

## Application of Discriminant Analysis for Alteration Separation; Sungun Copper Deposit, East Azerbaijan, Iran

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**Abstract:** The Sungun porphyry copper deposit that intruded Eocene volcano sedimentary and Cretaceous carbonate rocks hosted by a diorite/granodioritic to quartz- monzonitic stock. Copper mineralization is essentially associated more with potassic and less phyllic alteration. Therefore separating these two kinds of alteration is so important. In this paper, by applying the discriminant, it was attempt to separate the alteration zones "as well as" possible and discriminate as various mineralogical compositions. The principal component analysis method is actually based on the visual value, visual vector and the trajectory with the maximum changeability and discriminant analysis consists of finding a transform which gives the maximum ratio of the difference between two group multivariate means to the multivariate variance within the two groups. In this method, 24 electron microprobe element analysis related to the rock samples were used as the input data to identify the rock classification and separation the variety of alterations. Therefore, to aim this goal, the discriminate analysis method was applied within the Sungun deposit. First, the discriminate analysis method was applied to separate them effectively. In this method, for each of the variables (elements) their specific scores were obtained and finally the critical value ( $R_c$ ) for separation was obtained to be -73.1603. By comparing this value ( $R_c$ ) with the elements ( $R_i$ ), the alteration class would be determined. One of this method advantages is to introduce the transition zone. This zone is known as a boundary in which potassic changes to phyllic alteration gradually. Since it is very hard to separate the samples microscopically, this method could be able to separate them more effectively. Based on this method, the discriminate analysis could verify the exact boundary between the two well-known alteration zones (potassic and phyllic).

**Key words:** Sungun, Transition, Alteration, Boundary, Statistics.

### INTRODUCTION

The area of the Sungun deposit was first described by Bazin and Hübner, (1969), who reported skarn-type mineralization at the contact between Cretaceous limestone and the granodioritic stock. On the basis of the overall geological setting and alteration patterns, Etminan, (1977) proposed that the Sungun Cu deposit is porphyry-related and concluded that the overall characteristics of the deposit are very similar to those predicted by the generalized porphyry deposit model of Lowell and Guilbert, (1970). Detailed studies on fluid inclusions/isotopes and thermodynamic modeling have been provided by Hezarkhani and Williams-Jones, (1998), Hezarkhani *et al.* (1999) and Hezarkhani, (2002). During the alteration and mineralization three distinct hydrothermal fluids were identified (Hezarkhani, 2002; Hezarkhani and Williams-Jones, 1998). The first hydrothermal fluid caused potassic alteration and Cu ± Mo mineralization, was characterized by high temperatures and moderate to high salinities and was derived magmatically. The second hydrothermal fluid formed mainly by mixing magmatic fluid with a predominantly meteoric fluid, resulting in lower temperature and salinities. This fluid was responsible for transition alteration at depth and sericitization at higher levels. The third hydrothermal fluid consisted of relatively oxidized meteoric water, which produced a peripheral propylitic alteration zone outside the core of potassically altered rock. Therefore, the alteration in dioritic/granodioritic rocks at Sungun can be classified into three different types: (I) potassic, (II) propylitic,

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and (III) phyllic.

Several studies have been reported successful implementations as quantification technique to separating the alterations within the deposits. For example, Gresens, (1967) applied composition–volume relationships of metasomatism for alteration calculations. Grant, (1986) who modified the Gresens method applied the new one to calculate the alteration mass changes. Hezarkhani and Tahmasebi, (2008a) also used this technique for alteration separation and estimating changes in mass, volume and the concentrations after the mass transfers. Also, Tahmasebi and Hezarkhani, (2008) used the optimized neural networks to separate the alteration boundaries that according to their results, this method could able to separate and identify the alteration effectively. Another method which has been used by Hezarkhani and Tahmasebi, (2008b) was also based on a type of neural network which called probabilistic neural network to separate and embody the alterations location and identifying their boundaries. In both last studies by Tahmasebi and Hezarkhani, they used full elements which have been used in this study to associate all of the possible conditions.

During the recent years, variety of multivariate statistical methods has been applied as a tool for statistics calculations. One of the powerful tools was Discriminant Analysis that uses extensively in the mining and geology fields. Bull and Mazzucchelli, (1975) applied discriminant analysis to the geochemical evaluation of gossans. Cheng and others, (2000) integrated spatial and spectrum method for geochemical anomaly separation. Zhou and others, (1983) presented the dual extraction of R-Mode and Q-Mode factor solutions for mining tasks. Cheng and others, (1996) applied spatial analysis method for geochemical anomaly separation.

Many studies of porphyry copper deposits have provided descriptions of minerals present in different alteration zones, and chemical characteristics of alteration episodes (Mchrpartou, 1993; Brimhall, 1980; Carten, 1986). However, there have been only a few attempts to determine the distinguished evolutionary path of alteration, with corresponding quantification of alteration separation in different alteration zones during reaction with hydrothermal fluids (Brimhall, 1979; 1983). The only investigation based on discriminant analysis for alteration separation was performed by Asghari and Hezarkhani, (2008). They used the fluid inclusion data including six variables (as homogenization temperature, salinity, pressure, depth, density and the Cu grade) that have been measured and calculated for each sample. Applying this method, they could separate the alteration zones effectively.

In this paper, the alteration separation that accompanied alteration in dioritic/granodioritic rocks of the Sungun porphyry copper deposit is evaluated quantitatively. Application of discriminant analysis was enrolled to define the alteration boundaries. 24 rock related electron microprobe analysis were used to complete this method. These different alteration episode analysis results were used as the inputs. The alteration boundaries were defined base on this method. According to the results, discriminant analysis give the distinguish boundary. By comparing the results from this study with available data from previous papers, it would be possible to contribute a better understanding of the nature of numerical methods for alteration separation.

