Journal of Geochemical Exploration 165 (2016) 111–124

Contents lists available at ScienceDirect

Journal of Geochemical Exploration

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

Recognition of significant multi-element geochemical signatures of porphyry Cu deposits in Noghdouz area, NW Iran

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ARTICLE INFO

Article history:
Received 15 August 2015
Revised 8 March 2016
Accepted 9 March 2016
Available online 12 March 2016

Keywords:
Significant geochemical signatures
Stream sediment geochemical data
Sample catchment basin models
Contour maps
Prediction-area (P-A) plot
Success rate curve

ABSTRACT

Diversity and complexity of geological processes in different areas result in different element associations for prospecting a certain mineral deposit-type sought. In this regard, because element associations are affected by the diversity of geological characteristics of different areas, it is important to analyze and recognize significant geochemical signatures that represent the deposit-type sought. This paper aims to recognize significant multi-element geochemical signatures of porphyry-Cu deposits in the Noghdouz area, Iran, using stream sediment data. For this, we used factor analysis and two modeling methods of geochemical anomalies, sample catchment basin and contour map. Then, to recognize significant geochemical signatures of the deposit-type sought and evaluate the anomaly mapping methods, we adapted prediction-area (P-A) plot, normalized density, and success rate curve. By using these processes, we recognized the best geochemical signature of the deposit-type sought in the study area. The proposed methods in this paper can efficiently be used in other areas to recognize significant geochemical signatures of different types of mineral deposits.

1. Introduction

Maps of geochemical signatures are efficient evidence layers for integration with other exploration evidence layers in mineral prospectivity mapping (MPM) of certain types of deposits (e.g., Agterberg, 1992; Agterberg and Bonham-Carter, 2005; Carranza, 2008, 2011; Lusty et al., 2012; Wang et al., 2012; Liu et al., 2014; Carranza, 2015; Carranza and Laborte, 2015a, 2015b; Yousefi and Carranza, 2016). In preliminary exploration stages, stream sediment geochemical data are generally used to delineate anomalous areas (e.g., Carranza and Hale, 1997; Cheng, 2007; Zuo et al., 2009; Bai et al., 2010; Carranza, 2011; Zuo, 2011b; El-Makky and Sediek, 2012; Zheng et al., 2014; Wang et al., 2014; Wang and Zuo, 2015). For recognizing geochemical signatures related to a certain deposit-type sought, factor analysis (as a multivariate analysis method) has been used (e.g., Reimann et al., 2002; Kumru and Bakac, 2003; Helvoort et al., 2005; El-Makky, 2011; He et al., 2013; Sadeghi et al., 2015). Factor analysis reveals element associations that genetically present in the mineral deposits of the type sought (e.g., Sadeghi et al., 2013; He et al., 2014).

Recognition of significant mineralization-related multi-element geochemical signatures is a challenge, because factor analysis may reveal more than one multi-element association (i.e., factors) representing the same deposit of the type sought. On the other hand, factor analysis may reveal some factors in the chemical composition of stream sediment data that are not genetically related to the deposit-type sought (Yilmaz, 2003; Spadoni, 2006; Cheng, 2007; Zuo et al., 2009; Xie et al., 2010; Yousefi et al., 2012).

Modeling of geochemical anomalies especially in stream sediment data is another challenging issue because the materials of each stream sample have upstream sources (Spadoni, 2006; Carranza, 2008). In this regard, several methods have been proposed for mapping stream sediment geochemical signatures including point symbol maps, contour mapping or interpolation approaches (Howarth, 1983), sample catchment basins (SCB) (Bonham-Carter and Goodfellow, 1984, 1986; Bonham-Carter, 1994; Carranza and Hale, 1997; Moon, 1999; Spadoni et al., 2004; Carranza, 2008; Carranza, 2010b), stream orders (Carranza, 2004), extended sample catchment basins (Spadoni, 2006) and weighted drainage catchment basins (Yousefi et al., 2013). Various studies have applied contour mapping and SCB for modeling geochemical anomalies using stream sediment data (e.g., Hawkes, 1976; Bonham-Carter et al., 1987, 1988; Carranza, 2004, 2008, 2010a).

This study aims to recognize significant multi-element geochemical signatures and map geochemical anomalies associated with porphyry-Cu deposits to delineate target areas for further exploration in the Noghdouz area, northwestern Iran. For this, we used staged factor analysis proposed by Yousefi et al. (2012, 2014) with robust estimation of covariance matrix (Pison et al., 2003; Filzmoser et al., 2009b). We

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http://dx.doi.org/10.1016/j.gexplo.2016.03.009

