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Exploratory data analysis and singularity mapping in geochemical anomaly identification in Karamay, Xinjiang, China

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ABSTRACT

Hatu and Baogutu are two typical gold deposits in the study area. Hatu gold deposit is associated with magmatism and controlled by regional-scale faults; mineralisation mainly occurs within hydrothermally altered felsic rocks and quartz veins. In the west region of the Hatu mining area, Cu, Ag, As and Sb are present in high concentrations in carbon tuffaceous shale. Baogutu gold deposit is associated with the evolution of felsic magmas, and the porphyry copper-gold mineralisation and copper-gold ore body dominated by sulphide were formed in the rock or near the contract zone in the faults, respectively. The ore-forming elements include Au, As and Sb. In this study, exploratory data analysis (EDA) and singularity mapping (SM) techniques were applied to identify geochemical anomalies caused by Au-related mineralisation according to stream sediment geochemical data set in Karamay mineral district, northwestern China. Silver, As, Au and Sb were chosen as indicator elements. The results show that EDA could not well identify weak anomalies within the strong variance of the background, while SM can recognise effectively weak anomalies, and quantify the properties of enrichment caused by mineralisation. The results obtained by SM demonstrated that the anomalies are closely associated with the known Au deposits in the study area. The anomalous areas delineated by the SM have potential for follow-up mineral exploration. In addition, the results document that Ag, As, Au and Sb may be reliable indicator elements for Au-related mineralisation in the study area.

1. Introduction

Identifying anomalies during mineral exploration is one of the basic tasks in geochemical data utilisation. Several techniques can be used to identify anomalies in geochemical data sets, which can be broadly classified into two categories according to the number of thresholds used in the study area: (i) 'hard threshold techniques' (employing a global threshold level for all data in the study area), and (ii) 'soft threshold techniques' (which employs local, dynamical thresholds over a study area). For hard threshold techniques, the anomaly threshold is often calculated, e.g. by using the mean of a variable or element plus two or three times the variable/element's standard deviation (MSTD) (Reimann and Garrett, 2005; Reimann et al., 2005; Xie et al., 2008a), or by the value of the median of a variable or element plus two times the median absolute deviation (MMAD) (Bounessah and Atkin, 2003; Chipres et al., 2009; Reimann and Filzmoser, 2000; Reimann et al., 2005) or by using the concentration–area (C-A) multifractal model (Cheng et al., 1994). In soft threshold techniques, some window-based contrast filtering methods (Jin and Chen, 2011; Shi et al., 1999; Zhao et al., 2012b), such as the spectrum and area model (S-A model) (Cheng, 2000) and the SM technique developed by Cheng (2007a), are widely used (Chen et al., 2007; Cheng et al., 2009; Wang et al., 2013a, b; Zuo and Cheng, 2008; Zuo et al., 2013, 2015–in this issue).

In China, the MSTD is often used as the canonical anomaly threshold definition, in the statistical treatment of regional geochemical data for mineral exploration, even at the present time when computers and new and efficient techniques are available. MMAD, as a kind of exploratory data analysis (EDA), is considered a *robust* method of treating exploration data. By contrast, the C-A model has limited success in identifying weak anomalies in covered areas (Zuo et al., 2013), and expert knowledge is needed to determine the anomaly threshold according to the log-log plot. The problem in using contrast filtering methods is that the size of the window used needs to be determined according to *a priori* knowledge, which limits practical application. The S-A model is complicated and suffers from edge effects in irregularly shaped study areas (Zuo et al., 2013). By contrast, the SM technique has been reported widely and often produces meaningful results when used in the statistical treatment of geochemical data (Bai et al., 2010; Cheng, 2012; Sun et al., 2010; Xiao et al., 2012; Zuo et al., 2013).

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In this paper, the Hatu and Baogutu gold districts in Karamay, Xinjiang, China are selected as the study area used for comparison of the results of MMAD (hard threshold) and the SM technique (soft threshold) with respect to identifying geochemical anomalies associated with mineralisation.

2. Study area and data set

The study area (Fig. 1) is located in the western Junggar Basin, approximately 330 km northwest of Urumqi, Xinjiang, China. This district is mainly controlled by NNE faults. Major faults in this area include, from north to south, the Hatu, Anqi, Darabut and Yijiaren faults. The Darabut ophiolitic mélange belt, distributed as a band along the Darabut fault, is approximately 50 km^2 in size, which was tectonically disrupted, and now forms the present imbricate structure that is mainly controlled by thrust faults. Materials from the oceanic crust often appear in terrigenous detrital sediment at old continental margins, and exhibit geochemical characteristics that are similar to the materials from the mantle (Zhang and Huang, 1992). Major plutonic rocks are represented by Miaoergou, Hatu, Akebasitao, Red Mountain and north Karamay granite batholiths in this area, with an age of 300 Ma from zircon LA-ICP-MS U-Pb (Su et al., 2006). The distributions of intrusive rocks and ore deposits in this area are highly correlated with the faults.