Also, it is important to mention the importance of alteration separation in Sungun porphyry copper. Its importance is because of the complex geological setting which makes it difficult to separate and identify the alteration effectively, because the copper mineralization is essentially associated more with potassic and less phyllic alteration. Therefore, presenting a method which could be able to separate these two alterations to avoid more time and cost wasting is very important.

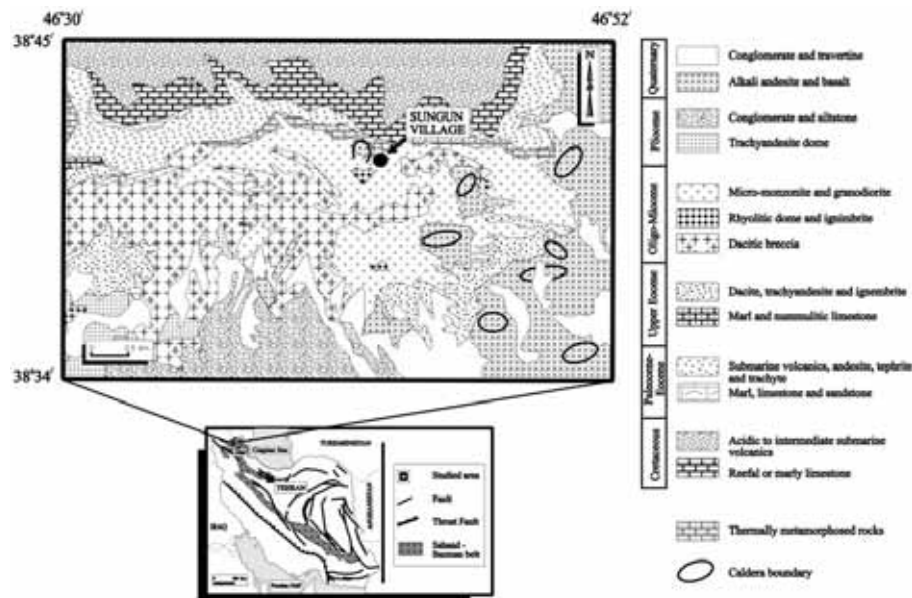
## **2- Geology Setting of Sungun Porphyry Copper Deposit:**

The Sungun porphyry copper deposit is one of two major copper deposits associated with calc-alkaline intrusive rocks (stocks) in the Cenozoic Sahand-Bazman volcanic belt, which extends north-westward from Sahand volcano in Azarbaijan province, to Bazman volcano in south-east Iran, a distance of approximately 1700 km (Figs. 1 and 2).

This belt, which was first identified by Stocklin, (1977), consists of alkaline and calc-alkaline volcanic rocks (Fig. 1) and related intrusives (I-type) and was formed by subduction of the Arabian plate beneath central Iran during the Alpine orogeny (Stocklin, 1977; Pourhosseini, 1981).

The major intrusive bodies are monzonite/quartzmonzonite in the west and later diorite/granodiorite in the east (Fig. 2). Both these units are bounded to the north and east by Cretaceous limestone. Andesitic to dacitic dykes are distributed mostly in the north and western parts of the Sungun deposit (outside the main stock). Mineralized trachyandesitic dykes occur mainly within the diorite/granodiorite and less commonly in the quartz-monzonite. Skarn-type alteration (and associated mineralization) occurs as a narrow rim along the eastern and northern margin of the stock in the Sungun valley (Mehrpartou, 1993). The oldest rocks in the Sungun area are Upper Cretaceous carbonate rocks and are overlain disconformably by Eocene basic volcanic rocks and sandstones. In the Early to Middle Tertiary (Eocene to Miocene), a major episode of volcanism, plutonism and

deformation occurred in the Sahand-Bazman belt. In the Sungun area, magmatism was initiated by eruption of Eocene volcanic rocks, which continued to Upper Miocene times. The composition of these rocks varies from andesite to rhyolite (Fig. 3). Associated intrusive rocks are mainly granodiorites, granites and monzonites. This episode was an expression of Andean-type magmatism that developed along the continental margin in response to subduction east towards the northeast.



**Fig. 1:** Simplified geologic map of the Sungun area (Hezarkhani *et al.*, 1998).

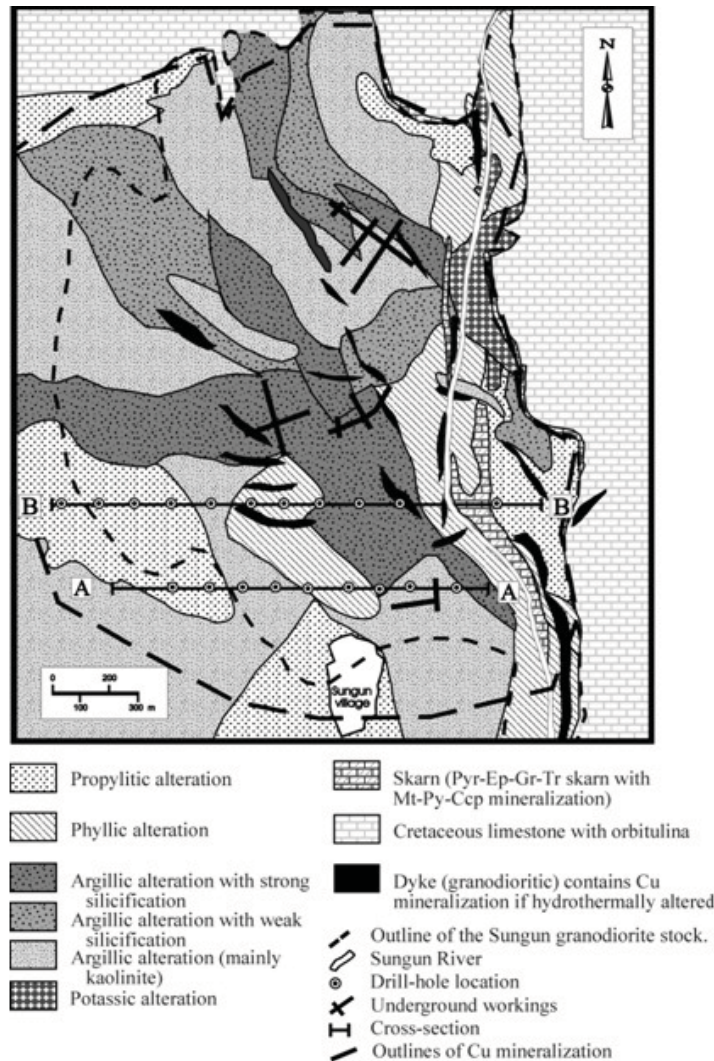
### 1-2- Alteration:

