Application of Correspondence Analysis for Anomaly Separation From Background Values at the Enjerd Skarn Area,Northern Iran

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ABSTRACT

Correspondence Analysis Method (CAM) is a non-structural method that it could be used to find the anomaly, and to separate it from the background values. To apply this method, the representative samples of a large area are enough but the exact location of the samples is not important. Based on this method, the litho-geochemical data would be mathematically processed to extract the valuable factors needed for plotting a two by two diagram. This method has been applied on available data in Enjerd skarn deposit. The final factors are potentially able to separate the anomaly from the background by the amount of variable sample separations. Five factors (as the suitable representative factors) have been calculated by applying this method, which has resulted in a final matrix, with 5 columns. According to these factors, we could plot variety diagrams, resulting in the very accurate anomaly separations. In most cases, Co and Ni are paragenetically related, since they show very clear co-separation features.

KEYWORDS:

Enjerd, non-structural method, variation diagrams

1. INTRODUCTION

Copper skarn deposits are mainly associated with granodiorite and quartz monzonite stocks in continental crust. Calcic Cu skarn deposits (as a group) are characterized by an association with felsic porphyry stocks, proximity to stock contacts, high garnet to pyroxene ratios, relatively oxidized assemblages (e.g., andradite garnet with diopsidic pyroxene, magnetite with hematite), and moderate to high contents of sulphide minerals of intermediate sulphidation state (e.g., pyrite, chalcopyrite, sphalerite) [11, 12].

Emplacement of hydrous magmas at shallow crustal levels leads to the liberation of large volumes of fluid into the surrounding country rocks and, in the case of calcareous rocks, the production of the skarn [14, 15]. One of the characteristic minerals crystallizing in higher temperature skarns is andradite, and a feature of this garnet is that it commonly displays complex, oscillatory zonation [12]. This feature has been proved within the Enjerd and is interpreted to reflect temporal variations in the composition of the fluid [11, 12, 13, 14], and thus potentially provides a valuable record of the evolution of the skarn-forming hydrothermal system [10].

The main purpose of this paper is applying a new method called "Correspondence Analysis Method (CAM)" as proposed by [6, 7] to separate the anomaly from background for the first time in a skarn deposit. This method responded very well and it is suggested to be used in other ore deposits, because of its simplicity, low coasts, and high accuracy.

2. GEOLOGICAL SETTINGS

Enjerd skarn copper mineralization is located 28 km north of Aharin the East -Azarbaijan province at northwest Iran, which is considered as a part of a very important Iranian metallogeny zone (Tarom-Gharahdagh belt). The area has been investigated for Cu since hundred years ago.

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The deposit is close to Sungun porphyry copper and Mazraeh (skarn type) deposits. Enjerd skarn has formed by the intrusion of a diorite-granodiorite and quartz-monzonite stock into the Sheivardagh carbonate rocks. The Enjerd shape and its mineralization type is quite similar to that of the eastern skarn part of the Sungun deposit.

The Enjerd stock was emplaced at about 20 Ma into Cretaceous marl and limestone (~500 m thickness), and lower Tertiary volcanic and related clastic sedimentary rocks (1000 to 1500 m thick). The marl and limestone units have been altered to skarn adjacent to diorite/granodiorite but, significantly, not where they are in contact with the earlier monzonite/quartz-monzonite. The bulk of the Cretaceous limestone unit consists of massive, medium- to coarse-grained, grey to white marble. The Enjerd skarn formed mainly in the marls and less commonly in the limestone and marble, in an 80 m wide zone extending 800 m along the eastern flank of the diorite/granodiorite and in narrower discontinuous bodies adjacent to its northern contact (Figures. 1 and 2). Metasomatic effects are evident along the faults and fractures, and are association with andesitic dykes [1, 2, 3, 4]..

In this research, based on the rock sample analyses, the CAM has been applied to separate the anomaly from the background. By factorial CAM and applying the mathematical softwares such as Matlab, two samples for Cu, one sample for Zn and one sample for Co have been identified as anomalies in northestern Enjerd. Generally both northwesternand southwest ern Enjerd skarns are found to be very important targets (in terms of economic geology) to the future explorations.

