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Fractal Dimension Change Point Model for Hydrothermal Alteration Anomalies in Silk Road Economic Belt, the Beishan Area, Gansu, China

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Abstract. Remote sensing plays an important role in mineral exploration of "One Belt One Road" plan. One of its applications is extracting and locating hydrothermal alteration zones that are related to mines. At present, the extracting method for alteration anomalies from principal component image mainly relies on the data's normal distribution, without considering the nonlinear characteristics of geological anomaly. In this study, a Fractal Dimension Change Point Model (FDCPM), calculated by the self-similarity and mutability of alteration anomalies, is employed to quantitatively acquire the critical threshold of alteration anomalies. The realization theory and access mechanism of the model are elaborated by an experiment with ASTER data in Beishan mineralization belt, also the results are compared with traditional method (De-Interfered Anomalous Principal Component Thresholding Technique, DIAPCTT). The results show that the findings produced by FDCPM are agree with well with a mounting body of evidence from different perspectives, with the extracting accuracy over 80%, indicating that FDCPM is an effective extracting method for remote sensing alteration anomalies, and could be used as an useful tool for mineral exploration in similar areas in Silk Road Economic Belt.

1. Introduction

Mineral exploration is a key building content for "One Belt One Road" plan. Remote sensing techniques plays an important role in extracting mineralization alteration areas, which is a key in exploration of mineral deposits [1]. Over the past years, multispectral and hyperspectral digital imaging have been successfully used for providing detailed information about the different altered minerals which were exposed on the earth's surface, such as clay minerals (kaolinite, illite), sulfate minerals (alunite), carbonate minerals (calcite, dolomite), iron oxides (hematite, goethite), and silica (quartz) [2]. The studies have shown that the band ratioing, principal component analysis (PCA) and the spectral angle mapper (SAM) image processing techniques could be employed to identify hydrothermally altered rocks and associated mineralization effectively [3,4]. However, these researches mainly focused on the identification of principal component image that containing alteration anomalies and ignores the discrimination for threshold of anomalies on principal component image. Based on the normal distribution of mineralization anomalies, Zhang proposed "De -Interfered Anomalous Principal Component Thresholding Technique" (DIAPCTT) [5], and the 'N' times standard deviation was used as the measure for anomaly slicing. Chen has reported the obvious nonlinear characteristics (self-similarity and mutability) of geological anomalies [6]. However, whether these nonlinear characteristics can be used to quantitatively calculate the critical threshold of anomalies on principal component image hasn't been documented yet.

In this study, a fractal dimension-change point model (FDCPM) which is based on calculating two independent attribute that are respectively self-similarity and mutability is proposed to extract geological anomaly's nonlinear characteristics. To test the model, the reflectance data of ASTER imagery in Beishan, an important ore concentration area in Silk Road Economic Belt, were evaluated as an example for discriminating the critical threshold of alteration anomalies.

2. Geological setting and data preparation

2.1. Geology

Beishan mineralization belt located at the boundary between Gansu and Xinjiang of China goes along NEE-EW-NWW trending beishan rift-orogeny. It is an important metal metallogenic belt for Au, Ag, Cu, Zn and others, in which there occur a number of middle -large scale mineral deposits [7]. Fangshankou area is located in the southwest of the Liuyuan ore concentration area in the beishan mineralization belt. The emergence stratum is the Devonian Three Wells Formations, and the main lithology includes feldspar quartz sandstone, feldspathic litharenite, feldspar sandstone with siltstone and pelitic siltstone. Moreover, the rift is growing, and the magma activity is intense. The metallotect characteristics of magmetic hydrothermal deposits which were formed in the Hercynian epoch is strictly controlled by faults, distributed spatially along the faults. The main types of the wall rock alteration include quartzitification, sericitization, chloritization, pyritization, limonitization, and carbonatization.

