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Determination of anomalies associated with Sb mineralization in soil geochemistry: A case study in Turhal (northern Turkey)

Gülten Yaylalı-Abanuz *

Department of Geological Engineering, Karadeniz Technical University, 61080 Trabzon, Turkey

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ABSTRACT

In this study, a soil geochemistry survey was conducted and most suitable pathfinder elements for the exploration of Sb deposits and anomaly distribution models of these elements were studied. In this regard, 138 samples taken from the A (top soil) and B horizons of the soil were analyzed for concentrations of Ag, Al, As, Au, Co, Cu, Fe, Hg, Mn, Ni, Pb, Sb, and Zn. All elements had asymmetrical rather than normal distributions. In soil samples from the A horizon, concentrations of Sb, As, Ag, Au and Hg are 0.42–2000 mg/kg, 2.10–5470.40 mg/kg, 10–348 μg/kg, 0.80–66.40 μg/kg and 22–1714 μg/kg, respectively. Concentrations of the same elements in the B horizon were 0.36–2000 mg/kg, 4.10–4019 mg/kg, 2–217 μg/kg, 0.20–53.70 μg/kg and 20–1853 μg/kg, respectively. Cluster analysis indicated that Ag, As, Au, and Hg are strongly correlated with Sb, and therefore, they are the most suitable pathfinder elements for the exploration of Sb deposits. Threshold values of these elements were determined with the use of median absolute deviation (MAD) method. In addition, an anomaly map of each element and the element groups yielding the most ideal results for the exploration of Sb deposits were also ascertained using multi-element mapping. Results indicate that As + Au and Ag + As + Au are the most ideal multi-elements in the exploration of Sb deposits. In this method, some elements that yield weak anomalies when solely used were found to be effective when combined with other elements. These element associations can be successfully used in future Sb geochemical exploration works.

According to enrichment factor (EF) and integrated pollution index (IPI) calculations, both A and B horizons of the soil are enriched in all examined elements. Element enrichment in A horizon is in the rank of Sb > As > Au > Ni > Hg > Co > Mn > Cu > Fe > Zn > Pb > Ag, while the rank of elements in B horizon is Sb > As > Ni > Hg > Au > Co > Cu > Fe > Mn > Zn > Pb and Ag. The A horizon hosts extremely high Sb and As enrichment; very high Au and Ni enrichment; and significant Co, Cu, Fe, Hg, Mn, Pb and Zn enrichment. B horizon is characterized by extremely high Sb and As enrichment; very high Ni enrichment; and significant Au, Co, Cu, Fe, Hg, Mn, Pb and Zn enrichment. According to integrated pollution index calculations, 44.9% of samples from the A horizon and 44.11% from the B horizon exhibit an extremely high level of pollution.

1. Introduction

The Tokat-Turhal antimony deposit is the largest antimony deposit in Turkey. In this area, there are several antimony deposits and occurrences, most of which are being extracted. Antimony deposits in the Tokat region are found within the Turhal Metamorphite that consists of metabasite, schist, carbonaceous quartzite, and marble blocks. Sb mineralization in the area is developed as a vein-type deposit and is structurally controlled. For about a century, the Turhal antimony mines have been exploited and they are currently operated by the Özdemir Antimuan Madenleri Ltd. In the field, there are numerous abandoned and active galleries, smelter and metal process facilities of the mining company.

Previous soil geochemical studies in the region have been successful in aiding local mineral exploration (Yaylalı-Abanuz and Tüysüz, 2011; Yaylalı-Abanuz et al., 2012). The A zone, which is the uppermost zone of the soil profile, is mostly composed of decomposed plant remnants and humus. The B horizon, which is affected by pedogenic processes, consists of clay minerals, organic material, Fe–Al oxides, and hydroxides. In this study, Turhal antimony mineralization was examined, and soil samples were collected from A and B horizons from the mineralized region. Various statistical methods were applied to the elements analyzed in these samples, elements with a strong association with Sb were determined and geochemical maps were drawn based on multi-element data.

The aims of this work are to (1) determine basic statistical variation for Sb and other elements in soils around the Tokat Sb deposit; (2) calculate the threshold values of Sb and the associated elements using the median + 2MAD method; (3) construct distribution maps with the use of these threshold values and single- and multi-element mapping

* Tel.: +90 462 3772073; fax: +90 462 3257405.
E-mail address: gultenyaylali@yahoo.com.

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techniques and determine pathfinder elements and the most ideal mapping technique that should be used in future Sb exploration works in the area; and (4) outline the soil contamination associated with Sb deposits in the region.

2. Description of the area

2.1. Geographic features

The study area is located at the north of Turhal between the cities of Amasya and Tokat in the Black Sea region (Fig. 1). The N–S running Yeşilırmak is the most important river in the region. There are also small creeks discharging to the Yeşilırmak. The climate is seasonal with summers being dry and hot; whereas winters are cold and wet. The annual precipitation is 400–500 mm/y. Temperatures commonly drop to below zero in winter, where snow occurs and above 30 °C in summer. Hills and ridges are covered with pine and juniper trees; whereas river margins are dominated by poplar, willow, and fruit trees. Sugar beet, vegetable, and cereal are grown along the Yeşilırmak River. The study area is rugged, and the average elevation is 550 m.

Soil type in the study area is brown podzolic. Soils in the region are of well-developed neutral and slightly alkaline (pH > 7), dark colored with low organic material (0.5–3%).

