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INTEGRATED SPATIAL AND SPECTRUM ANALYSIS FOR GEOCHEMICAL ANOMALY SEPARATION

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SUMMARY

A new approach for separating geochemical anomalies from background has been developed on the basis of an integration of spatial and spectrum analysis. A map generated from geochemical data can be transformed into a frequency domain in which a concentration-area fractal method can be applied to distinguish the patterns on the basis of the power-spectrum distribution. Three distinct classes can be generated: low, intermediate and high power-spectrum values which are generally corresponding to background, anomalies and noises of geochemical values in a spatial domain. An irregular filter can be consequently constructed on these distinct patterns with low and high power-spectrum values being removed. The image converted back to a spatial domain with the filter applied will show patterns which mainly reflect the geochemical anomalies with the influences of background and noises being removed. This method has been demonstrated using a case study of soil geochemical data from Mudik area, on the island of Sumatra in Indonesia. The results obtained from this method have also been compared with those obtained from other methods.

1. INTRODUCTION

Separation of anomaly from background is the fundamental task in geochemical exploration. The methods and strategies for conducting this task have been investigated by many authors and from various aspects of the geochemical data. The properties from which one can differentiate distinct populations of geochemical data often include value frequency, spatial variability of geochemical values, geometric characteristics and scaling properties of geochemical anomalies [1][3]-[5]. For example, one often classify anomalies according to quartile levels of geochemical values or the natural breaks of the value distributions. It has been noticed that the geometries of the geochemical anomalies often provide clues for anomaly interpretation, for example, linear anomalies may imply structural controls, and arcuated anomalies may be associated with intrusive bodies. It has been generally accepted that spatial and geometric information of anomalies might be essential for anomaly separation. There are various techniques available for characterizing spatial and geometric information of geochemical data (see review in [1]). In addition to spatial properties of the anomalies, frequency properties caused by different geological processes may be useful for anomaly identification. For example, patterns caused by random errors during sampling in the field and chemical analysis in the laboratory may show random patterns with high frequencies, the background patterns related to regional geological processes may correspond to large patterns with low frequencies, and mineralization of various types may generally cause anomalies with intermediate to high frequencies. On the other hand, anomalies may have variable frequencies which can not be identified by any regular sharp boundaries. However, the anomalies may show distinct patterns of spatial distribution of power-spectrum in the frequency domain which can be distinguished by spatial analysis methods such as the concentration-area fractal model. The distinct patterns separated can be converted back into a spatial domain to represent the anomalies with the influences of background and noise values removed.

Fourier transformation and inverse Fourier transformation provide the foundation for converting field (map) between spatial and frequency domains. Fourier transformation can convert geochemical values into a frequency domain in which different patterns of frequencies can be identified. The signals with certain ranges of frequencies can be converted back to a spatial domain by means of inverse Fourier transformation. In this paper, the spatial distribution of power-spectrum values in a frequency domain is characterized and distinct patterns are separated using the concentration-area fractal method which was originally developed for anomaly separation in a spatial domain [1][3]. Three distinct patterns of power-spectrum values were distinguished: patterns with high, intermediate and low power-spectrum values. These three patterns of power-spectrum values converted back into the spatial domain would correspond to geochemical patterns of background, anomalous and noise geochemical values.

2. SPECTRUM ANALYSIS

Spectrum analysis has been extensively applied in geophysics for image enhancement and anomaly separation, for example, distinguishing signals of different frequencies which may reflect the responses of geological bodies with different sizes and occurring at different depths from the earth surface [6]. From a spectrum analysis point of view, a pattern can be viewed in two different domains: in a spatial domain and in frequency domain. Mathematically, signals or patterns in a spatial domain can be considered as superimposed signals of different frequencies. These signals can be decomposed into components, each of which is of a certain range of frequencies. Fourier transformation can be used to convert signals from a spatial domain into a frequency domain. The decomposed signals of various frequencies can be recombined by means of inverse Fourier transformation to reconstruct the signals in a spatial domain [6].

