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Using of Local Singularity Analysis for Determining of Radioactive Zones based on Airborne Geophysical Data, NW Iran

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Abstract

The Khoja syncline is located about the middle of the Sarab-Tabriz-Salmas basin in NW of Iran and regarded as one of the most promising areas to explore for radioactive elements. The main purpose of this study is to utilize the fractal and multifractal geometry measurements, including the Local Singularity Analysis for data interpretation and delineation of radioactive anomalous zones as a mineral exploration tool in the sedimentary rock units of the Khoja syncline. To delineate uranium concentrations detected areas (high radioactivity zones) 5934 points of uranium gamma-ray spectrometry airborne geophysics were collected and saved as data. According to Local Singularity Analysis, uranium accumulation in the Khoja syncline follows a multiracial model in shape. Highly elevated radioactivity is detected inside the NW of the syncline in the limestone lithological unit. Based on the direct correlation between uranium high value and Ca, Mg, P, Sr, as and V, the limestone unit concentrated metals as a geochemical trap. The mineralization zone reflecting secondary uranium mineralization in this part of syncline with ≈ 74 to 800 ppm uranium consisted of 380 to 3500 counts per second radioactivity. The calculation function of the concerning mass and grade resolution, Local Singularity Analysis method yielded relatively efficient results referring to strong and weak uranium concentration as high radioactive zones.

Keywords: Fractal; Multifractal; Radioactivity; Uranium; Mineralization; Geochemical trap; Geostatistic.

Introduction

Efficiently delineating whether enriched or depleted zones are always the main purpose of mineral exploration assessments and are still one of the most significant objectives faced by airborne geophysical data processing. For example, Singh et al. used in situ radiation measurements with portable radiometers for delineations of the anomalous zones with high radiation rates and Ahmed with the integration of airborne geophysical data and satellite images identified the radioactive anomalous area. Related to the subject, the conventional geostatistical methods were used to identify the concentrated areas[1]. However, means of mathematics such as statistical analysis has been extensively put upon to support metal anomalous zones since the 1950s.

In the past several decades, different procedures have been applied for concentrated zones identification and threshold separation, mainly including the fractal and multifractal method. The fractal theory has been hypothesized by Mandelbrot first in 1983 as the non-Euclidean noticeable mathematical method in geometry. Mathematical modeling based on fractal and multiracial theory has a variety of usage in delineation of anomalous zones in the geosciences since the 1990s and polluted zones in environmental science since 1990s.

Among numerous fractal and multifractal models, the concentration-area (C–A), concentration-number (C–N) fractal model, spectrum-area (S–A) multifractal model and local singularity analysis method (LSA) is commonly used to recognize the anomalous zones in both geosciences and mineral exploration case studies [2].

These techniques have always their own upwards and downwards. To exemplify, as an instance; the LSA has developed to enhance the ability of anomaly detection.

LSA fractal and multifractal was used as methods in this study in which, they were applied on the occasion to delineate high radioactive (uranium) anomalous zones based on airborne geophysical data abstracted from the sedimentary rock units in Khoja area which is located in NW side of Tabriz city in NW part of Iran (Figure 1).

Method

Local singularity fractal model

The ore deposits of metal concentration processes can be modeled as fractal/multifractal geometric phenomena, because of the enrichment and dispersion regular procession of metals concentrations. For the geochemical and 2-dimensional airborne geophysical data, singularity analysis use singularity index (α) to characterize geological complexity that is related to anomalous zones within a multifractal context [3].

Singularity theory describes extreme geo-processes, which effect of significant amounts of energy release or metals accumulation to occur within a narrow space-time interval. In geosciences, the characterization of the fractal/multifractal properties of metals concentration in the Earth's crust obtains by the singularity analysis. Consider μ(A) as the total amount of metal concentration within an area A, and ρ(A) is the density of element concentration within an area A. From a multifractal point of view, the μ(A) and ρ(A) follow power-law relationships expressed:

$$\mu(A) \propto A^{\alpha/2} \qquad (1)$$

$$\rho(A) \propto A^{\alpha/2-1} \qquad (2)$$

The singularity index (α) calculated by a window-based method. The average spatial density of metal concentrations, ρ[A(ε)] can be obtained based on the following power-law formula:

$$\rho\,[A(\varepsilon)] = \frac{\mu[A(\varepsilon)]}{\varepsilon^2} = c\cdot\varepsilon^{\alpha-2} \qquad (3)$$

Where A, ε, and c are the study area, window size, and fractal density, respectively. On a log-log plot of ρ[A(ε)] versus ε, the slope (α-2) can be estimated by least squares method.

