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Spatial pattern and dynamic control for mineralization in the Pulang porphyry copper deposit, Yunnan, SW China: Perspective from fractal analysis

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ABSTRACT

The Pulang ore deposit, one of the largest porphyry copper deposits in China, is located in the Yidun continental arc, SW China. The alteration zones in the deposit transit upward and outward from early potassium-silicate, through quartz–sericite, to later propylitization. The wallrock near the porphyry stock was mostly changed into hornfels. The former two alterations host the main orebodies, constituting the core of mineralized zone; the later two alterations only develop weak mineralization surrounding the core. In this paper, various fractal indices, including the exponent of lacunarity, multifractal spectrum, correlation dimension and Hurst exponent, are applied to characterize the Cu spatial distribution in 114 drillcores in the Pulang ore deposit, with the aim to correlate the element spatial pattern with its dynamic drive. Compared to fractal indices in the propylitic zone and hornfels, the exponents of lacunarity in the potassium-silicate and quartz–sericite zones exhibit lower and more stable values, the correlation dimensions are higher and more consistent; yet the values of height difference of multifractal spectrum are lower and largely varied, and the Hurst exponents show little difference. Variations of the former three indices suggest that the core of mineralized zone has more homogeneity, stronger compactness of high concentrations, and greater proportion of high concentrations in the Cu distribution compared to the other parts of the deposit. More importantly, the correlation dimension, indicating the complexity of controls underpinning the system, is closely correlated to the exponent of lacunarity, which represents the homogeneity of spatial pattern. This correlation between those two indices implies a genetic link, that is to say the greater complexity of controls results in a more homogeneous spatial distribution of Cu in the porphyry deposit. The stability of the two indices is considered to reflect the development of thick orebody, providing a new perspective to understand the genesis of porphyry ore deposit. This interpretation from the fractal perspective is consistent with the geological understanding for the formation of porphyry deposits, which is considered to be subject to the complexity of ore fluid evolution with multifaceted physicochemical conditions. For a pragmatic use, these two fractal indices are successfully applied in the delineation of the core of mineralized zone in the plane view.

1. Introduction

Quantitative description of the spatial distribution of ore-forming elements in mineral deposits is significant for the mineral exploration and understanding of ore-forming processes. The concentrations of metallogenic metals in mineralized zones often exhibit skewed statistical distributions and similarities in spatial distributions across a range of scales of several magnitudes of difference, and can be described by various fractal models (Deng et al., 2009, 2010; Gumiel et al., 2010; He et al., 2013; Luz et al., 2014; Monecke et al., 2001; Wan et al., 2010; Wang et al., 2011a, 2012a, 2012b). The fractal models mostly belong to the self-similar domain, including the box-counting model (Mandelbrot, 1983; Rehman et al., 2013), number–size model (Turcotte, 2002; Wang et al., 2010a, 2010b), concentration–area model (Cheng et al., 1994; Zuo et al., 2013), and perimeter–area model (Cheng, 1995), and partly belong to the self-affine domain (Wang et al., 2007) and multifractal domain (Agterberg et al., 1996; Arias et al., 2011; Cheng, 1999, 2012; Deng et al., 2008, 2011; Wang et al., 2011b; Zuo and Wang, 2016). Some indices of fractal models, such as power-law exponent of lacunarity in the self-similar domain, multifractal spectrum and correlation dimension in the multifractal domain, and Hurst exponent in the self-affine domain, have been effectively applied in various disciplines. Moreover, the correlation dimension and Hurst exponent are considered to be significant in unveiling the dynamic mechanism of a system (Eckmann and Ruelle, 1985; Turcotte, 1997).

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Self-similar models are used to describe systems with self-similarity, meaning that each portion of such systems can be considered a reduced-scale image of a whole system of interest (Mandelbrot, 1967). The fractal dimension, a vital index in the self-similar domain, provides a statistical index of complexity comparing how detail in a fractal pattern changes with the scale at which it is measured (Mandelbrot, 1967). With the increasing application of the self-similar models, it was realized that the systems with the same fractal dimension can still bear different spatial structures. Accordingly, the lacunarity was proposed by Mandelbrot (1983) as a complementary measure to the fractal dimension and was improved by Allain and Cloitre (1991), Cheng (1997), and Roy et al. (2010). The lacunarity was first used to describe the spatial distribution of the gap sizes in a fractal system. It was further revealed that the lacunarity itself shows a scale-dependent feature (Allain and Cloitre, 1991; Plotnick et al., 1993). The exponent of the power-law relationship of lacunarity (named the exponent of lacunarity in this paper) is extracted to quantify heterogeneity of an object (Plotnick et al., 1996). Yet, there are relatively few applications of this index for the characterization of the geochemical distribution in ore deposits. The multifractal technique was first introduced by Mandelbrot (1974), and then it has been applied in several empirical and theoretical studies to depict the complex dynamical behavior of a system with inherent multiplicative cascade process (Agterberg, 2012; Stanley and Meakin, 1988; Xie et al., 2010). The correlation dimension and multifractal spectrum from the multifractal domain were extensively used to various geological subjects, such as fractures (Agterberg et al., 1996; Arias et al., 2011; Carranza, 2009; Zhao et al., 2011) and geochemical data (Wang et al., 2007, 2012a, 2012b; Zuo and Cheng, 2008; Zuo et al., 2015). In the multifractal domain, the correlation dimension is particularly sensitive to the functioning controls for the system of interest (Yılmaz and Güler, 2010). The Hurst exponent proposed by Hurst (1951) has been widely used in geosciences (Turcotte, 1997) to characterize the persistence and erratic feature of a system. It was illustrated that different fractal indices can draw the various aspects of the spatial pattern of a system and further unveil its dynamic mechanism.

