Journal of African Earth Sciences 134 (2017) 308–319

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

Determination of the relationship between major fault and zinc mineralization using fractal modeling in the Behabad fault zone, central Iran

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ARTICLE INFO

Article history:
Received 5 November 2016
Received in revised form
27 June 2017
Accepted 27 June 2017
Available online 28 June 2017

Keywords:
Concentration-Distance to Major Fault (C-DMF)
Area of Mineralized Zone-Distance to Major Fault (AMZ-DMF)
Concentration-Area (C-A)
Fractal models
Behabad fault zone

ABSTRACT

The aim of this study is to determine a relationship between zinc mineralization and a major fault in the Behabad area, central Iran, using the Concentration-Distance to Major Fault (C-DMF), Area of Mineralized Zone-Distance to Major Fault (AMZ-DMF), and Concentration-Area (C-A) fractal models for Zn deposit/mine classification according to their distance from the Behabad fault. Application of the C-DMF and the AMZ-DMF models for Zn mineralization classification in the Behabad fault zone reveals that the main Zn deposits have a good correlation with the major fault in the area. The distance from the known zinc deposits/mines with Zn values higher than 29% and the area of the mineralized zone of more than 900 m^2 to the major fault is lower than 1 km, which shows a positive correlation between Zn mineralization and the structural zone. As a result, the AMZ-DMF and C-DMF fractal models can be utilized for the delineation and the recognition of different mineralized zones in different types of magmatic and hydrothermal deposits.

1. Introduction

Mineralization occurs with several natural processes related to geological events such as structures, hydrothermal fluids, magmatism, and sedimentation, which are all essential for the exchange of mineralization characteristics, especially ore grade values and geometrical shapes (Sillitoe and Perello, 2005; Pirajno, 2009; Laznicka, 2010; Muto et al., 2015). Structural features, specifically main faults, play significant roles in the transportation of magmatic/hydrothermal and “meteoric” (groundwater) fluids during mineralization processes (Pirajno, 2009). Main faults (especially, activate faults) are important for the spatial distribution of ore deposit characteristics such as ore elements and geometrical shapes, especially in mineralized veins (Pirajno, 2009; Muto et al., 2015; Nouri et al., 2013; Yousefi and Nykänen, 2016). However, different ore types are associated with tectonic settings and structures, especially faults. The purpose of structural analysis and modelling is to recognize which deformation has influenced an increase or decrease of rock permeability for a better understanding of the transportation and the precipitation of ore-forming fluids (Sawkins, 1990; Robb, 2005; Laznicka, 2010). Moreover, hydrothermal and “meteoric” ore-forming fluids rise alongside fractures or faults. In addition, the fault zones, specifically in faults' intersections, have high geothermal gradients for heating of meteoric waters. Furthermore, structural settings consisting of faults, shear zones and fracture networks are suitable depositional sites for ore mineralization (Pirajno, 2009; Sawkins, 1990).

Conventional methods including calculation of mean and Standard Derivation (SD), probability graphs, Exploration Data Analysis (EDA), and multivariate data analysis have been mostly utilized in geochemical exploration. These methods, however, do not consider spatial variations within geochemical patterns. In the past decades, a number of complex structures and phenomena have been quantitatively characterized by the means of fractal/multifractal modelling in different kinds of deposits (e.g., Wang et al., 2012; Nouri et al., 2013; Xu and Cheng, 2001; Carranza

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http://dx.doi.org/10.1016/j.jafrearsci.2017.06.025
1464-343X/

et al., 2008; Davis, 2002; Zuo et al., 2009, 2015; Agterberg, 2012; Xiao et al., 2012; Afzal et al., 2013; Sadeghi et al., 2015; Wang and Zuo, 2015; Yasrebi, 2014). Some methods are employed for the modelling and the interpretation of geological (especially, geochemical) data, such as classical statistics (Davis, 2002; Tukey, 1997), fractal/multiracial modeling (Hirata, 1989; Cheng et al., 1994; Agterberg, 1995; Li et al., 2003; Zuo et al., 2015; Afzal et al., 2011, 2012; Yousefi and Carranza, 2015), and singularity modelling (Wang et al., 2012; Cheng, 2007). Fractal theory was established by Mandelbrot (1983) as a significant non-Euclidean branch in geometry. Since the 1980s, several models have been proposed and developed with respect to fractal geometry for application in the geosciences (Nouri et al., 2013; Sadeghi et al., 2015; Agterberg, 1995; Turcotte, 1997; Goncalves et al., 2001; Monecke et al., 2005; Gumiel et al., 2010; Zuo, 2011; Sadeghi et al., 2012; Parsa et al., 2016, 2017).

Geological processes, such as igneous and metamorphic activities, and the creation of ore deposits, occur at plate boundaries that are often identified by fault zones (Robb, 2005; Pirajno, 2009; Laznicka, 2010). Many Mississippi Valley Type (MVT) mineralizations/deposits, consisting of barite, lead, and zinc occurrences/deposits with the carbonate host rocks, were formed in the Behabad and the Mehdiabad regions (Piri and Asghari, 2012). The structural features, especially major faults and deformation, were effective in mineralization, particularly, for secondary enrichment mineralization (Walker and Jackson, 2004; Meyer and Le Dortz, 2007; Leach et al., 2010).

