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Application of geochemical anomaly identification methods in mapping of intermediate and felsic igneous rocks in eastern Tianshan, China

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ABSTRACT

Marine volcanic–sedimentary Fe deposit is an important type of mineral deposit in eastern Tianshan mineralization district, China. In this paper, igneous rocks associated with Fe mineralization are characterized by GIS-based methods of spatial analysis to support future mineral exploration. Some potentially mineralized areas are masked by overburden materials in the Gobi desert region. Stream sediment geochemical data of SiO_2, Al_2O_3, K_2O, Na_2O, CaO, MgO, Fe_2O_3, Ba, Be and Li are integrated using principal component analysis to map igneous rocks. In order to reduce the influence of covers on geochemical signal, the singularity index developed in the context of multifractals was applied to analyze stream sediment geochemical data to identify weak geochemical anomalies. Potential areas in the integration results of principal component analysis are constrained by confining influences of overburden on elemental migration in stream sediments. The integration of various geochemical anomalies indicates well the spatial distribution of either outcropping or concealed igneous rocks. Based on characteristics of the eastern Tianshan district, the current study demonstrates the usefulness of the methods described for recognition of possible concealed igneous rocks in a desert covered area.

1. Introduction

The eastern Tianshan district (Fig. 1) is an important mineralization zone in China. Among the various types of mineral deposit in the district, marine volcanic–sedimentary Fe deposits with great production and abundance have become a focus of study for Chinese researchers and substantial exploration efforts have been conducted in the district. In the past decades, mineral exploration in the district has discovered 125 Fe deposits, 87 (or about 70%) of which are spatially and genetically associated with magmatic activities (Table 1) (BGEDXP, 2009; Han and Zhao, 2003). A proper understanding of the spatial distribution of igneous rocks is therefore beneficial to Fe mineral exploration in this district. The locations of magmatic igneous rocks have been mapped by traditional geological mapping; however, the ones masked by overburden materials but maybe associated with Fe mineralization have not been investigated sufficiently. In order to enhance knowledge to support future mineral exploration, it is necessary to delineate areas where igneous rocks exist, including areas covered by overburden.

Benefitting from the development of computer sciences and geo-databases, extraction of geo-information from multi-source datasets can satisfy various objectives (e.g., mineral exploration, lithological analysis, age determination, etc.). GIS-based methods of spatial analysis provide efficient ways to quantitatively and qualitatively characterize geo-information in spatial and frequency domains (Bonham-Carter, 1994; Carranza, 2008; Darnley, 1995; Pan and Harris, 2000). Geochemical and geophysical signatures are primary indicators of physical and chemical properties of geological bodies. Geophysical surveys detect the presence of geological bodies in the subsurface. Geochemical data can provide clues about the presence and spatial distribution of geological bodies on/near the surface (Rose et al., 1979). In this paper, the focus is mainly on geochemical signatures of concealed igneous rocks in the eastern Tianshan district. A comprehensive assessment and prediction of mineral deposits in this area is referred to Cheng (2012).

The study area is a typical arid to semi-arid region in the Gobi desert covered by regolith, tepetate and aeolian sand (Xie and Wang, 2003; Zhuang et al., 2003). Areas above the snowline are snow-covered all year round. Glacier is well developed, the melting of which causes seasonal floods (BGEDXP, 2009; Wang, 2005b). Physical and chemical weathering can result decomposition of exposed igneous rocks. Elements in chemical weathering products occur in the form of solid mineral grains (e.g., quartz and opal), dissolved acid (e.g., silicic acid), silica minerals (e.g., kaolinite), ions (e.g., K^+ and Mg^{2+}), etc (Rose et al., 1979). Among these chemical weathering products, soluble and active materials (e.g., cations and colloidals) migrate by surface runoff; whereas insoluble and stable compounds

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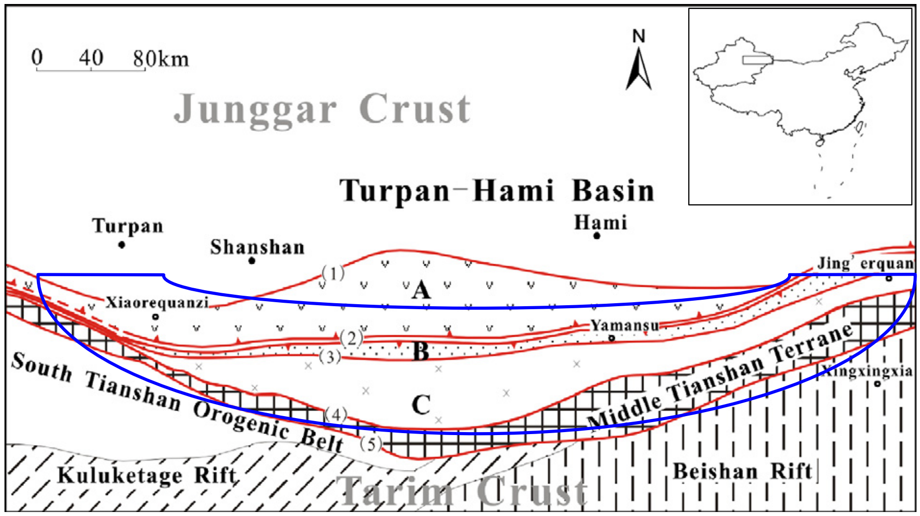

