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Multivariate regression analysis of lithogeochemical data to model subsurface mineralization: a case study from the Sari Gunay epithermal gold deposit, NW Iran

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ABSTRACT

In this contribution, multivariate regression was applied to surface channel rock and borehole geochemical data from the world-class Sari Gunay epithermal gold deposit, in northwest Iran, to model subsurface mineralization for further drilling. Multiple, factorial, polynomial and response surface regression models were applied to the geochemical data sets from a training mineralized area to evaluate the accuracy of these models using separate geochemical data from a test area. Geochemical data of 31 elements in surface channel rock samples were used as independent variables, and three parameters namely average grade, sum and productivity in individual 25 m by 25 m grid cells, obtained by kriging of borehole data, were used as dependent variables. All the multivariate regression models revealed high determination coefficients for three parameters, among which the response surface regression model yielded the highest values. The response surface regression yielded the best result, followed by the multiple regression, in modeling the geochemical data from the test area. Therefore, the result of the response surface regression was used to model subsurface gold mineralization at the Sari Gunay gold deposit in order to design additional drillings.

1. Introduction

Surface soil and rock geochemical data, in combination with other surface exploration data sets, are often used to define limited borehole locations for reconnaissance drilling. As systematic drilling is expensive, it is important and required to properly process surface geochemical data to define significant anomalies that accurately reflect expressions of subsurface mineralization. Many researchers have applied various data processing techniques to separate surface geochemical anomalies from background, and every technique yields results with varying degrees of uncertainties in mapping significant anomalies (Cheng et al., 1994; Hao et al., 2014; Parslow, 1974; Roquin and Zeegers, 1987; Sinclair, 1991; Zagayevskiy and Deutsch, 2014; Asadi et al., 2014). Aside from geochemical anomalies, exploration geologists often use reconnaissance or a-priori borehole information to set up further new drillings. However, there are very few published studies that consider the presence of known subsurface mineralization in setting up further drillings. Roshani et al. (2013) successfully used discrimination analysis to model relationships between surface geochemical anomalies and mineralized intersections in borehole data from the KuhPanj porphyry copper deposit in southeast Iran. To reduce uncertainty in locating new boreholes after a reconnaissance or during a systematic drilling survey, it is important to move one step further by analysis and integration of favorable subsurface information from such a drilling survey with information of favorable surface features.

The main objective of this contribution is to apply multivariate regression analysis to surface and boreholelitho-geochemical data from the Sari Gunay epithermal gold deposit in northwest Iran to define the favorable locations for further drilling. Four types of multivariate regression models, namely multiple regression (MR), factorial regression (FR), polynomial regression (PR) and response surface regression (RSR), were employed to define significant surface geochemical anomalies to identify subsurface gold mineralization using boreholelithogeochemical data as dependent variables and surface lithogeochemical data as independent variables.

Multivariate regression methods have been widely used by many researchers to define trend surfaces before kriging operation (Coburn et al., 2012; Howarth, 2001; Journal and Rossi, 1989 and Marcotte and David, 1988). Austria and Chork (1976) applied MR to stream sediment geochemical data to identify base metal anomalies in New Brunswick, Canada. This type of regression has also used in environmental geochemistry to identify geochemical anomalies that arise from anthropogenic activities (Selinus and Esbensen,

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1995). Stepwise MR has been used to identify lithological units that contain uranium anomalies in a regional scale (Frick and Strauss, 1989). Catchment basin analysis of stream sediment anomalies is another application of the MR model (Carranza, 2009, 2010a, 2010b; Carranza and Hale, 1997). In addition, MR has been successfully used by many researchers to model physical–mechanical parameters of rocks and soils (e.g., Chun et al., 2009; Karakus et al., 2005; Siddiqui and Syed Osman, 2013). Tolosana-Delgado and Eynatten (2010) and Akinbinu (2010) also used MR in modeling the grain size of stream sediment samples in order to predict fracture gradient in lithological formations of an oil field. The FR model was previously used as an interpolation method to model environmental impacts (e.g., Andrade and Stigter, 2013; Stigter et al., 2008). This method was also used for modeling and analyzing genotype by environmental reactions on agricultural crops (e.g., Baril et al., 1995; Reynolds et al., 2002; Voltas et al., 2005). Wang et al. (2002) used PR for spatial uncertainty analysis of Landsat satellite imagery. The RSR model, due to its nature, has been widely used in the earth sciences in comparison to the other multivariate regression models. The function obtained from RSR has been used to model the behavior of a dependent variable with respect to independent variables to find the optimal situation of influencing variables by certain parameters in the environmental sciences (Zhao et al., 2009), soil science (Boylu, 2011), forestry (Zhang et al., 2012), manufacturing technology (Mathivanan and Parthasarathy, 2009) and marine science (Mohanty et al., 2012).

2. Study area

The Sari Gunay epithermal gold deposit is located 60 km northwest of Hamadan city in northwest Iran (Fig. 1-A). It was first identified by the Rio Tinto Mining and Exploration Limited in 1999 (Richards et al., 2006) and, with 52 Mt oxide resource at a grade of 1.77 g/t gold, it is so far the largest discovered gold deposit in Iran (Ghorbani, 2013; Kouhestani et al., 2012). The gold mineralization occurs in an area of 1200 m × 600 and up to a depth of about 350 m (Asadi et al., 2014). Although there have been several drill holes and trenching in the Sari Gunay exploration area, additional drilling is required to increase the tonnage.