3. METHODOLOGY

According to geochemical characteristics of the samples, such as rock chemistry, mineral paragenesis and rock petrography it is shown that we are actually dealing with a classic skarn type mineralization. However, applying the simultaneous CAM, [6, 7] the relation between samples and supposed variations has been investigated. Based on this method, the results could be presented in two ways:

1- A one or several dispersion charts called Factorial Correspondence Analysis (FCA)

2- As a dendogram called Clustery Correspondence Analysis (CCA)

The CAM has a strong application in exploration data analysis [6, 7], especially for the geochemical anomaly diagnosis and also to identify the geochemical characteristics of the deposit. This method can easily separate the anomaly from the background. It is also very strong for investigating one or more element variations in the deposit to show the related element concentrations. To apply the CAM, we have to use one or more factors which could be enough to explain the complicated nature in a very accurate model.

4. MATHEMATICAL OPERATION OF CORRESPONDENCE ANALYSIS METHOD CAM

Based on the data available in a geochemical exploration activity, N is supposed to be the number of the samples; M is the number of the elements that have been identified according to the rock analyses. In order to complete the CAM, it is necessary to solve a matrix of $[X]_{n\times m}$ (m: number of elements, n: number of samples) [8].

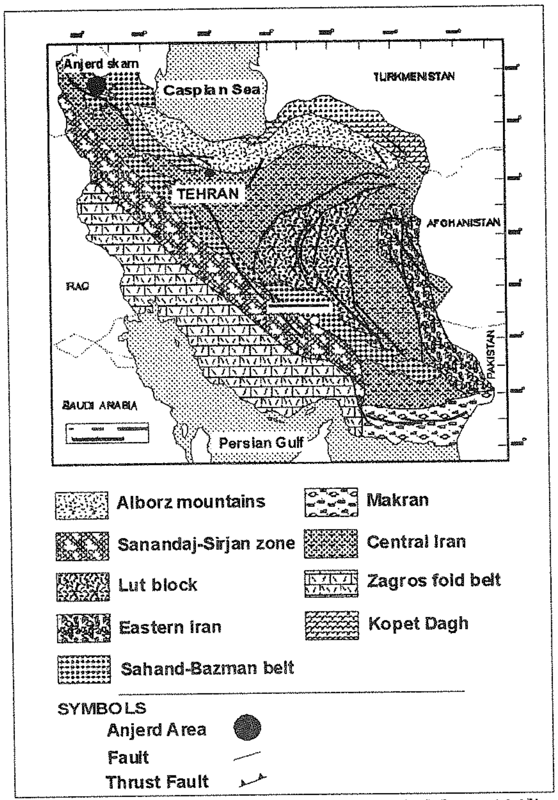

Figure 1. Geological map of Iran (modified from: [16]) showing major lithotectonic units as follows: *1) Zagros fold belt:* Paleozoic platform sediments overlain by miogeosynclinal mid-Triassic to Miocene sediments, and syn-orogenic Pliocene-Pleistocene conglomerates; *2) Sanandaj-Sirjan zone:* Mesozoic granodioritic intrusions and metamorphosed Mesozoic sediments; *3) Central Iran zone:* Paleozoic platform sediments disrupted by late Triassic tectonic activity, and including horsts of Precambrian crystalline basement and Cambrian to Triassic cover rocks; *4) Sahand-Bazman belt:* Calc-alkaline volcanic and quartz monzonite and quartz diorite intrusions of dominantly Miocene age, hosting Cu-Mo porphyry style mineralization; *5) Lut Block:* The Lut block is considered to be an old stable platform, covered by thick Mesozoic sediments and Eocene volcanics; *6) Alborz and Kopeh Dagh zones:* Eocene volcanic and volcanoclastic rocks in the Alborz segment, and in the Kopeh-Dagh segment; *7) The Eastern Iran and Makran zones:* Post-Cretaceous flysch-mollasse sediments.

Thirty two samples have been taken from the Enjerd skarn deposit. They have been selected from 32 different locations and each sample could represent an area of 1 km^2. All these samples have been analyzed using the Atomic Absorption Analytical Method (Table 1). Five variables representing the 5 elements of Ni, Co, Cu, Pb and Zn have been considered.

