Decomposion of Geochemical Map Patterns Using Scaling Properties to Separate Anomalies from Background

Qiuming Cheng
York University, Department of Earth and Atmospheric Science, Department of Geography
4700 Keele Street, Toronto, Canada, e-mail: qiuming@yorku.ca

1. INTRODUCTION

Separating signals into components and reducing noise to signal ratio commonly involves the process of pattern recognition. Geochemical determinations of total or bulk concentration of elements in soils, humus, tills and rocks are used commonly in geology for detecting the influences of particular geological processes such as mineralization. Decomposing bulk values into component patterns to reflect specific geological features is often essential for prediction of mineral resources and mineral exploration. A number of parameters have been used in the past for pattern recognition. These include the magnitude of patterns, frequency distributions, geometry and texture. More recently, scaling properties have been recognized and incorporated in the pattern recognition (Cheng, Agterberg and Ballantyne, 1994; Cheng, Xu and Grunsky, 1999; Cheng, 2000; Xu and Cheng, 2001). Scaling refers to the property that change of measuring unit does not alter the function type between measure and measuring unit. The governing function for scaling is the power-law function, $\mu(\varepsilon) \propto \varepsilon^{\alpha}$, where $\mu(\varepsilon)$ is a measure performed at scale ε, $\propto$ stands for "proportional to" and α is the power-law exponent. Homogeneity scaling needs only a one-dimensional function with a unique exponent; otherwise, for generalized scale invariance, additional functions are needed to characterize the directional and rotational scaling properties. Physical processes over different scaling ranges result in the mixing of different components. Consequently, multiple scaling properties may be anticipated in modeling such measures. This paper introduces a recently developed method for decomposing geochemical patterns on the basis of scaling breaks detected from the power spectrum field. A case study of airborne gamma ray spectrometer data (uranium/potassium) serves to demonstrate how the method can be used to separate radiometric anomalies from background to reflect late stage igneous activities related to U-Sn-W mineralization in southwestern Nova Scotia, Canada.

2. MULTIFRACTAL SCALING

Fractal scaling of a measure (fractal or multifractal) usually involves both the range of scale (ε) over which the measure holds the scale invariant property and the actual scaling governing power-law itself, $\mu(\varepsilon) \propto \varepsilon^{\alpha}$. The scaling range may be limited due to either the nature of the relevant physical process or the resolution and quality of the observed data. Therefore, while it is important to utilize the power-law exponent to characterize the scaling properties of the measure, the scaling range itself plays an important role for differentiating between superimposed fractals or multifractal measures with different scaling properties. There have been many examples of fractal quantities showing bi-fractal properties (texture and structure dimensions). Most of the bi-fractal examples documented in the literature are defined in the space domain with a geometric measuring scale. A new power-law model was developed from a multifractal point of view by Cheng (2000) to characterize the scaling property of the power-spectrum in the Fourier domain. It involves power-law relations, $A(\geq S) \propto S^{-2/\beta}$, between the power spectrum values ($S = \|F(W_x, W_y)\|$) and the "area" of the set with power spectrum values above S, $\{W_x, W_y: \geq S\}$, where F denotes Fourier transformation of the measure $\mu(x, y)$; W_x, and W_y represent wave numbers in horizontal and vertical directions, respectively. The range of the exponent is $0 < \beta \leq 2$ or $1 \leq 2/\beta$ with the special case of $\beta = 2$ or $2/\beta = 1$ corresponding to non-fractal or monofractal measure μ, and $1 < 2/\beta$ to multifractals (details in Cheng, 2000). This model holds true for both isotropic measures and measures with generalized scale invariance. Most patterns created from exploratory geochemical and geophysical data can be considered as mix components due to multiple processes. It may be anticipated that the power-law relationship $A(\geq S) \propto S^{-2/\beta}$ shows multi-scaling properties over multiple scale ranges. The scaling breaks bounding the multiple ranges of power spectra can be identified on log-log plots of $A(\geq S)$ vs. S. Each such scale range then can be used to define a filter. Taking two filters for example, and assuming two ranges of power spectrum can be identified by fitting two different power-law relationships with exponents β_1 and β_2, respectively, then the threshold S_0 obtained from these two power-law relations can be used to form the two sets $\{W_x, W_y: S \leq S_0, \beta_1\}$ and $\{W_x, W_y: S_0 \leq S, \beta_2\}$, which can be further used to define two filters $G_1(W_x, W_y) = 1$ if $W_x, W_y \in \{W_x, W_y: S \leq E_0, \beta_1\}$ and otherwise $G_1(W_x, W_y) = 0$. The other filter can be $G_2(W_x, W_y) = 1 - G_1(W_x, W_y)$. Inverse Fourier transformation can be applied with these filters to move the decomposed measures back into the space domain: $\mu_1(x, y) = (F\ G_1)^{-1}$ and $\mu_2(x, y) = (F\ G_2)^{-1}$. $\mu_1(x, y)$ and $\mu_2(x, y)$ are the decomposed patterns of $\mu(x, y)$. In this special case where $G_1 + G_2 \equiv 1$, then, $\mu_1(x, y) + \mu_2(x, y) = \mu(x, y)$. In the more general case that a small range of power spectrum corresponding to a noise component is removed during the definition of the filters, the sum of the decomposed components will be slightly different from the original patterns. The decomposed components, $\mu_1(x, y)$ and $\mu_2(x, y)$, can be nonfractal, fractal, or multifractal quantities with less variability in comparison with the bulk measure $\mu(x, y)$.

