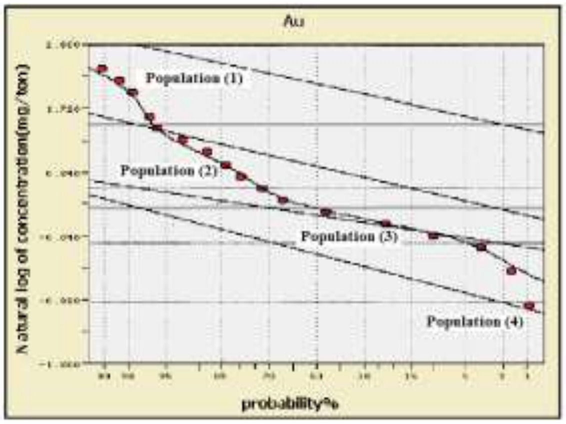

Fig.1. Probability diagram Modeling of Au element

In this model, four subpopulations were identified, and the boundaries of each subpopulation and its share in the total data were obtained. This information includes the threshold values and the percentage of each subpopulation is summarized in Table 1. The first subpopulation, which contains less than 5% of the data, can represent the background population. The second, third and fourth populations contain 65%, 28%, and less than 4% of the data, respectively. The second subpopulation may reflect the transition limit from background to anomaly, the third one is anomalous, and the fourth is the upper limit of the concentration for the anomalous subpopulation or mineral zone. Based on the threshold limits calculated for each subpopulation, the values of 5, 15 and 30 ppb concentrations (respectively representing the approximate upper limit of the second subpopulation, the mean of the third subpopulation, and the upper limit of the third subpopulation) were accordingly selected as the boundary of populations. Finally, 15 and 30 ppb values were introduced as the thresholds of anomalies.

Table 1. The result of the probability diagram modeling on the Au element data

Population	Percentage	Threshold (ppb)
1	4.8	0.11-2.28
2	64.53	0.72-4.16
3	27.59	2.11-32.11
4	3.16	31.70-380.62

Fig. 2 shows a map of anomalous areas with a threshold of 15 ppb. Levels of 30 ppb show the second stage of mineralization.

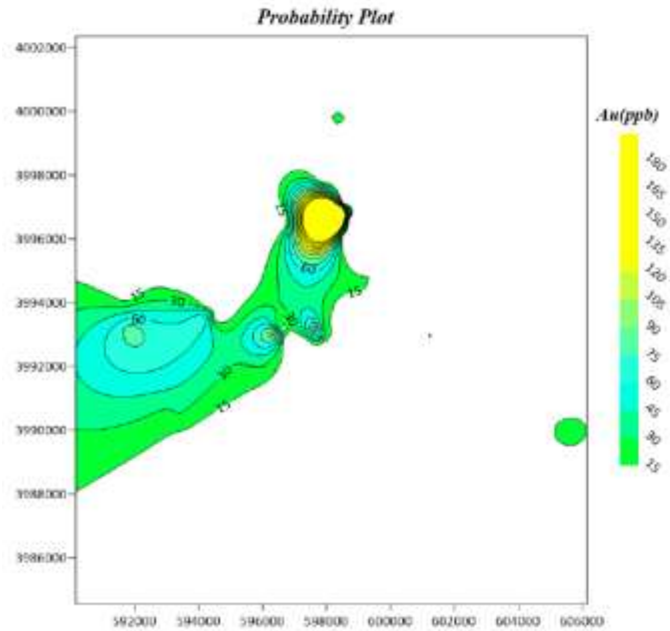

Fig.2. Map of anomaly areas by probability diagram Modeling

3- Implementation of discriminant analysis method on the gold element probability diagram model

By performing discriminant analysis, a function or set of functions is constructed and 1-n functions are defined for n groups. The first function has the best linear combination for predicting group membership. If the variables X1, X2, ... and Xk are measured in different groups, the total form of the discriminant function of Df is defined as Eq. (1):

$$Df = b_1 x_1 + b_2 x_2 + ... + b_k x_k \quad (1)$$

b1, b2, ... and bk are the effect coefficients obtained from the analysis for each of the variables. Anomalous samples of gold element were isolated from the background in the previous step by modeling the probability diagram. The separation of the four populations into sub-populations and anomalies is done taking into account the personal opinion of the geochemist, thus the accuracy of this opinion needs to be checked in a reliable way.. The multivariate method of discriminant analysis has been selected in order to examine the characteristics of sub-populations in more detail . Based on the results, a code was assigned to each of the sub-population samples for classification in discriminant analysis. As it is presented in Table 1, four codes were assigned to each population with the boundaries of the concentrations from the probability diagram.

