International Institute of Earthquake Engineering and Seismology (IIEES)

FRACTAL CONSIDERATIONS TO AIRBORNE MAGNETIC ANOMALIES AS A NEW STRATEGY FOR SEISMIC STUDIES IN NW OF IRAN

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ABSTRACT

Most of Earthquake measured Patterns generated by aeromagnetic multiplicative cascade processes show self-similarity which can be described by power-law type of functions. Recognition of the self-similarities (and following self-affinities) with respect to geospatial scaling, might provide decomposition of the patterns to distinct underlying processes. A concentration-area plot (C-A) and a power spectrum-area plot (S-A) have been applied to separation of aeromagnetic patterns on the basis of distinct self-similarity in space and frequency domain, respectively. The C-A method can decompose the geo-structural patterns into active and stable resources. The S-A plot is applied in a frequency domain to separate the power-spectrum into different levels with distinct self-similarities. Filters can be constructed on the basis of separated power spectrum levels. Conversion of aeromagnetic signal from the frequency domain back to the space domain using 2-D Inverse Fourier Transformation with these filters applied provides the lineaments prognosis patterns reflecting hazardous areas based on aeromagnetic fractal considerations.
As a result airborne magnetic values related to dependent structural lineaments in NW of Iran will be employed to demonstrate the applications and priorities of the C-A and S-A fractal methods versus traditional (Euclidean) techniques for better predictions and more geospatial integrative associations with earthquakes practically.

1. Introduction

A regional aeromagnetic map normally is constructed from a set of point measured in a remote detection system available over an area at a certain scale. The regional geophysical mapping has drawn a great attention of geophysists and seismologists because the map usually contains a large amount of information critical to seismological-structural studies. With respect to the prediction of earthquakes, aeromagnetic map usually is needed for determining structures, characterizing of magnetic values and separating background from anomalies as important resources for finding structural patterns corresponding to seismic hazard maps. An aeromagnetic 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 (Evans, 1983). There have been two basic approaches used to analyze regional aeromagnetic data: frequency analysis and spatial. The frequency statistical analysis refers to the techniques characterizing the frequency distribution of values.

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The results of such analysis often are observed on various type of plots such as histogram and Q-Q plot. It has been noticed that for the last two decades many methods based on the frequency statistics to the seismic values, such as histogram analysis, probability plot and box plot, have been extensively and in some cases successfully used in the geophysical data processing, especially in the separation of magnetic anomaly from background for seismic-structural studies (Turcotte, 1997).

Most of these methods use the values of magnetic data for determining lineaments and associate movements originate from initial source conditions with an assumption that the magnetic data obey a certain form of distribution (normal or log normal). The fundamental geophysical assumption for these methods is that the populations generated by initial deep resources is controlling seismological behaviors may be distinguishable statistically. In the contrary, the spatial analysis refers to the methods dealing with spatial aspects of the magnetic data such the spatial distribution of values in a 2-D map. The spatial analysis techniques such as Kriging and moving average were widely utilized by geophysists in such works as interpolating aeromagnetic map and smoothing a map to enhance the visibility of the hidden lineaments superimposed structural patterns.

Although the frequency and spatial-statistical analyses are the main techniques for the processing of regional aeromagnetic data, some disadvantages in these methods for separation of different components of an aeromagnetic field have been noticed:

For the frequency statistical analysis: **a.** the single or two global threshold (s) selected by such methods like histogram analysis and probability plot may not work well in the situation where the background of a magnetic field has significant variation; **b.** using the frequency information of value distribution may be not sufficient to divide the data set if the populations overlap each other severely in their values; and **c.** the spatial distribution and geometry of a magnetic anomaly are very important information for determining structural movements before quakes, which should not be ignored.

For the existing spatial statistical analysis techniques: **a.** the spatial analysis methods like Kriging and moving average generally are not the methods for the selection of thresholds; and **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 median or fence filters (Xu, 2000) request the predefined operating windows.