2.2. Remote sensing data preparation

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data are collected in 14 bands, three in the visible and near-infrared portion of the electromagnetic spectrum with 15 m spatial resolution, six in the short-wave infrared with 30 m spatial resolution, and five in the thermal infrared with 90 m spatial resolution. The relatively large number of bands (14 bands) and the wider spectrum (VIR 0.520–0.860 μm, SWIR 1.600–2.430 μm and TIR 8.125–11.650 μm) covered by the ASTER data allow discrimination between a wide range of rock compositions. Because of this advantage, ASTER data have been used increasingly for extracting mineralization alteration [2].

Data set ASTL1B 0010160457231106060060 was used for this research. To remove atmospheric effects and Crosstalk from ASTER SWIR data, the ENVI 4.8 software contain FLaash model and CrossTalk3.0 software were used. The resulting data can be assumed to be more representative of the soils or lithologies of the exposed areas than the unprocessed data. Hence, the spectrum will be more closely comparable to its corresponding library spectrum. Moreover, river, vegetation and other interferents were removed by mask technique.

3. Fractal dimension change point model

3.1. Self - similarity and Fractal Dimension Model

The essence of fractal dimension is self-similarity [8], and the size and number of geological anomalies have self-similarity characteristics [9]. Suppose there is a data set $\{X_i,\ i=1,2,\ \ldots,N\}$, the fractional model can be shown as below [10]:

$$N(r) = \sum_{i=1}^{N} Xi = Kr^{-D} \qquad (1)$$

where N(r) = Number of scale which is greater than or equal to X_i
r= Characteristic scale
K = Constant
D= Fractal dimension

$$\lg N(r) = \lg K - D \lg r \qquad (2)$$

Equation 2 is a deformation formula by evaluating the logarithm of equation 1. It is observed that there is an exact linear relation between lg$r$ and lgN（r）.

3.2. Mutability and change point mode

Han has reported the optimal number and position of change point could effectively be detected by the change point model, and its model as shown below [11].

1）When i=2，…，N, then the sample will divided into two sections (X_1, X_2, …, X_{i-1} and X_i, X_{i+1}, …, X_N) for each i. Nest ,the arithmetical mean（$\overline{X_{i1}}$ and $\overline{X_{i2}}$）and the square deviation （S_i）are calculated for each section.

$$S_i = \sum_{t=1}^{i-1} (X_t - \overline{X_{i1}})^2 + \sum_{t=i}^{N} (X_t - \overline{X_{i2}})^2 \qquad (3)$$

2）Calculate the arithmetical mean（$\overline{X}$）and the squared deviation for the sample（S）.

$$\overline{X} = \sum_{t=1}^{N} X_t / N \qquad (4)$$

$$S = \sum_{t=i}^{N} (X_t - \overline{X})^2 \qquad (5)$$

3）Calculate the expected value (E（S-S_i）).

$$E(S-S_i) = E[N^{-1}(i-1)(N-i+1)(\overline{X_{i1}} - \overline{X_{i2}})2],\quad i = 2, 3, \ldots N \qquad (6)$$

In a word, we can see that the change point can increase the difference between S and S_i. As shown in the formula 5, the S is a fixed value, and when the value of S_i reaches its minimum, the change point can be detected easily. The sample series is established by taking logarithmic operation for lgN（r）and lg$r$.

4. Extracting of hydrothermal minerals and its analysis

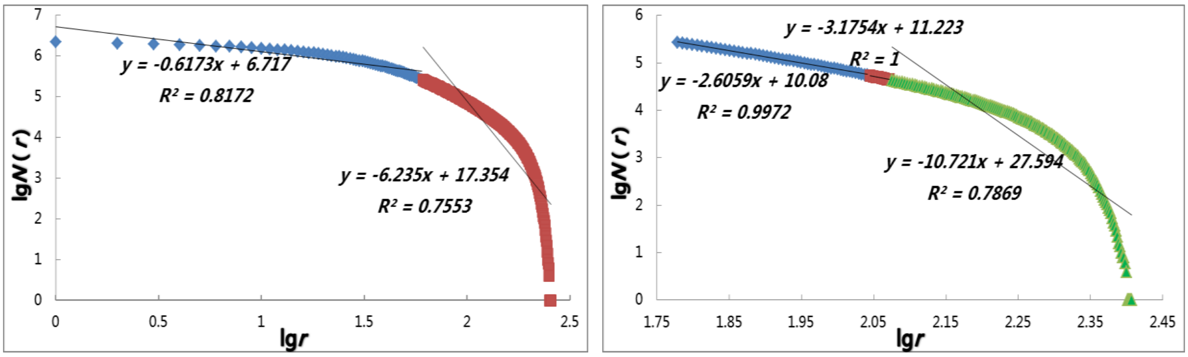
4.1. Extracting of hydrothermal minerals

