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Application of geographically weighted regression to identify spatially non-stationary relationships between Fe mineralization and its controlling factors in eastern Tianshan, China

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ABSTRACT

Marine volcanic-sedimentary Fe mineral deposit is one of the most productive mineralization types in eastern Tianshan mineral district, Uyghur Autonomous Region, China. Previous researches have revealed that Fe deposits in this area are mainly hosted by the Lower Carboniferous Yamansu bimodal volcanic rocks and characterized by extensive skarn alteration. Due to variable effects of controlling factors across the study area, Fe mineralization occurs at limited locations with favorable geological environment. In order to understand ore genesis of different Fe deposits and to assist in Fe mineral exploration in this area, it is essential to investigate the spatial relationships between Fe mineralization and its controlling factors across the study area. In this paper, Fe mineralization and its controlling factors are characterized and delineated on the basis of spatial distributions of geochemical signatures obtained by principal component analysis. The spatially non-stationary relationships between these spatial distributions of geochemical signatures are further analyzed by a geographically weighted regression (GWR) method. The comparison of applications of the ordinary regression and GWR shows that GWR is superior in depicting localized spatial relationships between Fe mineralization and its controlling factors. The GWR results demonstrate that influences of controlling factors on Fe mineralization are spatially varied and imply that geological environments favorable to Fe mineralization are diverse at different locations. Based on currently achieved results, suggestions to support future Fe mineral exploration at different subareas are proposed at the end of this paper.

1. Introduction

Ore deposits are characterized by accumulation of ore-forming elements and/or minerals in the crust and the formation of ore deposits is controlled by diverse geological factors such as fault systems, magmatic processes, and sedimentation. The superimposed effect of various controlling factors may confine the spatial distribution of ore deposits, which is often anisotropic over an entire mineral district (Cheng, 2007; Guilbert and Park, 1986; Wang et al., 2011, 2012, 2013; Yuan et al., 1979). Characterization of the spatial distribution and variation of ore controlling factors is essential not only for study of ore genesis but also for mineral exploration. GIS-based multivariate statistical methods might provide powerful tools for fulfilling the above objectives. In this paper we will apply geographically weighted regression (GWR) and principal component (PCA) methods to stream sediment geochemical data to model the spatially non-stationary influences of controlling factors on Fe deposits. Eastern Tianshan mineral district, Uyghur Autonomous Region, China, as the study area, is well known for its polymetallic mineralization (Fig. 1). Among various discovered mineral deposits in this area, marine volcanic-sedimentary Fe deposits yielding great profit have become one of the focuses of mineral exploration. Substantial and systematical geological work in past decades indicates that most of the Fe deposits of this type are located in the Carboniferous volcanic belt which is dominated by the Lower Carboniferous-Middle Permian volcanic extrusions and the Lower Carboniferous-Triassic felsic intrusions. The Yamansu Formation (C_1y) consisting of bimodal volcanic rocks, tuff, carbonate rocks, etc., is primary ore-hosting strata (BGEDXP, 2009; Han et al., 2002). Magmatic activities played important roles in marine volcanic-sedimentary Fe mineralization (Cheng, 2012; Han et al., 2002; Zhao et al., 2012). Ore-forming materials precipitated along contact zones between volcanic and sedimentary rocks during migration of ore-bearing magmas in the submarine environment after volcanic eruption. The previously formed ore bodies could be further enriched and concentrated by later magmatic intrusion and hydrothermal alteration (BGEDXP, 2009; Chen, 1999; Ma et al., 1993, 1997; Wang, 2005; Zhang and Xie, 2001). Therefore, geo-information regarding controlling factors (i.e., volcanic rocks and magmatic intrusions) is frequently considered for studying