Hydrothermal alteration and mineralization at Sungun are centered on the diorite/granodiorite intrusion and were broadly synchronous with its emplacement (Fig. 2, 3). Early hydrothermal alteration was dominantly potassic and propylitic, and was followed by later transition and phyllic alteration (Hezarkhan *et al.*, 1998; 1999).

#### 1-1-2- Potassic Alteration:

The earliest alteration in diorite/granodiorite, which was produced by fluxes of magmatic fluids away from the pluton center (Hezarkhan *et al.*, 1998; 1999). is represented by potassic mineral assemblages developed pervasively and as halos around veins in the deep and central parts of the Sungun stock (Figs. 2). Potassic alteration is characterized by K-feldspar, irregularly shaped crystals of Mg-rich biotite, and anhydrite. On average, potassically altered rocks contain 28% plagioclase, 35% orthoclase, 20% quartz, 15% mafic minerals (mainly biotite, and sericite and chlorite after biotite), 2% chalcopryrite, pyrite, titanite, and zircon, and traces of scheelite, uraninite, bismuthinite and rutile. Biotite occurs primarily as a replacement of hornblende, and as anhedral grains disseminated through the groundmass, and is inferred to be mainly of hydrothermal origin. It is greenish-brown, shows ragged, anhedral shapes and occurs generally interstitial to feldspar and quartz. Relict crystals of secondary biotite are observed almost everywhere in the stock, suggesting that potassic alteration was initially very extensive but has been subsequently overprinted by later alteration. Biotite that replaced amphibole commonly contains inclusions of chalcopryrite and/or pyrite. Primary biotite is present only as rare phenocrysts. Potassium feldspar can be magmatic, occurring mainly as perthitic phenocrysts, or hydrothermal, having formed during potassic alteration. K-feldspar domains in perthite have a compositional range of  $Or_{97}Ab_2An_1$  to  $Or_{99}Ab_1$ , and albite domain compositions ranging from  $Ab_{76}Or_1An_{23}$  to  $Ab_{81}Or_3An_{16}$ . The compositions of the perthitic feldspars require subsolidus exsolution at, 500 °C (Tuttle, and Bowen, 1958). Magmatic K-feldspar has a composition ranging from  $Or_{88}Ab_{10}An_2$  to  $Or_{99}Ab_1$ , and variable but relatively high barium contents (BaO up to 1.74 wt %). Hydrothermal K-feldspar is distinguished from its magmatic equivalent by the absence of perthitic intergrowths. Hydrothermal K-feldspar is also much more albitic having a

composition of  $Or_{72}Ab_{27}An_1$  to  $Or_{78}Ab_{10}An_{12}$ .



**Fig. 2:** Detailed alteration map of the Sungun deposit (Hezarkhani *et al.*, 1998).

**2-1-2- Propylitic Alteration:**

Propylitic alteration is characterized by chloritization of primary and secondary biotite, amphibole and groundmass material in rocks peripheral to the central potassic zone (Hezarkhan *et al.*, 1998; 1999). Epidote replaces plagioclase, but this replacement, is less pervasive and intense than chloritization. Microprobe analyses indicate that the chlorite composition corresponds mostly to that of clinocllore (Rule and Bailey, 1987; 1986). The variation in chlorite composition is minor, and is mainly reflected in  $Fe / (Fe + Mg)$  values. Minor minerals associated with propylitic alteration are albite, calcite, sericite, anhydrite (gypsum), and pyrite (see Fig. 3).

**3-1-2- Transition Alteration:**

The outermost part of the potassic alteration zone, which contains less biotite and K-feldspar, and a greater proportion of sericite, has been termed the transition zone. Mineralogically, this alteration is represented by chloritization and sericitization of both primary and secondary biotite, and sericitization in the groundmass. This alteration is also characterized by albite replacement of more An-rich plagioclase, and albite rims on orthoclase (Hezarkhan *et al.*, 1999). Minor sericite and pyrite also partially replaced plagioclase, biotite and hornblende.

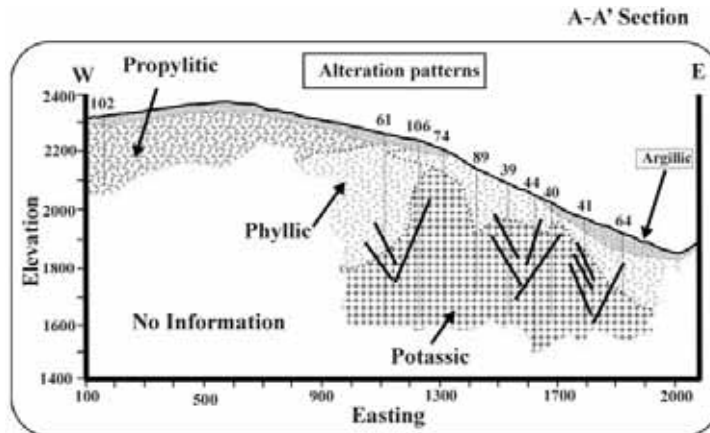
A distinguishing characteristic of this type of alteration is the white color of the affected rocks (see Fig. 3).