In the above matrix, the sum of the values in each row is named [r] vector, and the sum of the values in each column is named [c] vector. So every joint (member) of vector can be defined as:

$$r_i = x_{i1}+x_{i2}+x_{i3}+\ldots\ldots+x_{im} \quad (1)$$

$$c_j = x_{1j}+x_{2j}+x_{3j}+\ldots\ldots+x_{nj} \quad (2)$$

ri: is the sum of the variables in sample i

cj: is the sum of the values of j in all samples

So, two diagonal matrixes [R] with dimension of n×n and [C] with dimension of m×m could be considered:

$$[R] = \mathrm{didg}\ (r_1, r_2, r_3, r_4\ldots \mathrm{rn}) \quad (3)$$

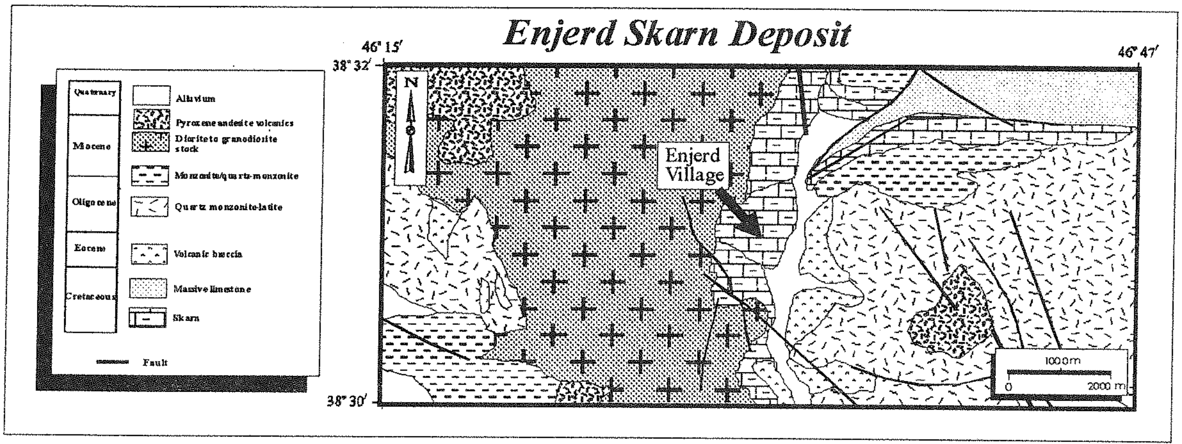

Figure 2. Simplified geological map of the Enjerd area.

Table 1 The analytical results of the Enjerd rock samples (ppm)

No	X(m)	Y(m)	Cu	Pb	Zn	Co	Ni	Ag	Fe
1	135	135	86	11	48	22	56	1.1	13000
2	163	135	72	13	32	14	9	<1	29000
3	190	148	2444	24	101	16	21	1.3	28000
4	225	143	13	7	28	5	11	<1	5000
5	215	125	66	9	52	14	14	<1	34000
6	280	125	116	11	51	11	25	1.1	11000
7	264	113	32	9	47	16	39	<1	35000
8	310	128	26	6	6	1	9	<1	2000
9	320	110	97	5	5	6	32	<1	2000
10	125	175	214	11	27	17	14	<1	36000
11	168	175	98	8	14	16	27	0.4	22000
12	180	178	1815	8	31	16	23	<1	15000
13	192	148	2444	24	309	10	76	21	9000
14	230	170	2445	4	51	14	21	<1	13000
15	298	171	327	4	9	1	8	<1	27000
16	158	207	2952	14	25	5	6	1.4	24000
17	207	238	15	1	11	5	9	<1	15000
18	136	280	42	10	19	9	14	<1	13000
19	155	267	41	4	7	1	4	<1	13000
20	130	320	50	18	20	13	51	1.8	23000
21	137	342	13	25	12	11	12	4.5	2000
22	123	353	31	6	25	7	1	<1	21000
23	153	317	78	5	9	5	6	<1	9000
24	178	340	1603	6	18	11	21	1.2	21000
25	157	342	391	25	22	11	19	3.1	7000
26	198	334	31	8	15	11	8	1.3	78000
27	153	366	17	16	16	10	31	21	3000
28	170	368	30	22	14	11	15	3.2	3000
29	200	385	30	11	12	10	8	<1	27000
30	235	393	13	6	23	12	9	<1	31000
31	204	373	63	10	8	8	20	1.8	9000
32	275	388	44	10	12	9	35	<1	13000

$$[C] = \mathrm{diag}\,(c_1, c_2, c_3, c_4 \ldots cm) \qquad (4)$$

[R] and [C] indicate the diagonal matrix and the values. Values in the parentheses indicate the elements on the main diameter matrix. Now, the following matrix [w] could be defined as:

$$[W] = [R]^{(-1/2)}\,[X]\,[C]^{(-1/2)} \qquad (5)$$

According to the above relationship, -1/2 indicates that, at the first step, it is necessary to actually square the matrix parameters to the power of (1/2), and then calculate the inverse matrix. Based on the calculations, the new matrix called "Matrix [H]" would be defined:

$$[H]= [W]^{T}\,[W] \qquad (6)$$

After defining the matrix [H], the values and vectors could be calculated. Based on these calculations, k "the special value" would be defined; these values are always between zero and one.