3. DECOMPOSITION OF AIRBORNE GAMMA RAY SPECTROMETER PATTERNS

For demonstrating the application of the preceding method, uranium (eU), thorium (eTh), and potassium (K) gamma ray spectrometer data were taken from Meguma Terrane, southwestern Nova Scotia, Canada. Rock types in this district are mainly Paleozoic granites and low grade metamorphosed sedimentary rocks (Fig. 1). A number of gold (Au), copper (Cu) and uranium-tin-tungsten (U-Sn-W) deposits have been recognized in the area. Most known U-Sn-W deposits are concentrated in the granites and all gold deposits occur in the metamorphosed sedimentary rocks (McMullin, Richardson and Goodwin, 1986). The late stage igneous activity is one of the main geological controlling factors of the U-Sn-W mineralization in the area (Chatterjee, 1983, Xu and Cheng, 2001). The patterns of eU, eTh and K ratios may reflect the variations of the phases of igneous complex. Fig. 2 shows the distribution of U/K. The space resolution of the map is 250 meter and the pixel values are ranging from 0 to 255. The values are linear transformations of the remotely sensed values of U, Th and K (Ford et al., 1989). Multifractalities of these data including their ratios were investigated by Cheng (2000) using multifractal and spatial analysis modelling. It was concluded that the values of U, Th and K are close to being monofractals but the U/K, Th/K and U/K are close to multifractals. U/K can be used again to

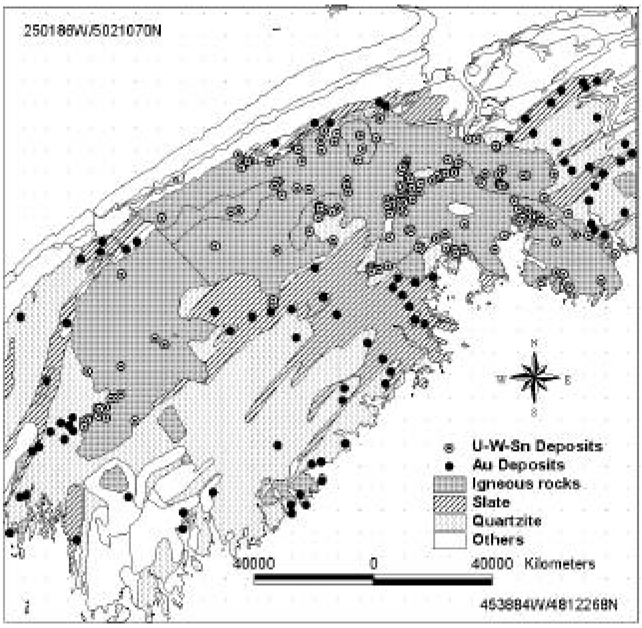

Fig. 1 Simplified geology of the southwestern Nova Scotia, Canada.

