Turkish Journal of Earth Sciences (Turkish J. Earth Sci.), Vol. **16**, 2007, pp. 33-55.

Stream Sediment Geochemical Exploration for Gold in the Kazdağ Dome in the Biga Peninsula, Western Turkey

HÜSEYİN YILMAZ

Dokuz Eylül Üniversitesi, Mühendislik Fakültesi, Jeoloji Mühendisliği Bölümü, Buca, TR–35160 İzmir, Turkey
(E-mail: huseyin.yilmaz@deu.edu.tr)

Abstract: The Tuztaşı Au-Ag mineralized system was discovered within the Kazdağ dome using BLEG (bulk leach extractable gold) and 180-μm stream sediment geochemical data collected across the Biga Peninsula in western Turkey. The deposit is located within the hinge of an antiform consisting mainly of high-grade metamorphic and mélange rocks that include the Altınoluk Pb-Zn-Cu-Ag-Au and Evciler Fe-Au-Cu deposits on the southern and on the northern flanks, respectively; no mineralization has been reported prior to this work which was first carried out in 1996 between Altınoluk and Evciler. The BLEG Ag/Au ratios at Tuztaşı (max 87) and Altınoluk (max 43) are very high to extremely high demonstrating the area to be relatively Ag-rich. This Ag enrichment is further demonstrated by rock chip Ag/Au ratios reaching up to 43 at the Tuztaşı deposit. Silver is a moderate to very effective pathfinder for Au at Tuztaşı. Arsenic is useful, being more mobile than Sb. Arsenic also constitutes the most coherent and the most significant geochemical anomaly in the northern half of the AYALE (Ayvacık-Altınova-Evciler) area which is underlain mainly by the mélange rocks intruded by granitoid. The BLEG sampling accompanied by further follow-up 180-μm stream-sediment sampling is a powerful technique in detecting Au-Ag deposits or occurrences. BLEG appears to be a time- and cost-efficient stream sediment geochemical technique for discovering relatively large primary geochemical halos encompassing the precious (Au, Ag) and base metal (Cu, Pb, Zn) deposits.

Key Words: BLEG sampling, geochemistry, gold, mineral exploration, Kazdağ, western Turkey

Biga Yarımadası Kazdağ Domundaki (Batı Anandolu) Dere Sedimanı Jeokimyasal Altın Aramaları

Özet: Tuztaşı mineralizasyon sistemi Biga Yarımadasında Kazdağ domunda (Batı Anadolu) BLEG (altının hacimsel ayrıştırılması) ve 180-μm dere tortulu jeokimyasal verilerini kullanarak keşfedilmiştir. Yatak çoğunlukla yüksek dereceli metamorfik ve melanj kayalarından oluşan bir antiform sırtında yer alır ve sırasıyla bu antiform güney ve kuzey kanatlarındaki Altınoluk Pb-Zn-Cu-Ag-Au ve Evciler Fe-Au-Cu yataklarını da kapsar; fakat ilk olarak 1966 da yapılan bu çalışma öncesinde literatürde Altınoluk ve Evciler arasındaki bir cevherleşmenin (Tuztaşı cevherleşmesi) varlığından söz edilmemiştir. Tuztaşındaki BLEG Ag/Au (maksiumum 87) ve Altınoluk (maksiumum 43) oranlarının oldukça yüksek oluşu sahanın göreceli Ag-zengini olduğuna işaret eder. Bu Ag zenginleşmesi 43'e kadar ulaşan kayaç Ag/Au oranlarıyla da gösterilir. Gümüş Tuztaşındaki Au'ın aranmasında oldukça etkin bir iz bulucudur. Antimondan daha hareketli olan As altın aramasında keza yararlıdır. Arsenik granotoid sokulumlu melanj kayalarınca altlanan çalışma alanının kuzey yarısındaki en tutarlı ve en önemli jeokimyasal anomaliyi oluşturur. BLEG örneklemesini takiben yapılan180-μm dere sedimanı Au-Ag yatak ve zuhurlarının bulunmasında güçlü bir tekniktir. BLEG, kıymetli (Au-Ag) ve baz metal (Cu, Pb, Zn) yataklarını çevreleyen göreceli büyük ilksel jeokimyasal halelerin aranmasında zaman ve maliyet açısından etkin bir dere tortulu jeokimyası tekniği olarak gözükür.

Anahtar Sözcükler: BLEG örneklemesi, jeokimya, altın, maden arama, Kazdağı, Batı Anadolu

Introduction

Systematic collection and analysis of drainage samples has been established as method of mineral exploration at both the reconnaissance and detailed scales in many parts of the earth (Ottesen & Theobald 1994). Obtaining maximum efficiency from a geochemical exploration program necessitates a balance between minimizing the density of sampling/maximizing the length of the detectable dispersion trains and significantly reducing the cost/time requirements (Cohen *et al.* 2005). Even when care is taken to obtain representative samples, gold explorations can vary markedly as a result of varying hydraulic processes in the stream and the different responses of high- to low-density minerals during transport (Nichols *et al.* 1994). Furthermore, slight changes in the slope of a stream bed, coupled with the particle scarcity effects on sample representativity may lead to the inhomogeneous Au distribution. Therefore, BLEG stream sediment sampling is considered as an alternative technique to that of 180-µm stream sediment technique to overcome the problem of erratic gold distribution. BLEG appears to be the best way to do reconnaissance-scale sampling for Au.

Western Turkey has been a focus of exploration for gold deposits in the last two decades. However, although geochemical surveys form a major part of most companies' strategies, little information is available on the geochemical dispersion of elements from deposits and prospects in western Turkey by which survey design may be optimized. The extraction of gold from large samples is a common approach that improves sample representativity and reduces detection limits; such as the bulk leach extractable gold (BLEG) method, described by Elliot & Towsey (1989), Radford (1996) and Yılmaz (2003).