**4-1-2- Phyllic Alteration:**

Phyllic alteration is characterized by replacement of almost all primary silicates by muscovite (sericite) and quartz, and overprints the earlier-formed potassic assemblage (Hezarkhan *et al.*, 1999). Sericite is generally the most abundant alteration mineral in the Sungun deposit, and occurs mainly in the phyllic and potassic alteration zones. Thirty microprobe analyses were performed on sericite. Sericite commonly forms as irregular, oriented grains containing relicts of biotite and amphibole, and inclusions of zircon. Some of these crystals are phengite. The concentration of fluorine in sericite ranges from 0.22 to 0.05 atom per molecule formula (apmf), whereas chlorine contents are lower, (0.01 apmf). Silicification was synchronous with phyllic alteration and variably affected much of the stock and most dykes (see Fig. 3).

**5-1-2- Argillic Alteration:**

Feldspar is altered locally to clay minerals to a depth of 400 m, and within 80 m of the present-day surface, all rocks have been altered to an assemblage of clays, hematite and quartz. XRD analysis indicate that kaolinite is the dominant phyllosilicate, and that it is generally accompanied by illite. This shallow alteration is interpreted to represent a supergene blanket over the deposit, and the deeper clay alteration of feldspar may have had the same origin. However, the possibility cannot be excluded that parts of the latter may locally represent an advanced argillic stage of hypogene alteration (see Fig. 3).



**Fig. 3:** Profiles showing the alteration zones along cross-sections A-A (Hezarkhani, 2008).

**3-theoretical Background:**

**1-3- Discriminant Analysis:**

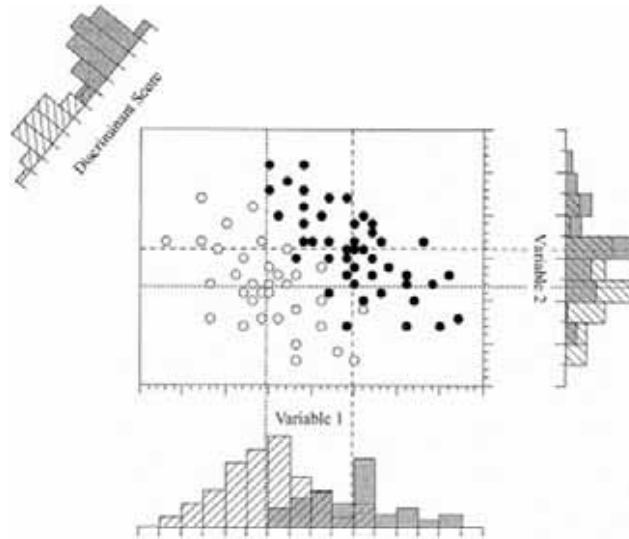
One of the most popular and prevalent statistical methods in earth sciences is the discriminant analysis. The reasons which help this method for its application are related to its powerful ability to solve the multivariate problems and convert it to a sample problem which its solving will be easy. Therefore, it is a like between the univariate and multivariate statistical problems.

One of the most important rules of discriminant analysis is to separate the variables into predefined groups Davis, (2002). This rule shows itself as a function to find a relationship between the groups which have the maximum difference them McLachlan, (1992). It is closely related to multiple regression and trend-surface analysis (Press and Wilson, 1978). The idea behind this statistical method is to identify the unknown groups which by using them; the problem solving would be easier. Actually, each of the involved groups are characterized by a set of variables which finding a simple relationship between them and its analysis is very difficult. But, by using this method through the some equations which represent multiple regression, it would be possible to discriminatiae the available groups and alter the problem into a simple and low dimensional ones.

As mentioned, this method is mainly based on its function. In the other hand, by using this function, it would be possible to weighting the involved variables. For example, a linear discriminant function is a tool which attributes an discriminant score to element (variable). Actually, the score which has been attributed to a variable, is a value which it represents the variable position along a line which defined by the liner discriminant function.

According to Fig. 4, it could be understood that the aim of using this method is to separate the groups as well as possible. In the other hand, in this figure which represents the samples location, it is very difficult to investigate and analysis the statistical properties of the groups easily. Therefore, because of these problems, it should be searched for an orientation which by applying that, the groups would be able to separate into different clusters of the groups which their alterability would be maximized Davis, (2002).

As discussed earlier, this method is based on the discriminant function which is a function that by using it, the discrimination procedure would be possible. Regression is a method which helps to finding the discriminant function.



**Fig. 4:** Schematic plot of distributions of two variables with scatter plot of both variables. Samples indicated by open circles are belong group1, those indicated by solid dots are belong group2. Dashed lines indicate bivariate means of the two groups. Distribution of discriminant scores also is shown along line parallel to discriminant axis (Davis, 2002).

