Anomaly Extraction Technique of Airborne Gamma Spectrometry Based on 2-D Wavelet

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Abstract: This paper uses 2-D wavelet transform to process the uranium specific activity data of 1:5000 airborne gamma-ray spectrometry production data in a survey area in Inner Mongolia, and uses the distribution of paleo-uranium abundance to correct the extracted anomaly areas. The experiment shows that, with small area and high uranium ore concentration, the anomaly areas extracted by 2-D wavelet method are consistent with the metallogenic environment. This method also appears to be insensitive to low concentration uranium areas which may help in guiding for metallogenic prognosis.

1 INTRODUCTION

Airborne gamma-ray spectrometric survey has the advantages of high detection efficiency, low cost, and covering large areas for surface concentrations of various gamma emitting radionuclides (Wan et al., 2012). At present, 80% of China's uranium deposits were found by airborne gamma-ray spectrometric survey (Liu et al., 2002). Due to the low intensity of airborne gamma-ray spectrometric signals, the signals caused by ore-bodies are easily combined with other external measurement signals (reflected information on detector by lithology, soil type, humidity, vegetation coverage density, water area distribution, etc.) (Ge et al., 2016, Xiong, 2016), making it more difficult to extract anomalous areas, making it more difficult to extract anomaly areas.

The method of extracting anomalous information from airborne gamma-ray spectrometry data is similar to geochemical data anomalous information extraction method. In recent years, many scholars have tried to use wavelet multi-scale analysis to extract anomaly information. Gan Yuan et al. (2013)used wavelet multi-scale analysis to filter and denoise wavelet on field X-ray fluorescence geochemical data (Gan, 2013). The extracted anomalous information areas are smaller than those extracted by the conventional method and are highly consistent with actual geological background. Nan Yan et al. (2017)applied wavelet analysis to delineate the anomaly limit of geochemical exploration in the Dabat area of Xinjiang(Nan et al., 2017). The extracted anomalous information is consistent with the spatial distribution of known ore sites and some extremely weak anomalies were extracted.

As the airborne gamma-ray spectrometric survey system is vulnerable to external factors, the collected usable signals are easily interfered by other signals. The wavelet transform has good time-frequency characteristics and is good at handling non-stationary signals. Traditional wavelet analysis ignores the spatial location information of survey areas. The 2-D wavelet transform combines the spatial location information of survey areas with the element content information, decomposing the data and reconstructing the low-frequency part. According to the reconstructed data, the anomalous information in the survey area is extracted to improve the accuracy of any anomaly information in the survey area and reduce the areas of false anomalies, which provides a basis for aiding in prospecting.

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2 METHODS

2.1 2-D Wavelet

The basic principles of 2-D wavelet used to extract the anomalous information from airborne gamma-ray spectrometry data are as follows. Let $f(x, y) \in L^2$ be a 2-D signal, x, y denote the horizontal and vertical coordinates, and Ψ (x, y) denotes 2-D wavelet basis function, then 2-D continuous wavelet definition is (Daubechies, 2011):

$$\Psi_{a;b_1,b_2}(x, y) = \left|\frac{1}{\sqrt{a}}\right| \Psi\left(\frac{x-b_1}{a}, \frac{x-b_2}{a}\right) \qquad a > 0; b_1, b_2 \in R \tag{1}$$

Where, $\Psi_{a;b_1,b_2}(x, y)$ is a 2-D wavelet generating function, a is a scaling factor, and b_1, b_2 is displacement factors. Let $a = 2^j, b = n * a; j \in Z$, so 2-D continuous wavelet transform can be discretized:

$$\Psi_{j;k_1,k_2}(x, y) = 2^{-\frac{j}{2}} \Psi\left(2^{-j}x - k_1, 2^{-j}x - k_2\right) \tag{2}$$

So 2-D discrete wavelet transform is:

$$WT_f(j; k_1, k_2) = \left\langle f(x, y), \Psi_{j;k_1,k_2}(x, y) \right\rangle = 2^{-j} \iint f(x, y) \Psi(2^{-j}x - k_1, 2^{-j}y - k_2) dxdy \tag{3}$$

The simplified formula for 2-D wavelet decomposition is as follows:

$$f(x, y) = L(x, y) + H^H(x, y) + H^Y(x, y) + H^D(x, y) \tag{4}$$

Where, $L(x, y)$ and $H^H(x, y)$, $H^Y(x, y)$, $H^D(x, y)$ are the approximate components of the original signal $f(x, y)$ and the detail components in the horizontal, vertical, and diagonal directions, respectively.