The study area selected for investigating the dispersion characteristics of various elements is located 50 km SE of Çanakkale and is accessible by the Çanakkale-Edremit highway (Figure 1). This area is contained within the Ayvacık-Altınova-Evciler (AYALE) structural dome where extensional features are cut by several NE-trending intrusions. The Kazdağ dome hosts numerous mineral occurrences and deposits (Figure 1). Three of these deposits, representing a range of deposit types and differing levels of emplacement, have been included in the study area. The first, the Altınoluk (Papazlık) Pb-Zn-Cu-Ag-Au deeper-polymetallic epithermal (?) vein deposit with a resource of 240 K tons grading 5 g/t Au and 25 g/t Ag, is located in the southern part of the area and has been intermittently exploited during the last century (MTA– Mineral Research and Exploration Institute of Turkey 1966, 1993). The second deposit, re-discovered during this study, is the Tuztaşı epithermal Au-Ag deposit where numerous small ancient workings were recognized. The third deposit is the Evciler (Ayazma) Fe-Au-Cu proximal-skarn deposit in the northern margin of the Kazdağ structural mountain range, which was exploited in ancient times (Yılmaz & Kara 1996). The area between the Evciler and Altınoluk areas was not known to contain gold and silver mineralization until this study (Yılmaz & Kara 1996).

Kılıç *et al.* (2004) reported that Au values ranging up to 14 ppm in soil and 3 ppm in silicified dacitic to andesitic volcanic lava dome rocks around Kırantepe/Kısacık village 13 km east of Ayvacık. Aydal *et al.* (2004) also noted the presence of gold anomalies in the silicified zones of ultramafic rocks at Alakeçili.

This study evaluates the effectiveness of the BLEG (bulk cyanide leach extractable gold) technique and aqua regia-digested metal contents of the 180-µm (-80 #) fraction of stream sediments as well as the 180-µm (-80 #) fraction of soil at AYALE, particularly in the Tuztaşı area, which is underlain by metamorphic rocks and mélange. The purpose of this study is to demonstrate the efficiency of the BLEG technique in exploring for gold as a case study rather than investigating the detailed genetic relationships among these three deposits with probable different levels of emplacement.

Regional Geology at AYALE

The AYALE is located in the southeastern part of the Kazdağ Mountain range (Figure 1), which forms a structural and topographic dome of high-grade metamorphic rocks (Schuling 1959; Bingöl 1969; Okay *et al.* 1991, 1996). The Kazdağ range trends NE–SW and, rising to 1767 m above sea-level, forms a topographic anomaly in the northeastern Aegean, where the average elevation is below 500 m. The Kazdağ Group forms a doubly plunging, NE–SW-trending anticliniorium (Duru *et al.* 2004). The Ezine Group, over three-km thick and containing systematic occurrences of carbonate rocks in the greenschist facies, represents a fragment of the Rhodopian passive margin, a consequence of Permo–Triassic rifting of the future Maliac/Meliata Ocean, also observed in Greece. The emplacement of the Denizgören ophiolite over the Ezine Group occurred during the Balkanic orogeny, a major compressional event, which affected the whole Rhodope area, and was characterized by northward nappe emplacement during Jurassic–Early Cretaceous times (Beccaletto & Jenny 2004).

Basement rocks in the Tuztaşı area consist of Palaeozoic gneiss, marble and amphibolite (Okay & Satır 2000), tectonically overlain by a highly deformed, Late Cretaceous to Palaeocene oceanic accretionary mélange comprising basalt, clastic sediments, limestone and serpentinites (Figure 2); the sequences are separated by the Alakeçili-Akpınar shear zone. The Kazdağ Massif, the shear zone, and the accretionary mélange are intruded by

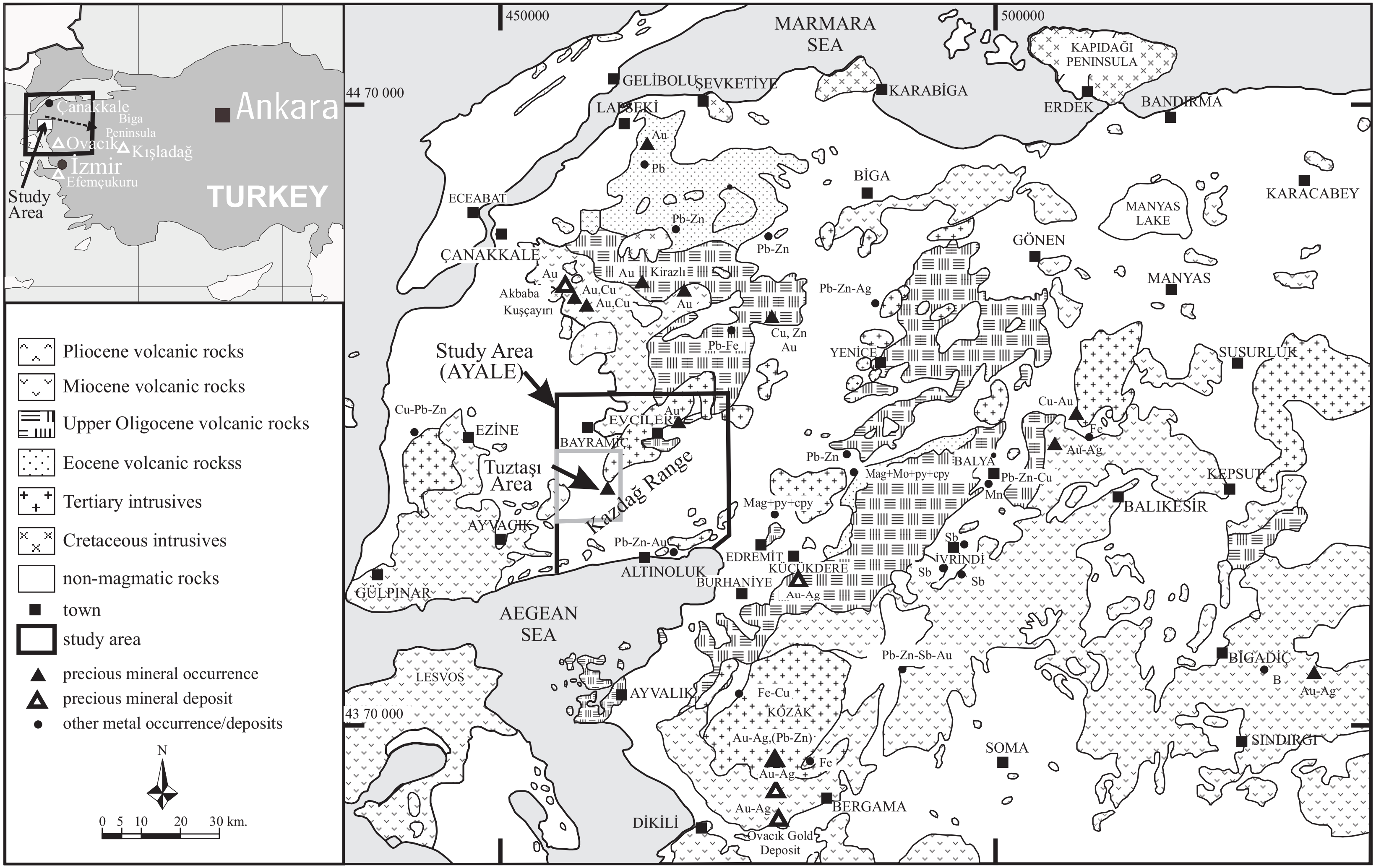

Figure 1. Simplified geological map of the Tertiary volcanic and plutonic field of northwest Turkey and location of the study area and significant mineralizations (volcanic and plutonic fields are modified from Ercan *et al.* 1984, 1995; Erkül *et al.* 2005; Tokçaer *et al.* 2005; Aldanmaz 2006).

