Application of the concentration- area method to separate induced polarization anomalies data against classical statistics: A case study of Hamyj Porphyry Copper Deposit; Iran

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Abstract

Determining geophysical anomalies from background is a fundamental process in geophysical exploration. In this paper, the threshold value for induced polarization data have been determined by concentration- area (C-A), gap statistics, probability graphs and normal distribution curves. A comparison between the determined thresholds and these methods has been carried out statistically. The fractal method (as well as the other methods) is usually applied in geochemical exploration studies but it has not been widely used in geo-electrical methods so far. In this research, this method has been successfully utilized to process IP data (separating induced polarization anomalies from the background in Hamyj copper deposit). Hamyj deposit is located about 80 kilometres west of Birjand city, South Khorasan province, eastern Iran. In this area, resistivity and induced polarization data have been collected by dipole-dipole array. Finally, it was revealed that the determined threshold by the fractal method is higher than the other three methods. Therefore, the fractal method could lead to reducing the anomaly area and decrease uncertainty significantly. The concentration-area method has determined a threshold with more reliability.

Keywords: Induced Polarization; Fractal Method; Gap Statistic; Probability Graphs; Normal Distribution.

1- Introduction

Integrated geophysical methods are commonly used in mineral exploration to obtain reliable results (Ramazi and Mostafaie, 2013; Pardo *et al*., 2012). Induced polarization (IP) is a technique in geophysics, and has been employed in base metal exploration and to a minor extent in groundwater prospecting. The voltage across the potential electrodes generally never drops to zero instantaneously, and decays rather slowly, after an initial large decrease from the original steady-state value (Telford *et al*., 1990). Although induced polarization was known in the 1920s, it was not until the 1950s that IP for detecting economic mineralization was used routinely (White *et al*., 2003). Measurements of induced polarization are common in both frequency and time domains. Measurements in the time domain are usually carried out more than the frequency domain according to quick measurement and time saved better in this method. (Holmann, 1975).

In the past decades, various methods have been applied to separate anomalies from background.

Statistical methods are one of the most widely used separation techniques. The conventional statistic methods such as probability graphs, normal distribution and etc. (Sinclair, 1974; Sinclair, 1976; Sinclair, 1991; Stanley *et al*., 1989; Govett, 1975) ignore spatial information and spatial autocorrelation structure of data. However, there are other statistical methods which significantly take the spatial structure of data into account (e.g. moving average method, factor analysis and etc.) (Grunsky and Agterberg, 1988). These methods have been developed further more in geochemical data than geophysical data. Fractal and multiracial models have also been applied to separate anomalies from background. These models include the Concentration- area model (C-A), Spectrum-Area model (S-A), Multifractal Singular Value Decomposition (MSVD), Concentration- Distance model (C-D) mapping singularity technique and etc. (Zuo *et al*., 2009).

A contour map provides a smoothed version of the spatial distribution of an element. The contour map is used to obtain relations between area A(p) and concentration value p, with A(p) decreasing for increasing p. When the area and concentration follow a fractal mode, a strong correlation is achieved between the area and concentration. This correlation is considered by Equation (1) (Cheng *et al*., 1994).

$$A(p) = Cp^{-\alpha} \qquad \text{Eq.1}$$

Where C is a constant and á is the exponent that may have several values for different ranges of concentration values (Cheng *et al*., 1994). The concentration-area method plots all logarithmic graphs of the concentration versus area (the cumulative counts). The fractal dimension anomaly is different from the fractal dimension background. Therefore, the corresponding value of fractured line is used as a threshold.

The gap statistic method is a statistic method based on the distribution function that can estimate the threshold (limit separation anomaly from background). The first step in using this method is to normalize utilized data, as this method reveals unbiased results as long as database shows normal distribution (Hassanipak, 2005). In the next step, the transformed data is sorted according to its value, they are standardized so that the mean and standard deviations of each element is zero to eliminate the effects of scale. The threshold level is determined by the gap statistic method.

The probability plot showing different slops can propose different classes . The most important issue separating mixed populations determines the mixing ratio of the population and obtains the separation boundary. (Hassanipak, 2005).