Anomaly Extraction Technique

2.2 Anomaly Extraction Technique

Differences in wavelet basis functions lead to differences in the results of different transformation types. It may not be easy to accurately distinguish the better and less preferable these extracted anomalous information by naked eye. Therefore, the standard deviation coefficient of variation (hereinafter referred to as CV) can be used to identify whether or not the optimal decomposition level has been reached after 2-D wavelet decomposition.

Since the ore-bearing areas are all in the areas with high CV (Sun, 2009), the CV of gamma-ray spectrometry can reflect the variation degree of the contents of uranium, thorium, and potassium contents in the survey area. Therefore, it can be used to study the spatial distribution of radioactive elements, as a geological general survey and prospecting tool.

CV is the ratio of the sample mean square error to the sample mean (Gilbert and Richardo, 1988). In the anomaly extraction of airborne gamma-ray spectrometry data, the standard deviation CV (Sun, 2009, Zhang and Xiong, 1990) is used to measure the degree of data dispersion and to predict metallogenetic probability. The formula is as follow:

$$CV = \frac{\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_i - \overline{X})^2}}{\overline{X}} \tag{5}$$

Where, $\overline{X}$ is the mean value of an element in the survey area; n is the total survey points of the survey area; X_i is the element content value of a survey point in the survey area. In a stable geological structure, the element content value has small fluctuation range, strong resistance to external disturbances, and low CV. With an inhomogeneous geological structure, the element content value in the ore-bearing strata has high CV, which is conducive to discovering ore-causing information.

The 2-D wavelet decomposition process is: First, the wavelet decomposition is carried out in the horizontal direction of the data matrix; secondly, decompose the two decomposed sub-bands along the vertical direction; reconstruct the reconstructed low-low frequency part and calculate its CV; identify if there is a mutation in the CV: if it is not mutated, iteratively decompose the low-low frequency part, and if it is mutated, output low-low frequency part.

3 RESULTS AND DISCUSSION

3.1 Survey Area

This project selects AGS863 Airborne γ spectrometry 1:5000 data of Chengdu University of Technology of a survey area in Inner Mongolia as a data source for data processing. The geological map of the survey area is shown in Figure 1. With five 4L NaI crystals, the AGS863 is a array NaI detectors installed in Y-12 aircraft.The aircraft is equipped with data collection system, radio altimeter, and global positioning system. Its flying speed is 250 km/h and the average flying height is 180 m. AGS863 records a data of full spectrum every second. Full spectrum measured by γ spectrometry is shown in Figure 2.

The survey area is approximately 1,000 square kilometers, with a total of 21 survey lines and 6,705 survey points. The measured data was corrected by altitude, atmospheric radon, aircraft background, and cosmic ray background. Use Kriging to interpolate the original data (256*256) and draw a contour map (shown in Figure 3). The highest uranium specific activity value is 37.204($\mu g/g$); the lowest value is 0.049($\mu g/g$); the average value is 3.968($\mu g/g$).

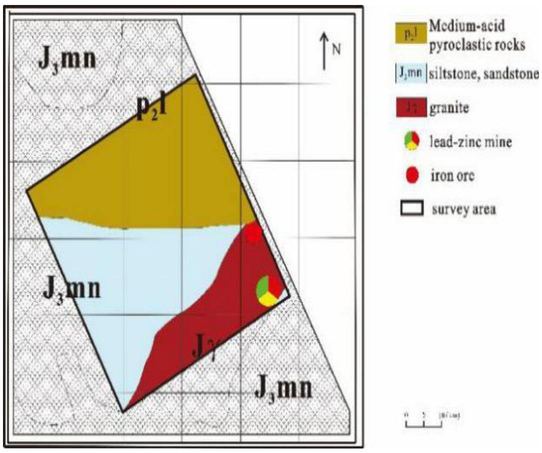

Figure 1: Geological map of the survey area.