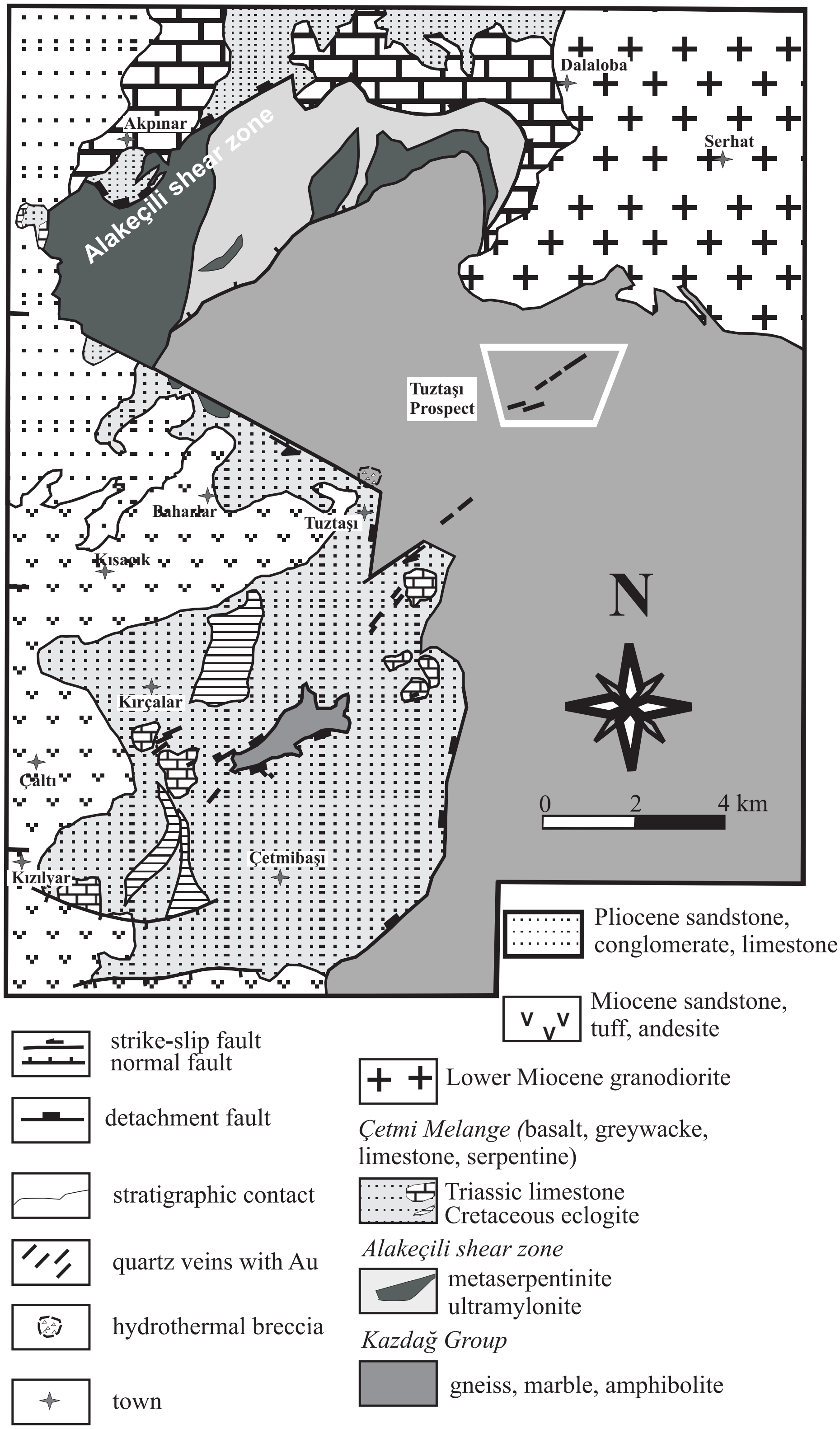

Figure 2. Geology (Okay & Satır 2000) and mineralization map of Tuztaşı area (this study).

Late Oligocene/Early Miocene granitoids (23.8 Ma: Delaloye & Bingöl 2000). The Alakeçili-Akpınar shear zone of strongly mylonitized gneiss and serpentinite, 2-km thick, occurs between the Kazdağ Massif and the accretionary mélange in the north (Okay *et al.* 1991). The Akpınar fault is interpreted as a low-angle detachment which juxtaposes brittly deformed upper crustal rocks over the ductilely-deformed mid-crustal rocks (Okay & Satır 2000). The Evciler granitoid is an elliptical, calc-alkaline pluton situated north of the Kazdağ range (Figures 1 & 2). The granitoid extends northeast–southwest parallel to the trend of the Kazdağ dome and the Akpınar shear zone. Its mineralogical composition ranges from monzodiorite through quartz diorite to granodiorite and the latter is the predominant facies constituting over 70% of the pluton (Öngen 1978, 1994; Genç 1998; Yücel-Öztürk *et al.* 2005). In the north the granitoid has intruded the Late Oligocene–Middle Miocene andesites, dacites and intercalated sedimentary rocks. These volcanic rocks are geochemically similar to the Evciler Pluton and are regarded as its extrusive equivalents (Genç 1998). Thermal metamorphism developed at the contacts between the Late Oligocene Evciler Granodiorite (Yücel-Öztürk 2005) and marble and/or metamorphic rocks hosting gold mineralization (Yılmaz & Kara 1996).

