Journal of Geochemical Exploration 178 (2017) 55–66

Contents lists available at ScienceDirect

Journal of Geochemical Exploration

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

Application of spatially weighted technology for mapping intermediate and felsic igneous rocks in Fujian Province, China

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ARTICLE INFO

Article history:
Received 19 February 2016
Revised 27 January 2017
Accepted 26 March 2017
Available online 29 March 2017

Keywords:
Weak information extraction
Spatial variability
Local singularity analysis
Spatially weighted logistic regression
Mineral resource assessment
Igneous rocks

ABSTRACT

Magmatic activity is of great significance to mineralization not only for heat and fluid it provides, but also for parts of material source it brings. Due to the cover of soil and vegetation and its spatial nonuniformity detected signals from the ground's surface may be weak and of spatial variability, and this brings serious challenges to mineral exploration in these areas. Two models based on spatially weighted technology, i.e., local singularity analysis (LSA) and spatially weighted logistic regression (SWLR) are applied in this study to deal with this challenge. Coverage cannot block the migration of geochemical elements, it is possible that the geochemical features of soil above concealed rocks can be different from surrounding environment, although this kind of differences are weak; coverage may also weaken the surface expression of geophysical fields. LSA is sensitive to weak changes in density or energy, which makes it effective to map the distribution of concealed igneous rock based on geochemical and geophysical properties. Data integration can produce better classification results than any single data analysis, but spatial variability of spatial variables caused by non-stationary coverage can greatly affect the results since sometimes it is hard to establish a global model. In this paper, SWLR is used to integrate all spatial layers extracted from both geochemical and geophysical data, and the iron polymetallic metallogenic belt in south-west of Fujian Province is used as s study case. It is found that LSA technique effectively extracts different sources of geologic anomalies; and the spatial distribution of intermediate and felsic igneous rocks delineated by SWLR shows higher accuracy compared with the result obtained via global logistic regression model.

1. Introduction

Different geological environments, temperatures, pressures, and magma cycles create different mechanisms of mineral formation and migration, and these in turn, can cause geochemical and geophysical differences between intrusive rocks and their surroundings. This makes it possible to distinguish different intrusions from their surroundings. However, due to the effects of soil and vegetation cover, geochemical signatures and geophysical features obtained at the surface of the Earth may be weak. Hence, it is difficult to extract this weak information effectively by using classical data processing methods based on frequency statistics. Cheng and his team have developed a new spatial statistical method based on fractal/multifractal theory, called local singularity analysis (LSA) (Cheng, 1997, 2001, 2004, 2006a, 2006b, 2006c), which can supplement classic geological statistical techniques. LSA is essentially a spatial neighborhood-window statistical method that considers the original value of each spatial location as well as the trends in variation of these values within a local window. This method can detect slight changes in spatial locations and quantify them for the purpose of extracting local singularity information, while avoiding interference from the surface media, to reveal deep geological features of the underground environment. For this reason, LSA has been used to map concealed rocks based on both geochemical data (Cheng, 2012; Zhao et al., 2012) and geophysical data (Wang et al., 2012).

Geochemical data and geophysical data were obtained to represent the chemical properties and the physical characteristics of rocks, respectively. These two different types of data were combined with one another using data integration methods, which can improve the accuracy and efficiency of intrusive rock mapping. Many different models for data integration have been applied in mineral prospectivity mapping, including logistic regression (Tukey, 1972; Agterberg, 1974, 1988; Chung and Agterberg, 1980; Wrigley and Dunn, 1986), weights-of-evidence (Bonham-Carter et al., 1988, 1989; Agterberg, 1989; Agterberg et al., 1990), fuzzy logic (An et al., 1991; Bonham-Carter, 1994) and neural networks (Singer and Kouda, 1996, 1997; Oh and Lee, 2010). Although

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http://dx.doi.org/10.1016/j.gexplo.2017.03.015
0375-6742/

these methods have been integrated into GIS software and can be used to deal with spatial data, the locations and neighborhoods of spatial objects are always ignored and the relationship between location attribute and other attributes are completely separated, thus there is no essential difference between these methods and classical statistics. In fact, the intensity and structure of correlations between the target variable and independent variables may be changed from place to place due to spatial heterogeneity and non-stationary. The development of geographically weighted regression (GWR) changes this condition (Brunsdon et al., 1996; Fotheringham et al., 1996, 1997, 2002). GWR is a spatially varying-coefficient model, in which regression model is performed within a local window at each location, and inverse distance weighted (IDW) model is applied to achieve weigh reduction from current location to the edges of local window. The grids near to the current location are given greater weight while those far from the current location given less weight or even 0. There are some applications of GWR in mineral prospectivity mapping, e.g., Zhao et al. (2013, 2014) used GWR to analyze the quantitative relationship and its changes between the iron resources and the ore-controlling factors in the east Tianshan Mountain, and provided an improved prediction map for iron deposits. But yet there are few reports about geographically weighted logistic regression method in mineral exploration, while the latter is more suitable since mineralization is a binary event. The first author developed a spatially weighted logistic regression (SWLR) model for mineral prospectivity mapping (Zhang, 2015), and in this study, this model was used for intermediate and felsic igneous rocks mapping. Local singularity analysis (LSA) technique was used to process geochemical and geophysical data in order to obtain individual factor maps for intermediate and felsic rocks, and then based on a map of known Mesozoic intermediate and felsic rocks, general logistic regression and SWLR were applied respectively to integrate these individual maps for delineating target areas that could indicate the location of concealed intermediate and felsic igneous rocks. Our study is an initial attempt of using spatially weighted local model to deal with geological exploration mapping problem, and hoping that it can provide a new idea for similar research in this field.