The fractal filtering technique is a recently-developed technique using both frequency and spatial information for geophysical map and image processing purposes (Grunsky, 2000, Mehrnia, 2005). The basic geological assumption for this method is that an aeromagnetic data generated by specific airborne processes may be distinctable in terms of fractal properties. The distribution of aeromagnetic values may abide a certain power-law relations with scaling. The previous works on fractal and multifractal have shown that most geological processes generate patterns showing scale invariant such as the magnetic field of the earth crust (Turcotte, 1997), the distribution of earthquakes and volcanic eruptions (Izawa, 1998), the surficial geochemical element concentration and Au-deposit distribution (Ballantyne, 1994). The scale invariant property often shows "self-similarity" or "self-affinity". These properties could be measured from both the frequency and spatial domains (Turcotte, 1997).

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 (Xu, 2000; Mehrnia, 2005). The fractal filter described in this paper is defined on the basis of the power law properties of a power spectrum into components, each of which has the same or similar scaling property.

The filter, therefore, can be used to decompose the magnetic anomalies from background and to extract the active lineaments from the originals in hazard maps. The fractal filters are defined in Fourier space by applying the fractal concentration-area (C-A) model (Cheng, 1994) to the power spectrum of the processed geochemical field. They are irregularly shaped filters due to the anisotropy and complex inner structure of the geochemical field. Each filter represents the regions where the power-spectrum shows the same or similar scaling properties. The inverse Fourier transform applied to the filtered signals will yield distinct geophysical patterns in the spatial domain with the corresponding scaling properties in the frequency domain.

The patterns obtained using the fractal filters may or may not relate to the active lineaments that we are interested in. in some complicate geological environments; the magnetic anomalies divided by the scaling properties may correspond to multiple processes, some of which may have nothing to do with the specific seismological processes. Therefore, the interpretation of the "meaningful anomalies" or identification of the "real anomalies" related to the hazardous area is needed. Geophysists usually evaluate an image of anomaly by its value, contrast, shape, element combination and geological association (Sincalir, 1991).

Also GIS technology has provided a very powerful tool for the cross-check and integration of the magnetic anomalies. This paper will show that with the aid of GIS, comprehensive interpretation of the resultant maps derived by the fractal filtering can give a better understanding of the relationships between aeromagnetic anomalies and background around active structures.This paper will first introduce the theory of the fractal filtering technique, and then gives a case study of application to finding active areas supplement to hazard maps of NW of Iran.

2. Frequency Filtering vs. Fractal Filters

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

2.1. Fractal concentration-area model (C-A)

Ballantyne (1994) developed a fractal method from a multifractal point of view to separate magnetic anomalies from background. It has been applied to analysis various types of data such as geochemical (Agterberg, 1996) and structures (Turcotte, 1997). It involves a concentration-area plot on log-log paper showing power-law relations between the areas A(ρ) with intensity value higher than ρ and the concentration value ρ as Eq.1

$$\mathbf{A(\rho) = C(\rho)^{-\alpha}} \qquad (1)$$

where **C** is a constant and **α** is the exponent that may have several values for different ranges of geophysical concentration values **ρ**. On the log-log paper, the values of **A(ρ)** against the ρ may be fitted by a number of straight lines. The break(s) of the straight lines and the corresponding values ρ can be picked up and used as the cutoff(s) to separate aeromagnetic values into different components such anomalies and background.

2.2. 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 (FT), which gives a pair of maps containing the real $\mathbf{F_r}$ and imaginary $\mathbf{F_i}$ components of a spectrum, respectively. Power spectrum can be calculated as Eq.2

$$\mathbf{E(W_x,W_y) = F_r^2(W_x,W_y) + F_i^2(W_x,W_y)} \qquad (2)$$

where $\mathbf{W_x}$ and $\mathbf{W_y}$ are spatial wave numbers in **x** & **y** directions, respectively. There are many geophysical data processing methods built up on the power spectra analysis. In the field of regional geophysical data processing, Specter and Grant (1970) initiated a famous filtering method (SG) for dividing the subsets from an aeromagnetic field through seeking breaks on the plot of **ln[E(r)]** against **r/2Π**, where $\mathbf{r = (w_x^2 + w_y^2)^{1/2}}$.