$$0<\lambda_k \leq \lambda_{k-1} \leq \ldots \leq \lambda_2 \leq \lambda_1<1 \qquad (7)$$

Then, the even matrixes with any different values could be calculated. Every even vector is correspondent with every even value. Now, two new matrixes could be defined as follow:

$$[A]_{(k\times k)}= \mathrm{diag}\,(\lambda_1, \lambda_2, \lambda_3 \ldots \lambda_k) \qquad (8)$$

$$[B]_{(M\times k)} = [[v_1]\,[v_2]\,[v_3]\,\ldots\,[v_k]] \qquad (9)$$

Matrix [A] is the diagonal matrix that the values on the main diameter are the special mentioned values, and [B] is the matrix, which every column is considered to be an special vector. So two new matrixes could be defined as follow:

$$[U] = [C]^{(-1/2)}\,[B]\,[A]^{(1/2)} \qquad (10)$$

$$[V] = [R]^{(-1/2)}\,[W]\,[B \qquad (11)$$

[U] is m×k dimension matrix, which indicates the relationship between variables and [v] is n×k dimension matrix, which indicates the relationship between samples. The final matrix, in which the main operation of CAM is based on, consists of the last two above mentioned matrixes. To get the final matrix, the value of the matrix [v] must be divided by the value of the matrix [u] (see equation 12). The final gained matrix consists of m+n rows and k columns. This matrix is called correspondence matrix and the columns correspond to the factors. This calculation has been performed by applying the MATLAB 6.0, and the plots have been shown by using the Tec-plot softwares. Since the final calculated values are very small numbers, in order to have better and clearer plots, we increase all the values by 100000 times.

$$[F]=\begin{bmatrix}[V]\\ [U]\end{bmatrix} \qquad (12)$$

In order to cover all the changes, five factors have been considered; and based on those, ten dispersion diagrams could be presented. Now, it is the time to discuss about the result of calculations. Figure 3 shows the dispersion diagram related to the factors 1 and 2. There is an obvious separation of Co, Cu and Ni from the other variables (elements). This separated variable could be the result of:

1- Anomaly value of that variable

2- The separation of one sample with respect to a variable could be the result of an anomaly value of that variable, or that the sample is actually an anomaly. According to this fact, based on figure 3, sample No. 21 shows a weak anomaly for Cu, and the samples No. 4 and 8 are enriched in Pb (anomaly), and samples No. 26, 29 and 30 are enriched in Co (anomaly).

Figure 4 shows the dispersion diagram related to the factors 1 and 3. As it is illustrated, sample No. 8 shows a clear orientation toward Cu. It means that, this sample has a Cu anomaly. Samples No. 26, 29 and 30 show a weak anomaly for Co.

