Ore Geology Reviews 81 (2017) 230–244

Contents lists available at ScienceDirect

Ore Geology Reviews

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

Spatial analysis of mineral deposit distribution: A review of methods and implications for structural controls on iron oxide-copper-gold mineralization in Carajás, Brazil

Paulo Miguel Haddad-Martim [a,*], Carlos Roberto de Souza Filho [a], Emmanuel John M. Carranza [a,b]

[a] Institute of Geociences, State University of Campinas (UNICAMP), Campinas, São Paulo, Brazil
[b] Economic Geology Research Centre (EGRU), James Cook University, Townsville, Queensland, Australia

ARTICLE INFO

Article history:
Received 12 April 2016
Accepted 30 September 2016
Available online 1 October 2016

Keywords:
Fractal analysis
Fry analysis
Spatial analysis
IOCG deposit
Mineralization control
Mineral prospecting

ABSTRACT

Mineral deposits are formed by interaction of various geological processes and conditioned by controls that favor their formation and preservation. The understanding of mineralization controls is critical for mineral exploration because it allows focusing exploration on regions where these controls are concentrated. The analysis of the spatial distribution of mineral deposits, particularly on a regional scale, can provide information relevant to the understanding of regional-scale processes involved during their formation. Here we present a review of Fry and fractal methods for spatial analysis of mineral deposit distribution and an application using the iron oxide-copper-gold (IOCG) deposits of the Carajás Mineral Province (Brazil). Results show that different IOCG mineralization structural controls acted in scales of <10–15 km, 15 to 40 km, and >40 km. The IOCG deposits cluster at scales of <40 km, whereas different clusters of IOCG deposits form WNW-ESE alignments at scales larger than 40 km. Structures oriented to WNW-ESE, E-W and NW-SE, with secondary trends to ENE-WSW and NNE-SSW, host the main IOCG deposits in Carajás. Additionally, Carajás IOCG deposits are located in areas with intermediate to high fractal dimensions, reflecting tracts with intermediate to high complexity of structural patterns. Information yielded in this work provides relevant criteria for further exploration for IOCG deposits in the region, including an indication of a possible new WNW-ESE central trend, apart from the northern and southern copper belts in the Carajás Mineral Province.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

Predictive mineral potential modeling typically uses a combination of: (i) knowledge of geological processes leading to the formation of mineral deposits, (ii) empirical evidence of spatial association between mineral deposits and certain geological features representing those geological processes (Carranza and Hale, 2002a, 2002b; Carranza et al., 2008; Lisitsin, 2015). In an area with a relatively large number of known mineral deposits, which are invariably represented as *points* on broad-scale maps, their spatial distribution can provide critical information on mineralization processes that operated at a range of scales, especially in cases where these processes have only cryptic expressions in traditional geological datasets (Carranza, 2009; Zuo et al., 2009; Lisitsin, 2015).

Point pattern analysis (Diggle, 1983; Boots and Getis, 1988), Fry (Fry, 1979) and fractal (Mandelbrot, 1983) analyses are well developed and have been used in a variety of geological research, including the study of distribution of mineral deposits and their structural controls (Carlson, 1991; Ford and Blenkinsop, 2008a; Raines, 2008; Carranza, 2009; Agterberg, 2013). As each method only characterizes a particular aspect of a point pattern, reasonable inferences about the spatial distribution of deposits can be made only after the integration of results provided by different methods (Carranza, 2008, 2009; Lisitsin, 2015). This paper reviews the theoretical aspects of the Fry and fractal analyses and their applications to the study of the spatial distribution of mineral deposits. Furthermore, to illustrate their potential in comprehensive exploratory spatial analysis of deposits distribution, the methods are used here in combination to investigate the regional-scale spatial pattern of iron oxide-copper-gold (IOCG) deposits in the Carajás Mineral Province (CMP), southeast Amazon Craton, Brazil. The results are used in conjunction with existing knowledge of the structural geology of the CMP to infer the structural controls of IOCG mineralization, complementing resource assessment and exploration targeting in the region.