Here, the basic principle of this method will be briefly explained Davis, (2002). The basic equation which composed this method is based on the following equation:

$$S\lambda = D \tag{1}$$

where  $S$  is a  $m \times m$  matrix of pooled variances and covariances of the  $m$  variables.  $\lambda$  (column vector) are used to represent the coefficients of the discriminant function.  $D$  represents the column vector of  $m$  differences between the means of the two groups, which we will refer to as  $A$  and  $B$ .

$$\lambda = S^{-1}D \tag{2}$$

Where  $S^{-1}$  is the inverse of the variance-covariance matrix formed by pooling the matrices of the sums of squares and cross products of the two alterations,  $A$  and  $B$ . To compute the discriminant function, we determined the various entries in the matrix equation. The mean differences are found by:

$$d_j = \bar{A}_j - \bar{B}_j = \frac{\sum_{i=1}^{n_a} a_{ij}}{n_a} - \frac{\sum_{i=1}^{n_b} b_{ij}}{n_b} \tag{3}$$

$a_{ij}$  is the  $i^{\text{th}}$  observation on variable  $j$  in group  $A$  and  $\bar{A}_j$  is the mean of variable  $j$  in group  $A$ , which is the arithmetic average of the  $n_a$  observations of variable  $j$  in group  $A$ . The same conventions apply to group  $B$ . The difference between these multivariate means therefore also forms a vector:

$$D = \bar{A} - \bar{B} \tag{4}$$

In expanded form,

$$\begin{bmatrix} d_1 \\ d_2 \\ \dots \\ d_m \end{bmatrix} = \begin{bmatrix} \bar{A}_1 \\ \bar{A}_2 \\ \dots \\ \bar{A}_m \end{bmatrix} - \begin{bmatrix} \bar{B}_1 \\ \bar{B}_2 \\ \dots \\ \bar{B}_m \end{bmatrix} \tag{5}$$

To construct the matrix of pooled variances and covariances, a matrix of sums of squares and cross products of all variables is computed in alteration *A* and a similar matrix for alteration *B*.

$$SP_{Ajk} = \sum_{i=1}^{n_a} a_{ij} a_{ik} - \frac{\sum_{i=1}^{n_a} a_{ij} \sum_{i=1}^{n_a} a_{ik}}{n_a} \tag{6}$$

where,  $a_{ij}$  denotes the  $i^{th}$  observation of variable  $j$  in group *A*, and  $a_{ik}$  denotes the  $i^{th}$  observation of variable  $k$  in the same group. This quantity is the sum of squares of variable  $k$  whenever  $j=k$ . Similarly, a matrix of sums of squares and cross products is found for alteration *B*:

$$SP_{Bjk} = \sum_{i=1}^{n_b} b_{ij} b_{ik} - \frac{\sum_{i=1}^{n_b} b_{ij} \sum_{i=1}^{n_b} b_{ik}}{n_b} \tag{7}$$

The sums of products matrix is denoted from alteration *A* as  $S_A$  and that from alteration *B* as  $S_B$ . The matrix of pooled variance can be found as:

$$S = \frac{S_A + S_B}{n_a + n_b - 2} \tag{8}$$

The set of  $\lambda$  coefficient we have found are entries in the discriminant function equation which has the form:

$$R_i = \lambda_1 x_{1i} + \lambda_2 x_{2i} \dots + \lambda_k x_{ki} \tag{9}$$

Equation 9 is a liner function. Actually, in this equation, it is tired to involve all of the available variables also; this equation represents the discriminant score,  $R_i$ .

Another parameter related to this equation is a point which represents the middle center between tow groups of *A* and *B*. This point ( $R_o$ ) is exactly located between the centers of tow groups.

In most of the aspects, discriminant analysis is like the multi regression and trend-surface analysis. It principals is similar to other multivariate statistical methods such as factor analysis, principal components analysis, because most of these methods are based on eigenvalues.

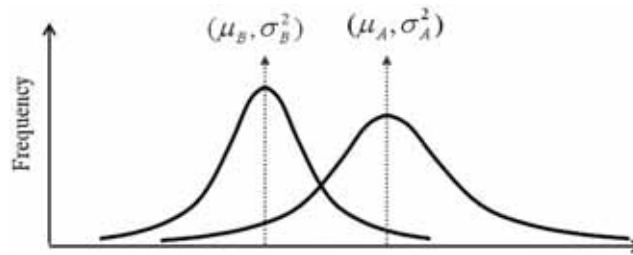
Using of eigenvectors has several advantages, because it presents a method based on eigenvector which it is has an ability to simulate the problem easily.

**4. Methodology:**

The technique that described, have been applied to the alteration separation of Sungun porphyry copper based on the microprobe results of sampling boreholes which the true alteration patterns were emphasized accurately. Table 1 presented the different value of each element (variables) which used in this investigation. Most of the data for each borehole were assigned to two variants sets. The first samples were from potassic alteration of size 44 and the second samples were from phyllic alteration of size 52 that were used as the data for each modeling in this investigation. Therefore, in this study we have assembled two collections of microprobe samples analysis of known potassic and phyllic alteration origin. We may have determined their origin from an examination of their mineral contents as discussed before in the alteration section.

A number of variables including the major and trace elements have been measured on each sample. As shown in Fig. 5, it is not possible to separate two assume alterations just with the given data by one variable,

since, the two alterations (populations) overlapped each other (Fig.6).



**Fig. 5:** Histogram of elements data shows that there is not a sharp boundary between the two potassic and phyllic alterations and they seem like two overlapped populations.

Discriminant analysis was applied according to mentioned steps in section 1.3. It is important to notice that the  $S$  was  $24 \times 24$  matrix of pooled variances and covariance of the 24 variables and also, the  $A$  and  $B$  groups were potassic and phyllic alteration zones respectively. By calculation the mentioned equations respectively and finally by using the Eq. (9), it yields the discriminant score ( $R_0$ ) to separate the alteration zones effectively.

## RESULTS AND DISCUSSION

### 5.1. Discriminant Analysis and Alteration Separation:

As it is clear, most of the geochemical dataset are lognormal. The reason for this behavior is mostly because of the nature of geochemical dataset which has been surveyed that most of them show an accumulation in themselves and causes to shows a skewed distribution (as presented in Fig. 6). Therefore, it should be improve this distribution and the using data should be pre-prepared for this statistical analysis. One of the methods which could improve and convert the unwilling distribution (lognormal) into the normal shape is to take the logarithms of the concentrations values Davis, (2002).