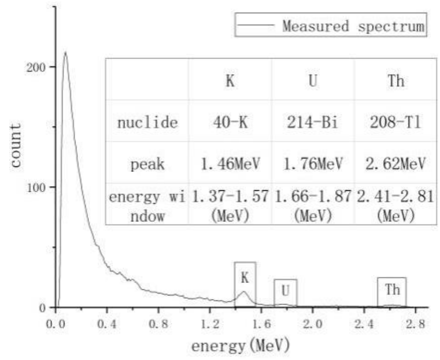

Figure 2: Actual measured full spectrum.

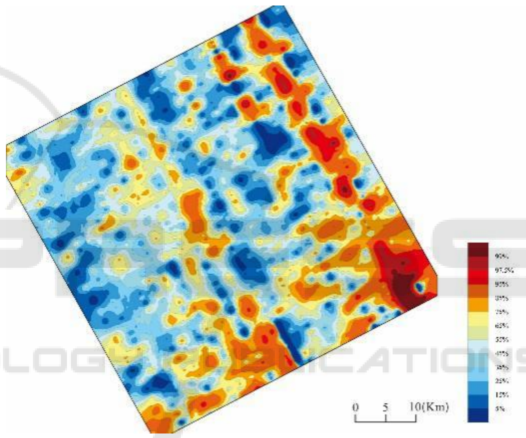

Figure 3: Uranium specific activity contour map.

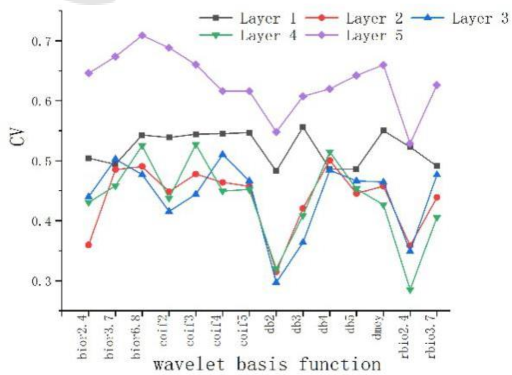

Figure 4: Coefficient of variation after decomposition and reconstruction of different wavelet basis functions.

3.2 Extraction of Uranium Elemental Anomaly Information

This paper uses 2-D wavelet transform method to extract anomalies and compares it with the traditional one. Because the airborne gamma-ray spectrometry data is discrete, the frequently-used wavelet basis functions that can be used for discrete wavelet transform are Biorthogonal (biorNr.Nd), Coiflets (coifN), Daubechies (dbN), Meyer (meyr) and ReverseBior (rbioNr.Nd) (the functions in the modules that contain wavelet basis functions in MATLAB can directly be called). Use the above five discrete wavelet basis functions to decompose and reconstruct the data, respectively, and calculate the CV of each processed data by formula (5). The results are shown in Figure 4.

Figure 4 shows that when decomposition level is the same, the CV of each data possessed by different wavelet basis functions are quite different. The CV of data processed by the same wavelet basis function have a negative correlation with the decomposition level at level 1-4, and when the decomposition level is at 5, the CV of the data reaches the maximum; when the decomposition level is at 1-4, the change rate of CV is small and the overall trend is relatively stable, which show that wavelet decomposition has a small impact on the whole data.

The author uses traditional statistical method and 2-D wavelet method (wavelet basis function is bior6.8; decomposition level is at 5) to extract anomalies from the data and compare the extracted anomalies. The results are shown in Figure 5.