This model actually creates band pass filters. It has been noted that the SG 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 power-law distribution in which its power spectrum **E** is proportional to a power **α** of spatial frequency **f** which can be express as Eq.3.

$$\mathbf{E(f) = f^{-\alpha}} \qquad (3)$$

where **α** is called isotropic scaling exponent (Pilkington, 1995), **f** equivalent to the **r/2Π** in Eq.2. For a potential field with the field source at the depth t below the measuring plane, the equation can be represented as Eq. 4

$$\mathbf{E\ (f) = e^{-2\,tf} . f^{-\alpha}} \qquad (4)$$

Where **α** is the isotropic exponent, **t** is the depth of source. If the **α** is a constant, the equation can be used to calculate the depth **t** according to relation of **E (f)** and *f*. if t equals to 0, the Eq.4 reduces to Eq.3. In this case, the different α 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 fields into subsets, each of which has the distinct scaling property. This model is essentially the same as SG models.

2.3. Fractal filtering Technique (S-A)

The SG 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 SG model is not suitable to process geophysical field due to its anisotropic nature, especially for those patterns give rise to magnetic destructions during thermal solution-related mineralization which is often controlled by linear structures such as faults or contact zones (Garland 1992).
The anisotropy structural information in a field is often reflected in 2-D power spectrum. This anisotropy can be characterized using a proper method based on the analysis of the distribution of power spectrum (Cheng, 2000). 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 magnetic field with isotropic scaling or generalizes invariant scaling property (Izawa, 1998).

$$\mathbf{A\ (\geq E) = E^{-\beta}} \qquad (5)$$

Different values of **β** estimated by plotting values of log **A** (≥E) vs. log E for various ranges of E, based on which filters can be constructed. This method is named S-A method (Xu, 2000). The SG model becomes the special case of S-A model with isotropic property.

Since the filters generated by Eq.5 in Fourier space can retain the anisotropy of the power spectrum with the identical scaling properties. The aeromagnetic patterns with the distinct fractal properties and anisotropy can be obtained in spatial domain by the Inverse Fourier Transform (IFT) with the filters applied.

2.4. Construction of filters using S-A plot

The implementation of the fractal filtering method for the purposes of processing aeromagnetic map consists of the following steps:

a. Transform data from space domain to Fourier domain using FT.
b. calculate its power spectrum.
c. Apply S-A plot to the obtained power spectrum, and determine breaks to convert the power spectrum map into binary patterns to form filters.
d. Multiply the filters to the real and imaginary FT maps obtained in step a, respectively, and then transform the filtered maps back to the spatial domain by means of the IFT technique.

The filters generated above for magnetic data processing have the following characteristics:

a. Filters are objectively constructed from the processed aeromagnetic map.
b. The shapes of these filters are often irregular due to the anisotropy of magnetic field.
c. Each filter dominated but not sharply bounded by certain frequency ranges such as high frequency or middle and low frequency ranges.

3. Casual Geology and Structures

The study area located in 250k sheets Mianeh, Azerbaijan province, NW of Iran. Mianeh as center of seismic area, covers about 400 km^2, and mainly consists of Jurassic limestone, shale and poorly exposed clastic sediments, basic sub-volcanic, dacitic to rhyodacitic extrusives and intermediate intrusives with the age of Jurassic, Eocene, Oligo-Miocene and Pleistosene respectively.

Most important geological occurrences are in close relationships with cross cutting structures (shearing zone) cause to various alterations containing siliceous aggregations in veinlets. A processed ETM image (base on Sabins, 1997) was prepared and composed by seismic evidences to finding structural associations with hazard maps as fig.1.