The Evciler, and several other I-type, medium to shallow-seated intrusive rocks of granite/granodiorite to monzodiorite compositions were emplaced into basement of the Kazdağ Group. Early Miocene volcanism within the Evciler area is characterized mainly by andesite and dacite lavas, and associated pyroclastic rocks (Genç 1998) whereas dacitic lava domes, lava flows and volcanoclastics are dominant facies in the Altınoluk area. The Evciler (Ayazma) Fe-Cu-Au, the Tuztaşı Au-Ag and Altınoluk (Papazlık) Pb-Zn-Cu-Ag-Au mineralized systems (Figure 1) occur within Kazdağ mountain range which is regarded as an extensional metamorphic core complex of Oligocene age, consisting of gneiss, marble and amphibolite at its footwall, and Early Tertiary accretionary mélange with exotic Upper Cretaceous eclogite blocks in its hanging wall (Okay & Satır 2000; Duman *et al.* 2004; Beccaletto & Jenny 2004; Beccaletto & Steiner 2005).

Local Geology and Mineralization at AYALE

Altınoluk-Papazlık Prospect

Information on the geology and mineralization of Altınoluk (Papazlık) base and precious metal deposit (Figure 1) is almost nil except for MTA inventories (MTA 1966, 1993). The Altınoluk vein-type Pb-Zn-Ag-Au mineralization is hosted by a sheared marble layer intercalated with amphibolite and gneiss of the Kazdağ metamorphic rocks. The thickness of the veins reaches 1.6 m over a strike length of several hundred meters. The ore consists predominantly of coarse crystalline galena, sphalerite, and pyrite with minor chalcopyrite and covellite. The Altınoluk mineralization forms a small-tonnage ore body (240 K tons) with grades of 8.2% Zn, 6.7% Pb, 5 ppm Au and 25 ppm Ag (MTA 1966, 1993).

Evciler-Ayazma Prospect

The Au concentration reported first at Evciler is associated primarily with massive pyrite-marcasite-pyrrhotite-chalcopyrite-quartz-calcite mineralization within marble and biotite amphibole gneiss intruded by the Evciler Pluton (Yılmaz & Kara 1996). The Evciler (Ayazma) Fe-Cu-Au mineralization occurs mainly as exoskarn consisting predominantly of prograde garnet and diopside with minor retrograde tremolite, epidote, chlorite, scapolite and sericite. Mineralization appears to be strongly controlled by the intercalated amphibole gneiss and marble contact which is cut by a porphyritic granodiorite sill of the Evciler pluton. A central core of mineralization with a 200 m strike length containing high-grade gold concentrations has intermittently outcropping, N50°E-trending lensoidal extensions towards the east (250 m) and west (500 m). The Au- and associated pyrite-pyrrhotite mineralization appears to be controlled by a NE-trending structure, dipping at 50°NW (Yılmaz & Kara 1996). Best rock chip results to date returned up to 14 ppm Au at 4 m with several other values above 4 ppm.

Based on earlier Au-exploration work (Yılmaz & Kara 1966), a detailed study of the Evciler skarn alteration was carried out by Yücel-Öztürk *et al.* (2005). They suggested that the geochemical characteristics of the Çavuşlu monzodiorite, Karaköy granodiorite and mesocratic Evciler rocks were similar to averages for Au-Cu and Fe-skarn granitoids, whereas the geochemical characteristics of the leucocratic Evciler rocks were similar to averages for Sn- and Mo-skarn granitoids. The Evciler granitoid is also characterized by relatively un-evolved to moderately evolved and oxidized suites, as in most Au-Cu core metal associations globally (Yücel-Öztürk *et al.* 2005). They concluded that 'composition and petrologic evolution of Evciler pluton have had the primary controls on skarn alteration, mineralization and metal content such as Cu, Au and Fe', despite the fact that there was either no analysis carried out for Cu and Au or no reference cited on Cu and Au mineralization in their study.

Tuztaşı Prospect

The Tuztaşı prospect and its surrounding area are underlain mainly by Kazdağ metamorphic rocks including gneiss, marble and amphibolite, and Çetmi mélange consisting of basalt, greywacke, siltstone, chert, limestone, serpentinite and eclogites, which are cut by the Late Oligocene/Early Miocene Evciler granitoid and andesites (23.8 Ma; Delaloye & Bingöl 2000). The Tuztaşı prospect, underlain by fine- to medium-grained gneiss and the Evciler pluton, contains three approximately N50°E-trending and 20° to 40°N-dipping quartz veins (Figure 3). Several additional Au-bearing quartz veins are recorded over a strike length of 8 km toward the southwest. However, east-southeast of Kırcalar the trends of the quartz veins vary between N70°E and N60°W (Figure 2). The drusy crystalline to saccharoidal quartz vein/breccia with vug-infill, comb and minor crustiform textures at the Tuztaşı prospect contains native Au and Ag, pyrite and arsenopyrite. The quartz veins, encompassed by a strong to weak argillic-silicic alteration halo of 600 m by 2500 m, have a mapped strike length of 1200 m, an average width of about 6 m, and reach a maximum width of 12 m. The argillic alteration within or around the quartz veins is represented by illite/sericite. Preliminary fluid inclusion analysis (40 Th °C measurements) of two samples indicates mineralization temperatures of 213 °C and 233 °C with salinities of 0.7 and 1.7 wt% NaCl equivalent. Fluid inclusions are typically irregular in shape and range in size from 10 to 100 µm and averaging 40–50 µm. Quartz textures, clay mineralogy and limited fluid inclusion results may indicate an epithermal style of Au-Ag mineralization. Ancient workings associated with earthy slag piles were also located along the quartz vein in the prospect area.

Exploration Geochemistry

A metamorphic core complex within the Kazdağ metamorphic dome stretches from Ayvacık to Evciler and is intruded by several NE-trending granitoids. This area was selected for the first orientation surveys on the use of exploration geochemistry including BLEG, 180-µm (-80 #) stream sediment and 180-µm soil geochemical sampling for discovering precious occurrences at AYALE in Turkey. The two deposits are 20 km apart and no precious metal mineralization between the deposits has been reported prior to the BLEG geochemical sampling by this study.

