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Evaluation of elemental mineralization rank using fractal and multivariate techniques and improving the performance by log-ratio transformation

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ABSTRACT

Background separation from anomalous populations in the polymetallic mineralization is a problematic issue in geochemical exploration. This study focuses on the applications of fractal modeling, correspondence analysis (CA), classical principal component analysis (PCA), and PCA method based on centred log-ratio (clr) transformation for the multi-elemental evaluation of geochemical data in Glojeh polymetallic mineralization, NW Iran. A Concentration-Number (C-N) multifractal modeling was applied to delineate individual self-similar patterns for elemental distributions simultaneously in terms of Au, Ag, Cu, Pb, and Zn. The differences between fractal dimensions and clockwise angle between fitted lines in the C-N Log-log plots could lead to evaluate mineralized rank corresponding to Au ≥ Ag ≥ Pb ≫ Cu ≈ Zn. A more comprehensive evaluation via CA and PCA of clr-transformed data could facilitate the vein structure identification in high-dimensional data. The PCA results of clr-transformed data revealed the potential intensification trend of (Pb, Ag, As, Te, Au) > (Mo, Zn, Be, Cu) > W > (S, Cd), that is more consistent with fractal and CA approaches. The closure effect problem was overcome by the clr transformation, and the total variance explained by the first factor increased from 28.2% in classical PCA to 43.7% in clr transformation. Accordingly, As, Sb and Cd were considered as potential pathfinder elements for Au in Glojeh deposit. The ability to handle zeros in the data matrix and determining an elemental eccentricity as a criterion are the advantages of CA method, while loading factors spread in a full circle and providing subcompositional coherence are the competitive advantages of PCA (calculated according to log-ratio transformation). However, the CA and PCA based on Log-Ratio transformation techniques showed significant potential to draw an inference in such deposits.

1. Introduction

Depending on physico-chemical conditions, magmatic hydrothermal fluids can migrate away from the magma chamber along ancient fractures or shear zones (Mao et al., 2011; Pirajno, 2012). When deeply circulating meteoric fluids and magmatic hydrothermal fluids interacted with surrounding volcanic wall rocks, low sulfidation epithermal deposits can be seen (Corbett, 2002; Oyman et al., 2003; Zhao et al., 2014). The interaction between a cooling hydrothermal fluid and the host rock at medium-high (250–450 °C) temperature is a complex process for zoning and elements dispersion in alteration assemblages (Barton and Johnson, 2000; Shanks, 2001). The richest mineral assemblages include Au, Ag, Cu, Pb, and Zn elements, which occur within brecciated veins and veinlets indicate a high sulfidation epithermal deposits, without notable effects of meteoric fluids. This type of mineralization is introduced by medium-high temperature ore-forming fluids, a certain mineralogy and geological characteristics (Zhong et al., 2017b). Generally, for these deposits, Au with sulfide minerals are also precipitated in the epithermal brecciated zone, and Cu may be related to subjacent porphyry deposits. A Cu (Mo) orebodies maybe have been found beneath Au-Ag-Pb-Zn orebodies (Zeng et al., 2013; Zhong et al., 2017a). However, Pb-Zn mineralization has been formed after Au-Ag mineralization, which has an intimate relationship with porphyry Mo mineralization (Pirajno et al., 1997; Zhong et al., 2017b). Therefore, polymetallic Ag-Au as a high sulfide mineralization may also relate to the porphyry Cu-Mo mineralization (Grancea et al., 2002; Li et al., 2016; Zhu et al., 2011). Polymetallic Au, Ag, Cu, Pb and Zn concentrations in epithermal vein mineralization at Glojeh (NW Iran) show high heterogeneous distributions, which can be well described by the uni-variate and multivariate analytical methods such as fractal modeling and correspondence analysis (CA), respectively.

Geochemical anomaly recognition is one of the most important stages in geochemical exploration (Asl et al., 2015; Heidari et al., 2013). Fractal and multi-fractal models such as concentration–area (Cheng et al., 1994; Cheng and Li, 2002; Sun et al., 2016; Wang et al., 2012), concentration–distance (Gumiel et al., 2010; Li et al., 2003;