The application of fractal and multifractal concepts has given rise to better understanding of geophysical phenomena from micro to macro levels. Various papers have been written based on the application of fractal on various fields such as oceanic waves, climatic and geophysical flow dynamics, etc. (Scholz and Mandelbrot, 1992; Barton and La Pointe, 1995; Barton and La Pointe, 1995; Dhu *et al*., 1999).

One of the difficulties in the interpretation of induced polarization data is to accurately separate anomaly from background. Experimental methods have been used so far and they have already been widely applied in the related fields. In this paper, various methods of separating anomalies from the background of induced polarization are compared with each other. These separation methods have been generally used in the geochemical data. In addition, this can create new methods to separate anomalies from background in geophysical interpretation like geochemistry data processing.

2- Study area

Hamyj copper deposit is located in Birjand province, eastern Iran. The access road is shown in Figure 1. The area chosen for this case study is the Cu porphyry mineralization district. The results of the remote sensing and geological surveys show the promising mineralization. As far as the petrological field is concerned, this area is composed of volcanic rocks such as Dacitic volcanic dome, Gabbro, Dacite, Altered Andesite and Andesite and sedimentary rocks such as old Gravel.

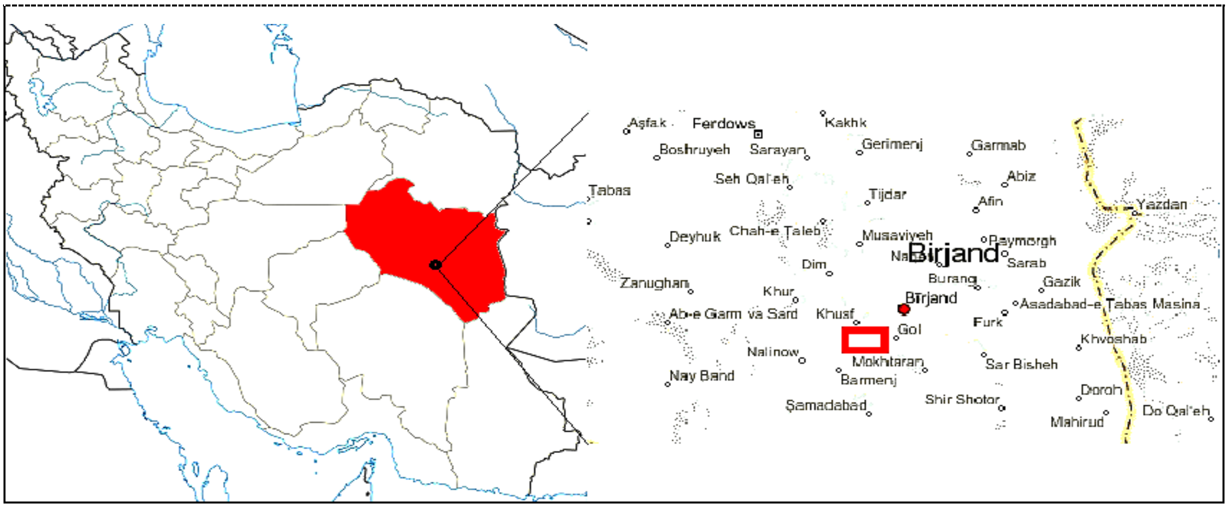

Figure 1) Map of Iran and the studied area.

Gabbro and Andesite Dacite are related to the age of the Cretaceous and Paleogene period, respectively. The geological map is presented in Figure 2. The geoelectrical surveying with electrode spacing of 20m was designed to study and model the mineralization more accurately with more details. The orientation of the two profiles which have been investigated is near N-S. Moreover, maximum depth is around 100m and ultimately 209 induced polarization data has been studied in this paper (Ferdows and Ramazi, 2015).