2. Fry analysis

Fry analysis is a graphical form of autocorrelation analysis developed by Fry (1979) to measure rock deformation using the relative positions

* Corresponding author.
E-mail addresses: paulomartim@ige.unicamp.br (P.M. Haddad-Martim), beto@ige.unicamp.br (C.R. Souza Filho), ejmcarranza@gmail.com (E.J.M. Carranza).

http://dx.doi.org/10.1016/j.oregeorev.2016.09.038
0169-1368/© 2016 Elsevier B.V. All rights reserved.

of geological markers in thin sections. In this analysis, geological objects (such as porphyroblasts, ooids or mineral grains) are represented as points and their pre-deformation distribution is assumed to be largely non-random, because their existence is due to non-random geological events (Hanna and Fry, 1979). Section 1 of the Supplementary material contains a brief review of the main aspects of randomness in point patterns, since these aspects are important to help understand the circumstances in which the use of Fry analysis is appropriate.

Fry analysis is performed through the construction of an autocorrelation diagram called Fry plot (Fig. 1). The diagram can be constructed manually or computationally, with the following procedure (Fry, 1979): (i) one of the points in the original distribution is placed at the center of the diagram, preserving the distances and orientation of all other points; (ii) the positions of every point of the original distribution are marked in the new diagram (i.e., "Fry points"); (iii) a second point in the original pattern is placed at the diagram center, and the positions of the remaining points are registered. This procedure is repeated until every point in the original distribution is used as the center of the diagram (Fig. 1).

For Fry analysis to be efficient, the objects of interest must (Fry, 1979): (i) be well dispersed, so they can be represented as points in a homogeneously deformed matrix; (ii) allow for numerically relevant sampling (dozens to hundreds of objects); and (iii) have a relatively regular or clustered pre-strain distribution. The third condition is critical because the Fry diagram of a set of objects with random distribution does not present relevant results (Fig. 2a–d). Note that the diagrams in Fig. 2b and d are nearly indistinguishable.

Fry analysis is able to highlight the existence of deformation that otherwise would not be evident by observing the patterns individually (Fig. 2e–h). Note in Fig. 2f the existence of a circular girdle at the center of the diagram, indicating the absence of deformation. In contrast, in Fig. 2h the ellipse at the center of the diagram indicates deformation. The ellipse shown by Fry analysis (Fig. 2h) represents how points – which were initially neighbors – shifted relative to each other, so that the girdle that appears in the center of the diagram can be used as an approximation to the measurement of the deformation ellipse (Fry, 1979).

Twenty years after the development of Fry analysis as a tool for the study of rock deformation, it has been successfully applied to study the spatial distribution of various types of mineral deposits, both at regional and local scales (Vearncombe and Vearncombe, 1999; Stubley, 2004; de Andrada and Carranza, 2005; Blenkinsop and Kadzviti, 2006; Kreuzer et al., 2007; Carranza, 2008, 2009). When applied to the investigation of mineral deposits, Fry analysis provides insight into directional controls on mineralization by using each and every spatial relationship between deposits (Vearncombe and Vearncombe, 1999). At regional scales, Fry analysis highlights patterns of direction and spacing associated with structures that control mineralization. At local scales, it can be applied to determine directions of orebodies based on the distribution of positive drill holes intersections – thus representing an alternative to directional variography (Vearncombe and Vearncombe, 1999). In either case, the investigation can be detailed by analyzing point subsets defined by proximity or other relevant property, such as deposit reserves or the grade of a borehole segment. This alternative use for Fry analysis has been applied by several authors to study the spatial distributions of mineral deposits of Au, Cu, Pb and other elements (Stubley, 2004; Kreuzer et al., 2007; Austin and Blenkinsop, 2009; Carranza, 2009; Carranza and Sadeghi, 2014), even in three-dimensions (Blenkinsop and Kadzviti, 2006). The typical results of these studies are the: (i) identification of subtle preferential orientations in the distribution of mineral deposits, which are hardly perceived from their original map locations (Vearncombe and Vearncombe, 1999; Lisitsin, 2015); (ii) recognition of structural trends of mineral occurrences at different spatial scales (Austin and Blenkinsop, 2009; Carranza, 2008, 2009); or (iii) recognition of preferred corridors for mineralization (Vearncombe and Vearncombe, 2002; Carranza and Sadeghi, 2010). These results are then integrated and employed to interpret structural controls on mineralization.