Most singularity indices with α≈2 indicate normal or lognormal distributions, whereas the rest of singularity indices with extremely high and low values (α≠2) may follow fractal/multifractal distributions.

For anomalous zones delineation, singularity indices can be divided into three groups: (1) α-values < 2 indicate enrichment of metal concentration, being positive singularity; (2) α-values more than 2 indicate depletion of metal concentration, being negative singularity; and (3) α- values closed to 2 indicate non-singular case. Therefore, estimation of singularity indices from a geophysical map can reflect different distribution patterns that can valuable information for mineral exploration studies [4].

Geological Setting

Regarding to the promising geological settings of uranium mineralization, Iran is divided into 20 zones including different source and host rocks (Fig. 1b). The Sarab-Tabriz-Salmas (STS) basin in SW Iran is one of the most important zones sketched from Sarab to the Turkish border (Figure 1a). This zone plays an important role in exploration of uranium mineralization and uranium concentrated area, considering spatial distribution of source rocks, host rocks and the hydrologic pattern (Figure 1).

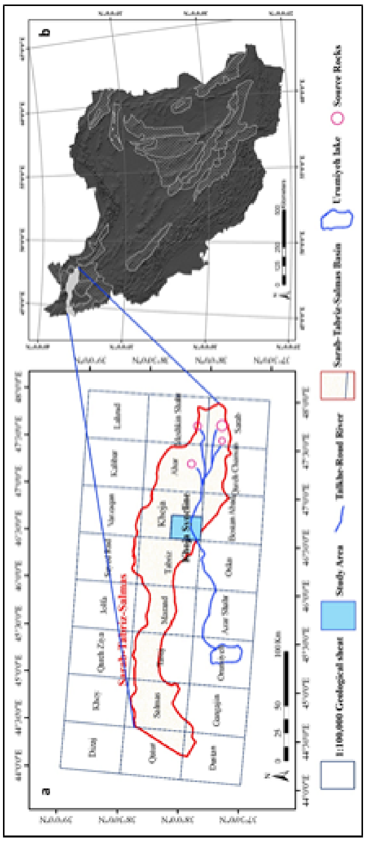

Figure 1: a. Situation of 20 prospective sedimentary uranium mineralization zones in Iran. b. Sarab-Tabriz-Salmas (STS) basin and relative situation of source rock and hydrologic pattern contributing in sedimentary uranium mineralization.

The Khoja (Khajeh) syncline is located in the NW of Iran, which is a major population center located nearly in the center of the STS zone (Figure 1a). This syncline is formed by a young sedimentary basin in the collision zone and classified as foreland basin [5-10]. The Khoja syncline consists of evaporate and clastic formations, which were deposited during calm periods and tectonic activities, respectively. The study area includes Neogene sediments that is unconformly covered the geologic settings. Terrigenous and evaporative units of Miocene constitute the bottom of lithological units. These units are overlaid by an evaporate unit of Miocene. Neogene sediments include gypsiferous shale, shale and grey marl, red shale, sandstone and siltstone, undivided red strata units and finally quaternary sediments (Figure 2).

In the middle part of the thick sandstone unit in west of the syncline, red-color strata including volcanic materials is formed, which change from green to grey marl and limy marl (marl and lime as Ls facies) that overlaid by white, creamy-grey limestone and marly limestone. The thickness of these strata is less than 50m. Regarding time of deposition, this facies is as same as the Shamloo facies that is believed to be occurred in deeper parts of the deposition basin (Figure 2).