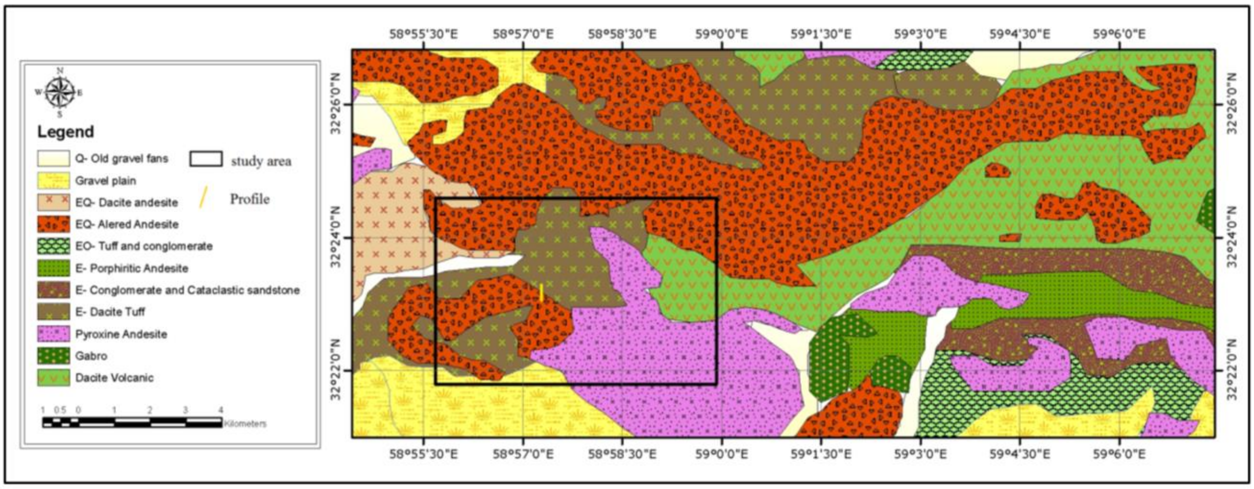

Figure 2) Geological map of the region, based on 1/100000 Birjand geological map (Sahbani et al., 1987)

3- Discussion

Low and high extreme values have been always considered a challenging problem in geophysical datasets. These extremes should be identified, replaced or removed. In this paper, it was done based on the Doerffel method at 95% confidence level. After detecting the noise data, polarization data were inversed by the Newton method. Inversion was done by Res2mod software. Then the following steps were performed on the data.

3.1- Concentration-Area Fractal Method

Induced polarization data must be classified in the first step for the concentration-area method.

Therefore, data were classified to seven classes according to Sturge's Rule. The difference between the upper and lower bound is equal to 7.9 mV/V per class. Since the distance between the electrodes is 20 m, the distance between the points is 20 m in the cross section. Therefore, each point covers a surface which has an area of 20 m×3.24 m, 20 m×10.25 m, 20 m×17.43 m, 20 m×25.33 m or 20 m×34.01 m for which the induced polarization is determined in the center of each cell. One of the sections is presented in Figure 3.