3. Fractal analysis

Fractals comprise a unique geometrical approach that can be used to study the spatial distribution of mineral deposits (Carlson, 1991), and its concept has had a major impact in several areas of geology (Turcotte, 1989, 1997; Turcotte and Huang, 1995; Kruhl, 2013). A fractal "*is a feature whose Hausdorff-Besicovitch dimension is greater than its topological dimension*" (Mandelbrot, 1983). The Hausdorff-Besicovitch dimension – also known as fractal dimension – is the main parameter used to characterize natural fractals, as discussed below. For a brief review of some fundamental concepts that lead to the definition of the fractal dimension, the reader is referred to Section 2 of the Supplementary material.

3.1. Natural fractals and their properties

Fractals are entities that have a self-similar or self-affine geometry at different spatial scales, and various geological features present such properties (Turcotte, 1989; Xu et al., 1993; Goryainov et al., 1997). This means that geological features have similar geometry even when observed in ranges of scales separated by several orders of magnitude (Fig. 3) (Hodkiewicz et al., 2005).

The importance of fractal geometry is that it provides definitions and tools that allow to quantify complex geometries - a difficult or even impossible task with the use of Euclidean geometry (Kruhl, 2013). However, fractal geometry applied to the study of natural features has limitations that must be considered, including the fact that some

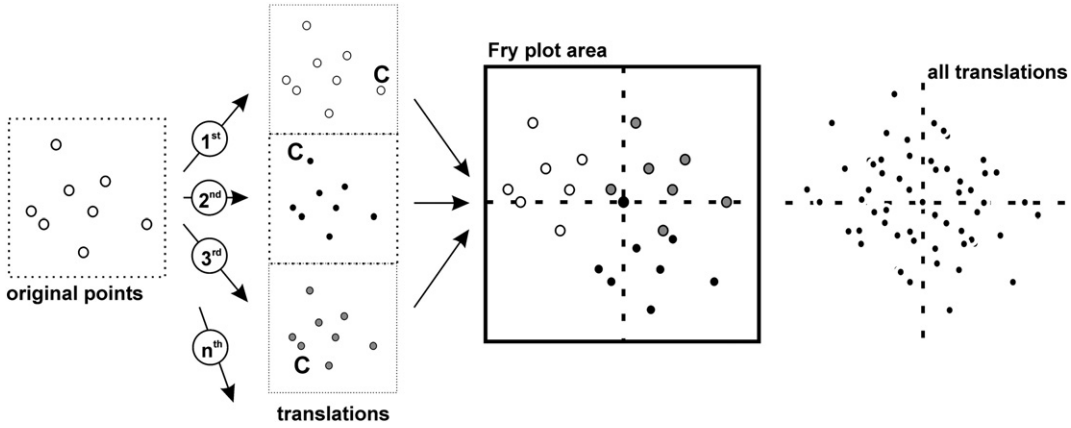

Fig. 1. Schematic procedure to construct a Fry plot. In the three translations shown, 'C' denotes the point used as center. When all original points are used as centers, all translations and the diagram are complete. For n original points there are n^2–n Fry points.

Download English Version:

https://daneshyari.com/en/article/6482022

Download Persian Version:

https://daneshyari.com/article/6482022

Daneshyari.com