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Zonation of primary haloes of Atud auriferous quartz vein deposit, Central Eastern Desert of Egypt: A potential exploration model targeting for hidden mesothermal gold deposits

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ABSTRACT

The Atud gold mine located in the Neoproterozoic diorite and metagabbro of the Central Eastern Desert of Egypt has been initially excavated during Pharaonic times. Between 1953 and 1969, the Egyptian Geological Survey and Mining Authority performed underground prospection in the auriferous quartz vein and metasomatic alteration zones in the main Atud area, estimating a principal gold lode of 19,000 tones (16.28 g/ton), and 1600 tons of damp (1.24 g/ton). Yet the potentiality of the deposit has not been exhausted. However, for exploration of hidden ore, quantitative characterization using trace elements zoning of mineralization haloes with 280 samples from surface and three underground mining levels is applied. This was through multivariate statistical analysis (Factor analysis) of 11 selected trace elements. Axial (vertical) extents of primary haloes above and beneath gently dipping orebody are also visualized to interpret the level of erosion, determine the direction of mineralizing solutions as well as to examine whether the hidden orebody is promising at the Atud mine.

Axial zones of primary dispersion aureoles of trace elements are: Ag, As, S and U around the auriferous quartz veins; Cu, and Pb in the surface horizons; and Zn, Ni, Co, and U along the lower margin of mineralization zone. Gold contents in bedrock and quartz vein samples from level-42M are the highest (5.7 and 40.3 ppm, respectively). In the transverse (lateral) direction, the maximum relative accumulation of Au and Zn occurs at the Northern Shaft; Pb, Cu, As, and U at the Main Shaft; and Ag, S, Co, and Ni at the Southern Shaft. The estimated axial zonation sequence of indicator elements using the variability index is Pb → Cu → Ag → Au → As → S → Ni → Co → U → Zn. According to this zonation, an index such as $(Pb \times Cu)_D/(U \times Zn)_D$ can be a significant for predicting the Au potentiality at a particular depth. In addition, the Pb/U zonality index is an appropriate indicator for the degree of erosion at the Atud gold mine. The degree of surficial zonality of the mineralization as deduced from geochemical maps and the level of erosion of the geochemical anomalies as well as the decreasing of gold content with depth recorded throughout the different underground mine workings make it necessary for the prospection model to evaluate the drainage patterns dissecting the mineralized zone.

The application of *R*-mode factor analysis estimated seven statistical factors, and factor score maps are portrayed. Factors 1 (Ag, Au, As, Co, S, U and Zn) and 2 (Zn, U, Co and S) significantly reflect the Au-mineralization (ore-controlled), and their score maps enable a more precise delineation of auriferous quartz veins and the area which may contain primary gold mineralization. The other factors reveal the distribution of Cu- and Pb-bearing minerals (supergene alteration factors), and Ba and Ni in the host diorite (lithologically-controlled). These are consistent with the calculated maximum relative accumulation of trace elements, proposing a potential model of exploration based on integrating underground geochemical data from old gold mine workings with spatial information from *R*-mode factor score maps.

1. Introduction

Primary haloes are multi-component; therefore, it is necessary to compare haloes of different elements to choose the appropriate indicator elements (Beus and Grigorian, 1977; Harris et al., 2000). This can be performed by the help of "Sequences", which indicate

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the zonality of an element, and are expressed by the "Coefficient of Contrast". In prospecting for hidden ore deposits, an increasing interest has been developed in the study of primary dispersion haloes associating the Au-bearing quartz veins (Koch and Link, 1967; El Bouseily, 1987; Lahtinen, 1989; Ames et al., 1991; Harraz, 1995; Yongqing et al., 2008; Wang et al., 2013). In most geochemical surveys, bedrock data are either represented as single point values or spatially contoured at the local scale by interpolating away from sample sites. However, instead of confining the analysis to one element at a time, multivariate analysis can be employed so that element associations and the relationship to bedrock geology can be examined (Wang et al., 2013). This means that multivariate analysis is better suited to detect common structures in the data as well as containing a high percentage of the information of the single element maps. In geochemistry chances to detect common processes determining element behavior are thus better when using multivariate analysis. Factor analysis is a statistical method for multivariate analysis that is capable of reducing dimensionality of geochemical exploration data. It is even more informative if factor analysis can be used to reveal unrecognized multivariate structures in the data that may be indicative of certain geochemical processes, or, in exploration geochemistry, of hidden mineral deposits. Factor scores has been successfully used for this purpose, instead of raw variables, for interpretation of field observations and location of anomalies (e.g. Nichol et al., 1969; Saager and Esselaar, 1969; Tripathi, 1979; Basilevsky, 1994; Reyment and Joreskog, 1996; Closs, 1997; Davis, 2002; Reimann et al., 2002). Element associations in geochemical data can be interpreted in terms of mineralization, wall-rock alterations and axial (vertical) and transverse (lateral) zonation or variations (Beus and Grigorian, 1977; Safronov, 1981; Solovov, 1987; Harraz, 1995; Chen and Zhao, 1998; Yongqing et al., 2008). The axial zonation is expressed in the direction of movement of ore-bearing solutions (Beus and Grigorian, 1977; Chen and Zhao, 1998).