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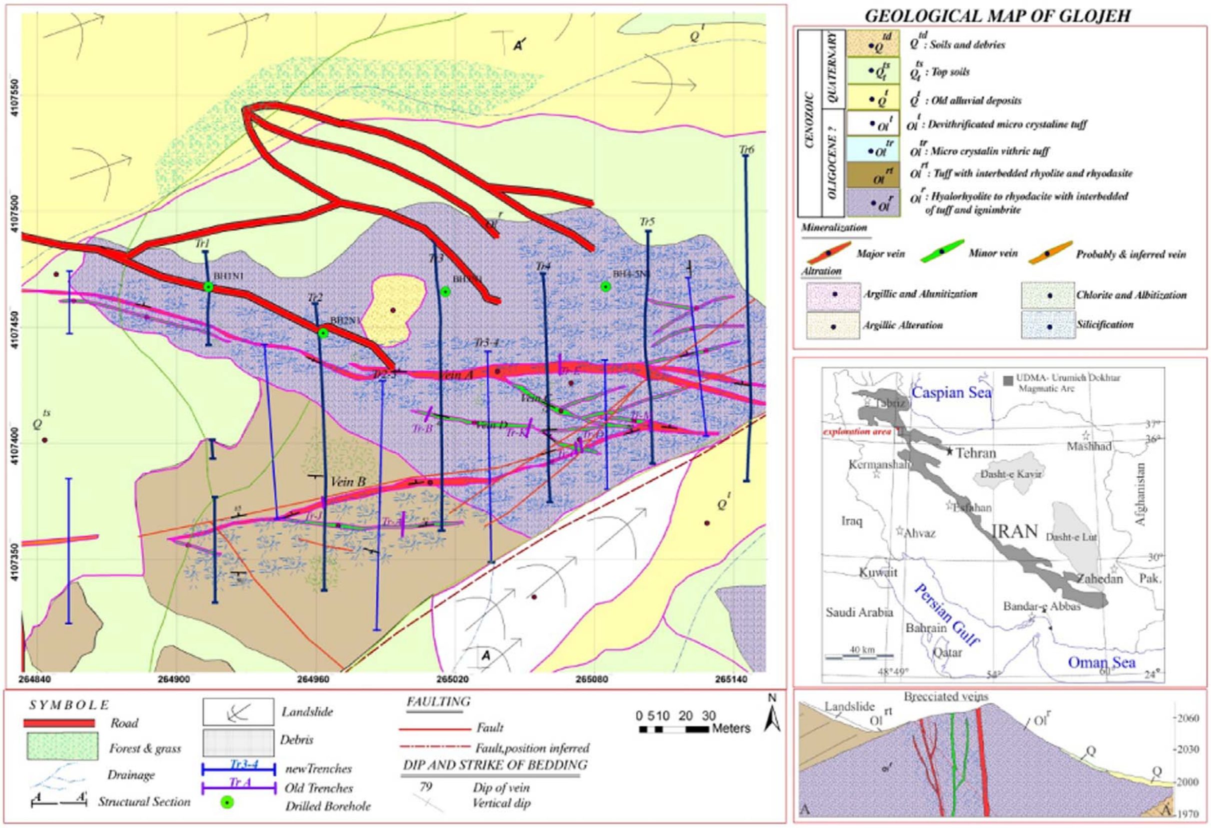

Fig. 1. Geological map of polymetallic Glojeh veins deposit.

Zhang et al., 2011; Zuo and Wang, 2016), concentration–volume (Afzal et al., 2011; Yijiang et al., 2010), concentration–number (Afzal et al., 2016) and power-law (Cheng et al., 2000; Zuo, 2011; Zuo and Wang, 2016) have been applied in different branches of geosciences. Fractal geometry has been used to recognize and delineate uni-elemental geochemical anomalies (Luz et al., 2014; Parsa et al., 2016), to compare different attributes (Gumiel et al., 2010; He et al., 2013; Monecke et al., 2001; Yasrebi et al., 2014; Yasrebi et al., 2013) and to distinguish different mineralization intensity (Deng et al., 2009; Deng et al., 2010). In this study, a concentration–number (C-N) fractal model was applied for determination of threshold value accompanied by different numbers of anomalous samples for each element (quantify the data). On the other hand, it can be used to delineate spatial distribution pattern and data clustering, elemental co-occurrences, mineralization intensity and variation between vein and host rock (description the quality of data) for Au, Ag, Cu, Pb and Zn. Moreover, for better comparison and reveal intensification of the polymetallic element and separation of polymetallic samples, a multi-element analytical method, was applied to verify the association of anomalous elements in the Glojeh polymetallic deposit.

PCA based on Log-Ratio transformation, cluster analysis, and CA are appropriate methods for geochemical classification (Belkhiri and Mouni, 2014; Belkhiri and Narany, 2015; Carranza, 2017; Deutsch et al., 2016; Liu et al., 2016; Tiri et al., 2014). These methods are used to reduce high-dimensional data into low-dimensional subspaces that explain the main variances among the data (Akbarpour et al., 2013; Carranza, 2009; Greenacre, 2011), while the closure effect of elements is an ordinary problem in the results from normal scores data. For overcoming this problem in PCA analysis, the data should be opened using log-ratio transformations like the centered log-ratio (clr), the isometric log-ratio (ilr), and the additive log-ratio (alr) (Carranza, 2017; Filzmoser and Hron, 2008; Filzmoser et al., 2009; Silverman et al., 2016; Templ et al., 2008). Among these multivariate methods, the CA is robust for compression of a large amount of information to interpretable factors or linear combinations of variables (Abdi et al., 2013; Greenacre, 2010; Sun et al., 2016). Moreover, it has been used to identify characteristics and relationship of mineralization phases (de Sá et al., 2014; Tekaia, 2016). It could provide an intuitive graphical display of element association in one or two dimensional visual illustration of one sample in one set (factor) compared with other samples (concentrations) in the same or other sets for interpretation of spatial distribution (Tekaia, 2016).

This paper deals with the distribution of ore elements and their corresponding association in an orebody have tried to use C-N fractal model, the CA, cluster and PCA. Determination of geochemical concentrations and spatial distribution of elements regarding geological features using different statistical methods is an essential analysis for mineral exploration (Cline et al., 2005; Guagliardi et al., 2012; McCuaig et al., 2010). Ford and Blenkinsop (2008) suggested a method with combination of fractal geometry and weights of evidence approach for evaluating the degree of clustering and spatial association respectively.

The aim of this study is to present a methodology (combination of fractal geometry and CA) for analyzing elemental distribution, clustering the elemental rank of mineralization, and spatial association between elements and samples in Glojeh polymetallic mineralization. Subsequently, the obtained results via the mentioned-above combination are used to demonstrate and evaluate mineralization in Glojeh polymetallic deposit. From a theoretical point of view, the extraction of qualitative and quantitative properties of mineralization in epithermal and porphyry deposits can be improved by these methods.

2. Geological setting

The Glojeh district is located in NW Iran, central part of the Tarom-Hashtjin Metallogenic Province (THMP), which is one of Iran's major metallogenic provinces. Structurally, this subduction-related