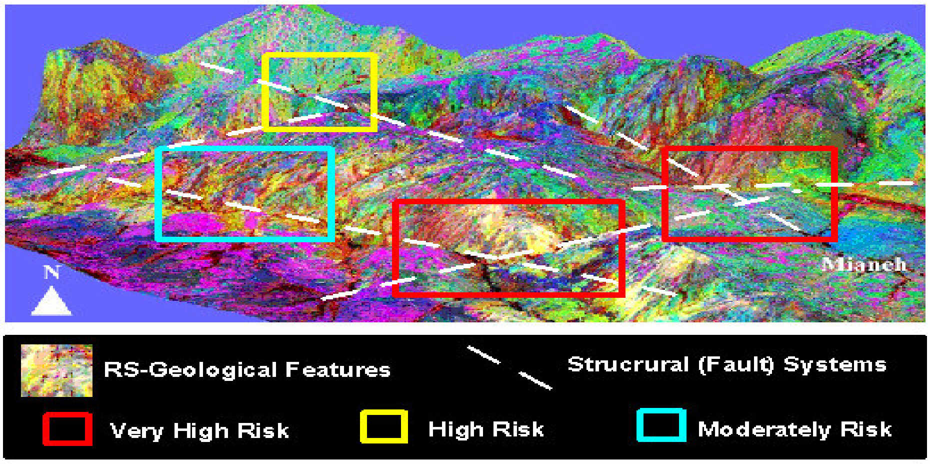

Figure 1. 3D supervised classification of ETM image shows:
Geological – structural patterns composed with seismic hazard areas around target-NW of Iran

Red colors indicate to igneous rocks tend to yellow or whitish colors next to the cross cutting structures (as seismic resources). Green colors indicate to urbans with possessive interferes to alluvials and soils (as collapse or sliding potential); and Blue color variations shows sedimentary formations overlaid structures with immeasurable values next to the metamorphic facies (as hidden structures with unknown variables).
As a result, Anatolian (Tabriz fault) and trans-Anatolian fault systems (fig.2) are known as important structures associate with taphrogenic movements (Neogene) based on geological, seismological and remote sensing integrated conclusions (Lescuyer 1979, GSI 2001, Ins. of Geoph. 2003).

4. Analysis of Magnetic Values in Target Area

Prior to the application of the S-A method, the frequency distribution of intensity values from 400 points (airborne stations) is checked by means of statistical analysis shown as fig.2, which give a general views of approximately normal distribution of magnetic intensity (n.t), based on IDW Interpolation results.