Climate, Topography and Regolith

AYALE has a semiarid-type climate with dry summers and cold, wet winters. July and August are the hottest months with average temperatures around 30 °C whereas January and February are the coldest with temperatures around -5 °C. Annual rainfall is 700 mm. The landscape at AYALE is dominated by ENE–WSW-trending first-order river valleys which are the surface expression of the ~E–W-trending grabens. Mountains, particularly in the Tuztaşı prospect area reach 800 m. Further north and south the topography is smoother and gentler with a maximum altitude of 250 m around the Evciler and Altınoluk areas. Major perennial rivers, such as Bayramiç Çayı, begin in narrow valleys and further west flow within a major graben; however, the majority of the streams are ephemeral. Hills in the AYALE are covered mainly by pine forest. Cultivation is restricted to olive groves on the south and fruit on the north because of lack of large valleys.

Weathering of the metamorphics and granites is generally shallow, with deeper weathering along faults and other structures. Neutral-pH grassland soils consist of a dark A-horizon overlying lighter-coloured parent material, which in turn underlain by B-horizon soils, include concretions and earthy accumulations of calcium carbonate. The soil material transported into the drainage system consists mainly of illite, quartz and metamorphic detritals with considerable organic substances and minor Fe-Mn oxides.

Sampling and Analysis

Sample points were selected from published 1:100,000 scale topographic maps to achieve a sampling density of 1 sample per 6–7 km^2 (Figure 3). A two-man team consisting of one geologist and one sampler collected an average of 15 samples per day. Active stream sediment

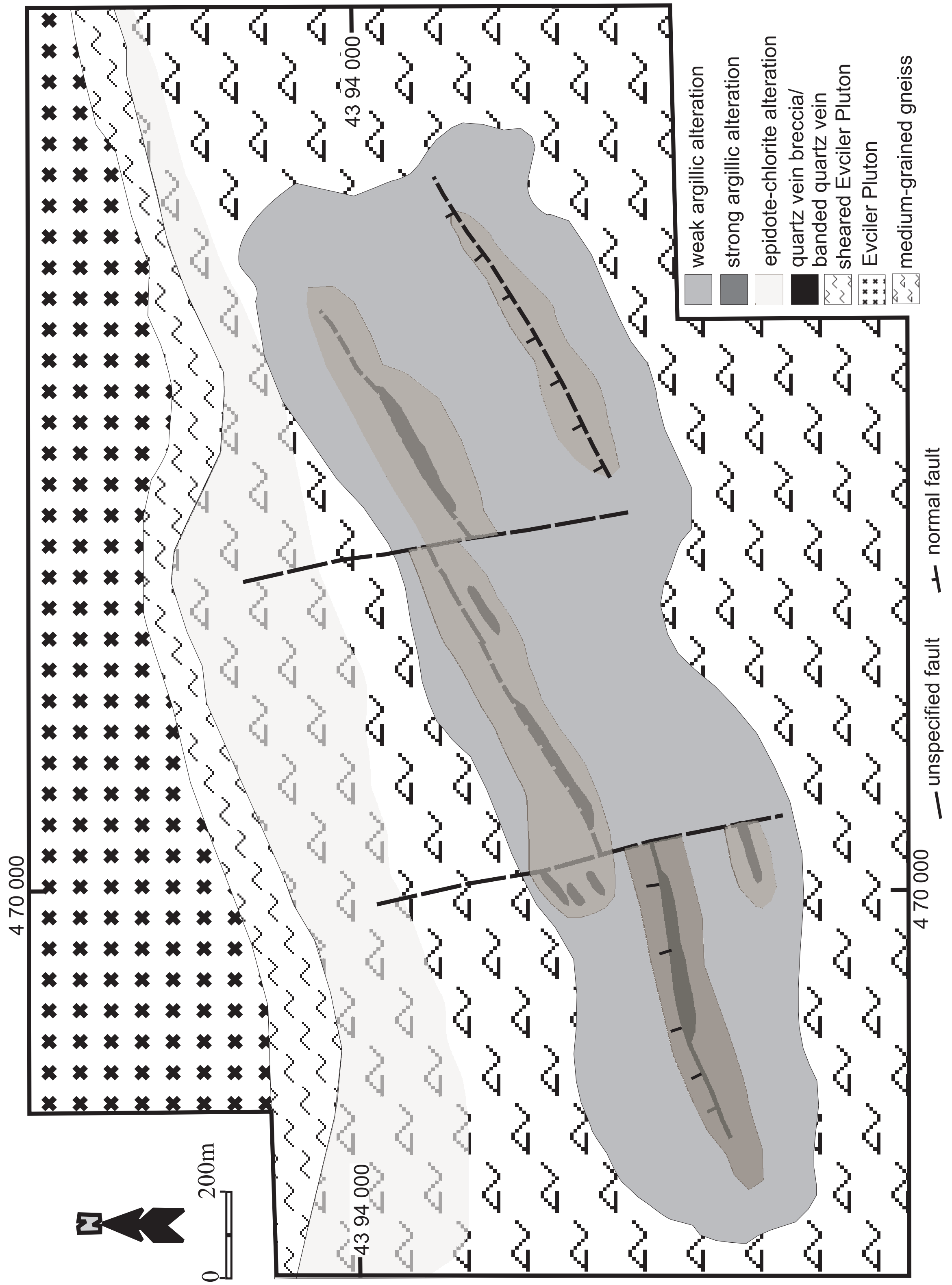

Figure 3. Geology, alteration and mineralization map of Tuztaşı prospect.

was collected along some 30 to 50 m of the stream and sieved on site to provide 2 kg of <1.2 mm fraction for BLEG analysis. Where the sediment is too wet to sieve, a bulk sample which ranges from 3 kg to 15 kg depending on the grain size of stream sediment, was collected for later drying and sieving. No flocculants were used for wet samples. The <1.2 mm fractions were forwarded to the Meggen metallurgical laboratory in Germany for metallurgical processing by cyanide leach. The BLEG anomalies were later followed up by collecting 180-µm stream sediment samples. The 180-µm stream sediment sampling density adopted during follow up was four samples or more per km^2 over the area (Figure 3). Finally, the Tuztaşı mineralization, which was detected during the 180-µm follow-up stream sediment sampling, was further evaluated by a 180-µm soil survey using B-horizon soils. The 180-µm soils were sampled over an area of 1 km^2 at a line spacing of 100 m with samples at 25 m intervals along lines.