3. FILTERING

A function, $f(x, y)$, (a geochemical map) in a spatial domain can be converted into $F(K_x, K_y)$, a function of "wave numbers" K_x and K_y in a frequency domain. This function F can be modified by multiplying a filter function, $G(K_x, K_y)$, so that certain ranges of wave numbers can be eliminated and others enhanced. The filtered map $F \times G$ in a frequency domain converted back to the spatial domain will represent the decomposed function and patterns with the influences of signals in certain wave lengths being enhanced and others eliminated. It can be seen that this process has a great similarity as the processes involved in geochemical anomaly separation. The conventional filters ($G(K_x, K_y)$) in physics, electrical engineering and geophysics are low-pass, high-pass, bandpass and directional bandpass etc. A low-pass filter generally eliminates the signals with long wavelengths. A high-pass filter eliminates short wavelength waves, therefore, enhances the signals in high frequencies. A bandpass is indeed a combination of low-pass and high-pass which can enhance signals with intermediate wavelengths. The common characteristics of these filters are that they are based either on regular patterns such as circular, elliptical and donate shapes delineated only by the wave numbers (K_x and K_y) without taking into account the spatial distribution of the power-spectrum values [2], or on a regular transformation of the power-spectrum [7][9]-[11]. In the current paper, filters with irregular shapes will be constructed on the basis of not only wave numbers (K_x and K_y) but also the spatial distribution of power-spectrum $F(K_x, K_y)$. Firstly, a map can be generated from the power-spectrum ($F(K_x, K_y)$) by means of Fourier transformation. Then the concentration-area fractal method can be applied to separate the power-spectrum patterns into different classes (for examples three classes identified in the case study to be illustrated in the next section) according to the self-similarities (self-affinities) of the distribution of power-spectra: low, intermediate and high power-spectrum values. A filter is then constructed by converting the high and low values of the FT into zero

$(G(K_x, K_y) = 0)$ and the intermediate values into one $(G(K_x, K_y) = 1)$.

4. GEOCHEMICAL ANOMALY SEPARATION

4.1. Cu Concentration Values In Soil Samples from Mudik, Indonesia

The method introduced in the previous sections will be applied to the geochemical data obtained from soil samples in Mudik area, Indonesia. The dataset consists of 1665 soil samples collected by Colony Pacific Exploration Inc. in Mudik area in 1997 (Fig. 1) [8]. These samples were analyzed for 29 elements including Au, Cu, Pb, Zn, As, Sb, Ba, etc. These data were studied using multivariate analysis techniques by Grunsky and Smee [8] for studying mineralization and volcanic ash distributions in the area. More detailed geology and other relevant information about the study area can be found in Grunsky and Smee [8]. In the current study, only will the Cu values be used to demonstrate the application of the integrated spatial and spectrum analysis method. It has been shown that the distribution of Cu concentration values in the study area might be related to mineralization [8]. The spatial variability of Cu values can be seen from the semivariogram and the contour map created by means of kriging in Figs. 2 and 3. The semivariogram shows a strong spatial correlation within 1.2 km which can be fitted by a power-law type model. The map created using kriging (Fig.3) clearly shows the anomalies with elevated Cu-values covering a large zone, oriented northwest-southeast, in the middle of the map but not the anomalies located in the upper-right part of the map where the background Cu-values are relatively low. In the following section, the integrated spatial and spectrum analysis will be applied to the map in order to enhance and separate the anomalies from background, especially those week anomalies in a background with relatively low Cu concentration values.

4.2 Integrated Spatial-Spectrum Analysis

In order to apply the integrated spatial and spectrum method, firstly, Fourier transformation was applied to the map created using kriging in Fig. 3. The obtained power-spectrum $F(K_x, K_y)$ is not displayed. High values of power-spectrum F are mainly distributed around the centre of the map, corresponding to low frequencies. The power-spectrum values decrease in general as moving away from the centre. The distance from the centre can be measured in wave numbers or inverse wavelengths. There have been many studies on the frequency distributions of power-spectrum, but most of them use a power-spectrum against wave numbers or wavelengths and few studies have been reported on the spatial distribution of the power-spectrum. Since the spatial distribution of power-spectrum is determined not only by the wave numbers but also by the power-spectrum function, it should be characterized by the concentration-area fractal method [3]. The areas against the values of the power-spectrum are plotted on log-log paper (Fig. 4). The values were fitted with three straight lines by means of LS which give two cutoff values 600 and 200 yielding three distinct patterns of power-spectrum values: power-spectrum > 600, power-spectrum value from 200 to 600 and power-spectrum value < 200. An irregular filter was constructed on the basis of these three patterns in such that the areas with power-spectrum values either greater than 600 or less than 200 have been removed (Fig. 5). Applying this filter to Fourier transformed power-spectrums and then converting them back to the spatial domain provides the geochemical map with the influences of high frequency noise and low frequency background signals being removed and thus anomalies being enhanced (Fig. 6). In addition to the anomalies with elevated Cu values which were highlighted in Fig. 3, several small east-west oriented anomalies have been identified in the right-upper part of the study area which could not be detected directly in the spatial domain using the concentration-area method (results not displayed).