demonstrate the decomposition of radiometric patters for separation of anomalies to reflect the U-Sn-W associated late stage igneous activities.The power spectra (S) were calculated for the U/K image using 2-D Fourier transformation. Logarithmic values of S and A were plotted against each other as shown in Fig. 3. Straight-line segments were fitted to the values representing different power-law relationships. The two straight lines fitted by means of LS yield exponents – 1.77 (±0.06, R = –0.997) and –0.97 (± 0.002, R = –0.964), respectively, where ± represents the standard error and R is the correlation coefficient. Results (see Cheng, 2000) obtained for other images eU, eTh, K, eU/eTh, and eTh/K have consistently shown that the power spectra of the measures, U, Th, K, U/Th and U/K possess two different power-law relationships or bi-fractal properties as observed from the plots of A(≥S) vs. S. The bi-fractal properties may imply that multiple geological processes led the observed the patterns of U, Th and K. The components with relatively higher frequencies (lower values of S) give larger slopes ($2/\beta > 1$) implying that these components may be multifractals whereas the background components with lower frequencies (higher values of S) may correspond to nonfractals or monofractals. The threshold $S_0 = 100$ ($\log S = 2$) obtained for U/K was used to form the two filters $\{W_x, W_y: S \leq 100, 1.77\}$ and $\{W_x, W_y: 100 \leq S, 0.97\}$. The decomposed component obtained from the inverse Fourier transform with the first filter applied provides the pattern related to the later stage of igneous activities as shown in Fig. 4. More complete application of S-A method to the U, Th, and K data can be found in Xu and Cheng, (2001).

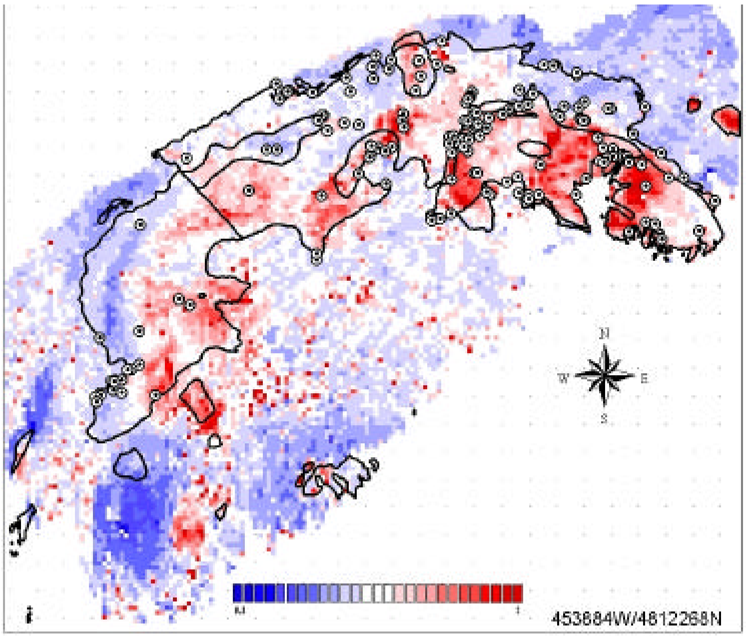

Fig. 2 Ratio of values U/K. Polygons represent igneous rocks. U and K images are from Ford et al. (1989).

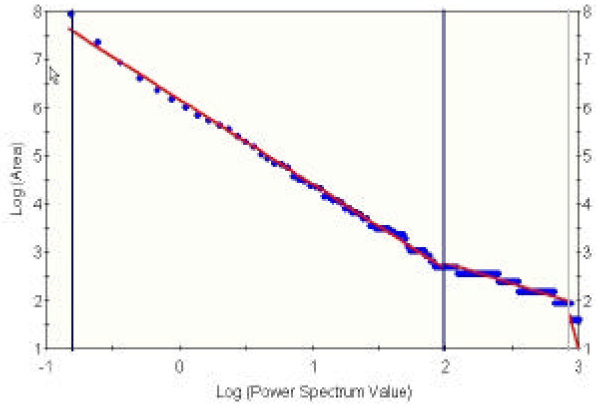

Fig. 3 Log-log plot showing relationships between power spectrum values calculated for U/K and areas with power spectrum above a threshold. Two main straight-lines were fitted to the values by means of least squares.

4. CONCLUSIONS

Multiple scaling including the bi-fractal property as the special case is a common phenomenon for modelling patterns created by multiple processes. Scaling breaks observed during fractal modelling may be used for distinguishing between patterns (fractal or multifractals) with distinct scaling properties including scaling ranges. Filters constructed on the basis of scaling breaks of power spectra for A(≥S) vs. S (S-A) plots provide a new way of decomposing patterns, which has potential as a general method of geochemical and geophysical anomaly separation.