The Hatu gold deposit in the NW and the Baogutu gold deposit in the SE of the study area are two representative deposits of the regional mineralisation geology. The Hatu gold deposit is controlled by two NE trending faults, namely, Anqi (extension fault) and Hatu (compression and scissor fault). Some NW, NE and EW trending secondary faults are associated with ore formation and with the NE trending fault. The ore bodies occur in groups, en échelon, and end-to-end alignment (Zhu et al., 2013). The Hatu gold deposit mainly consists of superficial quartz vein-type and altered rock-type ore bodies, and these ore bodies are products of a homologous hydrothermal flow (Zhang, 2003). Copper, Ag, As and Sb are present in high concentrations in carbon tuffaceous shale. Antimony occurs in the Lower Carboniferous stratum. Gold mineralisation is associated with silicification, sericitisation, pyritisation and arsenopyrite mineralisation. The main mineral assemblage is arsenopyrite-pyrite-native gold-native arsenic-native antimony-stibnite. Arsenopyrite is the ore mineral of this gold deposit, and its element association is Au, As and Sb (Zhu et al., 2013).

China's National Geochemical Mapping Project (Regional Geochemistry National Reconnaissance) was initiated in 1979 (Xie et al., 1997), and the project covered more than 6 million km^2 (Xie et al., 2008b). This project mainly collected stream sediment samples. In this study, the density was one sample per km^2. To reduce the laboratory load, four samples were composited into one sample for analysis representing 4 km^2 (Fig. 2). For the purposes of this study, four elements were selected from the 39 elements that were determined (Wang et al., 2011; Xie et al., 2008b), which are closely related to the mineralisation, namely, Ag, As, Au and Sb. Silver was determined using emission spectrometry (ES) with a detection limit of 0.1 mg/kg. Arsenic and Sb were determined by hydride generation–atomic fluorescence spectrometry (HG-AFS), and their detection limits were 0.005 and 0.1 mg/kg respectively. Gold was determined by graphite furnace–atomic absorption spectrometry (GF-AAS) with a detection limit of 0.1 mg/kg. Details on the quality control procedures are reported by Xie et al. (1996), Cheng et al. (1997) and Liu et al. (2015–in this issue).

Many research projects on geochemical anomaly recognition were conducted on the basis of China's National Geochemical Mapping Project, and these projects used methods such as the C-A fractal model (Cheng et al., 1994), the concentration–distance fractal model (Li et al., 2003), the spectrum–area (S-A) model (Cheng, 2000), and the SM technique (Cheng, 2007a; Wang et al., 2013b; Xiao et al., 2012; Zuo et al., 2009, 2012, 2013), which involved both the frequency distributions and the spatial self-similar properties of geochemical variables. These models are effective tools for decomposing complex and mixed geochemical populations, and for identifying weak geochemical anomalies hidden within a strong geochemical background (Cheng, 2007a; Cheng and Agterberg, 2009; Cheng et al., 2010). In the present paper, the effectiveness of EDA and SM techniques to identify geochemical anomalies related to gold deposits are compared using the stream sediment geochemical data from the Karamay area.

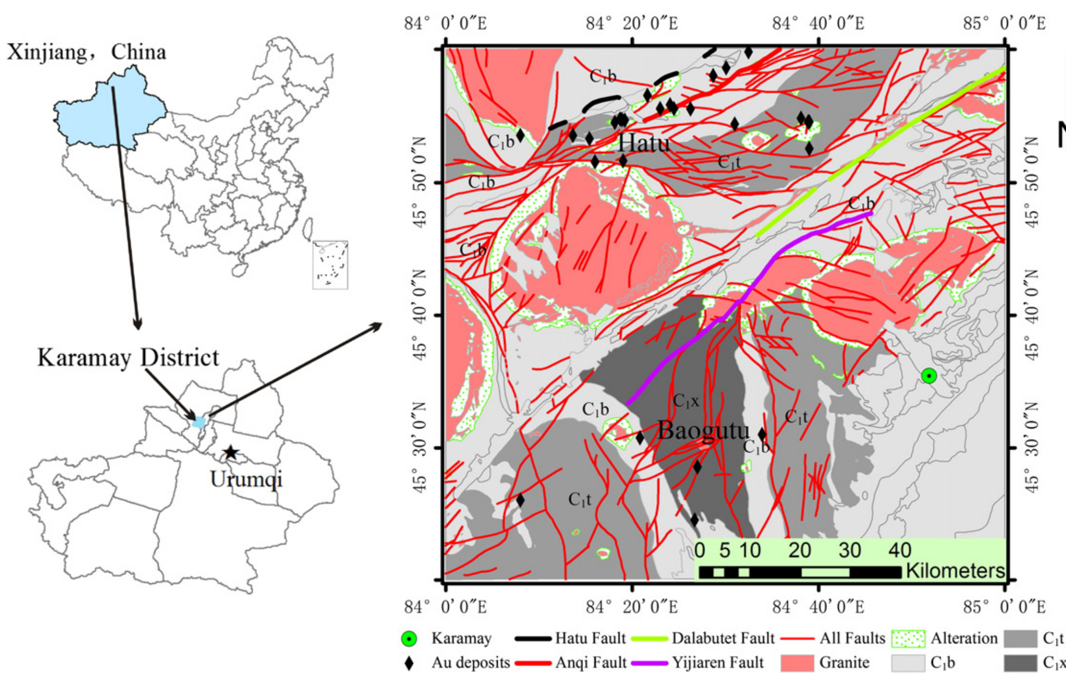

Fig. 1. Simplified map of regional tectonics, magmatic rocks and alteration districts in the northwestern Xinjiang Autonomous Region, China (C1x = Xibeikula formation; C1t = Tailegula formation; C1b = Baogutu formation).