[F]=

0.2442	1.9976	0.1629	0.093	5.762
0.3382	-1.3693	-2.2319	-0.8576	7.5422
-0.0068	-0.036	0.0103	-0.2597	0.127
-5.921	2.5247	-8.5733	3.0671	23.5385
-0.5552	0.5243	-3.5756	-0.584	7.3516
-0.7113	0.6033	-1.0728	-0.9687	4.5352
-0.3536	3.6	-1.3273	1.3402	10.6617
-6.2285	-0.7053	6.7756	-1.8321	22.0798
0.2562	2.3032	3.1587	-1.9728	5.8585
0.3848	-0.3152	-0.1753	-1.5118	2.3247
1.4914	0.8954	1.0769	-1.2246	5.0129
0.0142	-0.042	0.0417	-0.3581	0.1609
-0.0422	0.0006	-0.035	-0.2102	0.1551
0.0055	-0.0298	0.0246	-0.2798	0.1143
-0.0758	-0.2048	0.2721	-1.9119	0.9755
0.0025	-0.0364	0.0289	-0.2419	0.0874
3.6783	11.8295	-5.3156	0.0359	31.3681
0.074	-0.4555	-0.5782	-0.0496	12.7736
-3.2207	-2.1372	0.3765	-6.5472	12.4609
-0.2871	2.2786	3.422	1.3103	9.6263
-0.7435	-13.1752	4.5508	8.1084	24.9928
-1.1517	-2.9982	-10.491	-1.4117	15.8273
0.4423	-1.0134	0.1443	-4.0646	6.422
0.0155	-0.0473	0.0571	-0.4248	0.1768
-0.0541	-0.392	0.2424	-1.073	1.1487
3.7635	-2.4196	-2.7866	0.492	17.1894
-0.8116	1.7648	5.3263	4.6535	19.1509
-0.3044	-6.0982	2.7341	3.3051	16.4212
2.8377	-5.1106	-0.4901	1.3529	18.2464
4.421	0.7725	-9.3398	3.7804	24.876
0.6224	0.2687	3.0385	-1.1827	9.3974
0.1377	3.5967	4.5928	0.8289	12.1261
0.1414	-1.6652	1.7619	-16.836	14.5122
-12.1503	-66.0866	26.9159	32.9894	152.7241
-9.6392	8.9465	-41.39	1.3559	91.812
38.1904	-8.7014	-19.885	17.3177	144.8057
-2.8422	40.917	37.8828	13.2669	120.0996

F: Correspondence Matrix

Figure 5 shows the dispersion diagram related to the factors 1 and 4. According to this calculated diagram, for samples No. 23 and 19, Cu is clearly separated from the others, and it could be the evidence for copper anomaly in these samples. In samples No. 29, 30 and 19, Ni and Co are showing the same characteristics. Figure 6, is the result of calculations performed based on factors 1 and 5. In this figure, there is no sign of Cu separation, which means that no anomaly for this element can be observed in the related sample

Figure 7 shows the dispersion diagram related to the factors 2 and 3. In this figure it is clear that there is a separation for Co and Cu. It means that the sample is anomalous with respect to these elements.

Figure 8 shows the dispersion diagram related to factors 2 and 4. According to this diagram, for samples No. 23 and 19, Cu is clearly separated from the others, and it could be the evidence for copper anomaly in these samples. Figure 9 illustrates Ni and Co separation from the rest of the variables. It could be the reason for the homogeneous behavior of these elements in skarn deposits. In Figure 10, samples No. 23 and 19, again show a Cu anomaly, which is also reported in [9].

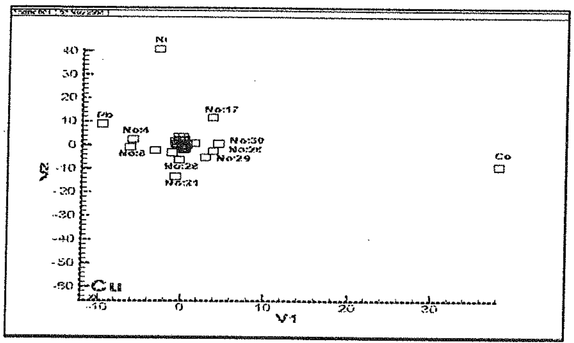

Figure: 3: A plot of factors 1 and 2.

