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CHAOTIC ANALYSES FOR SPACE SERIES OF GOLD GRADE

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A new powerful tool, chaotic theory, has been used to study mineralization through chaotic analysis for space series of gold grade in this paper. Both of the most important chaotic measures, Largest Lyapunov exponent (LLE) and fractal dimensional, for space series of gold grade in one gold deposit are computed. The positive LLE suggests that the space series of gold grade are chaotic series. When the phase space dimension approach 8∼10, a chaotic attractor appears and their fractal dimension values vary from 1.94 to 3.99. It indicates that the evolution of ore-forming fluid and the enrichment and deposition of gold element are chaotic dynamic process.

Keywords: Gold grade; space series; chaotic analysis.

1. Introduction

Non-linear dynamics theory opens new window for understanding behavior of mineralization. The gold grade of gold deposit is typically heterogeneous, a result of complex geological processes operating during deposition and mineralization. In fact, many investigates have proved that complex dynamical evolutions lead to chaotic regimes. In the last thirty years, experimental observations have pointed out that chaotic systems are common in nature.[1]

As a result of complexity and chronicity of evolution of ore-forming dynamic system, it is difficult to obtain the time series of gold grade accurately at some site. But it is easily to measure the space series of gold grade along some direction. In epizonal hydrothermal gold deposit, gold element often precipitating during Au-bearing fluids flow through the host rocks, so the space series of gold grade can reflect the temporal evolution of ore-forming dynamic system. Therefore, chaotic analysis of space series of gold grade can indicate the temporal evolution of ore-forming dynamic system and moreover discuss the dynamic mechanism of mineralization.

2. Chaotic Analysis for Space Series of Gold Grade

2.1. *The lyapounov exponent* (λ) *and fractal dimension* (D)

Chaotic dynamic systems are also deterministic but are very sensitive to initial conditions. This means that if two trajectories start close to one another in phase space, they can diverge away from each other in an exponential fashion. Quantitatively this divergence is measured by the Lyapounov exponent.[2] Chaotic processes are characterized by positive Lyapounov Exponents (LE). We have followed the approach of Wolf *et al.*[3] to construct the algorithm to analyze and to calculate Largest LE (LLE) from gold grade data.

The fractal dimension D is a measure of the extent to which trajectories on the attractor fill a region in the phase space; a strange attractor has a fractal dimension D. It can be calculated based on the algorithm constructed by Grassberger and Procaccia.[4]

2.2. *Characteristics of space series of gold grade*

All of the space series of gold grade are come from the Woxi Au-Sb-W deposit in NW Hunan province, China. In this study three major veins V_1, V_3 and V_4 of the deposit are sampled along with the horizontal tunnel and the sample's interval is 2 m (Fig. 1). Figure 1 indicates that the gold grades show a complex vibrational change at horizontal which may results from the complexity and chronicity of evolution of ore-forming dynamic system.

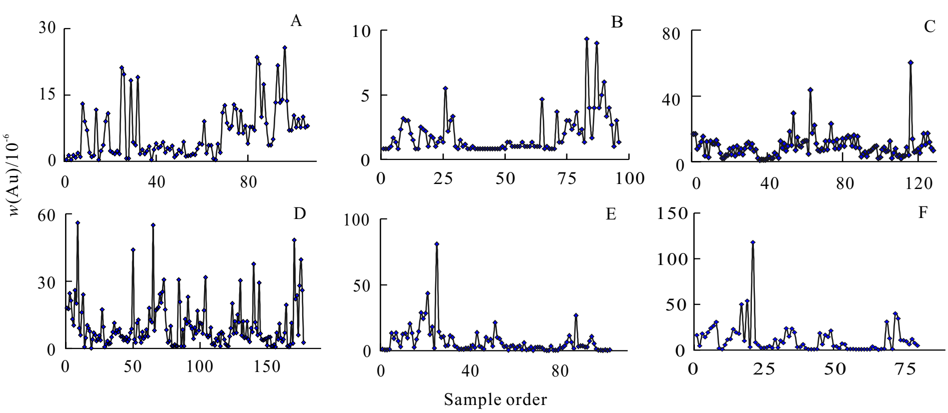

Fig. 1. Grade spatial variations of the Woxi Au-Sb-W deposit in NW Hunan province, China. All floors are sampled in turn from west to east. w is the gold grade and *Sample order* represents spatial situation of samples. (A) The 8th floor of V_1. (B) The 22nd floor of V_1. (C) The 15th floor of V_3. (D) The 20^{th} floor of V_3. (E) The 15th floor of V_4. (F) The 21st floor of V_4.

2.3. *Results of LLE (λ) and D for space series of gold grade*

We computed $C(\varepsilon, N, m)$ of the space series of gold grade data set show on Fig. 1 with dimensional embedding $m = 2$, 4, 6, 7, 8, 9, 10, 11. Starting fro $m = 6$, the slopes of the correlation curves are very close to each other (Fig. 2). A *plateau* can be observed when m arrives at 8–10. Table 1 shows the fractal dimension D results for all floors and the D values vary from 1.94 to 3.99. A finite, noninteger value of D is considered to be a strong indication of the presence of deterministic chaos. Thus the method should reveal the presence of chaos in the data.

