Ore Geology Reviews 73 (2016) 1–12

Contents lists available at ScienceDirect

Ore Geology Reviews

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

Identifying geochemical anomalies associated with Sb–Au–Pb–Zn–Ag mineralization in North Himalaya, southern Tibet

Xiang Sun [a,*], Youye Zheng [a,b], Changming Wang [a], Zhongying Zhao [c], Xuebin Geng [a]

[a] State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Beijing 100083, China
[b] Institute of Geological Survey, China University of Geosciences, Wuhan 430074, China
[c] Petrochina Research Institute of Petroleum Exploration & Development, Beijing 100083, China

ARTICLE INFO

Article history:
Received 23 August 2015
Received in revised form 13 October 2015
Accepted 14 October 2015
Available online 22 October 2015

Keywords:
Statistical method
Fractal
Singularity
Targeting

ABSTRACT

The North Himalaya is a prospective area for Sb, Sb–Au, Au, Pb–Zn(−Ag), and Sb–Pb–Zn–Ag mineralization. Geochemical anomalies for mineralizing elements and element associations were identified using concentration–area (C–A) fractal model together with statistical analyses, including the mean ± 2 standard deviation (Mean + 2STD) and the median ± 2 median absolute deviation (Median + 2MAD). The results show that the Mean + 2STD for log-transformed data and C–A model could well identify the geochemical anomalies associated with mineralization in the North Himalaya. Sb + Au anomalies show a better spatial association with Sb, Sb–Au, and Sb–Pb–Zn–Ag deposits than those of single Sb element. Au anomalies are associated with all deposits, and Pb + Zn + Ag anomalies are associated with Pb–Zn and Sb–Pb–Zn–Ag deposits. In addition, weak anomalies associated with Sb mineralization can be identified by the singularity method. With the utilization of the Sb + Au, Sb, Au and Pb + Zn + Ag anomalies identified by C–A fractal model and Mean + 2STD for log-transformed data, as well as the singularity method, we can facilitate the exploration targeting of various deposits in the North Himalaya. In addition, our results also show that principal component analysis (PCA) of centered logratio (clr) transformed data can accurately recognize three different geochemical assemblage compositions representing three different types of mineralization (i.e., Au, Pb–Zn–Ag and Sb) in the North Himalaya.

1. Introduction

Stream sediment surveys play an important role in mineral resource exploration, and different types of deposits have been discovered in China (Xie et al., 1997, 2008). However, it is challenging to process such data to detect multivariate geochemical patterns and signals associated with mineralization (Carranza, 2004). Principal component analysis (PCA) is an important tool in data analysis that can reduce the dimension of variables or identify factors that detect hidden structures in multivariate data (Cheng et al., 2006; Reimann et al., 2008). Several varieties of PCA, in addition to classic PCA, can be found in the literature, including fuzzy masking PCA (FMPCA; Cheng et al., 2011) and robust PCA (RPCA; Zuo, 2014). These approaches can be applied to (1) raw data, (2) log-transformed data, (3) additive logratio (alr) transformed and centered logratio (clr) transformed data (Aitchison, 1986), and (4) isometric logratio (ilr) transformed data (Egozcue et al., 2003). Carranza (2010) applied classic PCA to log-transformed stream sediment geochemical data and derived a new factor for Cu–Ni–As, represented by the integrated third principle component (PC3) with positive loadings of Cu and As × (means multiply) fourth principle component (PC4) with positive loadings of Ni and As, as a proxy for Au mineralization in the Aroroy district in Philippines. Using this method, anomalous areas were found to exhibit good spatial associations with known epithermal Au deposits. Zheng et al. (2014a) conducted PCA on raw data and used PC4 with positive loadings of Cu and Au to reveal geochemical anomalies at Zhunuo in the Gangdese belt, southern Tibet, and this played a role in the discovery of the Zhunuo porphyry Cu deposit. Based on RPCA on geochemical data from the Fanshan district, China, Zuo (2014) considered that first principle component (PC1) comprises two different compositional groups: (1) Pb, Zn, Sn, W, Mo, Bi, Hg, and Ag with positive loadings that characterize epithermal-type Cu–Au mineralization; and (2) As, Au, Cu, Sb, and Mn with negative loadings that characterize epithermal-type Cu–Au mineralization. Subsequently, spectrum–area (S–A) fractal modeling was applied to decompose the mixed geochemical patterns, from which a number of geochemical anomalies were identified.