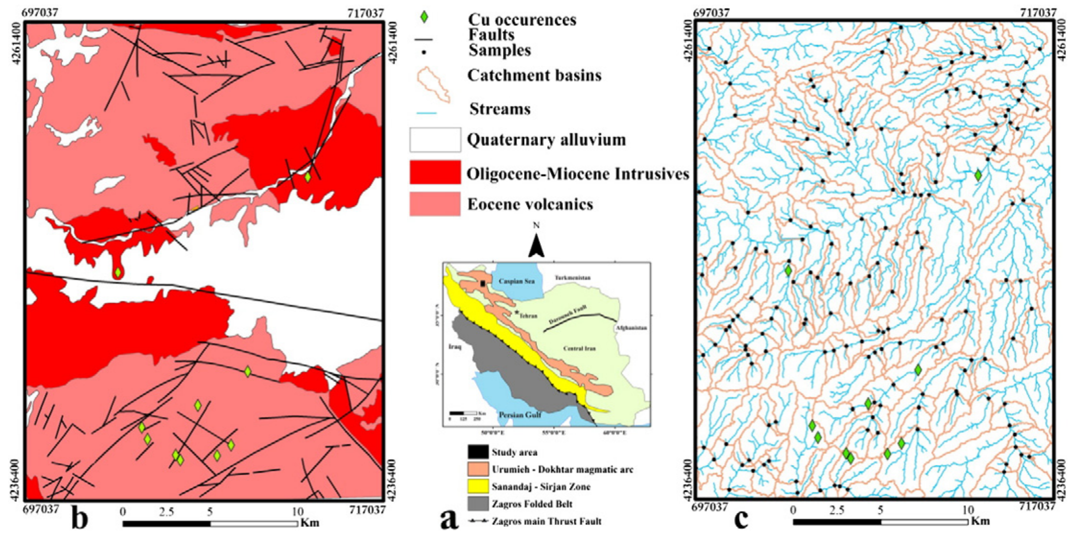

Fig. 1. (a) Location of the study area in Urumieh–Dokhtar magmatic belt, (b) simplified geological map of the study area (after Mahdavi and Amini Fazl, 1988) and (c) the location of samples and their related catchment basins.

applied SCB and contour mapping methods to model anomalies. For selecting a stronger geochemical evidence layer of the deposit-type sought in the study area, we compared the results of integration of both SCB model and contour map with another geological evidence layer in MPM. We used two models because different areas have different characteristics and complexity (Ford and Blenkinsop, 2008; Van Loon, 2002), so at least two different models should be generated and compared in an area to select the better model for MPM (e.g., Harris et al., 2003; Yousefi and Carranza, 2015c). In this paper, for recognition of significant multi-element geochemical signatures we used the location of 10 known mineral occurrences in the study area (e.g., Agterberg and Bonham-Carter, 2005; Porwal et al., 2003, 2004, 2006; Yousefi et al., 2012, 2013, 2014; Carranza and Laborte, 2015c; Gholami et al., 2012). These deposits were utilized only as testing points for assessing the ability of generated models to predict the presence of mineral deposits. Prediction-area (P-A) plot (Yousefi and Carranza, 2015a, 2015b, 2015c), normalized density (Mihalasky and Bonham-Carter, 2001; Yousefi and Carranza, 2015b) and success rate curve (Chung and Fabrri, 2003; Agterberg and Bonham-Carter, 2005) as modified by Parsa et al. (2016) were utilized for evaluating multi-element geochemical signatures derived by robust staged factor analysis.

2. The study area and porphyry copper mineralization

The study area is situated in the northern part of Urumieh–Dokhtar magmatic arc (UDMA) (Fig. 1a). The UDMA is an Andean type magmatic arc (Berberian et al., 1982), which has been formed by the subduction of Arabian plate beneath Central Iran during the Alpine orogeny in the Late Cretaceous (Berberian and King, 1981; Mohajjel and Fergusson, 2000; Babaie et al., 2001). Porphyry-Cu deposits show a strong tendency to form in island and continental-arc settings (e.g., UDMA) (Billa et al., 2004; Cooke et al., 2005; Mitchell, 1973; Sillitoe, 1972, 2010). The exploration results and known mineral occurrences in the UDMA indicate that this belt has great potential for prospecting porphyry-Cu deposits in Iran (e.g., Richards et al., 2012; Ayati et al., 2013; Zarasvandi et al., 2015).

The study area with a surface of ~600 km^2 is covered by 1:50,000 scale quadrangle map of Noghdouz. Quaternary alluvial deposits,

Table 1
Rotated component matrix of the first and second stages of robust factor analysis. Loadings in bold represent the selected elements based on the absolute threshold value of 0.5.

First stage					Second stage			
Element	F1	F2	F3	F4	Element	F1	F2	F3
Au	**−0.559**	−0.229	−0.229	−0.111	Au	**0.569**	−0.625	−0.317
Cr	0.281	−0.124	0.252	**0.519**	Ag	**0.54**	−0.619	−0.342
Mn	−0.136	**0.873**	0.112	0.274	As	−0.165	**0.869**	0.145
Ba	0.267	**0.601**	0.234	0.113	Cu	**0.719**	−0.561	−0.286
Ag	**−0.557**	−0.292	−0.266	−0.121	Mo	**0.765**	−0.322	0.121
As	0.121	0.211	**0.8**	−0.194	Pb	−0.729	−0.221	**0.629**
Co	−0.127	0.211	−0.112	**0.837**	Sb	−0.125	**0.651**	0.114
Cu	**−0.65**	−0.216	−0.254	−0.1	Zn	−0.671	−0.182	**0.868**
Mo	**−0.627**	−0.168	−0.243	−0.133	Var.	32.9	30.1	19.2
Ni	0.112	−0.114	−0.196	**0.89**	Cum. Var.	32.9	63	82.1
Pb	**0.777**	0.247	0.126	−0.269				
Sb	0.302	−0.213	**0.731**	−0.219				
Zn	**0.514**	0.194	0.11	0.102				
Sn	0.248	**0.515**	0.212	−0.133				
W	0.295	**0.717**	0.278	−0.231				
Var.	32.6	20.1	15.3	14.4				
Cum. Var.	32.6	52.7	68	82.4				