Base on the available method and the function that are represented in section 1.3, the  $R_0$  was obtained -73.1603. The discriminant index,  $R_0$ , is the point along the discriminant function line that is exactly halfway between the center of potassic and the center of phyllic alteration. The multivariate mean of potassic alteration into the equation is substituted to obtain  $R_A$  and substitute the multivariate mean of group  $B$  to obtain  $R_B$ . The centers of the two original alteration projected onto the axis defined by the discriminant function are  $R_A$  and  $R_B$  that obtained -66.9637 and -79.3568 respectively.

As described, by using the  $R_0$ , it would be possible to have a point that exactly halfway between the centers of potassic and phyllic alterations. These values are the *raw discriminant scores*. These points are plotted in Fig. 7, but here because of the long distance between these two centers, it was avoid showing them and two assumptive lines set as the mixed boundary. In fact, every observation in this analysis is entered into the equation and its position along the discriminant function located (Fig. 7). According to this figure, a few members of potassic alteration are located on the phyllic alteration side of  $R_0$  and a few members of phyllic alteration are located on the potassic alteration side.

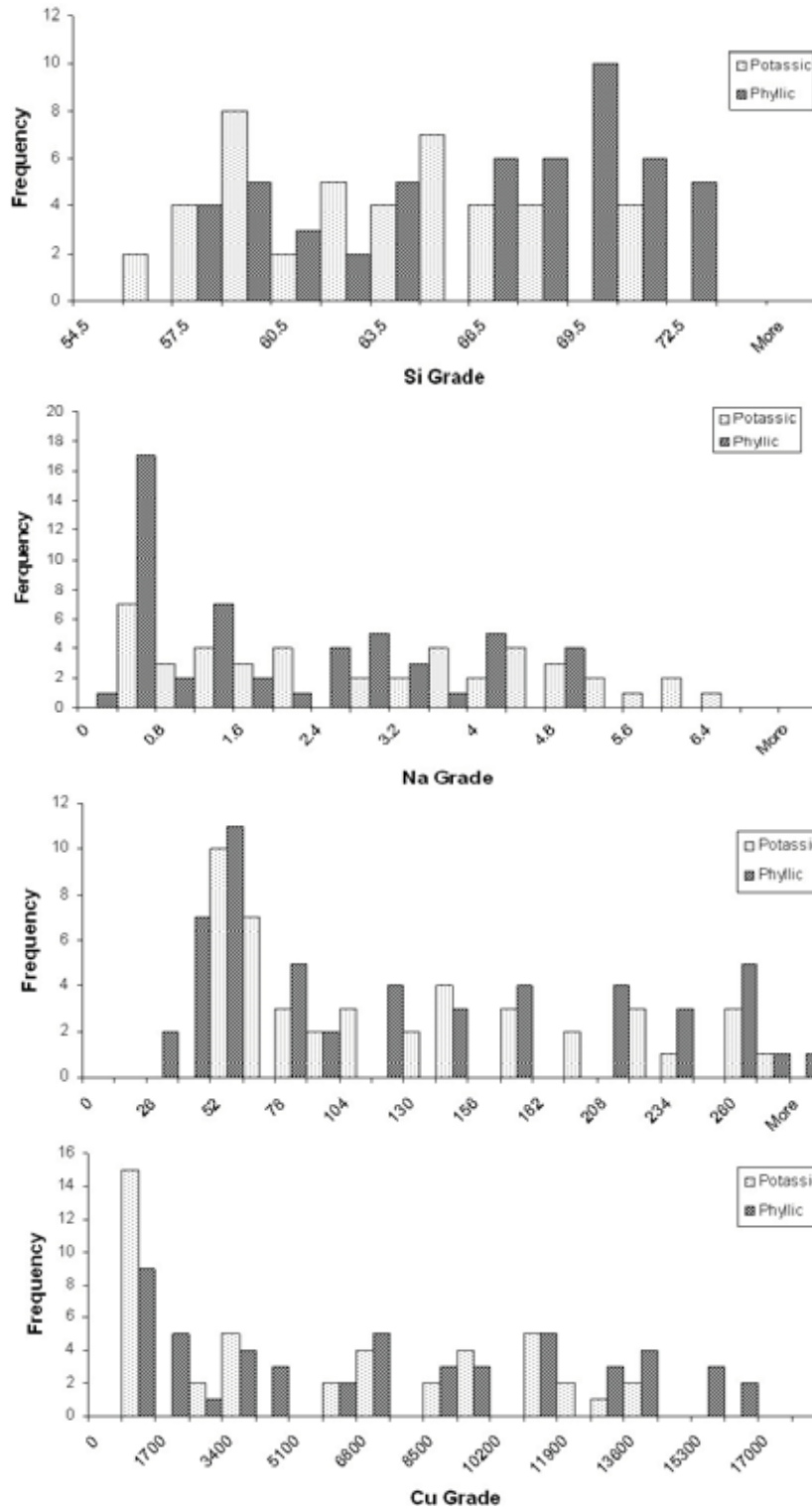
According to obtained results, there are some samples that have been misclassified which can not identify the samples correctly. In mathematical and calculation methods, these misclassifications could be undesired, but in geological description, it may mean a valuable result. As discussed in alteration part, there is a wide boundary between two potassic and phyllic alterations as transition zone. It is difficult to classify the samples in the correct alteration which are located in this zone.

The  $R_i$  for 22 based sample was calculated according to Eq. (9). The results base on the two supposed lines (see Table 2), demonstrate a good correlation between the alteration zones. Also, the results of testing samples are presented in Table 3. It is very difficult to identify the transition zone only by applying the microscopic investigations, but by this method (discriminant) it is very easy and reliable to separate this zone from the potassic and phyllic alteration zones. Because, this method present a quantify boundary to separate the alteration zones.