Discriminant analysis was performed in steps. The variable with the least effect on the differentiation function was identified in each step based on statistical tests and then removed from the set of variables. Given that the 4 sub-populations are defined for gold element three discriminant functions were defined. Results of the variable coefficients for these three functions are presented in Table 2. Among the 21 elements participating in the differentiation analysis, 6 elements were selected with the greatest impact on the identification of background and anomalous areas. These elements include Ag, Au, Co, Mn, Mo, and V.

Table 2. The coefficient of the variables

	Function		
	1	2	3
Ag	-9.199	-23.276	11.832
Au	0.162	0.005	-0.013
Co	0.075	-0.085	0.96
Mn	0.001	0.004	0.001
Mo	0.163	0.797	0.081
V	-0.012	-0.01	-0.033
(Constant)	-1.615	1.136	-0.054

The distribution map of the samples and the center of the groups (background, margin, and anomaly) are illustrated in Fig.3. As shown in the figure, samples from two anomalous populations (Code 4 and Code 3) show a clearer separation from the other two populations, indicating good classification. Background and transition samples (Code 1 and 2) show an overlap between data due to the fusion effect. Since the first function can be the best function, the frequency diagram of the whole sample was drawn based on the scores (Fig.7). In Fig.4, two anomaly populations, especially the second phase anomaly, are well separated from other populations,indicating the presence of mineralization samples in this zone. The transition population of the background to anomaly overlaps with populations 1 and 3 due to the fusion effect.

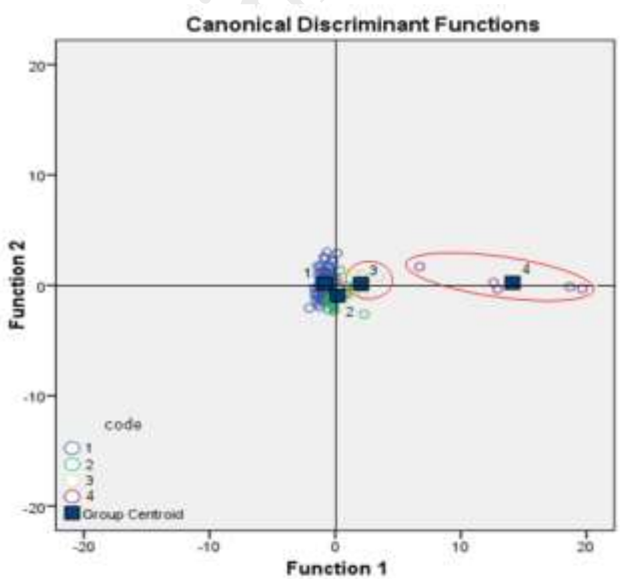

Fig.3. Position of the samples in the classificated groups

CONCLUSIONS

According to the importance of mineralization populations in correctly identifying anomalous areas of the gold element, it was possible to isolate these populations using diagram modeling. The results of this method provided four anomaly populations and contexts, thus that two background populations and two anomalous populations were separated. In the next step, the multivariate method of discriminant analysis was implemented and results showed that these northern sub-populations include a background population, an underlying transition populations to an anomaly, and first and second phases of the anomaly (probabilistic and definite anomalies, respectively).

In order to reduce the risks and minimize the costs in exploration projects, the variables differentiating this type of gold mineralization from other types can be defined as a set of functions and the state of mineralization can be defined with a new range of samples data and placing the measured variables in the discriminant function.

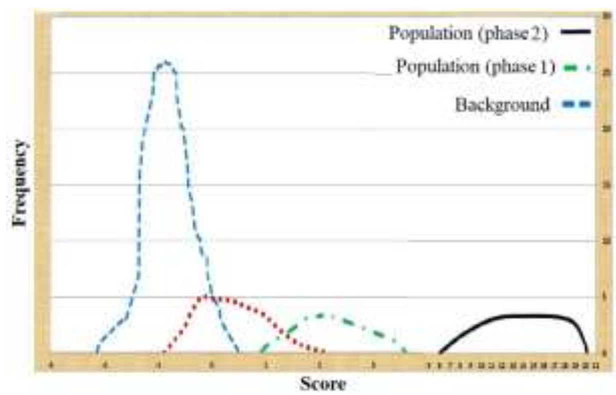

Figure 4. Classification of the samples based on the discriminant analysis

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