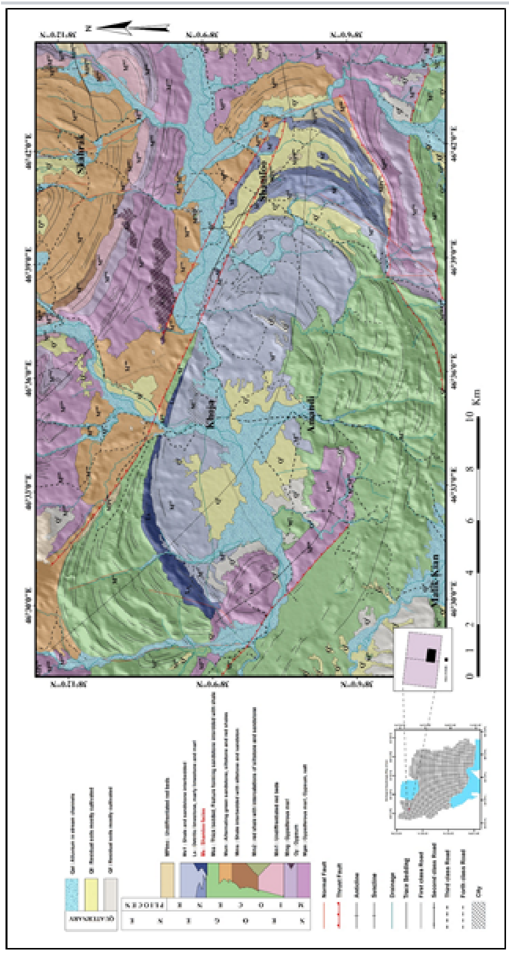

Figure 2: Geology map of the Khoja syncline.

Data Used and Analytical Techniques

From 1976 to 1978, airborne geophysical surveys of Iran is conducted by Austrex Co. 5934 points resulted of uranium radioactivity (eppm) in the Khoja syncline were used in the present study. These surveys are conducted in an air route grid of 1000×500m with 200m interval of flight lines. Table 1 presents statistical parameters of airborne geophysical data in the Khoja syncline. Figure 3 shows coverage of the acquired data in the study area.

N	Min (eppm)	Max (eppm)	Average	Median	St. Deviation
5934	0.330	7.090	1.752	1.740	0.37

Table 1: Statistical parameters of airborne geophysical surveys in the Khoja syncline.

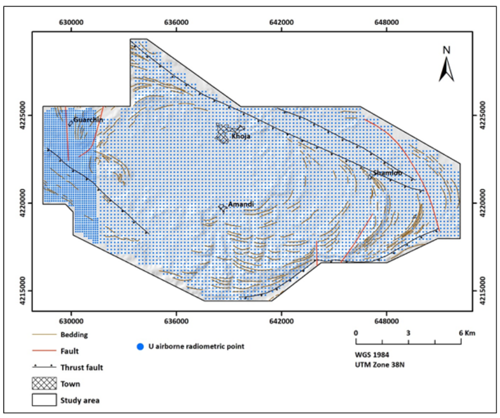

Figure 3: Coverage of the acquired data in the airborne geophysical surveys of the Khoja.

By means of validating the identified anomalies of multifractal analysis, six litho-geochemical rock samples are taken from anomalous zone and are analyzed after milling due to produce powder of 200 mesh in ICP-MS laboratory of Geological Survey of Iran (GSI).

The field radiometry is performed using scintillometer SPP2 (made in France) and Table 2 presents the results of litho-geochemical data used for validation the concentrated zone.

Sample	cps*	As	Ca	Cu	K	Mg	Mo	P	Pb	Se	Sr	Th	U	V	Zn
AM1	3500	44	301831	43.7	11298	57976	1.5	1154	6.9	2.92	1768	7.46	804.36	106	60.8
AM2	450	15	314290	20.5	1984	31314	0.6	719	5.3	1.70	2386	2.30	110	313	9.4
AM3	380	12.9	261327	11.1	1356	28033	0.6	549	4.8	1.60	2551	1.24	74.70	254	8.8
AM4	125	20.4	50194	58.8	3153	12408	0.9	513	5.6	1.43	186	4.47	2.94	61	27.9
AM5	110	2.8	58173	9.6	4111	10993	0.5	402	6.2	0.94	123	4.16	1.03	50	26.9
AM6	90	1.6	82724	74.1	4044	10327	0.3	480	9.5	0.86	120	4.11	0.86	50	23.9
cps: count per second															

Table 2: Litho-geochemical data used for validation the radioactive elements concentrated zone.