Three principal component images containing Limonitization, Sericitization, and Chloritization are extracted by the Adaptive Coherence Estimator (ACE) method based on USGS mineral spectrum library for ASTER data. Then the fractal dimension model was used to analyze the self-similarity of different geological anomalies. Nest, the change point method was used to analyze the mutabiliyt of different geological anomalies, and when Si reaches its minimum, we got the precise location of the change point for different classification.

The results show that when the value of i is 59, Si reaches its minimum, and the value of r is 60, so we can consider that the value(r=60) is the critical threshold to distinguish the geological background and the grade 3 Limonitization. On the same principle, the value(r=111) was gotten to distinguish the grade 3 Limonitization and the grade 2 Limonitization, last the value(r=119) were got to distinguish the grade 2 Limonitization and the grade 1 Limonitization. In addition, the three values of r for Sericitization are 74, 125 and 132 respectively, and the three values of r for Chloritization are 170, 221 and 229 respectively.

Figure 1-a shows the self-similarity and the optimum imitative straight line for geological background and limonitization, with a fitting coefficient of 0.7553, which indicate that self-similarity can effectively distinguish the alteration anomalies. Figure 1-b shows the three critical thresholds and imitative straight line for different limonitization alteration grade. Then, the alteration anomaly map

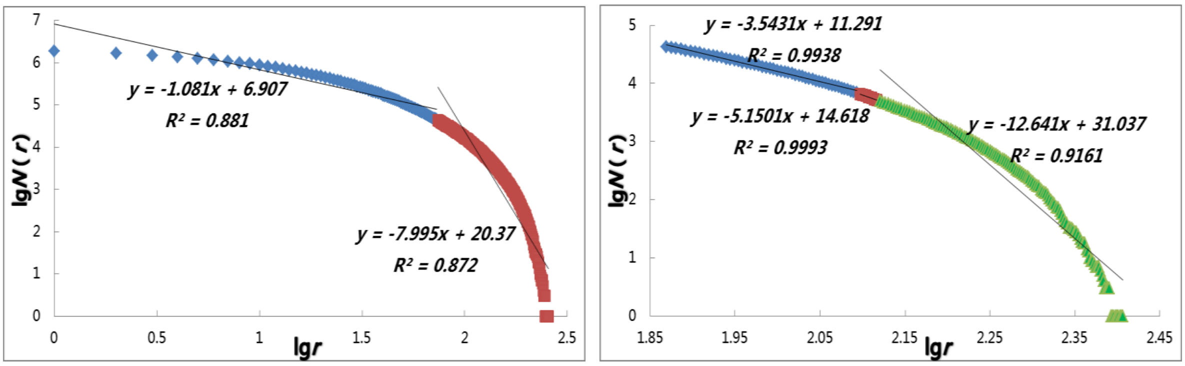
can be made. Similarly, figure 2 and figure 3 describes the fractal characteristic for Sericitization and Chloritization.