Fig. 1. The study area and its tectonic setting (modified from Mao et al., 2005). A = Kanggurtag–Halierke area. B = Qiugemingtashi–Huangshan ductile shear zone. C = Aqishan–Yamansu island arc. (1) = Dacaotan fault. (2) = Kanggurtag–Huangshan fault. (3) = Yamansu fault. (4) = Aqikekuduke–Shaquanzi fault. (5) = South margin fault of Middle Tianshan. The study area is outlined in blue.

(e.g., quartz and kaolinite) remain kept in situ (Rose et al., 1979). These insoluble and stable compounds constitute the regolith in the eastern Tianshan district (Wang et al., 2001). Inherited from the protoliths, the geochemical signatures of these compounds in the regolith can be analyzed to infer the covered protoliths (Brantley and White, 2009; Wang et al., 2001). Furthermore, physical transport (e.g., by aeolian and fluvial processes) of weathering products in the study area results lateral drift of overburden (e.g., regolith and exotic sediments). Mechanical dispersion of igneous rocks can produce high regional elemental background in their associated regolith (Wang et al., 2003). In contrast, dispersion of exotic materials may mask the regolith and produce low regional elemental background above regolith of igneous rocks (Wang et al., 2001). Therefore tepetate and aeolian sand, as typical overburden in the study area, often impede geological exploration. To assist geological and mineral exploration stream sediment geochemical samples in sizes of −4 to 20 meshes have been collected in the eastern Tianshan district (Zhuang et al, 2003). For the igneous rocks currently studied, the constituent minerals of the protolith and associated regolith are composed of O, Si, Al, Fe, Ca, Na, K, Mg, etc., which were measured as oxides in stream sediment geochemical data.

From a geological point of view, igneous rocks are produced by geo-processes accompanied by enormous energy release and material accumulation, which may be identified by singular differences with their surroundings (Cheng, 2007; Wang et al., 2011). The singular differences can be tracked in stream sediments (Davenport, 1990; Harris et al., 2001; Rencz et al., 2002; Rose et al., 1979). These kinds of singular differences can be recognized as so-called relative anomalies in stream sediment geochemical data. In regards to choice of method for geochemical anomaly recognition, it is important that spatial analysis of geochemical data allows removal of the influences of overburden on bedrock signal and, therefore, identification of not only strong anomalies but also weak anomalies from background. Fractal/multifractal methods consider both spatial and frequency properties of geochemical data and, thus, are suitable candidates (Dimri, 2005; Mandelbrot, 1972). In this paper, the singularity index (Cheng, 1999) developed in the context of multifractals was applied to stream sediment geochemical data to characterize geo-anomalies of elements associated with igneous rocks. Principal component analysis (PCA) was then applied for integrating elemental anomalies to identify areas with exposed and/or concealed igneous rocks to support future Fe exploration in the eastern Tianshan district, of China.

2. Study area

The eastern Tianshan district is located in the eastern part of Xinjiang province, China (Fig. 1). It is bounded to the north by the Turpan–Hami basin (part of the Junggar block), to the south by the Aqikekuduke–Shaquanzi fault zone, to the west by Xiaorequanzi area, and to the east by the Late Paleozoic Beishan rift.

From a tectonic perspective, the district lies in the collision zone between the Junggar oceanic crust and the Tarim continental crust (Fig. 1). The Aqikekuduke–Shaquanzi fault, separating eastern and middle Tianshan, was formed by the Early Paleozoic subduction of the Junggar crust under the Tarim crust (Ma et al., 1993; Wang et al., 1994; Zhang et al., 2005). It developed into a strike-slip fault in the Mesozoic (Han and Zhao, 2003; Mao et al., 2002a). The E–W trending Yamansu fault in the middle of the district is the northern

Table 1
The properties of typical igneous-sedimentary related iron deposits in the eastern Tianshan district, China (modified from BGEDXP, 2009).

	Deposit types	Mineralization time		Typical deposit	
		Total	Time (amount, percentage)	Name	Mineralization Process
Igneous-related	Magmatic-hydrothermal	27	C1 (2, 7.4%) C2 (10, 37%) P1 (15, 55.6%)	Tieling #1, Shuangjingzi	Late Carboniferous granite intruded into Lower-Carboniferous Yamansu volcanic formation
	Marine volcanic	48	C1 (19, 39.6%) C2 (29, 60.4%)	Yamansu, Shaquanzi, Hongyuntan, Bailingshan, Baishanquan, Shuangfengshan	Carboniferous volcanism overlaid by post-igneous hydrothermal alteration.
Sedimentary-related	Marine volcanic–sedimentary	12	C1 (9, 75%) C2 (3, 25%)	Kumutag, Lingtietan	Sedimentation of marine volcanics and carbonates overlaid by post-igneous hydrothermal alteration.