Two kg samples for BLEG analysis were leached in 2 litres of 0.1% to 0.3% cyanide plus lime or NaOH, solution within a bottle roller for 12 hours. The extraction efficiency is dependent upon cyanide concentration as well as pH, available oxygen, the agitation time, particle size, availability of gold and, the absence of competing precipitants for gold, e.g. organic matter and sulfides (Mazzucchelli 1990; Beeson 1995). The metals, which are leached in 2 liters of cyanide solution, were precipitated on zinc powder which was re-dissolved in acid and analyzed at the Normandy Mining Ltd. laboratory, Australia for Au, Ag and Cu by AAS. Zinc is normally re-dissolved in acid to re-solubilize the gold. The zinc was then filtered from the solution and then analyzed for Au, Cu and Ag. The 180-µm stream sediment and soil samples were analyzed by ICP-OS for 32 elements including Ag, Cu, Pb, Zn, As, Sb, Mo, Cd, W, Bi and S following a $HNO_3/HClO_4$ digestion. Gold was determined by GFAAS at SGS in France after a 3/2/4 $HCl/HNO_3/HF$ attack and dissolution with HBr followed by uptake in MIBK (Meier 1980). Precision for all sample types was better than 10% at the 95% confidence level using the method of Thompson & Howarth (1978). One duplicate sample analysis was done every other 40 samples. Soil Au, Ag, As, Sb, Cu, Pb and Zn values are manually scanned and plotted to obtain an appropriate feel but were subjectively selected at constant interval-concentration increments to indicate areas worthy of follow up. Approximately 205 BLEG, and 585 180-µm stream sediment, and 533 180-µm soil samples were analyzed from the AYALE area.

Results

Trace Element Background and Threshold Values

As no previous regional geochemical survey had been carried out, background trace element concentrations within the major underlying rock formations were estimated from the literature. Average trace-element contents (ppm) from literature in ophiolites and metamorphics, respectively, are: 0.006 and 0.005–0.006 for Au, 0.07 and 0.06–0.1 for Ag, 30–45 and 10 for Cu, 15–20 and 0.1 for Pb, 30–40 and 50 for Zn, 2–13 and 1 for As, 0.2–1.5 and 0.1 for Sb , 2400 and 100 for S (Beus & Grigorian 1977), 2–2.6 and 0.3 for Mo, 2 and 0.1–0.5 for W, no data and 0.1–0.5 for Bi (Taylor 1966). Average concentrations (ppm) for these elements in soil are also reported by Levinson (1974) as: 0.1 for Ag, 2–100 for Cu, 2–200 for Pb, 10–300 for Zn, 1–50 for As, 5 for Sb, 2 for Mo, 20–500 for W and no data for Au, Bi and S.

The trace background values of the study area, which are taken as *mean* and *median* values of lognormal distributions (Rose *et al.* 1979; Xueqiu *et al.* 1999) are shown in Tables 1, 2, 3 and 4 whereas the *median* of lognormal distribution is suggested as the *background* by Levinson (1974). The separation between background and anomalous values was defined using a classical statistical treatment, with the thresholds calculated from the *mean* and *median* plus *two standard deviations* (Rose *et al.* 1979).

Results from the global data set and the data from each area were treated statistically by cumulative frequency plots. The statistical populations obtained for each area were more or less similar; reflecting the similar target lithologies sought. Therefore, the statistical treatment of the data set resulted in adoption of two threshold values of 5.8 ppb Au ($Threshold_2$= mean + 2 SD) and 5.2 ppb Au ($Threshold_1$= median + 2 SD). Background values averaged 1.5 ppb Au. Data below the values of detection limits are assumed as the minimum value of the analyzed element and then the statistical parameters are computed on this presumption. A combination of RockWorks-2002, Minpet-2.02 and Excel-2003 soft wares were used for statistical analysis.

Regional BLEG and 180-μm Survey in AYALE Area

Reconnaissance BLEG sampling carried out in the AYALE area yielded anomalous values ranging from 0.6 to 15.2 ppb Au and 0.1 to 190 ppb Ag (Figure 4). Table 1 contains the summary statistics for three variables. Skewness coefficients for raw data indicate that all distributions are positively skewed. Although BLEG Au at the 95th percentile level appears to represent the very anomalous values and is more or less similar to those of Au-Ag threshold$_{1+2}$ values (Table 1), log-transformed BLEG Au and Ag threshold$_{1+2}$ values are slightly higher for Au and 2.6 times lower for Ag. Therefore, the decision was made to work with log$_{10}$-transformed values of the data instead of the raw values, which reduces the asymmetry of the distribution as indicated by the skewness coefficient (log). The log-transformation has helped the reduce skewness in all cases but a very small positive skewness usually remains.

The BLEG anomalies were followed up using 180-μm stream sediments. These samples yielded weak to very strong Au, Cu, Pb, Zn, As, and Sb anomalies (Table 2, Figure 5) with peak values of 285 ppb Au, 14 ppm Ag, 130 ppm Cu, 1280 ppm Pb, 1250 ppm Zn, 253 ppm As and 121 ppm Sb. In twenty four of the 585 180-μm stream sediment samples Au, Ag, Cu, Pb, Zn, As and Sb values are greater than 23 ppb and, 5, 70, 54, 133, 65 and 18 ppm, respectively, for the 95th percentile. These values are indicative of moderately anomalous metal contents. The threshold$_{1+2}$ values derived from the raw data (Table 2) are 2 to 6 times higher than those derived from the log-transformed data. As indicated by the row data, all distributions are slightly to moderately positively skewed whereas distributions appear to be symmetric at log-transformed data, although a small positive or negative residual skewness usually remains. Results of the180-μm stream sediment sampling indicate three coherent clusters of anomalous Au-Sb-As-Cu values (Figure 5). The clusters of major Au and Sb anomalies exhibit similar dispersion patterns and appear to be peripheral to the cluster of extensive As anomalies. Rock-chip sampling from quartz veins with minor sulfides, particularly in the Tuztaşı prospect area, shows Au values up to 5.4 ppm, with 42 samples greater than 0.5 ppm Au and 30 samples greater than 1 ppm Au (Table 3, Figure 6). Negligible Au is detected within samples containing ore grade Cu, Pb and Zn. This may indicate that Au is situated within quartz rather than sulfide minerals. An association of Ag with Au in quartz veins is demonstrated by relatively high values (up to 130 ppm Ag) within As-rich zones. However, no correlations occur between Au-Ag and As (Table 5). Antimony is generally weakly and locally (south of Evciler) strongly anomalous and has a similar dispersion pattern to that of Au in 180-μm stream sediment samples at this location. Stream samples exhibit coherent and very strong As anomalies, overlapping those of Au. Lead and Zn anomalies are generally weak but very strong in two isolated locations. They are overlapped by the As dispersion patterns.