（a）log-log plot of anomalous principal component （b）log-log plot of anomalous classification

(blue represents geological background and red represents Alteration Anomalies) （intersection of different colors represents a different critical threshold for classification）

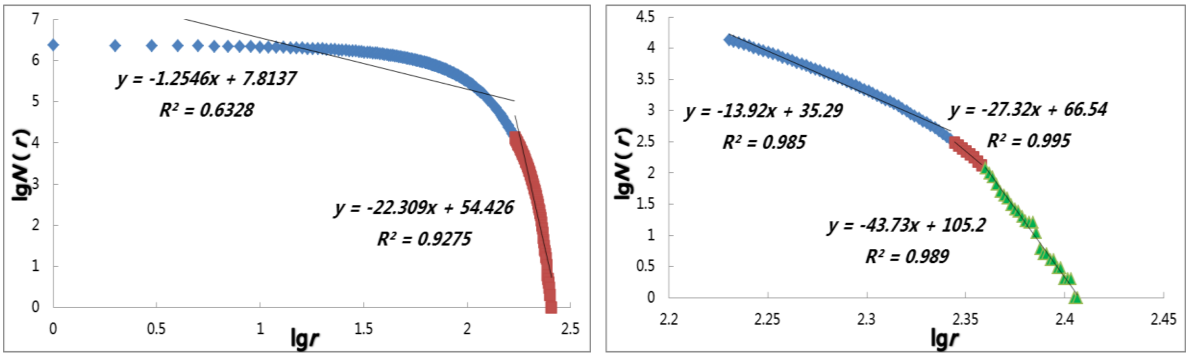
Fig.1 Fractal characteristic analysis diagram of limonitization



（a）log-log plot of anomalous principal component （b）log-log plot of anomalous classification

(blue represents geological background and red represents Alteration Anomalies) （intersection of different colors represents a different critical threshold for classification）

Fig.2 Fractal characteristic analysis diagram of sericitization



（a）log-log plot of anomalous principal component （b）log-log plot of anomalous classification

(blue represents geological background and red represents Alteration Anomalies) （intersection of different colors represents a different critical threshold for classification）

Fig.3 Fractal characteristic analysis diagram of chloritization

4.2. Spatial distribution of alteration minerals

Figure 4 is a remote sensing alteration anomalies map in the testing area. As can be seen from the map, the alteration anomalies show a linear distribution along nearly EW trending which is consistent with regional structures. The known ore and mineralized points are almost lying in the anomaly area or its boundary, moreover the remote sensing alteration anomalies are agreed well with a mounting body of evidence from heavy mineral anomaly and geochemical anomaly. What's more important is the field verification also confirmed the above phenomenon.