Results and Discussion

The LSA method used to separate anomalous zones for uranium concentration and then utilized to develop the LSA map for uranium potential assessment. Values of uranium from the 5934 airborne geophysical points were used for mapping the LSA map. The square windows with half window sizes ranging from rmin = 1 km to 13 km = rmax with intervals of 2 km. For the whole windows, the average value of uranium concentration ρ[A(εi)] can be computed by averaging the values of all samples dropping within the window. By applying similar processes for each window size centered at the locations one can generate two sets of values: average concentration value and size of the window. These two sets of values drawn show a linear trend on a log-log plot, which can then be fitted with a straight (without curve) line by means of the least square method [11]. The Value of α-2 can be calculated by the slope estimation of the straight line. Values of α were calculated for uranium using ArcFractal. Figure 4 illustrates the Goodness of fitting of data fits a distribution from a certain population and figure 5 illustrates distributions of α values estimated by means of the windows-based method for uranium concentration.

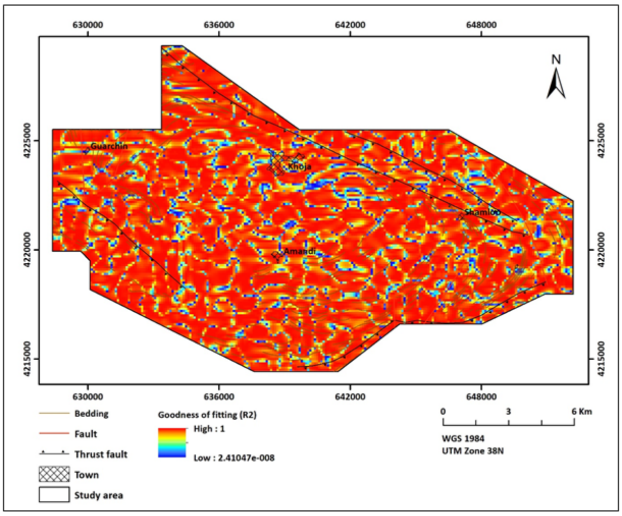

Figure 4: Goodness of fitting of LSA of the airborne geophysical data in the Khoja syncline.

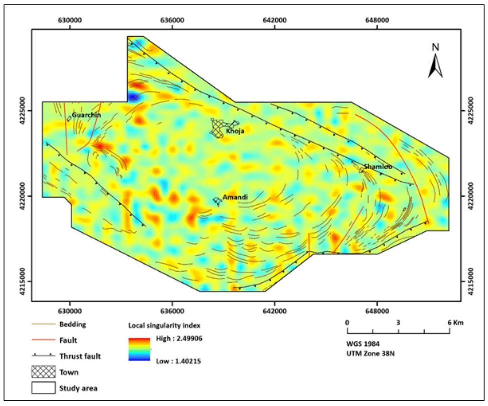

Figure 5: Uranium distribution map of the Khoja syncline based on LSA method.

High radioactive values of uranium are identified in the NW of the Khoja syncline based on LSA methods (Figure 5,6). Uranium concentration of three litho-geochemical samples (AM1, AM2, and AM3) is 74.40 ppm, 101 ppm, and 804 ppm, respectively (Table 2 and Figure 6). The concentration is associated with the limestone unit of Ls facies (Figure 7). The highest uranium concentration is located in the central part of an extreme anomalous district consisting of uranium mineralization with radioactivity of 3500 cps (Table 2 and Figure 7). According to litho-geochemical samples (AM4, AM5, and AM6), the areas lacking airborne geophysical data associated with sandstone lithology and shale interlayers are of no considerable uranium anomaly (Table 2 and Figure 7). Anomaly checking by litho-geochemical samples led to concentration of sedimentary uranium mineralization within the limestone rock unit of Ls facies associated with the maximum concentration of 74.70 ppm to 804.36 ppm, and uranium mineralization. Moreover, there is a direct correlation between uranium and Ca (26-31 wt. %), Mg (2.8-5.7 wt. %), P (550-1150 ppm), Sr (1760-2550 ppm), As (13-44 ppm) and V (106-313 ppm) (Table 2). The Ls facies as a geochemical trap enriched and concentrated uranium and other metals [12-14]. The geochemical tarp deposited the uranium complexes in groundwater. The flow of meteoric water and groundwater can be solving the uranium mineralization in this rock unit and will migrate to aquifer. Recently, the water and other rock units near the flow of mixed groundwater and meteoric water may be contaminated or concentrated by radioactivity.