2. Methods

2.1. Local singularity analysis (LSA)

Fractal/multifractal models are representative tools of nonlinear science that have been used for extraction of metallogenic information ever since nonlinear science techniques were developed. Fractal theory was initially used to characterize self-similar properties of geometric objects at different scales when the parts amplified were like the whole to some degree (Mandelbrot, 1975; Cheng et al., 1994; Cheng, 2016). Later, fractal/multifractal modeling was used to describe natural events with singularities, such as earthquakes, clouds, mountain torrents, hurricanes, landslides and wildfires, when there was a fractal/multifractal (or power-law) relationship between the frequency and size of the objects under study (Schertzer and Lovejoy, 1987; Bak et al., 1992; Malamud et al., 1996; Turcotte, 1997; Veneziano, 2002; Malamud et al., 2004; Sornette, 2004). Additionally, Cheng (1994) brought spatial information to bear on the power-law relationship and developed the concentration-area (C-A) model, which was considered as the first attempt to use fractal method to separate geochemical anomalies from background (Li et al., 2003). Later, Cheng (1997, 1999, 2005) proposed local singularity analysis (LSA) technology which can be seen as an application of the C-A model within a local window for local anomaly information extraction.

The most important choice that needs to be made during LSA, is the selection of an appropriate window size for the calculation of the local singularity index. The optimum window size is usually defined experimentally. If the window size is too small, LSA captures detailed information may include random noise, whereas a window size that is too large results in relatively smooth maps with less resolution. The singularity index is obtained by the following power-law model (Cheng, 1997):

$$\rho(\varepsilon) = c\varepsilon^{\alpha-2} \quad (1)$$

where c is a constant, ε represents window size, ρ represents average local density within a local window of size ε, and α is the singularity

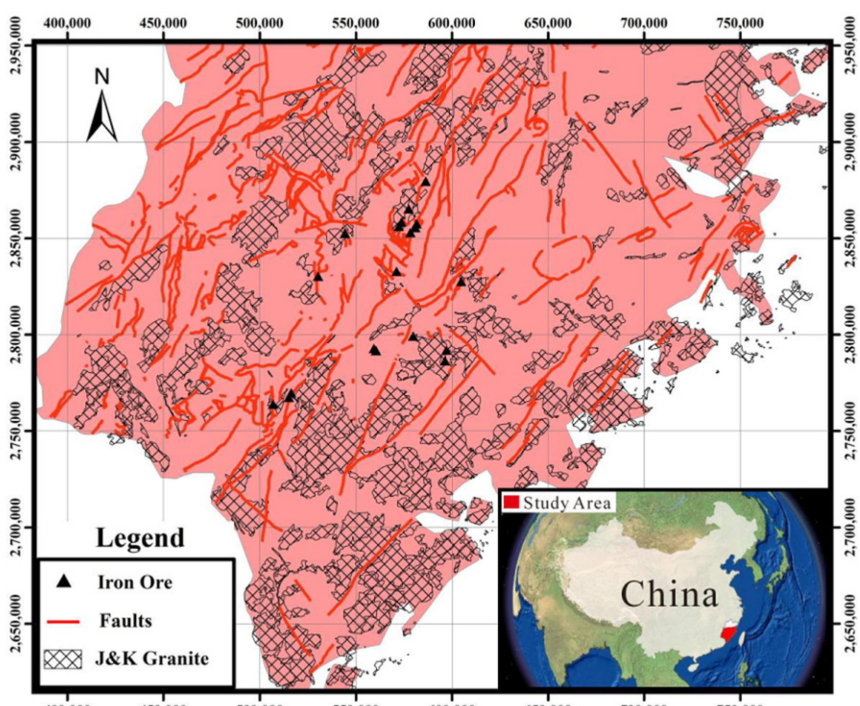

Fig. 1. The location of the study area, where J&K Granite represents the intermediate and felsic igneous rocks formed in Jurassic and Cretaceous of Mesozoic era.