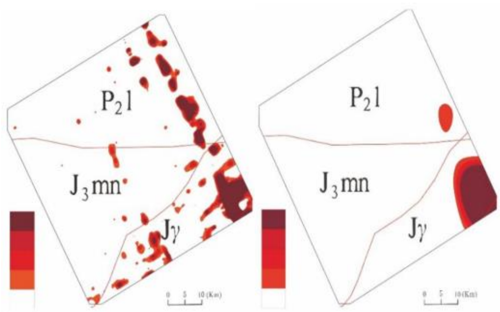

Figure 5(a): Traditional method to extract the anomaly area. (left)

Figure 5(b): 2-D wavelet to extract the anomaly area. (right)

As shown in Figure 5(a), the anomalous information extracted by the traditional statistical method has a large area, and the banded anomaly interference information is obvious and scattered. The reason is that the original data does not have an approximately normal distribution, and the high-value point data is missing during iterative reject phase, resulting in the anomaly threshold value being determined only by the background value.

The advantage of the 2-D wavelet method is that it can combine the element content information of survey points with the spatial position information; there are two ore occurrences in the survey area, one is lead-zinc ore with high U content and one is iron ore with low U content. In Figure 5(b), there are only two anomalies. The central location and anomaly shape of the anomalous areas are consistent with the actual ore occurrences, indicating that the results do not contain false anomalies. Since the low-frequency parts only contain ore-bearing and background information, and the ore-bearing information are represented by high value anomalies. Therefore, the anomaly areas in the figure may be ore-bearing areas.

3.3 Verification of Uranium Elemental Anomaly Information

The paleo-uranium abundance refers to the uranium content of an area in its beginning of diagenesis. In the initial stage of diagenesis, U and Th have the same chemical properties and no migration occurs; When the later environment becomes an oxidation environment, U migrates, while the chemical properties of Th are relatively stable and remain in place. The uranium anomaly areas indicated by paleo-uranium abundance are source beds. Formula 6 is the formula for the calculation of paleo-uranium abundance(Dai, 2002):

$$Gu = Th \Big/ \left(\frac{\overline{Th}}{\overline{U}}\right) \tag{6}$$

In formula (6): Th is the thorium content of a certain survey point in the survey area; $\overline{Th}$ is the average thorium content in the survey area; $\overline{U}$ is the average uranium content in the survey area.

Using formula (6) to calculate the paleo-uranium abundance in the survey area, the result is shown in Figure 6.

At the beginning of diagenesis, uranium is mainly concentrated in granite. The main lithology in the southeastern part of the survey area is granite, with an approximately triangular distribution. Figure 6 shows that the primary uranium element is mainly concentrated in the southeast of the survey area, and its distribution profile coincides with the profile of the high uranium value area, indicating that there are ore-bearing strata in this area and it has metallogenic conditions. Therefore, 2-D wavelet processing was effective at locating ore-bearing units.

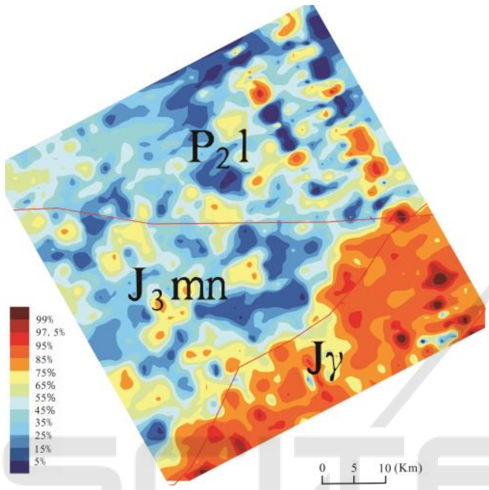

Figure 6: Distribution of paleo-uranium abundance.

4 CONCLUSIONS

In order to explore the advantages of 2-D wavelet method in the extraction of anomalous information of airborne gamma spectrometry data, combined with the distribution of ancient uranium, an anomaly extraction technique based on two-dimensional wavelet method was applied to a gamma-ray survey area. Compared with anomaly areas extracted by traditional method, the anomaly areas extracted by 2-D wavelet methods were smaller and have a more obvious concentration trend. These anomalous areas were in accordance with the actual ore occurrences and no false anomalies in the survey area were detected. The result shows that the 2-D wavelet methods can effectively extract the anomalous information from airborne gamma-ray spectrometry, and provide a basis for aiding in prospecting. However, This method is insensitive to very weak anomalies. It can only extract anomalous information and somehow depends on the quality of the original data, so it needs to be further developed.

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