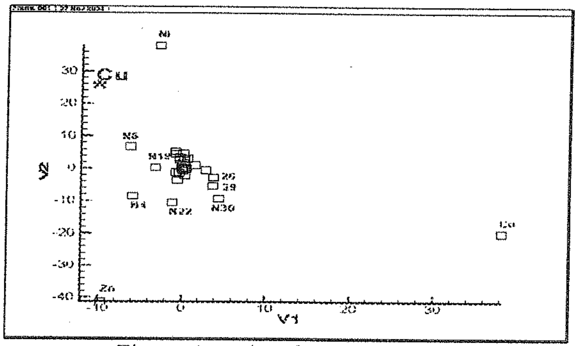

Figure: 4: A plot of factors 1 and 3

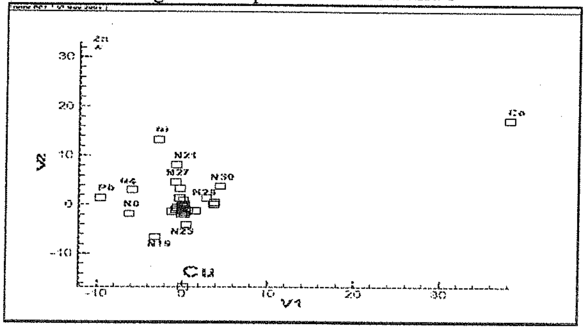

Figure: 5: A plot of factors 1 and 4

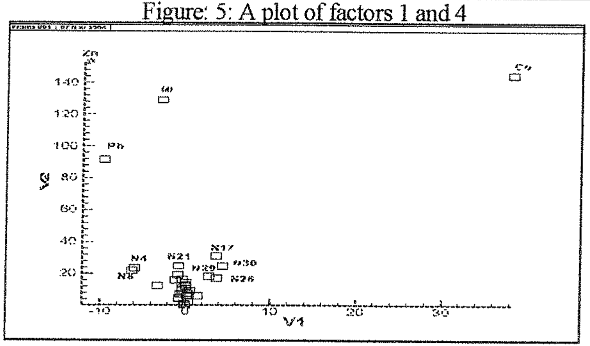

Figure: 6: A plot of factors 1 and 5

Figure 11 shows the dispersion diagram related to factors 3 and 4. In Figure 12, again in samples No. 19 and 23, Cu is clearly separated from the others, and it could be the evidence for copper anomaly in these samples. For Ni and Co, there is also a clear separation from the rest of the variables. It could be the reason for the homogeneous behavior of these elements in skarn deposits.