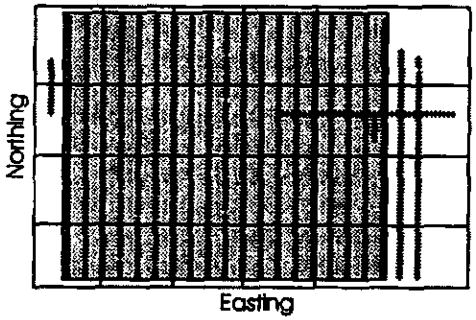

Fig. 1. Locations of 1665 soil samples collected for a mineral exploration program by Colony Pacific International Inc. in the Mudik area, Indonesia (Grunsky and Smee, in press)

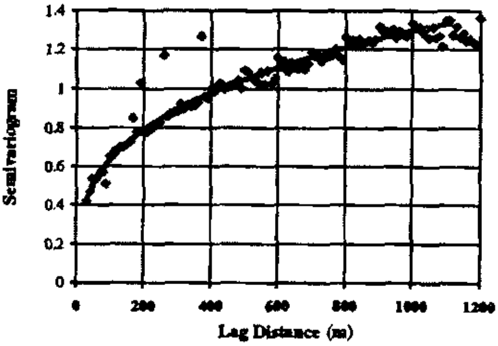

Fig. 2. Semivariogram obtained for Cu-values. Dots represent observed values and smooth line was fitted by means of LS in a log-log scale.

Fig. 3. Kriging map from 1665 Cu-values. Power-law model was used. Solid lines represent relatively high values and dashed lines for relatively low values. The shaded patterns represent the anomalies identified by means of the concentration - area fractal model in a spatial domain (see text for detailed explanation).

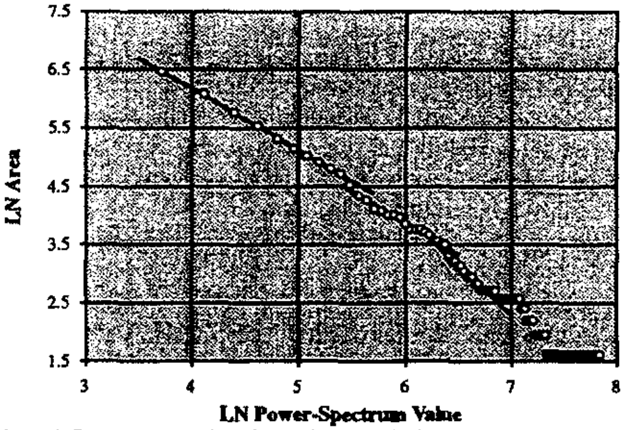

Fig. 4. Log-log plot showing relationship between areas and power-spectrum values. Dots represent the values of the power-spectrum and areas. Three straight line segments were fitted using LS. Logarithm is natural logarithm. The three cutoff obtained are 200, 600 and 920, respectively.

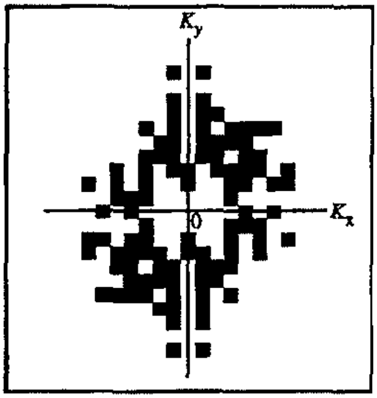

Fig. 5. A filter constructed on the basis of three distinct patterns identified on Fig. 4. The black patterns represent the areas with power-spectrum values between 200 and 600.

Fig. 6. A geochemical anomaly map obtained by inverse FT with the filter on Fig. 5. The shaded patterns represent the anomalies with the influences of background and noise signals being removed (see text for detailed explanations).

5. CONCLUSIONS

The integrated spatial and spectrum analysis newly proposed in this paper uses an irregular filter constructed on the basis of the distinct characteristics of the spatial distribution of power-spectrum. It can generate a geochemical map in a spatial domain such that the components of signals which show self-similar patterns in a frequency domain can be eliminated or enhanced. The distinct patterns identified by means of the concentration-area fractal method in a frequency domain do not correspond to sharp bounds of wave numbers, although, generally represent low, intermediate and high frequencies. Therefore, the anomalies obtained on the inverse Fourier transformed geochemical anomaly map do not have the same frequency in a frequency domain but show spatially related patterns with intermediate frequencies in the frequency domain which can be distinguished in terms of self-similarity or self-affinity. Comparing the results obtained from Cu values in the Mudik area using the concentration-area fractal method in a spatial domain, with those obtained using the integrated spatial and spectrum in frequency domain, shows that the large anomalies with elevated Cu values in a background with a relatively high Cu values can be identified both in a spatial domain using the concentration-area method and a frequency domain by means of spatial and spectrum analysis. However, anomalies located in the background with relatively low Cu-values can be detected only by the integrated spatial and spectrum analysis in a frequency domain.

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