Several methods have been proposed to separate geochemical anomalies from background, including (1) traditional statistical analysis techniques such as probability graphs (Sinclair, 1974), univariate and multivariate analysis methods (Tukey, 1977; Aitchison, 1986; Sun et al., 2009), and fractal and multifractal models such as number–size (N–S; Mandelbrot, 1983; Agterberg, 1995; Wang et al., 2010a, 2010b; Yang et al., 2015), concentration–area (C–A; Cheng et al., 1994; Deng

* Corresponding author.
E-mail address: sunxiang8003@sina.com (X. Sun).

http://dx.doi.org/10.1016/j.oregeorev.2015.10.020
0169-1368/

et al., 2009, 2010, 2011; Wang et al., 2011a, 2012), concentration–distance (C–D; Li et al., 2003), concentration–volume (C–V; Afzal et al., 2011), spectrum–area (S–A; Cheng et al., 2000), and the local singularity (Cheng, 2007). Reimann et al. (2005) compared various statistical methods for the determination of element concentration threshold values and showed that boxplot, median ± 2 median absolute deviations (Median + 2MAD) and empirical cumulative distribution functions are better suited for estimating anomaly threshold values than is the mean ± 2 standard deviations (Mean + 2STD). Considering the spatial autocorrelation nature of the geochemical data, fractal and multifractal methods have been widely applied to identify geochemical anomalies (e.g., Cheng, 2007; Sun et al., 2010a; Zuo et al., 2013).

Many Sb, Sb–Au, Au, Pb–Zn, and Sb–Pb–Zn–Ag deposits occur throughout North Himalaya, southern Tibet, China. Hou and Cook (2009) commented on the Sb, Sb–Au, and Au deposits but did not discuss a genetic model for the mineralization. Nevertheless, they did suggest that the mineralization in the region was related to the South Tibet Detachment System (STDS) and probably formed during the Miocene in a post-collisional setting. However, Sun et al. (2010b) and Zhai et al. (2014) suggested the Bangbu Au and Mazhala Sb–Au deposits to be orogenic-type based on the fluid inclusion studies. Recent researches have shown that the mineralization at Zhaxikang formed during two distinct phases: an early phase of Pb–Zn(−Ag) mineralization and a later Sb mineralization (Zheng et al., 2012, 2014b; Liang et al., 2013). The multiple phases and various types of mineralization in the North Himalaya suggest that the concentration distributions of elements associated with mineralization are complicated.

The objective of this paper is to apply various traditional statistical and fractal methods to stream sediment geochemical data collected in the North Himalaya, southern Tibet, and evaluate the best approaches for characterizing anomalies associated with particular styles of mineralization. Our results will be helpful for not only understanding the mineralization in the North Himalaya but also the exploration targeting.

2. Regional geology in the north Himalaya

As one of the world's largest and youngest collisional orogens, the Himalaya can be divided into four belts (from north to south): North Himalaya, Higher Himalaya, Lower Himalaya, and sub-Himalaya (Fig. 1A). These belts are separated (from north to south) by the South Tibet Detachment System (STDS), the Main Central Thrust (MCT), and the Main Boundary Thrust (MBT), respectively, and are flanked to the south by the Main Frontal Thrust (MFT) (Yin, 2006). The North Himalaya is composed of the Tethyan Himalayan sequence (THS), which consists predominantly of low-grade Proterozoic to Cretaceous metasediments that are thought to have been deposited along the northern edge of the Indian continent (Liu and Einsele, 1994; Pan et al., 2004; Fig. 1B). The THS was generally divided into the northern and southern zones (Liu and Einsele, 1994), separated by the north-dipping Gyrong–Kangmar thrust (GKT in Fig. 1A; the term is a synonym to Gyrong–Tingri–Gamba–Luozha fault, Pan et al., 2004). It should be noted that ore deposits discovered up to now in the southern Tibet are located in the northern zone.

Igneous rocks in the North Himalaya are dominated by the Late Jurassic–Early Cretaceous mafic rocks and Cenozoic granitoids. The Late Jurassic–Early Cretaceous (145–130 Ma) mafic rocks are exposed in the Jurassic–Cretaceous sedimentary sequences and consist of basaltic lavas, mafic sills and dikes, and gabbroic intrusions, the petrogenesis of which were suggested to be associated with the mantle plume (Zhu et al., 2008, 2009). The Cenozoic granitoids in the North Himalaya consist of the Eocene granitoids and the Miocene leucogranites, two-mica