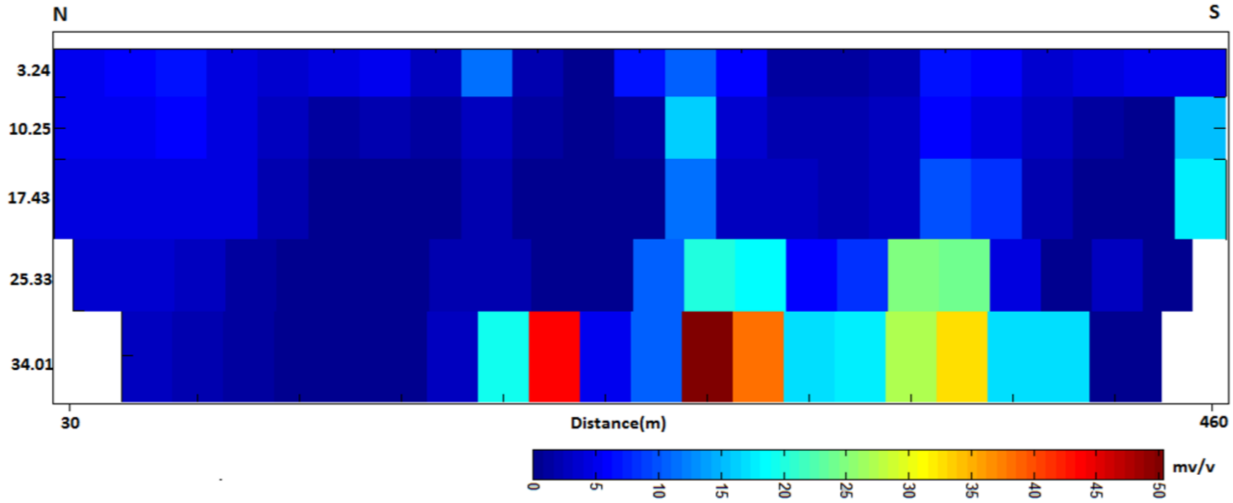

Figure 3) Cell layout induction of polarization data area of 20 × 20.

In the second phase, the area of the induced polarization should be calculated, (the graphs of all logarithmic is traced so that induced polarization is on the horizontal axis and the area is on the vertical axis) (Figure 4).

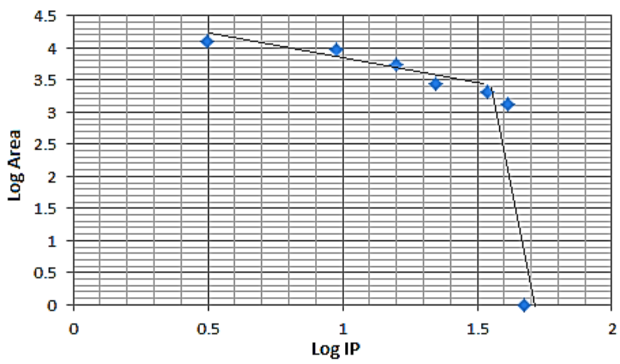

Figure 4) Graph of logarithmic induced polarization- area.

Figure 4 shows that two lines are consistent on the points (Equation 2 and 3) that are most correlated with the data. In these Equations, R is the correlation coefficient. In statistics, the coefficient of determination is the proportion of the variance in the dependent variable that is predictable from the independent variable(s).

$y= -0.714x + 4.5244; \; R^2=0.812$ Eq. 2

$y= -23.959x+40.618; \; R^2=0.804$ Eq. 3

Breakpoint lines indicate changes in population; therefore, the breakpoint should be considered as the threshold, because the fractal dimension of anomaly is different from fractal dimension of background in the mentioned point. According to Figure 4, the amount corresponding to the fractal is determined as 28 mV/V after back transformation. Hence, according to this method, approximately 3.9 percent of the data are anomalies.

3.2- Gap Statistic

The distribution of induced polarization data has been transformed to normal standard data by Minitab16 software, Johnson transformation. The following steps were performed to determine gap statistics.

A) Calculating the difference between two successive values (z_{i+1}- z_i)

B) Calculating the average of the two successive standardized values, so called ($m=\frac{zi+1+zi}{2}$)

C) Calculating the gap statistic according to the following equation for the standard normal data.

$$f(m) = 0.3989 \times (e^{\left(-\frac{1}{2}*m\right)}) \quad \text{Eq. 4}$$

After calculating the gap statistic, these values are multiplied by the difference between two successive values (G(i)) and the value of m, corresponding to the maximum value chosen as a guideline (Hassanipak 2005). The value of m is equal to 1.56. The value of m is achieved as the threshold if it is multiplied by the standard deviation and summed by the data mean. The parameter of the mentioned process has been reviewed in Table 1.

Given the amount of Standard Deviation data, 9.15, and mean data equal to 6.6, the threshold based on gap statistic is estimated as 20.9 millivolt per volt according to Equation (5).

$$\mu + |-1.56| * s = 6.6 + 1.56 * 9.15 = 20.9 \quad \text{Eq. 5}$$

Approximately 7.3 percent of the surveyed data are considered as anomaly based on this method.

Table 1) Partial gap statistic methods.

z(i+1)-z(i)	m	f(m)	G(i)
0.049317	1.7576-	0.954875	0.047092
0.046411	1.70973-	0.932444	0.043276
0.003761	1.68465-	0.9209	0.003464
0.051982	1.65678-	0.908241	0.047212
0.002153	1.62971-	0.896113	0.001929
0.142135	1.55757-	0.864575	0.122887

3.3- Probability Graph

In order to ensure to the non-normal distribution of the induced polarization data, the probability plot and histogram were plotted (Figure 5a and 5b).