2.2. Geological setting

The Turhal antimony deposit occurs in metamorphic rocks known as Tokat massif. The metamorphic rocks of the basement are overlain by Jurassic–Cretaceous limestones and Eocene sedimentary units. The metamorphic rocks are named by Gökçe (1983) as the Turhal Metamorphite. The Turhal Metamorphite is of Paleozoic Age and consists of phyllite, schist (mica schist–chlorite schist), carbonaceous quartzite, metabasite, and marble (Fig. 1).

Four styles of mineralization are observed: stratiform type in black phyllites; stockwork in carbonaceous quartzites; vein-type cutting metabasites and carbonaceous quartzites, and stratabound type along the phyllite–quartzite contacts (Gökçe and Köksoy, 1984).

The mineralization can be observed as irregular exposures around the Hacılar and Elalmış villages. Here, vein type deposits occur along fault zones that cut bedding and schistosity planes along the limbs of an E–W trending anticline. There are two major fracture systems in the region; those that trend E–W and in an orientation 20–25°E of north. E–W trending veins cut the 020°–025° trending veins. Sb mineralization is mainly associated with the E–W fractures although can occur in the 020°–025° vein set. These fracture zones are very common in the Tokat Metamorphites and particularly in carbonaceous quartzites, where veins thicken and antimonite grade increases. Quartz–antimonite veins are observed where the fracture zones pass through metabasites and barren crushed zones in phyllites. These antimonite and quartz veinlets can be parallel or crosscutting within the broader ore zone and are commonly symmetrical (Gökçe and Köksoy, 1984).

Antimonite, quartz, and wall rock fragments are the major components of the ore zones. In some locations, veins are composed of massive antimonite; whereas in other locations, they occur as quartz–antimonite veins (Fig. 2). The antimonite mineralization is

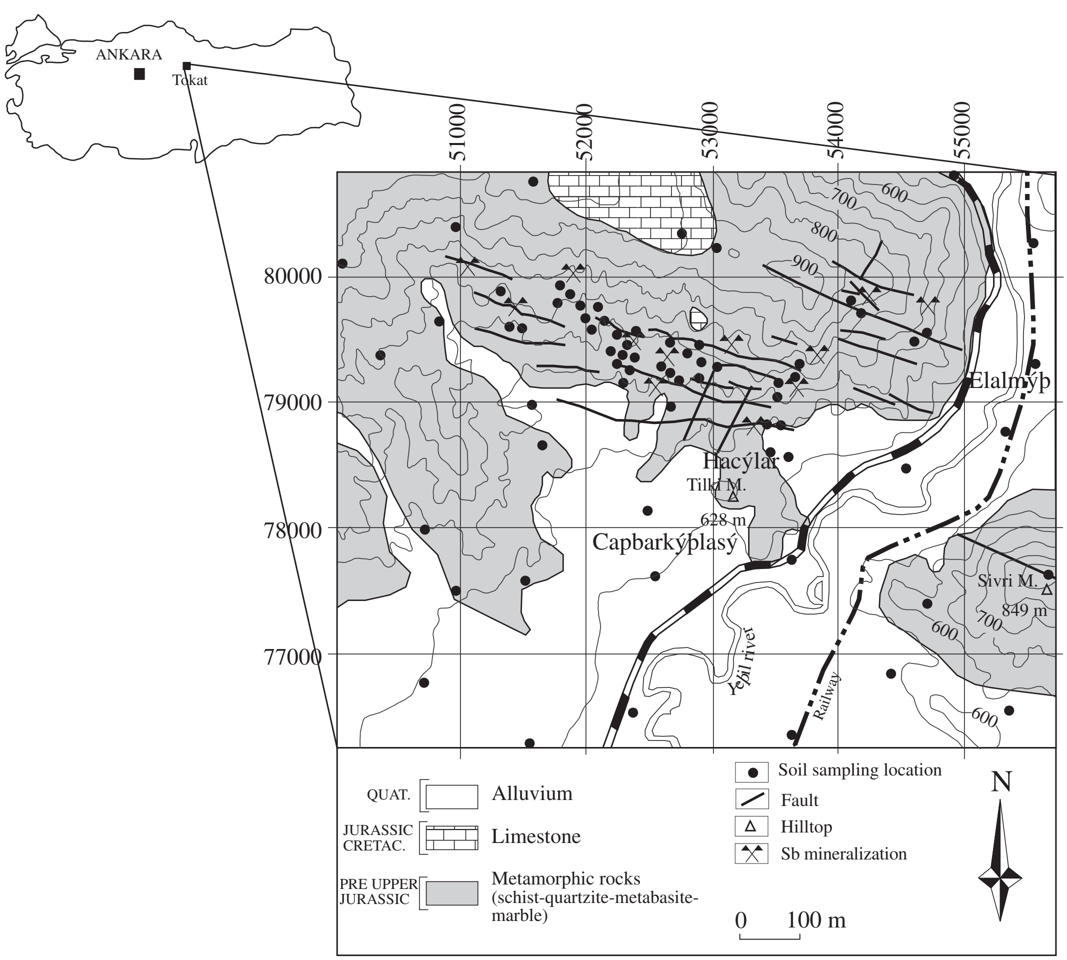

Fig. 1. Geologic map and sample locations of the study area.
Modified after Gökçe (1983).