Based on the discriminant analysis results, the A-A section interpreted for second time and the samples



which their  $R_{(i)}$  scores was between two lines range with approximately mentioned values, introduced as potassic-phyllitic alteration (or transition zone). Fig. 8 shows the A-A section after the new mentioned interpretation.



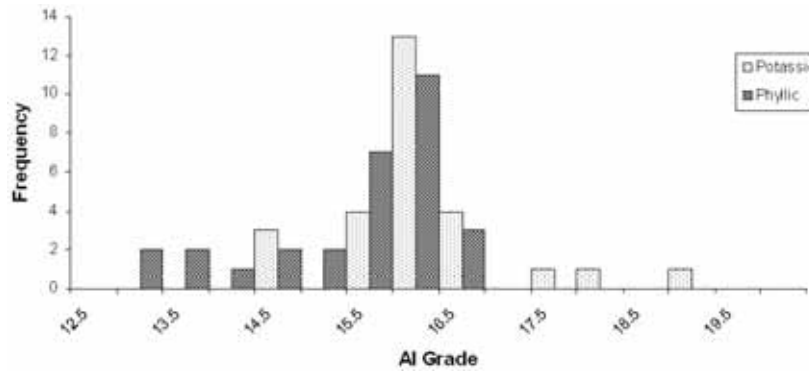


Fig. 6: Potassic and phyllic alteration projections of onto discriminant line function.  $R_A$  is projection of 24 variant mean of potassic alteration. It was also could introduce the area between tow lines ( $R_1 \sim -75.5$ ,  $R_2 \sim -71$ ) as transition alteration (potassic-phyllic).

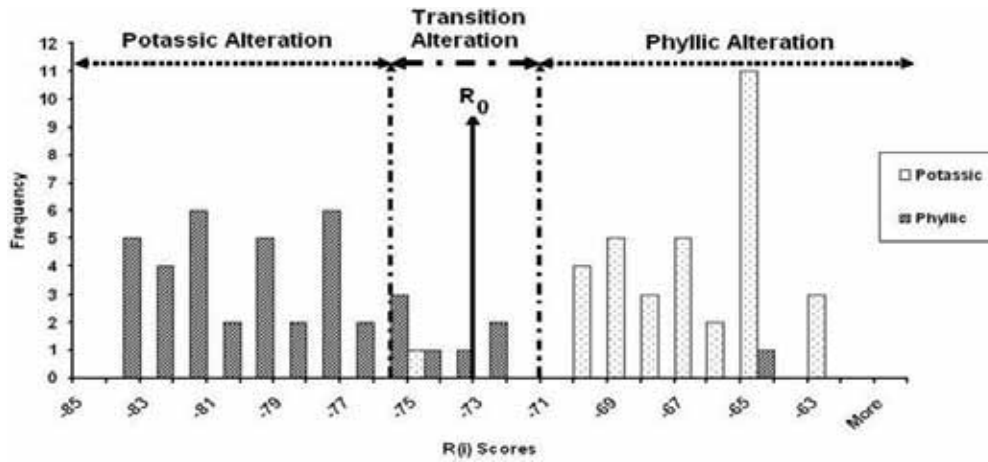
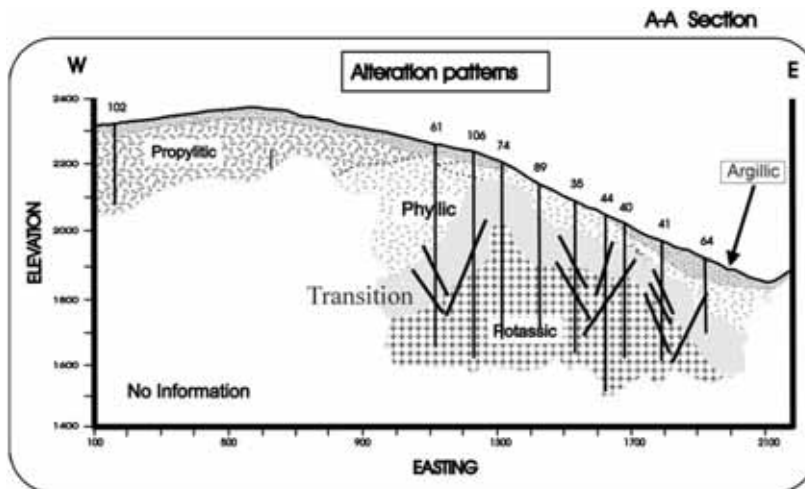


Fig. 7: Profile after interpretation of the discriminant analysis results illustrating the pattern of hypogene alteration zones (potassic, potassic-phyllic, phyllic, argillic and potassic-phyllic or transition zone).



**Fig. 8:** Scatter plot of principal component score-projection of observations in Table 5 onto their principal components.