The Sari Gunay is a low sulphidation epithermal gold deposit, situated in the Sanandaj–Sirjan zone of the Zagros Orogenic belt of western Iran (Fig. 1-A). The geology of western Iran is part of the Tethyian metallogenic belt and it reveals several evidence of the closure of the TethyianOcean (Alavi, 1994; Bagheri and Stampfli, 2008; Stampfli and Borel, 2004; Stőcklin, 1968). The Sanandaj–Sirjan magmatic–metamorphic zone and the Urumieh–Dokhtar volcanic arc are the main segments of the Zagros orogenic belt in western Iran (Alavi, 1994). These two zones extend in parallel for 2000 km in a NW–SE direction across Iran (Fig. 1-A), and they include areas with the most important gold and copper potential in Iran (Aliyari et al., 2012). Mineralizations in these two zones are mostly related to subduction and subsequent orogenic processes from Jurassic to Miocene (Dargahi et al., 2010; Mirnejad et al., 2011; Moosavi et al., 2008).

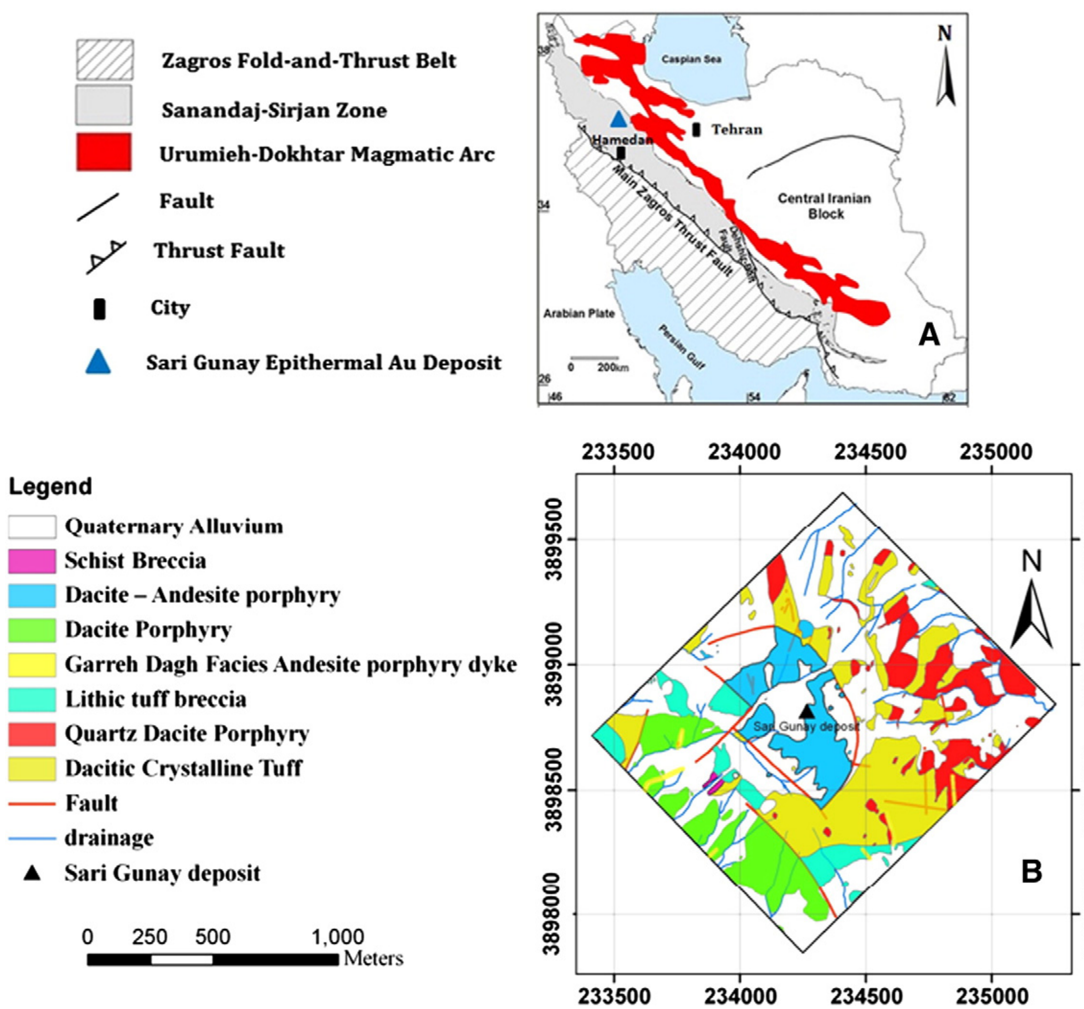

Fig. 1. Locations of the Sanandaj–Sirjan zone and the Urumieh–Dokhtar magmatic belt in Iran (A), and geological map of Sari Gunay epithermal gold deposit (B), (modified after Wilkinson, 2005).