The purpose of this study is to classify the Zn-Pb MVT deposits hosted in carbonate rocks with regard to their distance from the major fault (in this case the Behabad Fault) using the Concentration-Area (C-A: Cheng et al., 1994), the Area of Mineralized Zone-Distance Major fault (AMZ-DMF), and the Concentration-Distance Major Fault (C-DMF) (Nouri et al., 2013) models, and applying the fractal models in the Behabad fault zone of central Iran. The structural features of the Behabad fault zone were mapped using remote sensing and field observations. Furthermore, the faults rose diagrams were correlated with those possessing the structural features of the MVT deposits in the Behabad region.

2. Methodology

Mandelbrot (1983) established a Number-Size (N-S) fractal model for the description of natural features' distribution, which has the following form:

$$N\ (S \geq \upsilon) = aS^{-D} \quad (1)$$

where N ($S \geq \upsilon$) is the number of features (for example: fault lengths) with size (S) greater than or equal to υ, and D is the fractal dimension. Several researchers show that the fault systems have self-similarity and fractal dimensions (Hirata, 1989; Aviles et al., 1987; Sornette et al., 1990; Fagereng, 2011). Various fractal models were established based on the N-S model; these fractal models have been applied in the different fields of the geosciences.

2.1. C-A fractal model

Cheng et al. (1994) proposed the C-A fractal model, which may be utilized to describe wall rocks and different anomalies/mineralized zones based on the occupied areas, in the following form (Cheng et al., 1994):

$$A\ (\rho \leq \upsilon) \propto \rho^{-a1};\ A\ (\rho \geq \upsilon) \propto \rho^{-a2} \quad (2)$$

where A (ρ) represents the area with concentration values greater than the ρ value; υ denotes the threshold, and a1 and a2 are the characteristic exponents. The breakpoints between straight-line segments in a log–log plot and the corresponding values of ρ have been utilized as thresholds to categorize the geochemical values into different components indicating the various causal factors, such as lithological, alteration, and structural differences as well as the geochemical processes. Factors such as mineralizing events, surficial elemental concentrations, and surficial weathering by meteoric waters with a relationship to the faults are necessary, and should be considered (Lima et al., 2003; Afzal et al., 2010)

2.2. Concentration-Distance Major Fault fractal model

The Concentration-Distance Major Fault (C-DMF) fractal model was proposed by Nouri et al. (2013), which is used for determining relationships between major faults and ore deposits (Nouri et al., 2013). This model has the following form:

$$DMF\ (\geq\rho) = F\rho^{-D} \quad (3)$$

where ρ indicates elemental concentration, DMF ($\geq\rho$) reveals a cumulative distance from the major faults of sampled sites with concentration values greater than or equal to ρ, F is a constant, and D is the scaling exponent or fractal dimension of the distribution of elemental concentrations. Based on the aforementioned model, the ore deposits and occurrences were classified based on their distance from the major faults.

2.3. Area of Mineralized Zone-Distance Major Fault fractal model

The Area of Mineralized Zone-Distance Major Fault (AMZ-DMF) fractal model is utilized for the delineation of relationships between the major faults and the mineralized zones in this study. The model has the following form:

$$DMF\ (\geq AMZ) = FA^{-D} \quad (4)$$

where A illustrates the area of the mineralized zone, DMF ($\geq$AMZ) reveals a cumulative distance from the major faults of mineralization (for example: vein or strata) with area values greater than or equal to A, F is a constant, and D is the scaling exponent or the fractal dimension of the distribution of the mineralized zones.

3. Geological setting of the studied area

The Behabad area is located in the central Iran structural zone and monitors the accommodation of Cenozoic shortening within the Arabia–Eurasia collision zone (Fig. 1). The Kuhbanan and Behabad faults have played a major role in the geological and mineralization history of this region, which resulted in the separation of the various structural zones in the district. These faults separate the Posht-e-Badam block from the Tabas block and the Behabad zone from the Abdoghi-Ravar tectonic zone, respectively (Aghanabati, 2004).

The different lithotectonic units with the NNE-structural trend include the Eocene Chapedony metamorphic core complex in the north, which is parallel to the prominent Cenozoic NNE-trending Chapedony and the Posht-e-Badam strike-slip faults. Moreover, the Behabad and Kuhbanan faults are parallel to the Zagros fold-thrust belt, and represent dextral strike-slip faulting and NE thrust faults, respectively. The thrusts represent a back-thrust component to the Zagros fold-thrust belt (Allen et al., 2004; Soffel et al., 1996). The tectonic activities have deformed Jurassic shale, sandstone, limestone, and Permo-Triassic dolomites. The Kuhbanan and the Behabad faults have played a key role in