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Geochemical mineralization probability index (GMPI): A new approach to generate enhanced stream sediment geochemical evidential map for increasing probability of success in mineral potential mapping

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ABSTRACT

Integration of stream sediment geochemical data with other types of mineral exploration data, especially in knowledge-driven mineral potential mapping (MPM), is a challenging issue. In this regard, multivariate analyses (e.g., factor analysis) are generally used to extract significant anomalous geochemical signature of the mineral deposit-type sought. In this study, we used stepwise factor analysis to generate a geochemical mineralization probability index (GMPI) through a new approach to create stream sediment geochemical evidential maps. GMPI is a weight that can be mapped, and hence, can be used as an evidential map in MPM. Using stepwise factor analysis enhances recognition of anomalous geochemical signatures, increases geochemical anomaly intensity and increases the percentage of the total explained variability of data. With the GMPI, we developed a new data-driven fuzzification technique for (a) effective assignment of weights to stream sediment geochemical anomaly classes, and (b) improving the prediction rate of mineral potential maps and consequently increasing exploration success. Furthermore, the predictive capacity of each stream sediment geochemical sample for prospecting the deposit-type sought upstream of its location can be evaluated individually using GMPI. In addition, the GMPI can be used efficiently in knowledge-driven MPM as a new exploratory data analysis tool to generate a weighted evidential map in less explored areas. In this paper, we successfully demonstrated the application of GMPI to generate a reliable geochemical evidential map for porphyry-Cu potential mapping in an area in Kerman province, southeast of Iran.

1. Introduction

Mineral potential mapping (MPM) is a multi-step process of generating evidential maps (i.e., extracting and weighting of features indicating the presence of the mineral deposit-type sought), combining evidential maps, and finally ranking promising target areas for further exploration. Knowledge- and data-driven methods are two types of approaches to assign evidential weights and combine various evidential maps for MPM (Bonham-Carter, 1994; Carranza, 2008). Integration of stream sediment geochemical data with other types of mineral exploration data in knowledge-driven MPM is a challenging issue that needs careful analysis of multi-element geochemical anomalies as evidence of the presence of the deposit-type sought.

Analysis of stream sediment samples can reveal various geochemical associations, some of which can be considered as surficial geochemical signature of the deposit-type sought. A fundamental problem with regard to stream sediment geochemistry is to determine a multi-element anomalous signature of the deposit-type sought. Multivariate analyses are especially useful for that purpose because the relative importance of the combinations of geochemical variables can be evaluated.

There are many studies that have used multivariate methods for analysis of geochemical exploration data (e.g., Chandrajith et al., 2001; Grunsky et al., 2009; Halfpenny and Mazzucchelli, 1999). Factor analysis, as one of the methods of multivariate analysis, has been widely used for interpretation of stream sediment geochemical data (e.g., Borovec, 1996; Helvoort et al., 2005; Kumru and Bakac, 2003; Reimann et al., 2002; Sun et al., 2009). The principal aim of factor analysis is to explain the variations in a multivariate data set by a few factors as possible and to detect hidden multivariate data structures (Johnson and Wichern, 2002; Krumbein and Graybill, 1965; Tripathi, 1979). Thus, theoretically, factor analysis is suitable for analysis of the variability inherent in a geochemical data set with many analyzed elements. Consequently, factor analysis is often applied as a tool for exploratory data analysis. Reimann et al. (2002) and Helvoort et al. (2005) state some of the most critical questions to be considered when performing factor analysis, namely: 1) How many factors should be extracted? 2) Which elements should be included in the factor model? 3) How can the information contained in many single element maps be presented in just a few factor maps?