The 180-μm soils at the Tuztaşı Prospect were sampled over an area of 1 km^2 at a line spacing of 100 m with samples at 25 m along lines (Figure 7). The 180-μm soils contained values ranging from <1 to 2100 ppb Au, <0.5 to >20 ppm Ag, 1 to 435 ppm Cu, 1 to 949 ppm Pb, 1 to 418 ppm Zn, 1 to 521 ppm As, 1 to 2029 ppm Sb, 1 to 10 ppm Mo, 1 to 34 ppm W and 1 to 13 ppm Bi (Table 4, Figure 7). Median Au, Ag, Cu, Pb, Zn, As and W values are slightly low to very low (in particular Au) in comparison to their means due to the presence of high values in one half the distribution. About 27 of 533 original Au, Cu, Pb, Zn, As and Sb values are greater than 0.18, 103, 41, 184, 104 and 29 ppm, respectively, for the 95th percentile. These values, in particular those of Au and As, indicate very anomalous metal contents. The threshold1 values for Au, Ag, As and Sb derived from the raw data (Table 4) are 2 to 10 times greater than those originating from the log-transformed data, whereas the threshold2 values for Au, Ag, As and Sb derived from the raw data are 2 to 25 times greater than those originated from the log-transformed data. This means that the number of anomalies generated decreases significantly if the raw data are taken into account, whereas the number of anomalies increases significantly when the log$_{10}$-transformed data are considered for the further investigations of these anomalies. An elongated soil Au anomaly (Figure 7) located between XL1 and XL11 is almost 1200-m long and 200-m wide and is defined by >25 ppb Au. This correlates well with As. To the east, an area 400-m long and 150-m wide is defined by >25 ppb Au. Another smaller soil gold anomaly to the southeast, occurring between XL2 and XL12, has dimensions of about 50–150 m x 1000 m. The first and the second soil Au anomalies overlap with the As anomaly. A moderate to strong soil As anomaly in an area 50-200 m by 1800 m (between XL1 and XL17) returned As values generally

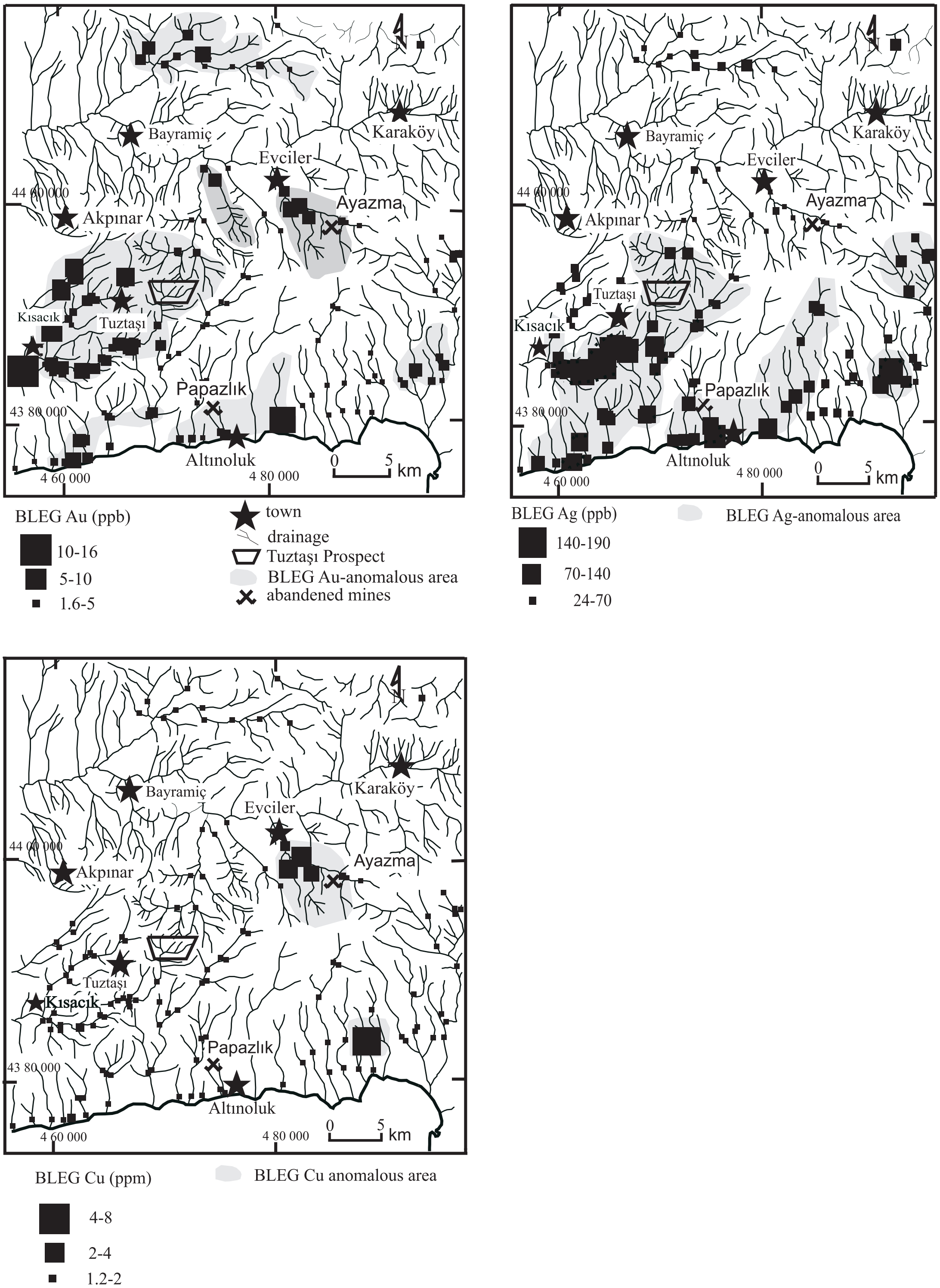

Figure 4. BLEG sample location and Au, Ag and Cu assay results from Ayvacık-Altınova-Evciler (AYALE) area.

Table 1. Statistical values for the 1.18 mm BLEG geochemical data set of the AYALE area.