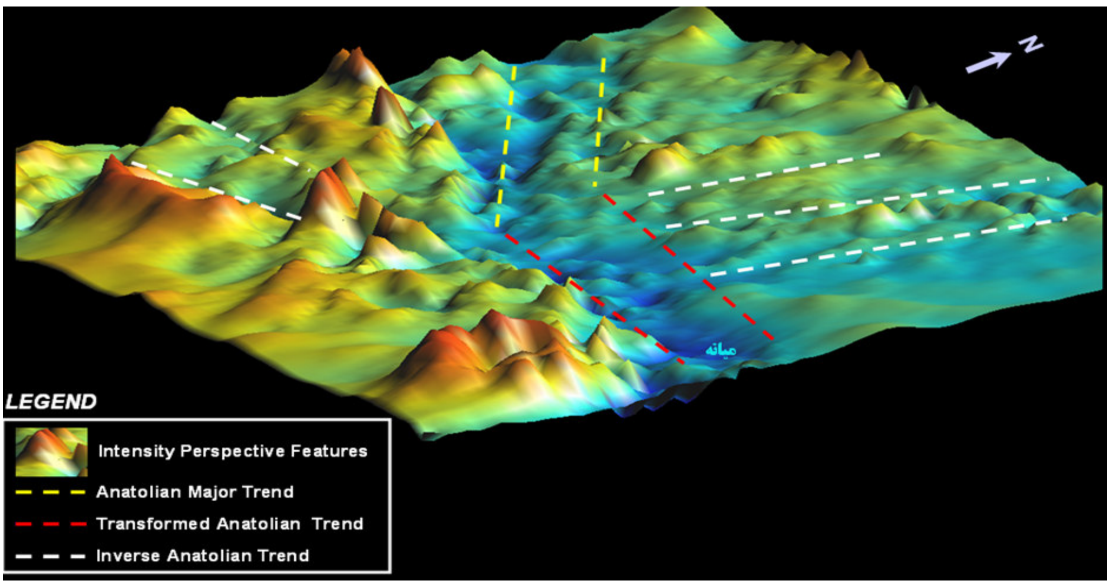

Figure 2. 3D Aeromagnetic values for structural patterns in study area (NW of Iran)

4.1. Preliminary analysis for determining active areas:

Fig.3 shows the intensity variations (n.t) corresponding to geospatial distributions based on IDW (Arcview analysis possibilities) interpolation techniques.

Comparing intensity distributions (fig.3) with ETM photomap (fig.1) shows relationships between magnetic fabrics and seismic behaviors. Therefore applying S-A functions to aeromagnetic data may be used to predicting activities (movement potential) around hidden lineaments.

4.2. Construction filters for magnetic decomposed values as seismic resources

For intensity values corresponding to active zones, statistical interpolations have been changed discontinuous data into continuous datasets as shown in fig.4.

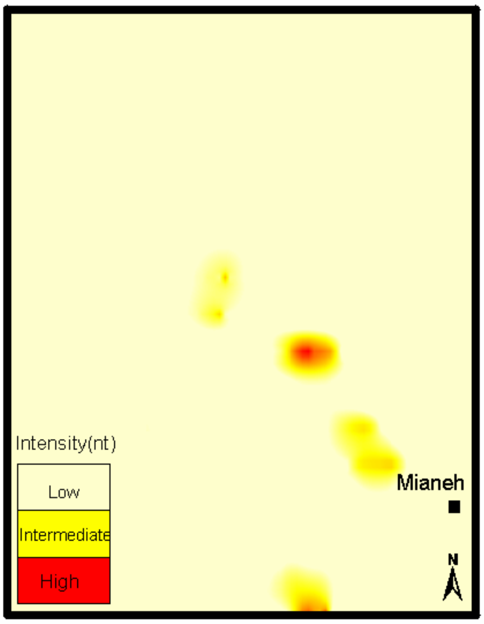

Figure 3. Spatial distribution of mag. Intensity

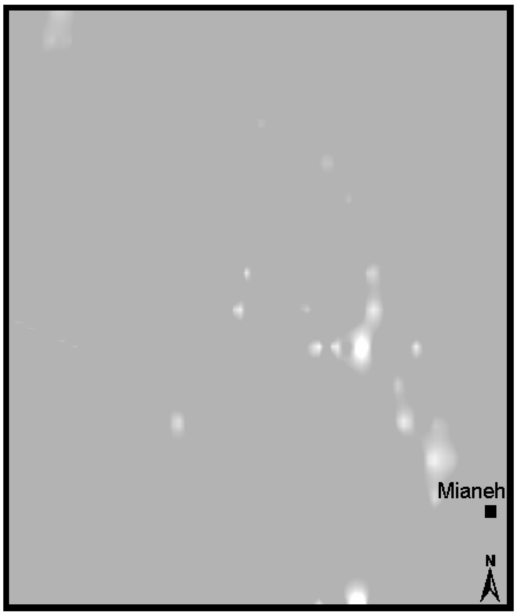

Figure 4. Filter results for Mag. Values

The generated IDW map could be converted to the frequency domain by means of S-A models which made new relationships between the values of contours and the areas enclosed by the contours as shown in fig.5.Three straight lines have been fitted by means of least square (LS) method shown in fig.6. The filter data have significant slope variations comparing to other values in fractal population.