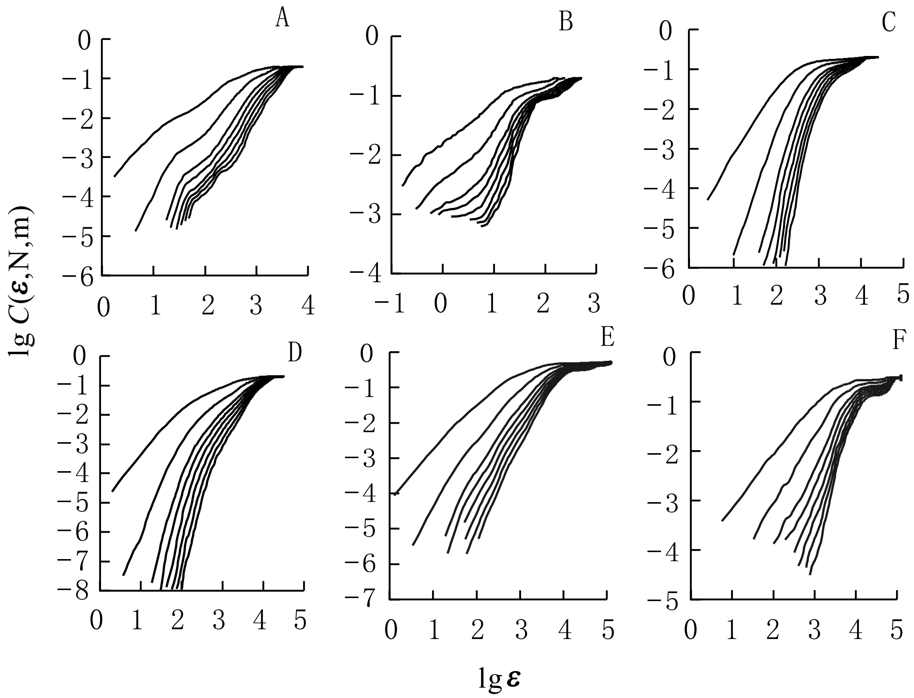

Fig. 2. Calculate of fractal dimension of space series of gold grade of the Woxi Au-Sb-W deposit in NW Hunan province, China. The dimensional embedding m is equal to 2, 4, 6, 7, 8, 9, 10, 11 in turn from up to down. (A) The 8th floor of V_1. (B) The 22nd floor of V_1. (C) The 15th floor of V_3. (D) The 20th floor of V_3. (E) The 15th floor of V_4. (F) The 21st floor of V_4.

Table 1. Chaotic analysis for space series of gold grade of the Woxi Au-Sb-W deposit in NW Hunan province, China. (N: Number of samples, m: Embedding dimension.)

Floor	V_1-8	V_1-22	V_3-15	V_3-20	V_4-15	V_4-21
N	106	96	128	177	102	80
m	10	10	9	8	9	10
$\lambda_{\max}$	0.0856	0.056	0.1209	0.224	0.1232	0.1128
D	1.94	2.39	3.99	2.35	1.99	2.53

We calculate the LLE (λ) for embedding dimensions equal to the dimension $\boldsymbol{m}$ estimated from the correlation dimension test and keep the delay time was kept constant at $\tau = 1$. Table 1 shows the results for all floors and exhibit positive λ which ulteriorly suggests that all six data sets are consistent with a deterministic chaos and the evolution of ore-forming fluid and the enrichment and deposition of gold element are chaotic dynamic process.

3. Discussion and Conclusions

Any hydrothermal gold deposit is emergent self-organized phenomena whose formation is a consequence of structurally localized perturbations within crustal scale hydrothermal systems. These complex dynamical systems are generated by the coupling of deformation, magmatism, groundwater flow, and magmatic vapor interactions over a wide range of scales from the molecular to the regional. Epizonal gold mineralization characteristically develops incrementally through the complex interaction of a range of short timescale processes resulting from phase separation effects, consequent heat transfer and fluid flow effects, and molecular scale interactions between solutes and reactive host rocks,[5] Such interactions lead to non-linear feedback processes between fluid and host rock and the potential to amplify small differences in rock properties, for example, through to the formation of giant gold deposits with complex spatial variation of grade.[6]

Positive LLE (λ) of space series of gold grade suggest that the space series of gold grade are chaotic series. When the phase space dimension approach 8$\sim$10, a chaotic attractor appears and their fractal dimension (D) vary from 1.94 to 3.99. It indicates that the evolution of ore-forming fluid and the enrichment and deposition of gold element are chaotic dynamic process. In generally, the mineral deposition is a complex nonlinear dynamic process. Minerals in hydrothermal system will deposit at appropriate place at last through complex nonlinear feedback effect among structural stress, fluid flow and fluid-rock reaction and lead the fractal and chaotic characteristics of deposits and grade distribution.

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References

1. S. Boccaletti, C. Grebogi, Y.-C. Lai, H. Mancini and D. Mazaet, *Physics Reports* **329**, 108 (2000).
2. G. Nicolis, *Cambridge University Press, Cambridge* (1989), p. 316
3. A. Wolf, J. B. Swift, L. H. Swinney and J. A. Vastano, *Physica* **D16**, 285 (1985).
4. P. Grassberger and I. Procaccia, *Physics Review Letter* **50**, 346 (1983).
5. D. Curewitz and J. A. Karson, *J. Volconal Geotherm Res.* **79**, 149 (1997).
6. C. A. Carlson, *Geology* **19**, 111 (1991).