The Atud area is located in the Central Eastern Desert of Egypt at the intersection of latitude 25° 0′ 10″ N and longitude 34° 24′ 10″ E. The mine is approximately 58 km west of Mersa Alam on the Red Sea coast and *ca*. 5 km south of the Idfu-Mersa Alam paved road (Fig. 1). It is one of several gold mines in the Arabian Nubian Shield of the Eastern Desert of Egypt, which has been initially excavated during Pharaonic times. The Atud gold mineralization is considered to be mesothermal vein type of orogenic Au-deposits (6–12 km) (Harraz, 2002). The Au-bearing quartz veins are localized at the eastern and southeastern slopes of Gabal Atud (Fig. 1), where mineralized quartz veins are hosted mainly in dioritic rocks (Pohl, 1988). Between 1953 and 1969, the Egyptian Geologic Survey and Mining Authority performed underground prospecting work in the Main Atud area through three expeditions. Drifting was done on three levels along the strike of the main lode (NNW–SSE) for a total length of 690 m. These levels are connected by three inclined shafts down the dip of the lode for a total length of 230 m (Fig. 2). The depth of excavation varies from <20 to 78 m and the Au

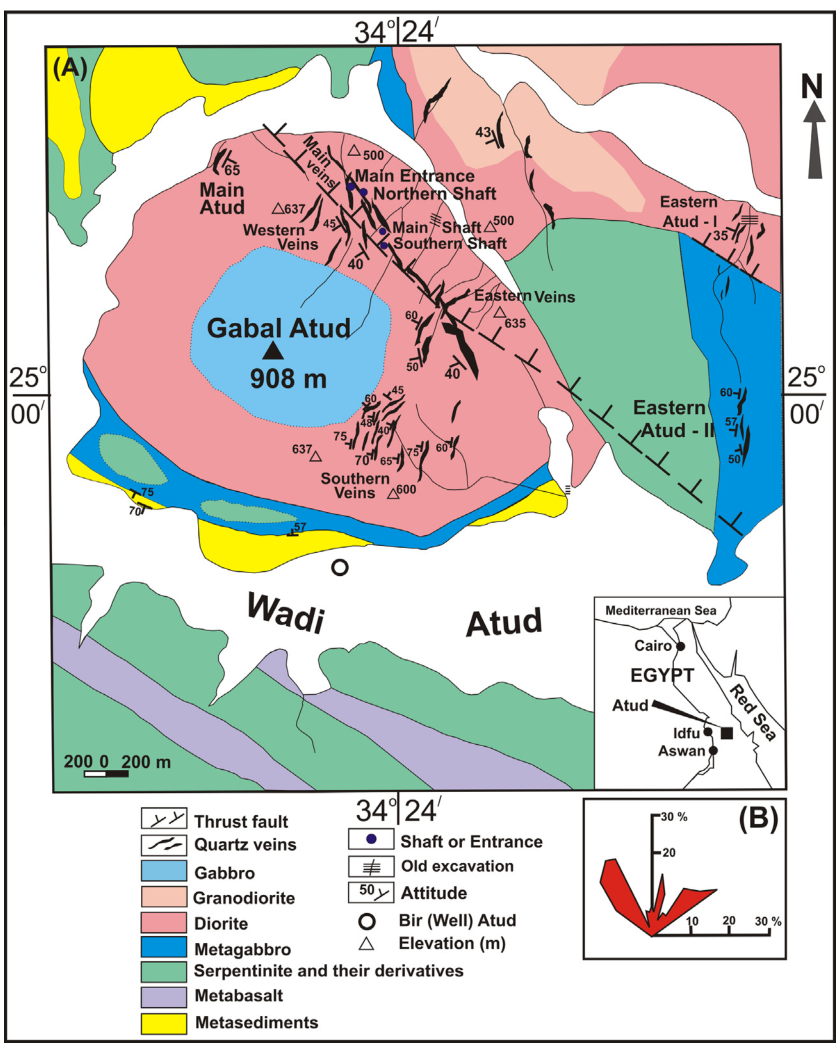

Fig. 1. (A) Detailed geological map of the Atud gold mine area (after Harraz, 1999). (B) Rose frequency diagram of field measured quartz veins in the Atud gold mine (n = 192).