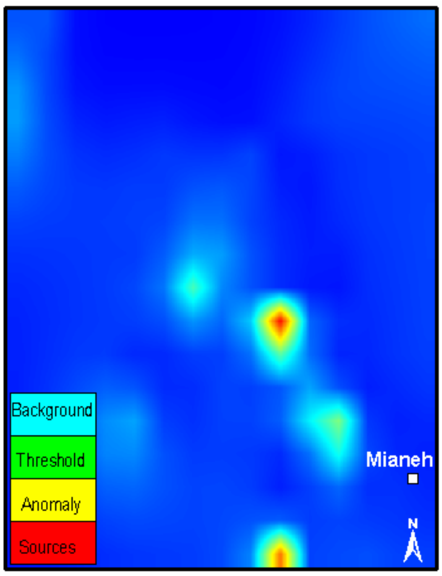

Figure 5. Mag. Frequency Conversion

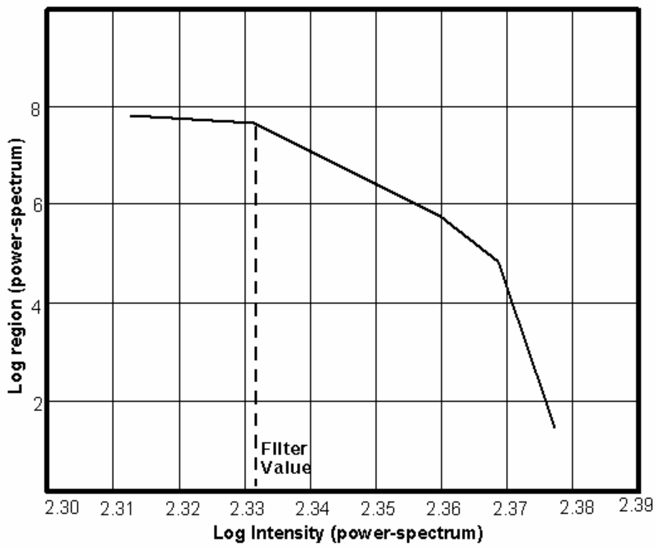

Figure 6. Power-Spectrum model of mag. values

The cutoff value 2.33 indicated by the one vertical line on the plot was applied to generate the binary corresponding filter shown in fig.7 based on the power spectrum model.

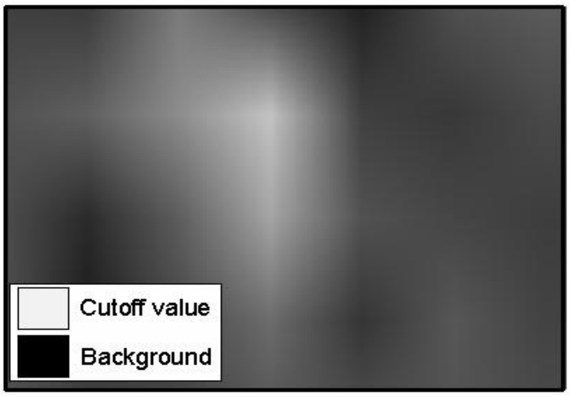

Figure7 . Determining Cutoff values based on S-A results of mag. values

Applying the filter obtained from S-A plot to Fourier transformed intensity values and converting them back to the spatial domain (IFT), gives two new images from magnetic hidden lineaments as fig.8.