ACKOWNLEDGEMENTS

Thanks are due to the IAMG for the financial support for presenting this paper at the ISI2001 meeting. The author would like to thank Dr. F.P. Agterberg for inviting this contribution and reviewing the manuscript and to Dr. A. Panahi for reading the manuscript and constructive comments.

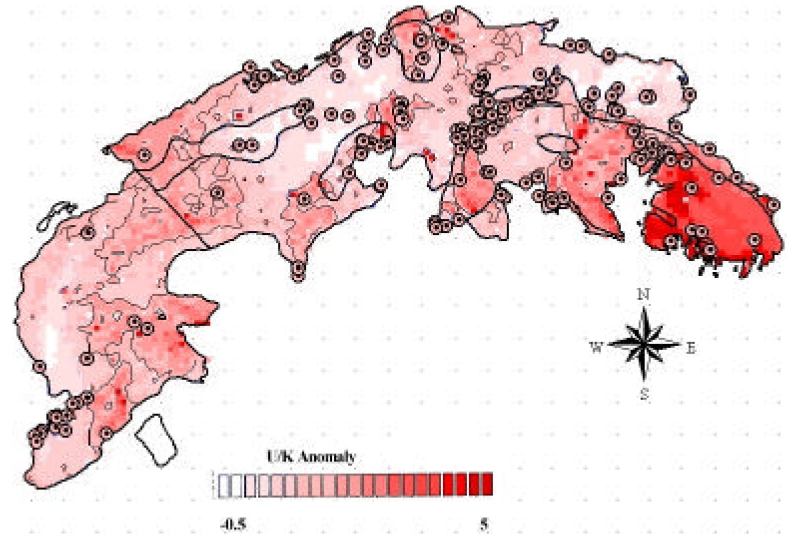

Fig. 4 Anomalies obtained from applying the filter with power spectrum values < 100 shown as the left segment on Fig. 3.

REFERENCES

Chatterjee, A. K., 1983, Metallogenic map of Nova Sotia, ver. 1, scale 1:500,000, Department of Mines and Energy, Nova Scotia, Canada.

Cheng, Q., 2001, Selection of Multifractal Scaling Breaks and Separation of Geochemical and Geophysical Anomalies, China J. Earth Sciences (in press).

Cheng, Q., 2000, Multifractal modeling and spectral analysis of gamma ray spectrometer data, J. Mathematical Geology (under review).

Cheng, Q., Xu, Y., and Grunsky, E., 1999, Integrated spatial and spectral analysis for geochemical anomaly separation, in Proc. of the Conference of the International Association for Mathematical Geology, S.J. Lippard, A. Naess and R. Sinding-Larsen (eds.) Trondheim, Norway, v. 1, p. 87-92.

Cheng, Q., Agterberg, F. P., and Ballantyne, S. B., 1994. The separation of geochemical anomalies from background by fractal methods. J. Geochem. Explor. 51, 109-130.

Ford, K.L., Carson, J.M., Grant, J.A., and Holman, P.B., 1989, Radioactivity maps of Nova Scotia. Geological Survey of Canada, Map 35006G (scale, 1:500,000).

McMullin, J., Richardson, G., and Goodwin, T., 1986, Gold compilation of the Meguma Terrane in Nova Scotia, Nova Scotia Department of Mines and Energy, Open Files 86-055, 056.

Xu, Y. & Cheng, Q., 2001, Detection of alterations using GIS techniques, J. Economic Geol., accepted.

RESUME The recent development of application of scaling properties for decomposion of patterns has provided a new way for separating geochemical and geophysical anomalies. Scaling distinctions (scaling range and power-law exponent) can be detected from the power spectrum field (S) by employing a newly developed $A(\geq S) \propto S^{-2\beta}$ (Spectrum - Area) multifractal model. Multiple scaling properties (bi-fractal properties as a special case) are observed from airborne gamma ray spectrometer data (U, Th and K) from Nova Scotia, Canada. The components decomposed using the scaling property of power spectrum in the lower value range (S < 100) may reflect the anomalous patterns related to U-Sn-W mineralization and the exponent $2/\beta = 1.77$ (>1) may indicate multifractal anomalous patterns, whereas the background values obtained using the power spectrum (S > 100) with the exponent $2/\beta$ close to 1 may represent non-fractal patterns.