Fractal analysis of geochemical data in prospecting for oil

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Abstract - **In this paper the structure of Shannon's** *Abstract*: **The paper describes possible ways of interpreting a complex of geochemical anomalies used in prospecting for oil and connected with the analysis of gas survey. The use of fractal features of power spectra and gas diffusion peculiarities in the fractal medium has allowed constructing a linearized model of spatial hydrocarbon migration. The proposed procedure of the fractal analysis of geochemical data is tested on a number of practical examples.**

I. INTRODUCTION

A geochemical map normally is constructed from a set of geochemical point data sampled in the surficial media available over an area at a certain scale. With respect to the prediction of hydrocarbon accumulations, the geochemical map usually is needed for determining anomalies and characterizing background of concentration values of A geochemical map can, however, be completely understood and then serves to the above purposes correctly and effectively only after its raw data have been processed properly. This is because the sampled data usually are the end products of many geological processes, especially for the dataset from the "secondary media" such as stream sediments and lake sediments. The point data from different locations may have different sources , so does the value in a single sample.

There have been two basic approaches used to analyze regional geochemical data: frequency analysis and spatial analysis. The frequency statistical analysis refers to the techniques characterizing the frequency distribution of values. It has been noticed that for the last two decades many methods based on the frequency statistics have been extensively and in some cases successfully used in the geochemical data exploration [1-4]. Most of these methods use the values of sampled data for differentiating samples coming from different source areas with an assumption that the geochemical data obey a certain form of distribution (normal or log normal). The fundamental geological assumption for these methods is that the populations generated by different geological processes may be distinguishable statistically.

In the contrary, the spatial analysis refers to the methods dealing with spatial aspects of the geochemical data such as the spatial distribution of values in a 2-D map. Although the frequency statistical and spatial statistical analysis are the main techniques for the processing of local and regional geochemical data, some disadvantages in these methods for separation of different components of a geochemical field have been noticed [5]. For the frequency statistical analysis:

a) the single or two global thresholds selected by such methods like histogram analysis and probability plot may not work well in the situation where the background of a geochemical field has significant variation;

b) using the frequency information of value distribution may be not sufficient to divide the data set if the sourses overlap each other severely in their values;

c) the spatial distribution and geometry of a geochemical anomaly are very important information for mineral exploration, which should not be ignored.

For the traditional spatial statistical analysis techniques:

a) the spatial analysis methods like Kriging and the moving average generally are not the methods for the selection of a threshold or thresholds;

b) the interference caused by the size and shape of a pre-defined operating window often exists, for instance, whether the moving average methods or the other spatial filters such as the fractal concentration area model [6,7] in which the both frequency and spatial data were considered.

The basic geological assumption for this method is that a geochemical field or image generated by specific geological processes may be distinctable in terms of fractal properties. The distribution of geochemical values may abide a certain power-law relations with scaling. The previous works on fractal and multifractals have shown that most geological processes generate patterns showing scale invariant The scale invariant property often shows "self-similarity" or "self-affinity". These properties could be measured from both the frequency and spatial domains [8]. In the spatial domain, the scaling properties are related to the spatial geometry of the patterns, the distribution of the values and the varying in its geometry corresponding to the changing in its value. In the frequency domain, such properties are mainly represented by the distribution of power spectra [6,9].

The fractal filter described in this paper is defined on the basis of the power law properties of a power spectrum and wavelet transform. The purpose to do so is to extract the components, each of which has the same or similar scaling property. The filter, therefore, can be used to decompose the anomalies from background.

II. FREQUENCY AND FRACTAL FILTERING

Since the fractal filtering technique was developed on the basis of the fractal concentration area model and the frequency filtering technique, both of them will be briefly reviewed at the following two sections.

Fractal Concentration-area Model . Cheng, Agterberg and Ballantyne [7] developed a fractal method from a mutifractal point of view to separate geochemical anomalies from the background.. It involves a concentration-area plot on log-log paper showing power-law relations between the area A(ρ) with an element concentration value higher than ρand the concentration value ρ

$$A(\rho) \propto C\rho^{\alpha} \quad (1)$$

where ∝stands for "proportional to where C is a constant and αis the exponent that may have several values for different ranges of geochemical concentration values ρ. On the log-log paper, the values of A(ρ) against the ρmay be fitted by a number of straight lines. The breaks of the straight line and the corresponding values ρcan be picked up and used as the cutoff(s) to separate geochemical values into different components such as anomalies and background.