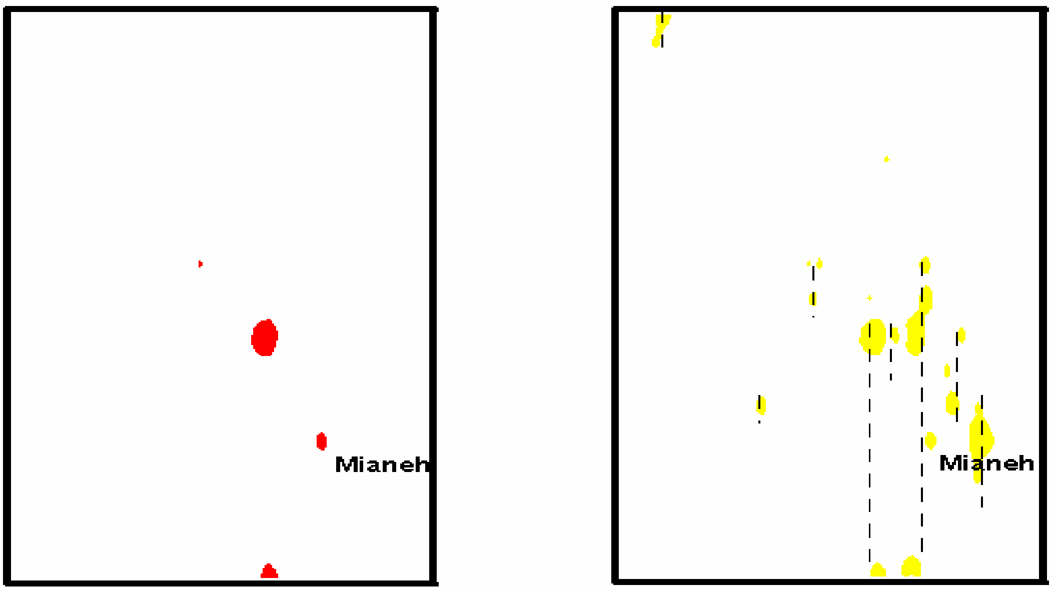

Figure8. Decomposed magnetization based on fractal filtering techniques
Left: resources coincide with seismic hazard ; Right: lineaments around resources

Binary filter represent relatively high and low frequency power-spectra without regularly bounds in fig. 8. The left image is a converted grid map using inverse Fourier transform with filter area < 2.333 applied. And the right is a converted map using same method, with filter area > 2.333 applied. The one with the low power-spectrum filter applied; will represent the hidden lineaments corresponding to seismic structures, whereas the other with the higher power-spectrum filter applied, represent to spatial distribution of magnetic resources coincide with seismic hazard map as fig.1.

This type of spectrum-area plots can separate two distinct groups of self-similarities with different governance power-law relations. The magnetism pattern separated on the basis of self-similarities may shows active resources (at least 3 points on fig.8-left) specified by magnetic Intensity values for predicting seismological activities next to the lineaments (fig.8-right) may controlling dynamics-structural behaviors through earthquakes.

5. Conclusions

The fractal filtering technique is an effective method for decomposing different components of an aeromagnetic data according to its scaling properties. Each of those filters is built upon the distribution of power spectrum of the processed images.

Frequencies-related intensities obtained using filters, give rise to new set of background and anomalous indications may refer to initial frequencies conditions (as mag. resources) and structural spectrums (lineaments) respectively.

Filter construction technique based on S-A models is prevalent to geophysical datasets, while frequency-based GIS method, for aeromagnetic statistical comparing with seismic results (see fig.1) is completely private to this paper.

With due consideration to predicting earthquake probabilities around targets, a proper procedure to interpret individual intensity values decomposed by the fractal filter is needed. Also integrating S-A results with the geological features and evidences is recommended to finding new aspects and more prognostic factors.

The case study has shown that magnetic lineaments are in close relationships with seismic activities at the North-South directions (fig.8-right) may be declined to trans-Anatolian fault systems. Therefore it is necessary to pay more attentions to same results use other geophysical decomposed anomalies (such as gravimetric, radiometric, etc) for assessing lineaments as new pathfinders due to seismological investigations.

6. Acknowledgments

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