Distribution characteristics of elemental grade and mineralization grade of Jiama copper deposit

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Abstract. The change of metallogenic element grade in borehole has strong randomness and nonlinearity. Quantitative analysis of metallogenic element grade distribution is one of the important ways to reveal the degree of mineralization enrichment. Taking Jiama porphyry copper deposit as an example, the distribution structure of Cu grade series in exploration lines 32 and 36 is analyzed by lacunarity method, and this paper discusses the relationship between lacunarity index and mineralization intensity. It is found that both the lacunarity index and parameters of Cu element in different boreholes exist distinction, the higher the mineralization intensity, the smaller the lacunarity index and the smoother the curve, pointing that the high-grade Cu element is more enriched and uniform. The size of lacunarity index and the variation trend of lacunarity curve have a certain indicative effect on mineralization grade.

1. Introduction
Due to the chronicity and complexity of geological processes, various geochemical elements are gradually enriched or depleted in geological bodies, showing abnormal structure of spatial distribution of elements, and their enrichment rules and spatial distribution have fractal characteristics [1-2]. Lacunarity method is one of the fractal methods for quantitative analysis of structural distribution, which can describe fractal sets with the same fractal dimension value but different aggregated distribution structures [3-5]. The methods for calculating lacunarity values include: number box method, gliding box method and periodic boundary method, among which the gliding box method proposed by Allain and Cloitre is the most widely used [6].

This paper takes some boreholes of Jiama deposit in Tibet as an example, the lacunarity curves of Cu grade series in different boreholes are worked out using gliding box method, to explore the structural characteristics of Cu grade aggregation distribution and the significance of mineralization, it provides data support and scientific basis for the regional metallogenic grade judgment.

2. Materials and methods

2.1. Study area and data source
The Jiama porphyry-skarn Cu-polymetallic deposit is located in Maizhokunggar County, approximately 68 km east of Lhasa, the capital city of Tibet. The Jiama porphyry deposit contains typical alteration system of porphyry deposit with slight difference of alteration zonation. The Jiama deposit is composed of four types, including skarn, skarnized hornfels and skarnized marbles, and the main elements associated with them are Cu, Mo, Pb, Zn, Au and Ag [7].

In this paper, the Cu grade series of 14 boreholes in 32 and 36 exploratory lines in Jiama deposit is selected as the research object, the sampling depth of line32 is between -253m and -511m, the sampling...
depth of line 36 is between -79m and -315m, their sampling spacing is 2m, and the element content unit is wt%.

Based on variation in mineralization density, the drifts are classified into the three rank: (I) barely mineralized drifts, in which the proportion of Cu grades is greater than 0.3 wt % and lower than 20 %, and the orebodies are barely developed; (II) moderately mineralized drifts, in which the proportion of Cu grades is greater than 0.3 wt % and between 20 % and 50 %, and the mineralization is relatively intermittent and thin; (III) intensely mineralized drifts, in which the proportion of Cu grades is not less than 0.3 wt % and larger than 50 %, and the mineralization is very thick [8].

2.2. Lacunarity

Lacunarity can not only be used to calculate binary data, but also can be extended to the calculation of continuous data. Gliding box algorithm is selected as the method to estimate the lacunarity index. The steps are as follows [9-10]:

A box of length $r$ is placed to the left of a data set of length $L$, if the data set consisted with 0 and 1, the mass $M$ is the number of data values of 1 in this box, while in the case of continuous data, the mass $M$ is the sum of data in this box, then this box moves one step to right, repeat this process until the whole data is traversed. The probability distribution of mass $M$ in a gliding box of length $r$ is calculated by

$$P(M, r) = \frac{n(M, r)}{N(r)}$$

(1)

Where $n(M, r)$ is the number of gliding boxes which length is $r$ with mass $M$, and $N(r) = L - r + 1$ is the total number of times the box glides. The corresponding statistical moments of order $q(q=1,2)$ are given by

$$M^{(q)}(r) = \sum_{M=1}^{r} M^{q} P(M, r)$$

(2)