Frequency Filtering Technique. The frequency filtering techniques are popular for signal processing in physics, geophysics and engineering. Signals or patterns in a spatial domain are considered as superimposed signals with various wavelengths. These signals or patterns can be decomposed into the corresponding components, each of which falls in a special range of frequencies. Two dimensional signals or maps in spatial domain can be readily transformed into the frequency domain by means of Fourier transform, which gives a pair of maps containing the real (F_r) and imaginary (F_i) components of a spectrum, respectively. Power spectrum can be calculated as [10]:

$$E(\omega_x , \omega_y) = F_r (\omega_x , \omega_y)+ F_i(\omega_x , \omega_y),$$

where ω_x and ω_y are spatial wave numbers in x and y directions, respectively.

There are many geophysical data processing and image processing methods built up on the power spectral analysis. In the field of regional geophysical data processing, Specter and Grant [11] initiated a famous filtering method for dividing the subsets from an aeromagnetic field through seeking break(s) on the plot of ln [*E(f)*] against $f=r/2\pi$, where $r = \sqrt{\omega_x^2 + \omega_x^2}$ It has been noted that the model can be improved if a geophysical field is treated as the fractal field. The self-similarity or self-affinity nature could be characterized by a powerlaw distribution in which its power spectrum (E) is proportional to a power (α) of spatial frequency (f) [14,15], which can be expressed as)

$$E(f) \propto f^{-\alpha} \quad (2)$$

where αis called isotropic scaling exponent [13,14]. For a potential field with the field source at the depth *h* below the measuring plane, the equation can be represented as [12].

$$E(f) = e^{-2hf} f^{-\alpha} \quad (3)$$

where αis the isotropic exponent, *h* is the depth of source. If the αis a constant, the equation can be used to calculate the depth t according to relation of *E (f)* and *f*. If *h* equals to 0, the equation (3) reduces to (2). In this case, the different values may be extracted for different ranges of *f*on the log (*E*) against log (*f*) plot, which can generate filters to decompose the original field into subsets, each of which has the distinct scaling property.

These model uses the relationships between power spectrum *E*(*f*) and its frequency *f*in the partition of a field. Since it has the isotropic assumption, the model is not suitable to process geochemical field due to its anisotropic nature, especially for the geological patterns caused by thermal solution-related mineralization which is often controlled by linear structures such as faults or contact zones.

The anisotropy structural information in a field is often reflected in the twodimensional power spectrum. This anisotropy can be characterized using a proper method based on the analysis of the distribution of power spectrum [5, 9, 15, 16]. The relationship between the 'area', A(≥ E), on the power spectrum plane with power spectrum values above a threshold E and the power spectrum E may show power-law relationships. It has been proved the power-law relationship holds true at least for the field with isotropic scaling or generalized invariant scaling property [16]

$$A(\geq E) \propto E^{-\beta} \quad (4)$$

Different values of βestimated by plotting values of log A(≥ E) vs log E for various ranges of E, based on which filters can be constructed.

Since the filters generated by equation (4) in Fourier space can retain the anisotropy of the power spectrum with the identical scaling properties. The patterns with the distinct fractal properties and anisotropy can be obtained in spatial domain by the inverse Fourier transform with the filters applied.

The described techniques has been applied to analysis various types of geochemical data such as lake sediment [17], rock samples [7], and humus [18], for predicting the turbiditehosted, gold deposits [5]. However in prospecting for oil-and-gas reservoirs the fractal filtering is still used insufficiently wide.

III. FRACTAL FILTERING AND WAVELET TRANSFORM

In a oil prospecting, geochemical researches take a special place. Complicated ways of migration of hydrocarbons do not allow to compare univalently with geochemical anomaly and its sources.

Nevertheless, at some assumptions it is possible to construct similar scheme of interpretation of geochemical data [19].

Let's consider basic elements of such scheme

1. Check of power-law relations between the area A(ρ) with an element concentration value higher than ρand the concentration value ρ

In figure 1 it is shown, that (for various regions and various chemical elements) on the log-log paper, the values of A(ρ) against the ρmay be fitted by a number of straight lines. So the breaks of the straight line and the corresponding values ρcan be picked up and used as the cutoffs to separate geochemical values into different components such as anomalies and background.