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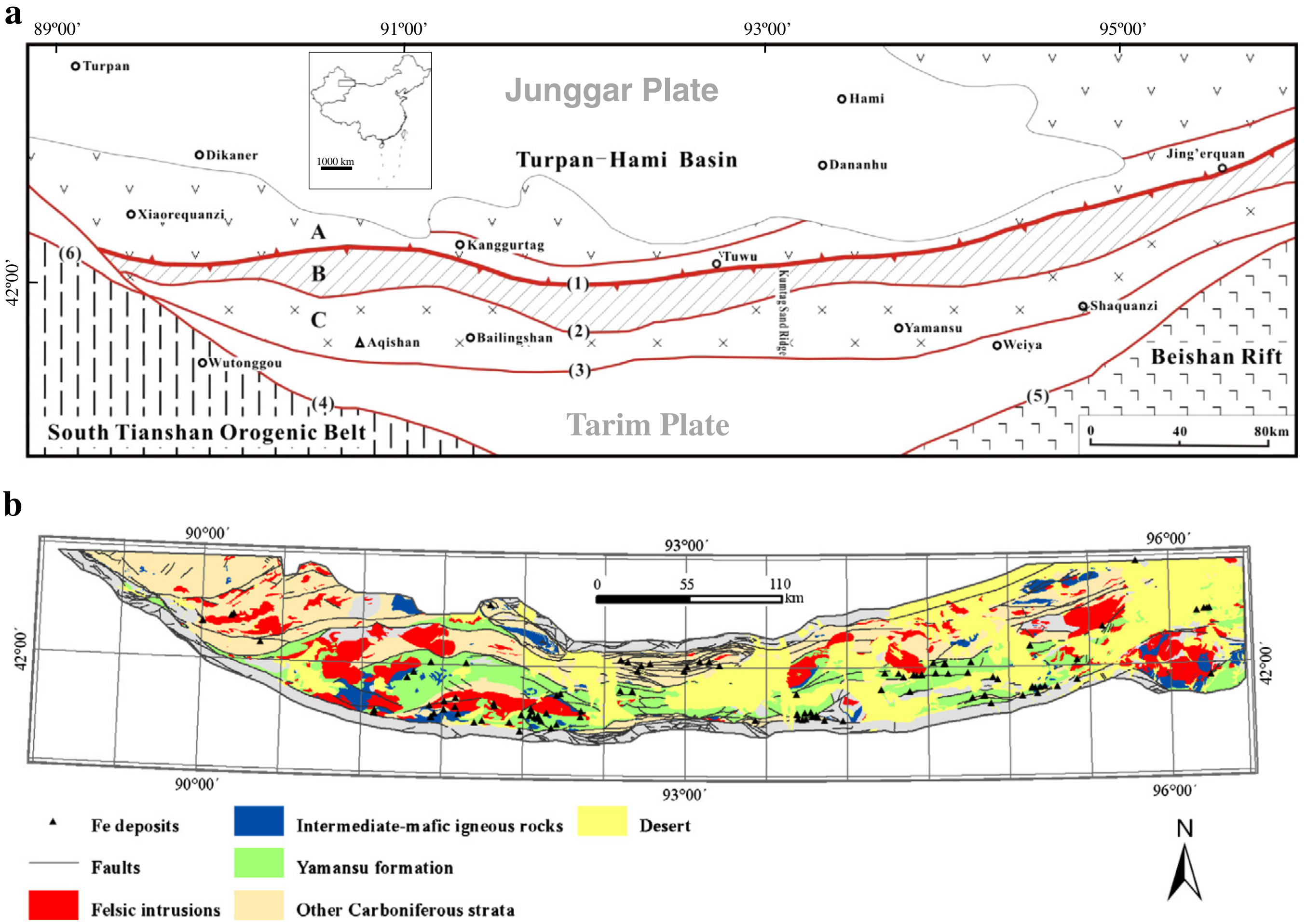

Fig. 1. Simplified geological maps. a. The study area and its tectonic settings (Modified from Mao et al., 2005; Yang et al., 1996). A = the Kanggurtag-Harlik area. B = the Qiugemingtashi-Huangshan ductile shear zone. C = the Aqishan-Yamansu volcanic basin. (1) = the Kanggurtag-Huangshan fault. (2) = the Yamansu fault. (3) = the Aqikekuduke-Shaquanzi fault. (4) = the Toksun-Gangou fault. (5) = the Xingxingxia fault. (6) = the south-edge fault of middle Tianshan. b. The distribution of the lithologic units of the study area.

mechanism of the Fe mineralization as well as for mineral exploration modeling in the area (BGEDXP, 2009; Cheng, 2012; Zhao et al., 2012).

Although the Carboniferous volcanic rocks are the main ore host rocks within which most of the discovered mineral deposits are located, the locations of ore deposits are related to other superimposed effects of controlling factors such as fault systems and geo-fluid systems. The relationships between Fe mineralization and diverse controlling factors may vary from location to location in the study area. The spatial variation of such relationship is termed as spatial non-stationarity (Brunsdon et al., 1996; Fotheringham et al., 1996, 1998). The spatially non-stationary relationships may considerably influence the prediction of the location of mineral deposits as well as the evaluation for Fe mineral resources. Therefore, it is important to investigate the spatially non-stationary relationships between Fe mineralization and its controlling factors for purposes of both mineral deposit modeling and mineral exploration.

Regression analysis is a common method to discern relationships between a single dependent variable such as ore deposit and one or more independent variables such as magmatic rocks, strata, and geochemical background (Fotheringham et al., 1998; Ryan, 2009). By modeling the spatial relationships, regression analysis allows to predict occurrences of events on the basis of explanatory factors (Fotheringham and Brunsdon, 1999). Based on scales of observation, relationships between variables can be examined by global and local regression models (Fotheringham et al., 2002). A global model (e.g., ordinary least square, OLS) generates constant estimations of regression parameters for a whole area. It is incapable of depicting the spatially non-stationary relationships between variables (Fotheringham et al., 2002). Geographically weighted regression (GWR) proposed by Brunsdon et al. (1996) is a local regression model which can examine non-stationary relationships between dependent and independent variables across the study area and improves the spatial accuracy of regression model by calibrating errors of global model at different locations (Brunsdon et al., 1996, 2001). For one set of variables, local regression can be treated as spatial disaggregation of global regression in space. By their natures, ordinary regression models investigate global similarity of relationships between variables in the entire study area; whereas, local regression models concern localized relationships of variables (Fotheringham et al., 2002).

Stream sediment geochemical data is used in the current research to characterize spatial distributions of geological bodies associated with Fe mineralization (Cheng et al., 2011; Rose et al., 1979; Wang et al., 2011, 2012). The same dataset has been successfully used to identify magmatic rocks with overburden in this area (Cheng, 2012; Zhao et al., 2012). First, PCA is applied to the geochemical data to inspect geochemical anomalies associated with various geological controlling factors including the Yamansu Formation, felsic intrusions, and mafic rocks. Secondly, GWR is further utilized to investigate the spatially non-stationary relationships between Fe mineralization and its controlling factors on the basis of their geochemical signatures. The spatially variable relationships depicted by the GWR are beneficial to analyze the favorable geological environment and the metallogenic mechanism of marine volcanic-sedimentary Fe deposits at different locations. The