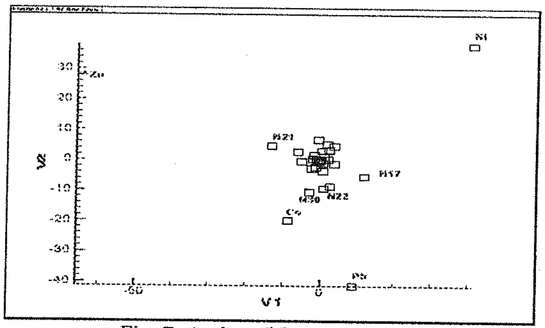

Fig. 7: A plot of factors 2 and 3

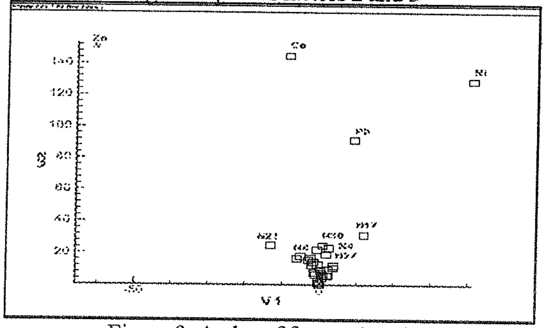

Figure 9: A plot of factors 2 and 5

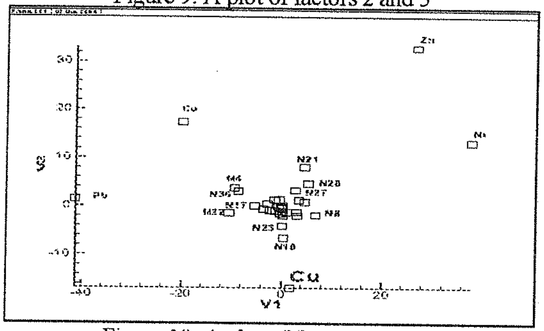

Figure 10: A plot of factors 3 and 4

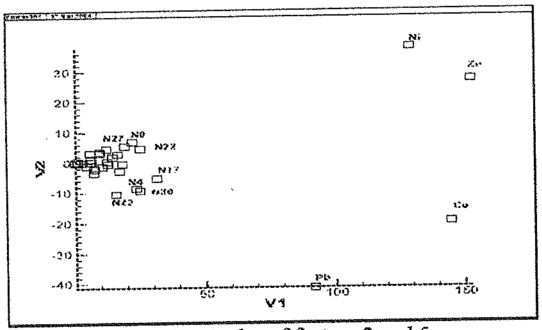

Figure 11: A plot of factors 3 and 5

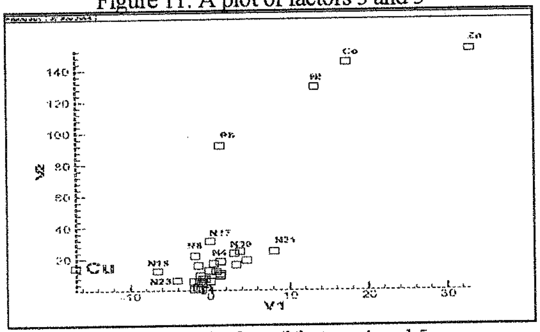

Figure 12: A plot of factors 4 and 5

5. CONCLUSION

The Enjerd diorite/granodiorite stock intruded the Cretaceous marl and limestone at approximately 20 Ma (Miocene), and produced Enjerd skarn alteration assemblage. For the first time, a new method called CAM, has been applied to separate the background from anomaly in this type of deposits. Applying the CAM, based on the rock geochemical data, different anomalies have been defined in the Enjerd skarn deposit. Ten factors have been considered and based on the calculations (discussed in the text) it is revealed that samples No. 19 (41ppm) and 23 (78ppm) (as the representative sample for a large area) contain economic levels of Cu, and sample 22 contains economic level of Zn and samples 26, 29 and 30 contain almost large contents of Ni and Co. Samples No. 26, 29 and 30 are also showing Pb anomaly. The same behavior for Ni and Co is considered to illustrate their similar geochemical characteristics in the Enjerd skarn. This method helped us to eliminate the geochemical exploration target within the studied area and it could be used to easily find other economic ore deposit targets in various geological regions.

6. REFERENCES

[1] Berberian, M. (1976), Contribution of the Seismotectonics of Iran (PartII). Geological Survey of Iran. v. 39, 518

[2] Berberian, M., (1983), The Southern Caspian: A compressional depression floored by a trapped, modified oceanic crust: Canadian Journal of Earth Sciences. v. 20,.163-183

[3] Mehrpartou, M. (1993). Contribution to the geology, geochemistry, ore genesis and fluid inclusion investigations on Sungun Cu-Mo porphyry deposit, (north-west of Iran), Ph.D thesis, Hamburg Univ., Hamburg, 245p.

[4] Stocklin, J. (1977). Structural correlation of the Alpine ranges between Iran and Centeral Asia. Mem. H. Aser. Society of Geologique France, p. 333-353.

[5] Berberian, M., and King, G. C. (1981). Toward a Paleogeography and tectonic evolution of Iran: Canadian Journal of Earth Sciences. v. 18, p. 210-265.

[6] Hongjin, J., Youngzheng, Z., and Xisheng, W. (1995). Correspondence cluster analysis and its application in exploration geochemistry, Journal of Geochemical Exploration, v. 55, p. 137-144.

[7] Valenchon, F. (1982), The use of correspondence analysis in geochemistry, Mathematical Geology, v.14 (4), p. 331-342.

[8] Hassanipak, A. and Sharafodin, M. (2002), Exploration data analysis, Tehran University Publication.

[9] Hezarkhani, A. (2003). Enjerd skarn geochemistry and its association with economic copper mineralization, Azarbaijan - Iran, Journal of Amirkabir University, p.158-175.

[10] Yardley, B. W. D., Rochelle, C. A., Barnicoat, A. C., and Lloyd, G. E. (1991). Oscillatory zoning in metamorphic minerals: an indicator of infiltration metasomatism: Mineralogical Magazine, v. 55, p. 357-365.

[11] Jamtveit, B. (1991). Oscillatory zonation patterns in hydrothermal grossular-andradite garnet: non-linear dynamics in regions of immiscibility. American Mineralogist, v. 76, p. 1319-1327.

[12] Jamtveit, B., Bucher-Nurminen, K., and Stijfhoorn, D. E. (1992). Contact metamorphism of layered shale-carbonate sequence in the Oslo Rift: I. Buffering, infiltration and the mechanisms of mass transport: Journal of Petrology, v. 33, p. 327-422.

[13] Kwak, T. A. P., and Tan, T. H. (1981). The geochemistry of zoning in skarn minerals at the King Island (Dolphin) Mine: Economic Geology, v. 76, p. 468-497.

[14] Crawford, M. L. (1977). Calcium zoning in almandine garnet, Wissahickon Formation, Philadelphia, Pennsylvania: Canadian Mineralogist, v. 15, p. 243-249.

[15] Einaudi, M. T. (1977). Petrogenesis of the copper-bearing skarn at the Mason Valley mine, Yerington district, Nevada: Economic Geology, v. 72, p. 769-795.

[16] Hezarkhani, A., and Williams-Jones, A. E. (1998). Controls of alteration and mineralization in the Sungun porphyry copper deposit: Evidence from fluid inclusion and stable isotopes. Economic Geology, v. 93, p. 651-670.