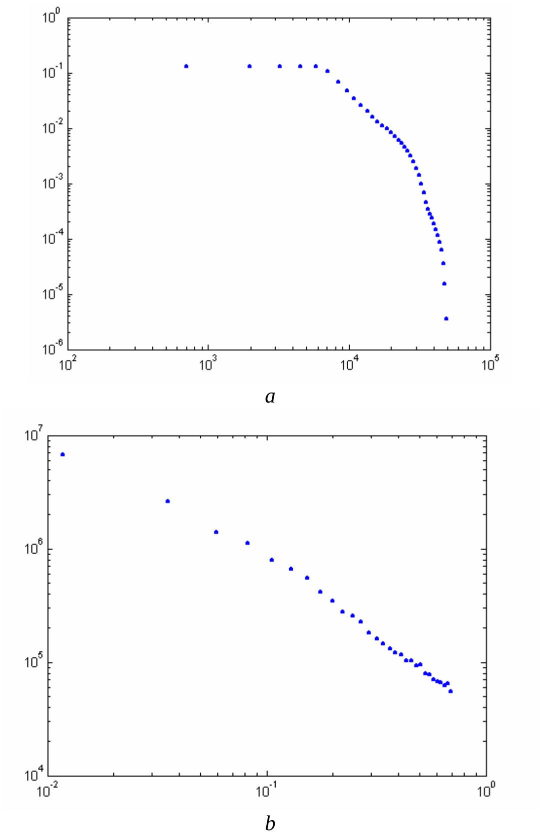

Fig.1 Power-law relations between the area A(ρ) with an element concentration value higher than ρand the concentration value ρ (a -for C_2H_2 the south of western Siberia, b- C_2H_6 the north of western Siberia)

2. Geochemical anomalies above oil accumulations and gas are formed as a result of migration of hydrocarbons. Process of formation of anomalies is controlled by a diffusion equation in fractal medium.

Examination of various processes in fractal medium usually result ins to the equations in fractional derivatives, which is defined by Oldham and Spanier (1974). It is generally accepted that for a spatially correlated media such as fractally fractured reservoirs, the memory of the fluid and non-locality are very important in all stage of production as previously explained. It is known that fractional calculus successfullv describes such characteristics of the anomalous diffusion. There are two major approaches of fractional calculus for the study of anomalous diffusion. The latter is known to fully describe diffusional feature relatively well. In this study, Metzler et al.'s work is applied to the derivation of a three-dimensional fractional diffusion equation. The material balance equation for radial diffusion is

$$\frac{\partial^{2/d_w}}{\partial t_D^{2/d_w}} p_D(r_D, t_D) =$$

$$= \frac{1}{r_D^{2d_f/d_w - 1}} \frac{\partial}{\partial r_D}\left(r_D^{2d_f/d_w - 1}\right) \frac{\partial}{\partial r_D} p_D(r_D, t_D)$$

where d_f – spatial fractal dimension, d_w – dynamic fractal dimension, characterizing diffusion exponent (in fractal medium $d_w > 2$), p_D, t_D- dimensionless variables of the pressure and the time.

Thereof the simple relations taking place for potential fields and connecting measured parameters of a geochemical field, essentially become complicated.

Nevertheless, it is possible to gain relations similar (3) and to coordinate a power spectrum of the measured geochemical field, its fractal performances, and a source distance

$$E(\omega_x, \varpi_y) = e^{-2hg(\omega_x, \varpi_y, d_f)} g(\omega_x, \varpi_y, d_f)^{-\alpha}$$

where g - the function depending from spatial and temporary frequencies

By means of these relations it is possible to separate geochemical values into different components.

But we used some other approach.

3. As the basic tool for selection of subsurface of identical fractal dimension the wavelet transform.has been used

It is well known; the wavelet transform (WT) is a localized transform in both time (space) and frequency (wavenumber) [20], and this property can be advantageously used to extract information from a signal that is not possible to unravel with conventional Fourier or even windowed Fourier analysis. The wavelet multiresolution representation also provides an extra dimension to visualize and analyze a signal. There are various types of wavelets, orthogonal, biorthogonal or non-orthogonal, that can be chosen for wavelet analysis.The wavelet is helpful in analyzing signals in time and frequency simultaneously, while the wavelet phase is useful in locating discontinuities and identifying fractures, layering and also the fractal nature of data. With the information of wavelet variance, or spectrum, one can identify at what WT voices coherent events of interest are best expressed and perform detailed analysis at those voices.