The lacunarity index in the box of length $r$ is defined by the first and second moments as

$$\Lambda(r) = \frac{M^{(2)}(r)}{[M^{(1)}(r)]^2}$$

(3)

In order to better compute the lacunarity index of continuous data and observe the statistical significance of the lacunarity index, some simple transformations are made to the calculation formula of the lacunarity index:

$$\Lambda(r) = \frac{Z^{(2)}(r)}{[Z^{(1)}(r)]^2} = 1 + \frac{D(r)}{[E(r)]^2} \propto a r^{-\beta}$$

(4)

Where $E(r)$ is the mean of grade in the sliding box length of $r$, and $D(r)$ is the variance of grade in the corresponding box. As can be seen from equation (4), the curve of lacunarity index versus $r$ is a decreasing curve with the change of $r$, using the power function to perform linear regression fitting to the curve, and the corresponding parameters $\alpha$ and $\beta$ are computed, they can be used for quantitative analysis of the lacunarity curve. When $\alpha$ is the same, the greater the $\beta$ value is, the more concave the curve is, and the more obvious the change is, in other words, when the box length increases, the lacunarity index drops more sharply, and the sequence distribution becomes more uniform; When $\beta$ is the same, the larger $\alpha$, the larger $\Lambda(1)$, that is say, when the box length is small, the sequence distribution is uneven.
3. Analysis

3.1. Statistical description and normality test
The mean value, standard deviation, skewness and kurtosis of the Cu grade series of six boreholes are figured out, and the Jarque-Bena (JB) normality test is conducted at the confidence level of 5%, the statistical value as follows:

\[ F_{JB} = \frac{n}{6} [S^2 + \frac{(K - 3)^2}{4}] \]  

Where S is skewness and K is kurtosis. The basic statistical results are shown in table 1. The skewness values are higher than 0, so its distribution pattern is right-skewed; the kurtosis values are higher than 0 except ZK3213, compared with the normal distribution, their distribution is leptokurtic; the JB statistic values are exceed the critical value, and the null hypothesis was rejected at the significance level of 5%. Therefore, the Cu grade distribution of ZK3213 is right-skewed and non-normal distribution with platykuritc, while the others shows a right-skewed and thin tails compared to a normal distribution.

Table 1. Descriptive statistics of element contents and test results.

| Borehole | Mean (wt%) | Standard deviation | Skewness | Kurtosis | JB statistic |
|----------|------------|---------------------|----------|----------|--------------|
| ZK3213   | 0.3111     | 0.2331              | 0.7612   | -0.0671  | 12.578*      |
| ZK3214   | 0.3350     | 0.1688              | 0.9976   | 1.1556   | 28.795*      |
| ZK3215   | 0.2738     | 0.1567              | 0.6998   | 0.0468   | 10.622*      |
| ZK3217   | 0.3189     | 0.1520              | 1.3968   | 3.1216   | 95.055*      |
| ZK3218   | 0.3594     | 0.1321              | 0.7913   | 0.2588   | 13.930*      |
| ZK3219   | 0.2456     | 0.1766              | 1.9005   | 5.3544   | 233.551*     |
| ZK3221   | 0.2840     | 0.1578              | 0.9676   | 0.4950   | 21.612*      |
| ZK3226   | 0.0929     | 0.0839              | 1.8047   | 3.3860   | 132.671*     |
| ZK3603   | 0.2273     | 0.2078              | 3.2224   | 11.985   | 918.202*     |
| ZK3608   | 0.1876     | 0.1399              | 1.8222   | 3.3307   | 120.864*     |
| ZK3662   | 0.4412     | 0.1729              | 0.9275   | 1.1896   | 24.078*      |
| ZK3666   | 0.5214     | 0.1755              | 0.8389   | 0.7457   | 16.714*      |
| ZK3668   | 0.4286     | 0.1533              | 0.6709   | 0.0231   | 8.931*       |
| ZK3670   | 0.2673     | 0.1652              | 1.4249   | 2.5971   | 73.712*      |

* significant at the confidence level of 5%.