The inflection point was determined in the first step in order to use gap statistics to separate anomaly from background, and the first inflection point was considered as 10. The probability plot and histograms have been plotted in Figures 6a and 6b.

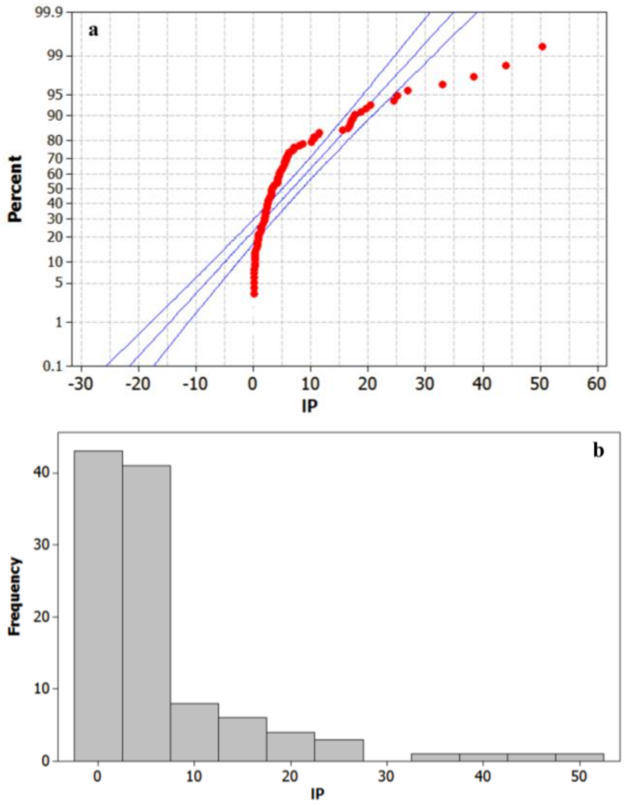

Figure 5a) Probability plot data; b) Histograms data.

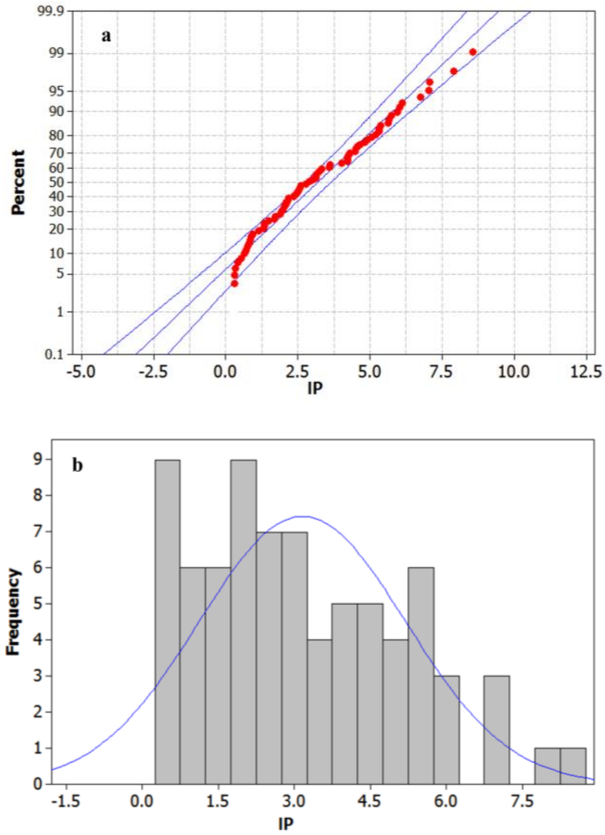

Figure 6a) Probability plot of data is less than 10; b) Histograms of data is less than 10.