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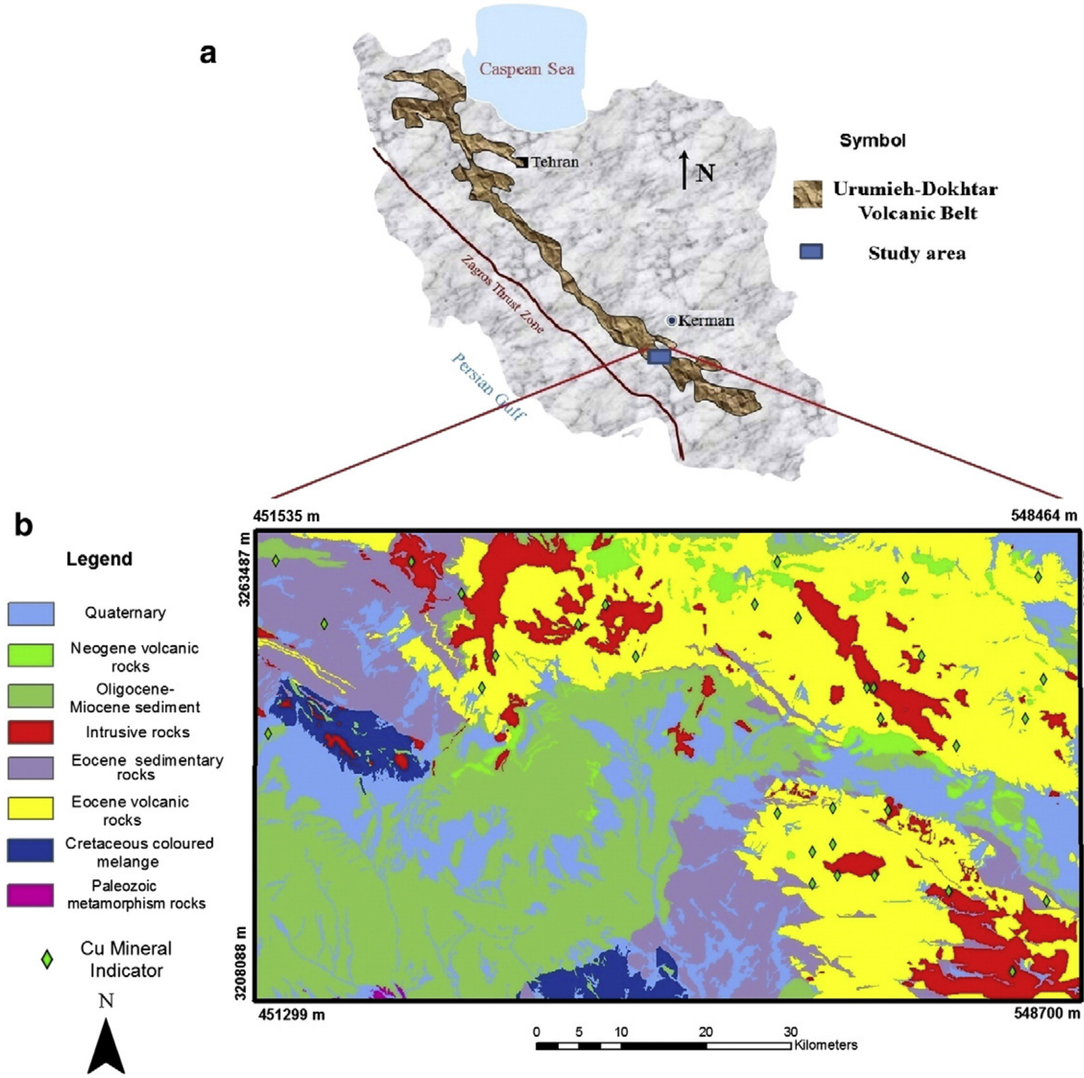

Fig. 1. Location of study area in Iran (a), and simplified geological map (b).

In this study, a large regional-scale geochemical data set containing many samples is used in an attempt to answer some fundamental questions with regard to the use of factor analysis in generating stream sediment geochemical evidential maps for MPM. Here, we applied stepwise factor analysis to enhance geochemical anomalies and to generate weighted geochemical evidential maps, so as to increase the prediction rate of mineral potential maps. If an enhanced geochemical evidential map is combined with other evidential maps (e.g., geological and geophysical evidential maps) in MPM, it provides more reliable target areas for further exploration of the deposit-type sought. Hence, the probability of success in MPM is increased.

In MPM, especially in knowledge-driven modeling techniques, there are still some challenging aspects in generating stream sediment geochemical evidential maps with strong predictive capacity. The weighting of geochemical anomaly classes, for example, is a challenging aspect discussed in this paper. Therefore, the aim of this paper is to develop a new approach to generate stream sediment geochemical evidential map for integration with other evidential maps in MPM. In this approach, we introduced a geochemical mineralization probability index (GMPI), which is consistent with the concept of probability, whereby a method for weighting classes of geochemical anomalies has been adapted using stepwise factor analysis and the theory of probability.

In this study, we selected an area in the Kerman province, southeast of Iran, as a case study. Geochemical analyses of 1804 stream sediment samples for ten elements (Cu, Au, Mo, Zn, Pb, As, Sb, Ni, Cr, Co), collected by the Geological Survey of Iran (GSI), have been used to test the proposed approach using the GMPI. In all geochemical data distribution maps described in this paper, the cumulative percentile equivalent to 95% frequency has been considered as a reference value/threshold to evaluate and compare the efficiency of the methods discussed in this research.

Table 1
Rotated component matrix of factor analysis in first step: loadings in bold represent the selected factors based on threshold of 0.6 (the absolute threshold value).

	Component			
	F1	F2	F3	F4
Zn	.132	**.872**	.048	.121
Pb	−.445	**.794**	.012	−.033
Cu	.017	.337	.209	**.751**
As	.122	−.109	**.867**	−.065
Sb	−.419	.559	−.553	.179
Mo	−.178	.212	**.766**	.162
Au	−.105	−.108	−.112	**.806**
Ni	**.842**	−.170	−.137	−.207
Cr	**.813**	−.268	.325	−.198
Co	**.785**	.250	−.048	.398
Eigen-value	3.192	1.896	1.647	1.112
Variance (%)	31.9	18.9	16.5	11.1
Cumulative variance (%)	31.9	50.8	67.3	78.4