**Table 1:** Descriptive statistics of 52 samples from phyllic alteration and 44 samples from potassic alteration.

Type	Potassic Alteration					Phyllic Alteration				
	Max.	Min.	Mean	Var.	S.D.	Max.	Min.	Mean	Var.	S.D.
SiO2	70.73	54.93	62.39	13.51	3.68	72.38	57.25	68.40	13.96	3.74
TiO2	0.99	0.39	0.58	0.02	0.13	0.76	0.18	0.52	0.01	0.11
Al2O3	18.84	14.10	15.85	0.89	0.94	16.32	12.99	15.11	0.96	0.98
Fe2O3	6.99	1.27	3.59	2.82	1.68	4.83	0.07	2.09	1.78	1.33
MnO	0.14	0.01	0.06	0.00	0.04	0.10	0.00	0.02	0.00	0.02
MgO	5.62	0.84	2.10	0.99	1.00	3.45	0.02	1.31	0.59	0.77
CaO	7.58	0.38	2.95	2.45	1.57	4.77	0.09	1.52	1.99	1.41
Na2O	6.03	0.16	2.54	3.07	1.75	4.61	0.00	0.74	1.14	1.07
K2O	6.94	1.65	4.50	2.57	1.60	5.18	0.22	4.41	0.91	0.95
P2O5	0.51	0.18	0.28	0.00	0.07	0.55	0.16	0.30	0.01	0.10
BaO	2044.00	20.44	1031.52	229146.26	478.69	1264.00	361.00	659.93	68570.78	261.86
Ce	192.00	14.00	93.54	1901.59	43.61	215.00	0.00	71.14	2075.27	45.56
Cr2O3	269.00	40.00	82.64	3172.68	56.33	279.00	23.00	68.46	3919.25	62.60
Cu	13050.00	36.00	3235.96	17212741.67	4148.82	16024.00	467.00	5526.29	24101396.85	4909.32
Ni	96.00	15.00	38.82	589.71	24.28	154.00	0.00	42.39	1256.17	35.44
V	185.00	53.00	86.04	1169.52	34.20	106.00	17.00	69.18	461.00	21.47
Zn	2353.00	21.00	583.61	545481.58	738.57	1657.00	0.00	237.75	223474.62	472.73
Nb	22.00	9.00	15.48	11.99	3.46	23.00	1.00	14.25	24.24	4.92
Pb	36.00	0.00	16.59	69.61	8.34	22.00	0.00	5.10	50.09	7.08
Rb	124.80	34.00	88.46	719.97	26.83	125.00	61.00	90.99	191.54	13.84
Sr	1194.00	180.00	620.77	87735.79	296.20	1242.00	34.00	254.53	100145.06	316.46
Th	27.00	1.80	16.24	44.48	6.67	68.00	0.00	16.16	135.41	11.64
Y	18.00	7.00	12.83	9.73	3.12	15.00	1.00	7.59	19.84	4.45
Zr	169.00	104.80	124.76	350.96	18.73	169.00	88.70	136.27	359.72	18.97

**Table 2:** Results of the discriminant analysis scores.

Variables (xi)	Discriminant Scores (λi)
SiO2	-73.8612
TiO2	-5.3059
Al2O3	113.1645
Fe2O3	-0.2503
MnO	15.0067
MgO	-16.2580
CaO	-4.9400
Na2O	0.6603
K2O	27.2702
P2O5	0.7886
BaO	-1.3156
Ce	-10.6488
Cr2O3	10.6171
Cu	-2.5536
Ni	-1.7120
V	4.7725
Zn	1.7008
Nb	2.2917
Pb	11.6621
Rb	4.1495
Sr	2.5290
Th	-0.3674
Y	-47.3301
Zr	-73.8612

**Table 3:** Results of the discriminant analysis test for the new samples.

Sample#	Alteration type	Discriminant Scores	Predicted Group
1	Potassic	-82.126	Potassic
2	Potassic	-75.253	Transition
3	Potassic	-78.548	Potassic
4	Phyllic	-68.158	Phyllic
5	Phyllic	-72.103	Transition
6	Phyllic	-64.587	Phyllic
7	Potassic	-74.493	Transition

8	Potassic	-81.248	Potassic
9	Phyllic	-69.148	Phyllic
10	Phyllic	-67.572	Phyllic

Table 3: Continue

11	Phyllic	-64.793	Phyllic
12	Phyllic	-67.846	Phyllic
13	Potassic	-78.486	Potassic
14	Potassic	-79.128	Potassic
15	Potassic	-83.012	Potassic
16	Phyllic	-65.712	Phyllic
17	Phyllic	-66.426	Phyllic
18	Phyllic	-71.846	Transition
19	Phyllic	-65.482	Phyllic
20	Phyllic	-70.021	Phyllic
21	Potassic	-72.105	Transition
22	Potassic	-77.864	Potassic

**Conclusion:**

The goal of this paper was to study a numerical method for alteration separation. This method was discriminant analysis. This statistical tool applied to study the alteration boundary and separate them "as well as" possible that the results of this application was agreed with the mineralogical and microprobe analysis. Based on discriminant analysis results, this method properly could to separate the alteration zones and definite a boundary (numeric limit up on 24 microprobe analysis) to separate them effectively. In this method, for each of the variables (elements) their specific scores were obtained and also, the critical value ( $R_0$ ) for separation was finally obtained -73.1603. By comparing this value ( $R_0$ ) with the elements values ( $R_i$ ), we could able to classified the alteration types. According to obtained results, this method could able to separate the alterations finely and the samples that have a near value to  $R_0$  also were introduced as transition zone that in fact this zone is between the potassic and phyllic alterations. Discriminant analysis presents a numerical method and dose not needs more time and interoperation. Since, in Sungun porphyry copper, the mineralization was mostly occurs in potassic alteration, therefore by applying this statistical method, it would be possible to avoid time and money wasting and also focused on the mineralized zones to get the best results in the next investigations and drilling operation. For example in this case, if the rock analysis of the drilling samples reached the near value of  $R_0$ , the drilling operation could be stopped because, as mentioned most of the mineralization in Sungun porphyry copper has been occurred in potassic alteration. Also one of the advantages of this method is to introduce the transition zone which is started from potassic to phyllic alteration gradually. Therefore, since it is very hard to separate the samples microscopically, this method could be very helpful for geochemists to make decision about the alteration zones and the mine future operations. According to obtained results, discriminant analysis could be a powerful tool for mining and petroleum engineers and geologists to applying it in the most earth science problems to achieve the better and more reliable results. Also, it would recommend applying this method in order to identify and quantifying the complex boundaries which need a lot of time and cost.

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