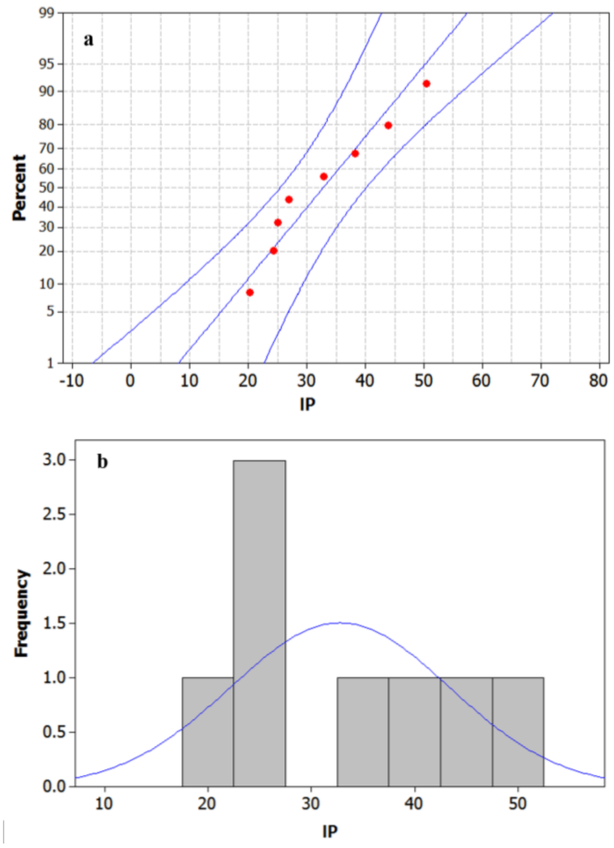

Figure 7a) Probability plot the data higher than 20; b) Histograms data higher than 20

According to Figure 6a, since the probability plot is a straight line, the data are relevant to a population. However, this does not occur for the data over 10. According to the probability plot in Figure 7, the second inflection point is 20 mV/V. The probability plot and histogram were drawn for values from 10 to 20 and above 20 mV/V. The probability plot and histogram are given for above 20 in Figures 7a and 7b.

Table 2) Results of different methods to determine threshold of induced polarization data.

Method	Threshold(mV/V)
Fractal(C-A)	28
Gap statistic	20.9
Probability plot	20
Normal distribution	20

According to the probability plot, three populations were partitioned. Thus, values higher than 20 mV/V are considered as the anomalies. Based on this method, approximately 7.3% of the data are anomalies.

Table 2 summarizes the threshold parameters due to fractal, gap statistic, probability plot and normal distribution process of the studied area.

4- Conclusions

In this paper, four methods have been used (fractal, gap statistics, probability plot and normal distribution) to separate anomaly data from the background dataset of induced polarization. These separation methods have been vastly used in geochemical data. In addition, this can create an innovative method to separate anomalies from background in geophysical interpretation as well as geochemical data processing. The mentioned processes lead to obtaining the following results:

A) Gap statistic, probability graph and normal distribution reveal almost an analogy results for threshold of induced polarization data. However, the gap statistic is preferable due to a strong scientific basis in comparison with the other two methods. The probability graph is not recommended due to employing the trial and error technique. Thus it is a very time consuming process and there is a risk of confusion. Also, by calculating the threshold using probability plot, gap statistic and normal distribution about 5 percent of data were considered as anomalies.

The three studied methods also revealed lower threshold than the fractal method, therefore they are suitable for areas with a low number of anomalous data.

B) The fractal method has set out a higher threshold as compared to the other three methods. This method can be used in a case where a high number of anomalies data exist and it could be argued that this method has acted more confidently due to a much higher threshold. The fractal method revealed the anomalies standing as three percent of the database.

C) By calculating the threshold via the fractal method, approximately three percent of the data were considered as anomalies. Reducing anomalous zones can significantly decrease the cost of drilling.

According to the above results, attempts have been made to order the process of separating anomalies of induced polarization data with the given methods. If the number of anomalous data is high, the fractal method (C-A) can lead to more reliable and accurate results and the gap statistic reveals better results in a case that the low anomaly of data with a small range of data exist. As far as accuracy of the process is concerned, the gap statistic is better than the other two statistical methods.

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