Wavelet-transformation with its hierarchical base it is well adapted for the analysis of cascade processes, turbulent signals, fractal and multifractal sets having the hierarchical nature.

Energy (or a variance) coefficients of wavelet-transform is proportional to a variance of analyzed data and gives an energy distribution of process on scales. The opportunity of reception of this performance locally allows, for example, at the analysis of turbulent processes not only to gain a set of the characteristic scales, on and objectively to define the scales related to coherent structures, and to explore variability of process

On coefficients wavelet transform, and also on values of local extremes it is possible to calculate dimensionality analyzed fractal object or spectrum of dimensionalities multifractal object/

It is necessary to note, that the choice of wavelet type is not simple problem without a definite form of a signal in source. In calculations it was usually used Daubechies-wavelet [20], but this problem demands additional study.

4. The basic geological assumption is that a geochemical field One of the basic assumptions for this method is that only vertical migration of hydrocarbons has been considered. It has allowed to connect subsurface of the certain fractal dimensions, allocated by means of wavelet transform and a apparent depth, on which such object could be.

In aggregate it has allowed to build hypothetical 3-D models of distribution of a studied element with depth. It allows to compare with the given geochemistries to other methods more adequately.

The example of such construction is shown in figure 2

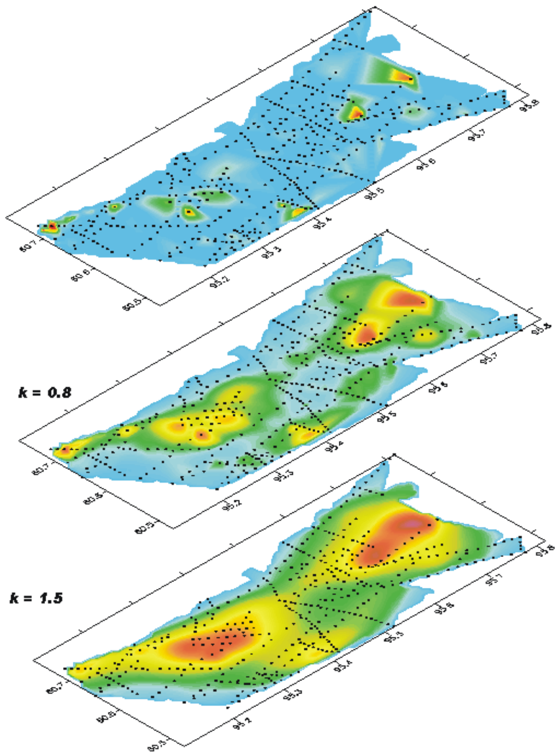

Fig. 2. Results of fractal filtration of geochemical data (black points are the measurement site of geochemical parameters, k-values of angular factors of the straight lines segments selected by means of a power-law relations between the area A(ρ) with an element concentration value higher than ρ and the concentration value ρ

In figure 3 is shown the comparison of results of 3-D simulation of geochemical anomaly with structural prospect mapped using seismic methods on an investigated site.

IV. CONCLUSIONS

The fractal filtering technique is an effective method for decomposing the different components of a geochemical map according to its scaling properties. The anomalous and background patterns obtained using these filters from the geochemical data may reflect the normal geological processes, respectively. The technique does not need to pre-define operating windows. Instead, decisions on defining filters are made based on the processed geochemical field.

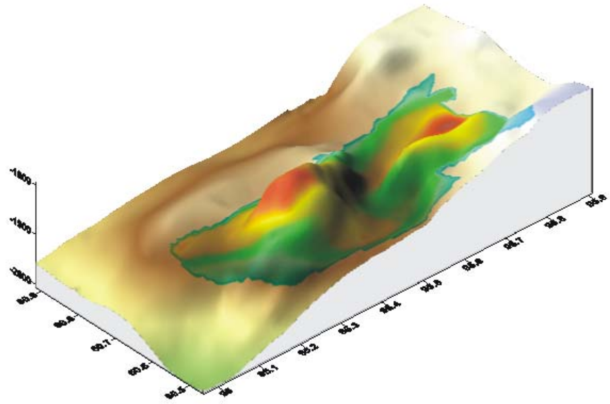

Fig. 3. Results of superposition the geochemical anomaly received after 3D constructions and structure, selected by results of seismic researches

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