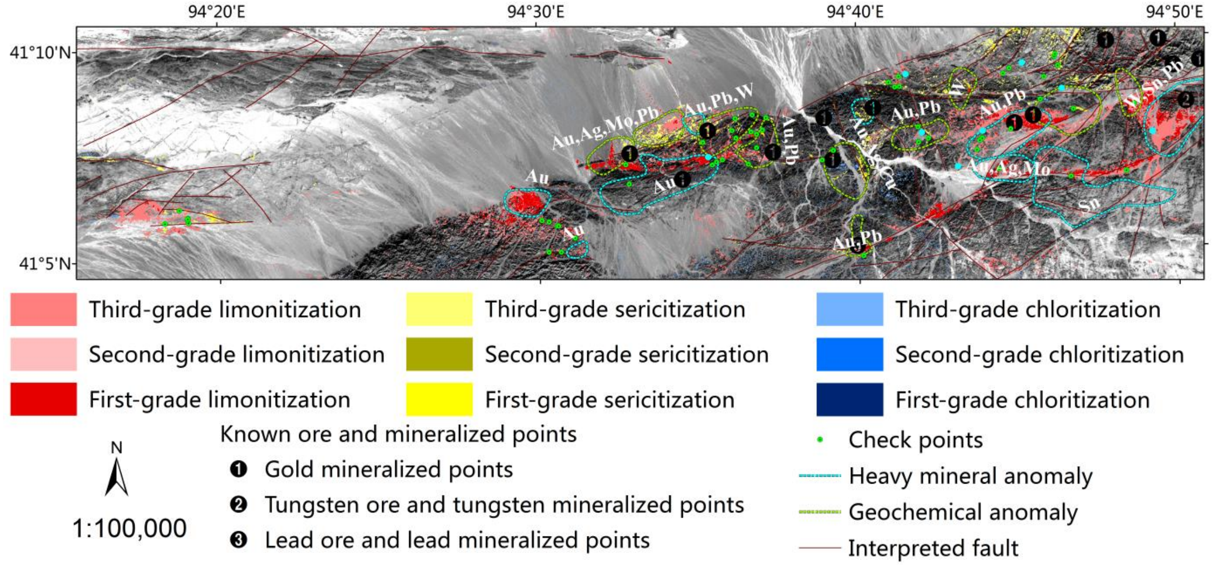


Fig.4 Remote sensing alteration anomalies map in the testing area

64 points were randomly selected to verify the accuracy of remote sensing alteration anomalies. The results show that the fractal dimension-change point model is an effective extracting method for remote sensing alteration anomalies, and its accuracy could over 80% (see table 1).

Table 1. Confusion matrix of alteration minerals.

Extracting / Checking	Limonitization	Sericitization	Chloritization
Limonitization	28	3	2
Sericitization	1	17	
Chloritization	3	1	8
None	1		
Total	33	21	10
Accuracy（%）	84.85	80.96	80

4.3. Compare with DIAPCTT

Table 2 shows the different results of critical threshold by DIAPCTT and FDCPM, also the corresponding 'N' value for DIAPCTT were given. It can be seen that there is a great difference for threshold by different methods. The proportion of limonitization information which is obtained by DIAPCTT is 7.48%, and the proportion which is obtained by FDCPM is 10.48%, this means that we have got more limonitization information. For sericitization and Chloritization, the proportion of alteration anomalies information got by DIAPCTT much larger than the result obtained by FDCPM, this may reflect that the threshold range got by previous method is too wide. On the other hand, the N values in DIAPCTT can directly affect the amount of anomalies information, but it can't be quantitative selected until now. Through the above comparison, we can sure that the FDCPM be more objective and effective for people who is deficient in geological experience or had no information about the geological background of the study area.

Table 2. Statistical information of remote sensing alteration anomalies.

AA	Method	Average	SD	Third-grade			Second-grade			First-grade		
				TH	PP	'N'	TH	PP	'N'	TH	PP	'N'
LI	DIAPCTT	25.94	29.36	69.98	7.48	1.5	84.65	4.61	2	99.33	2.93	2.5
	FDCPM			60	10.48	1.16	111	2.14	2.9	119	1.72	3.17

SE	DIAPCTT	12.29	18.38	39.86	6.76	1.5	19.06	4.37	2	58.25	3.02	2.5
	FDCPM			74	1.70	3.36	125	0.26	6.13	132	0.20	6.51
Ch	DIAPCTT	54.03	38.37	111.58	8.15	1.5	130.76	3.71	2	149.94	1.52	2.5
	FDCPM			170	0.53	3.02	221	0.01	4.35	229	0.01	4.56

(Abbreviations: AA-alteration anomalies, LI-Limonitization, SE-Sericitization, CH-Chloritization, DIAPCTT-De-Interfered Anomalous Principal Component Thresholding Technique, FDCPM- Fractal Dimension-Change Point Model, SD-Standard deviation, TH- Threshold, PP- Pixel proportion)

5. Conclusions

This study proposed a new method which was named fractal dimension-change point model (FDCPM). Then, we explore the performance characteristics of the model for quantitative calculating the critical threshold of remote sensing alteration anomalies and locating the hydrothermal mineralized alteration zones in Beishan, which is an important mineralization area in the silk road economic belt. This approach is based on the self-similarity and mutability of alteration anomalies. The experiment result indicates that FDCPM is an effective method and its extracting accuracy could over 80%. What's more important is its findings agree well with a mounting body of evidence from different perspectives. These results indicate that our method is promising for identifying alteration zones and is a useful tool for mineral exploration in similar areas in the silk road economic belt. Also, this model will be a useful addition for DIAPCTT to choose the thresholding value quantificationally.

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