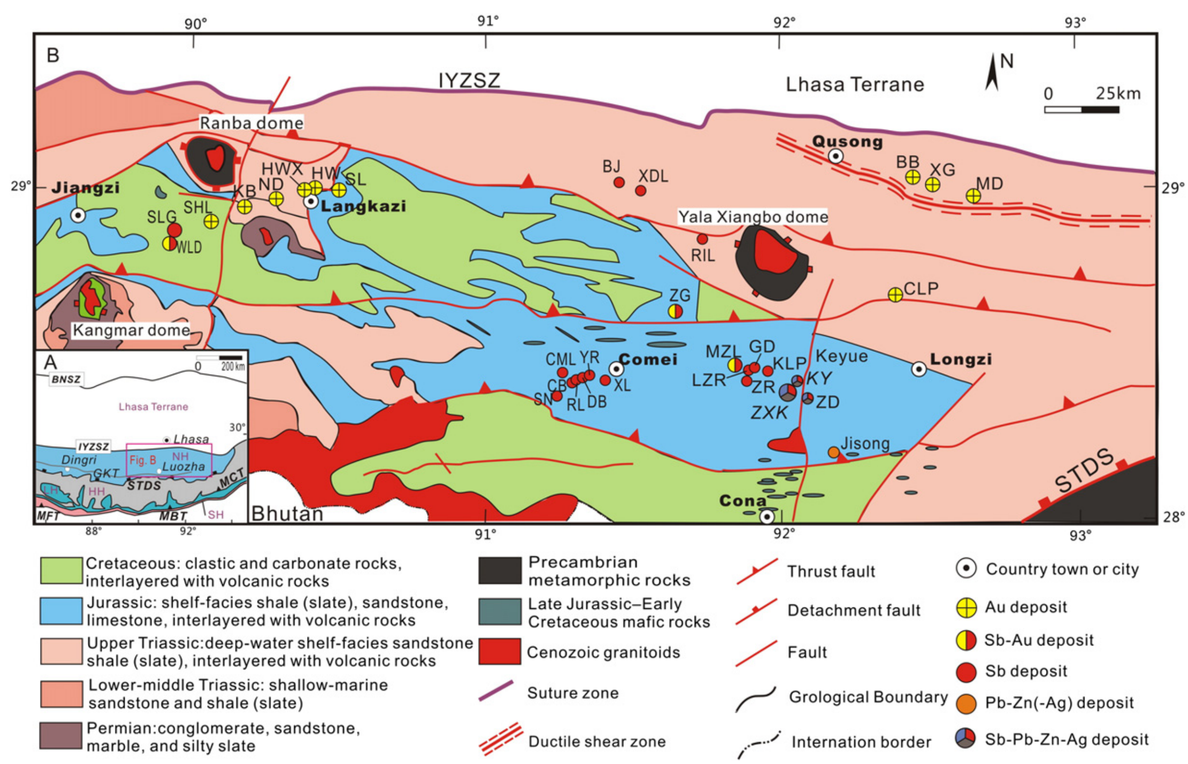

Fig. 1. (A) Tectonic outline of the Tibetan Plateau (after Yin, 2006). (B) Geological map of the North Himalayan Polymetallic Metallogenic Belt (modified after Zhu et al., 2011; Zheng et al., 2014b). BNSZ, Bangong–Nujiang Suture Zone; IYZSZ = Indus–Yarlung Zangbo Suture Zone, MFT = Main Frontal Thrust, MBT = Main Boundary Thrust Fault, MCT = Main Central Thrust Fault, STDS = South Tibet Detachment System, NH = North Himalaya, HH = Higher Himalaya, LH = Lower Himalaya, SH = Sub-Himalaya. Au deposits: XG–Xigong, BB–Bangbu, MD–Muda, CLP–Chalapu, HW–Hawong, HWX–Hawongxi, KB–Kangbugunba, SL–Sheli, ND–Naodong, and SHL–Shengla. Sb deposits: GD–Guidui, LZR–Longzhongri, KLP–Kelupu, ZR–Zheri, CB–Cheqiongzhuobu, YR–Yongri, RL–Rangla, XL–Xuela, DB–Duoba, CML–Chimalong, SN–Shangni, SLG–Shalagang, BJ–Baijia, RIL–Rila, and XDL–Xiangdala. Sb–Au deposits: MZL–Mazhala, ZG–Zhegu, and WLD–Wuladui. Pb–Zn(−Ag) deposit: JS–Jisong. Sb–Pb–Zn–Ag deposits: ZXK–Zhaxikang, KY–Keyue, and ZD–Zhedang.