3.2. Results and discussion
The gliding box method is used to calculate the lacunarity index of 14 boreholes on number 32 and 36 exploratory lines, the length of gliding box is \( r = 1, 5, 10, ..., 50 \), and gliding one step each time. Figure 1 (a)-(b) show the curve plot of lacunarity index \( \Lambda(r) \) as different length of \( r \) for 14 samples, then use the power function to fit the lacunarity curve, the fitting parameters \( \alpha, \beta \) and the goodness-of-fit \( R^2 \) obtained were shown in Table 2.

The lacunarity curves of Cu elements in all boreholes show a downward concave monotonically decreasing trend, and the decreasing rate decreases and tends to be horizontal with the increase of \( r \) (Figure 1). The \( \Lambda(1) \) value of Cu element series is most evident, between 1.112 and 1.828, ZK3603 is the largest and ZK3666 is the smallest. According to the least square fitting parameters of lacunarity curve, goodness-of-fit \( R^2 \) of all boreholes are exceed 0.9, indicating a high degree of fitting. The range of \( \alpha \) value of ZK3226, ZK3603 and ZK3608 is 1.532-1.845, the range of \( \beta \) value is 0.087-1.133; the scope of \( \alpha \) value of ZK3213, ZK3214, ZK3215, ZK3217, ZK3219, ZK3221 and ZK3670 is 1.228-1.538,
the scope of $\beta$ value is 0.038-0.097; the region of $\alpha$ value of ZK3218, ZK3662, ZK3666 and ZK3668 is 1.104-1.133, the region of $\beta$ value is 0.026-0.034. Overall, from the variation range of $\alpha$ value and $\beta$ value, it can be seen that the value of intensely mineralized drifts is relatively small, and that of moderately and barely mineralized drifts is relatively large, its results show that the high-grade distribution of the Cu element in intensely mineralized drifts is uniform, but not locally enriched, the low-grade distribution of the Cu element in moderately and barely mineralized drifts is depleted locally, and high-grade aggregation.

| Borehole | $\Lambda(1)$ | $\alpha$ | $\beta$ | Rank |
|----------|--------------|----------|---------|------|
| ZK3213   | 1.557        | 1.538    | 0.078   | II   |
| ZK3214   | 1.252        | 1.256    | 0.043   | II   |
| ZK3215   | 1.325        | 1.342    | 0.060   | II   |
| ZK3217   | 1.225        | 1.228    | 0.038   | II   |
| ZK3218   | 1.134        | 1.116    | 0.028   | III  |
| ZK3219   | 1.513        | 1.489    | 0.097   | II   |
| ZK3221   | 1.306        | 1.283    | 0.065   | II   |
| ZK3226   | 1.808        | 1.672    | 0.133   | I    |
| ZK3603   | 1.828        | 1.845    | 0.113   | I    |
| ZK3608   | 1.552        | 1.532    | 0.087   | I    |
| ZK3662   | 1.152        | 1.133    | 0.034   | III  |
| ZK3666   | 1.112        | 1.104    | 0.026   | III  |
| ZK3668   | 1.127        | 1.116    | 0.028   | III  |
| ZK3670   | 1.379        | 1.364    | 0.058   | II   |

Figure 1 lacunarity index curve.
(a) exploration line 32; (b) exploration line 36.

4. Conclusion
The lacunarity method is used to study the distribution characteristics of multi-boreholes Cu grade sequences in two exploration lines of Jiama porphyry copper deposit. The results show that the lacunarity curves of Cu element contain distinctions among different boreholes, in which the smaller the lacunarity index is, the more homogenous the high-grade distribution is, and the higher the mineralization degree is; while the larger the lacunarity index is, the heterogeneous the high-grade distribution is. It indicates that the lacunarity index can reflect the aggregation degree of high-grade distribution, and can be used as a potential parameter to identify the mineralization intensity, providing
a reference for further identifying the mineralization enrichment process and explaining the spatial and temporal structure of geochemical field.

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