The Pulang ore deposit, one of the largest porphyry copper deposits in China (Deng et al., 2012, 2014a; Mao et al., 2012, 2014), is characterized by typical porphyry-type alteration zone. The geological features of the deposit, including the alteration types and their zonation, the geometry of orebody, metallogenic time, and geodynamic setting have been extensively researched (Leng et al., 2012; Li et al., 2011, 2013). Despite these, the spatial distribution of ore-forming elements, which is the direct result of ore-forming process and thus the important medium for us to understand the process, has not been well addressed. In this

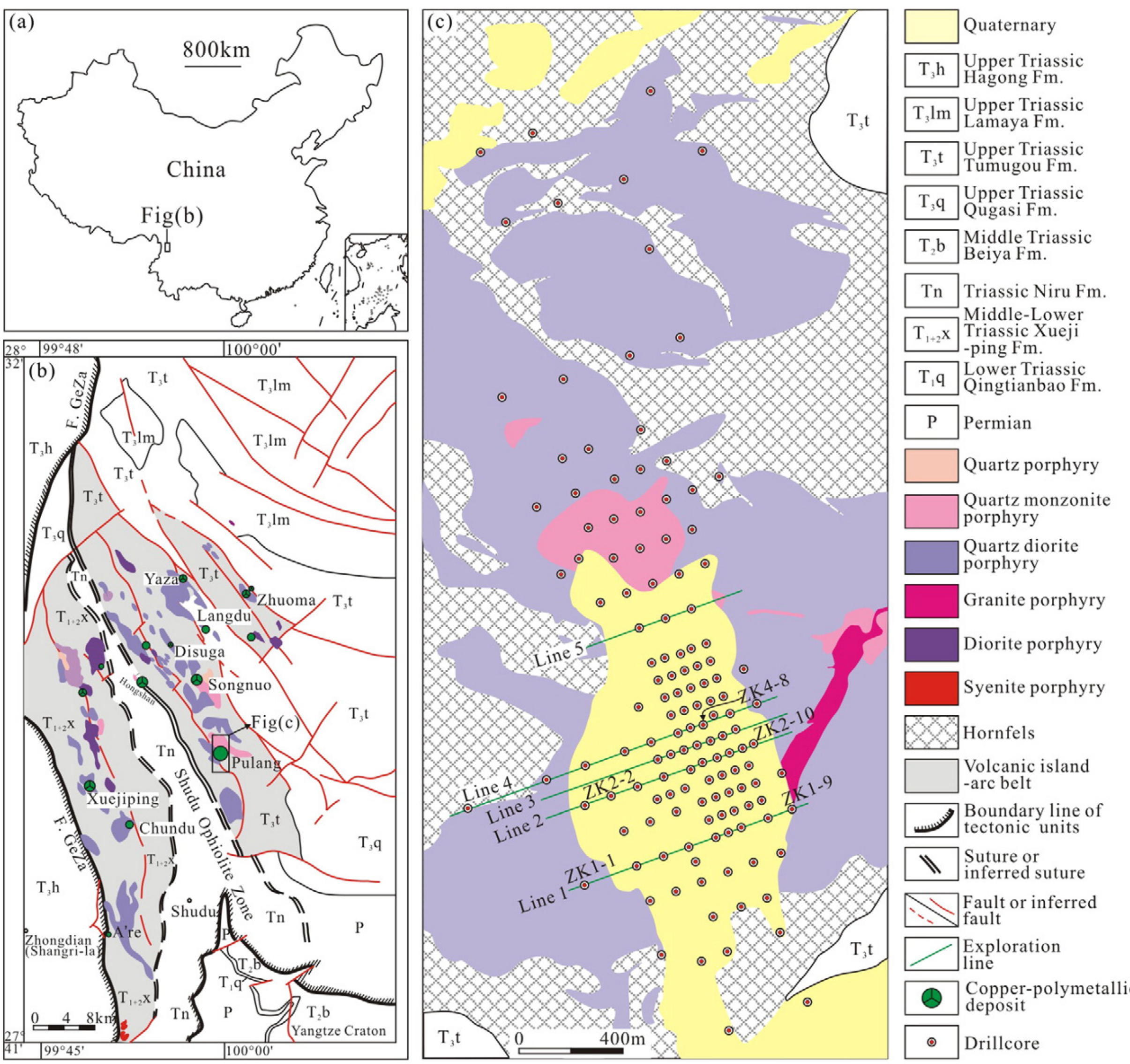

Fig. 1. Geological map of the Pulang porphyry copper deposit, SW China. Modified after Yunnan Diqing Nonferrous Metal Co. Ltd., 2009.