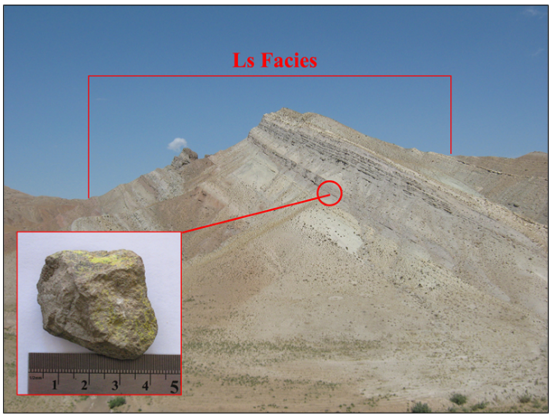

Figure 6: Uranium mineralization as main mineralization in limestone unit of Ls facies.

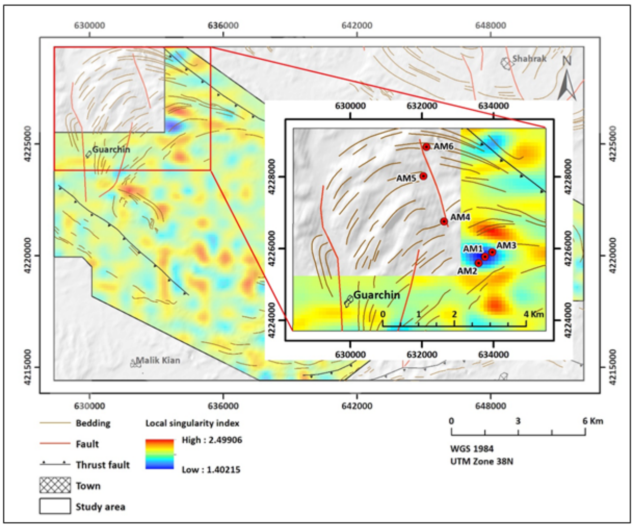

Figure 7: Spatial distribution of litho-geochemical samples in the anomalous zone.

Based on LSA technique, weak anomaly of uranium delineated at the east of syncline near the Shamloo village [15]. The secondary copper mineralization (malachite) and planet remains with ~1000 count per second radioactivity as main trace factors for exploration of sedimentary uranium mineralization type are recorded in the weak anomaly near the Shamloo village.

Conclusion

In conclusion and following the findings, the novelty of this research lies in using LSA fractal/multifractal method for radioactive elements potential assessment. The high prospectively radioactive zone was delineated by using the LSA multifractal method in the NW of the Khoja syncline. The exports are based on gamma-ray spectrometry data acquired during airborne geophysical surveying. This method is appropriate and favorable for regional delineation of anomalous radioactive zones and as the following step the portable radiometric surveys utilized for local exploration delineated. The LSA method is a very applicable tool for delineation weak and strong geological uranium radiation for metal concentration and radioactivity zones. Moreover, this method can be useable for recognizing of radioactive anomalous zones for mineral exploration studies.

Applying the LSA procedure to an airborne geophysical map, the singularity value (α) close to 2 corresponds to background value or considerably stable concentration value of radioactivity and the α value less than 2 corresponds to high radioactive zones or enriched radioactive elements concentration values, whereas the α value more than 2 corresponds to depleted zones. Accordingly, the estimation of singularities from an airborne geophysical data set can be used to determine the patterns with singular radioactive metals concentration values, which might provide advantageous data for interpreting geophysical anomalies associated with ambient radioactive zones or radioactive minerals exploration. Moreover, the LSA technique is a potent tool for delineation the weak anomalies of radioactive sources from a multifractal perspective as seen in the east of the Khoja syncline under the Shamloo village.

The LSA provides airborne geophysical data that complement radioactive elements concentration values and can quantify the enrichment and depletion caused by uranium mineralization.

Producing LSA maps of the airborne geophysical spectrometric map can help to identify uranium anomalies in complex geological regions.

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