Elements	Au	Ag	Cu	Au	Ag	Cu
Data	Raw			Log-transformed		
Minimum	0.1	<0,1	<0,01	-1.00	-1.00	-2.00
Maximum	15.2	185.6	8.00	1.20	2.30	0.90
Mean	1.8	25.0	0.3	0.08	1.30	-0.85
Median	1.2	18.0	0.13	0.08	1.26	0.88
Mode	0.6	10.5	0.06	0.20	1.00	-1.22
S.D	2.0	23.2	0.77	0.39	0.36	0.44
Q_1	0.4	10.0	0.07	-0.19	1.00	-1.15
Q_3	1.1	26.0	18.00	0.24	1.40	-0.74
95th percentile	4.8	63.8	0.30	0.68	1.80	-0.52
Skewness	3.0	3.0	6.60	0.14	0.95	1.10
Kurtosis	12.6	13.4	54.00	0.08	6.75	2.44
N	205	205	205	205	205	205
BG_1	1.8	25	0.30	1.20	22.00	0.14
$Threhold_1$	5.8	71	1.84	5.80	27.00	5.54
BG_2	1.2	18	0.13	1.20	19.00	0.14
$Threshold_2$	5.2	64	1.67	5.80	24.00	5.54
C	1.1	0.9	2.50	2.0	0.1	19.3

Au and Ag data in ppb. Cu data in ppm. SD– standard deviation, C– coefficient of variation Q_1 and Q_3 - first and third quartiles, N– Number of samples. Mean– background (BG_1), $Threshold_1$ - BG_1+ 2 standard deviation, Median - background (BG_2), $Threshold_2$ - BG_2+ 2 standard deviation. Detection limits - Au: 0,05 ppb, Ag: 0.1 ppb, Cu: 0,01 ppm.

exceeding 50 ppm. The location of the Au and As soil anomalies coincides well with the location of the quartz veins (Figure 7).

Discussion

Advantage and Disadvantage of Using the BLEG Method in Regional Stream Sediment Sampling

BLEG stream sediment geochemical sampling is a time and cost-efficient method in assessing large areas of rugged terrain (1350 km^2 in this case). This is particularly evident when comparing the collection of 205 BLEG samples during a 17 day period with the collection of 1350 180-μm stream samples which may take 3 months from the same area. Average sampling density achieved was one sample per 10 km^2 (Yılmaz 2003), compared to one sample per 5 km^2 in areas underlain by carbonate rocks, which provides alkaline water and tends to reduce base metal solubility, thereby shortening anomalous dispersion trails (Wilhelm & Artignan 1994). The BLEG leach is only partial for coarse-gold particles. The BLEG method suppresses the 'nugget' effect to the extent that any coarse gold present in the sample is only partially affected (Mazzucchelli 1994). Bulk cyanide leaching of large samples (2 kg) overcomes the problem that fine-gold flakes that are distributed heterogeneously within the sample (Yılmaz 2003). Therefore, the bigger the analytical sub-sample (with respect to eroded material) the better it is (Radford 1996). The method has the attraction of being a relatively cheap regional sampling technique with a good sensitivity as well (Wood *et al.* 1990).

BLEG technique has also defects. It makes no allowance for dilution by variable quantities of windblown loess or barren quartz, which are features of the drainage systems of arid terrains as in Australia, as well as chemistry of the cyanide extraction being sensitive to variations in clay mineralogy and organic matter (Mazzucchelli 1994). Temperate climatic condition prevails in the study area and therefore, no dilution factor from wind-blown loess may suppress the BLEG results. Carbonaceous material is capable of removing gold from the pregnant cyanide solution prior to treatment with zinc powder thus leading to low values. However, pre-conditioning or oxidation of the sample, with strong hypochlorite substantially reduces the activity of organic matter, thereby preventing the absorbtion of gold-cyanide complex by organic matter (Mazzucchelli 1990).

Table 2. Statistical values for the 180-μm stream sediment geochemical data set of the AYALE area.

Elements	Au	Ag	Cu	Pb	Zn	As	Sb	Au	Ag	Cu	Pb	Zn	As	Sb
Data	Raw							Log10-trransformed						
Minimum	<1	<0,5	<1	<1	<9	<1	<1	0.0	-0.30	0.00	0.00	0.95	0.0	0.0
Maximum	280	14.00	130	1280	1250	253	121	2.4	1.14	2.11	3.11	3.10	2.4	2.1
Mean	5	1.26	25	26	77	21	10	0.3	-0.30	1.16	1.22	1.84	1.1	0.6
Median	1	0.50	21	21	69	13	8	0.0	-0.30	1.32	1.32	1.84	1.1	0.7
Mode	1	0.50	1	1	49	1	1	0.0	-0.30	0.00	0.00	1.69	0.8	0.5
S.D	16	1.86	22	56	60	25	10	0.5	0.40	0.57	0.44	0.19	0.5	0.5
Q_1	1	0.50	10	14	54	6	1	0.0	-0.30	1.00	1.15	1.73	0.8	0.0
Q_3	2	0.50	35	28	88	28	9	0.3	-0.30	1.55	1.45	1.95	1.4	1.0
95^{th} percentile	23	5.00	70	54	133	65	18	1.4	-0.30	1.85	1.73	2.12	1.8	1.3
Skewness	10	3.00	1	19	13	3	7	1.8	0.70	1.00	1.18	0.48	0.5	-0.1
Kurtosis	154	10.00	3	420	248	20	93	2.4	3.80	0.03	2.53	4.75	0.1	-1.3
N	585	585	585	585	585	585	585	585	585	585	585	585	585	585
BG_1	5	1.26	25	26	77	21	10	2.0	0.90	14	16	69	13	4
$Threshold_1$	37	5.00	69	138	197	71	30	10	4.30	22	22	71	19	10
BG_2	1	0.50	21	21	69	13	8	0.0	0.90	20	20	68	13	5
$Threshold_2$	33	3.72	65	133	189	63	28	6.0	4.30	28	26	72	19	8
C	3.2	1.5	0.9	2.1	0.8	25.2	1.0	2.0	2.80	0.3	0.2	0.0	0.3	0.8

Ag, Cu, Pb, Zn, As and Sb data in ppm; data for Au in ppb, SD– standard deviation, C– coefficient of variation, Q_1 and Q_3– first and third quartiles, N– number of samples. Mean: Background (BG_1), $Threshold_1$: BG_1 + 2 standard deviaton. Median: Background (BG_2), $Threshold_2$: BG_2 + 2 standard deviation. Detection limits: Au: 1 ppb, Ag: 0.5 ppm, Cu: 1 ppm, Pb: 1ppm, Zn: 1ppm, As: 1 ppm, Sb: 1ppm

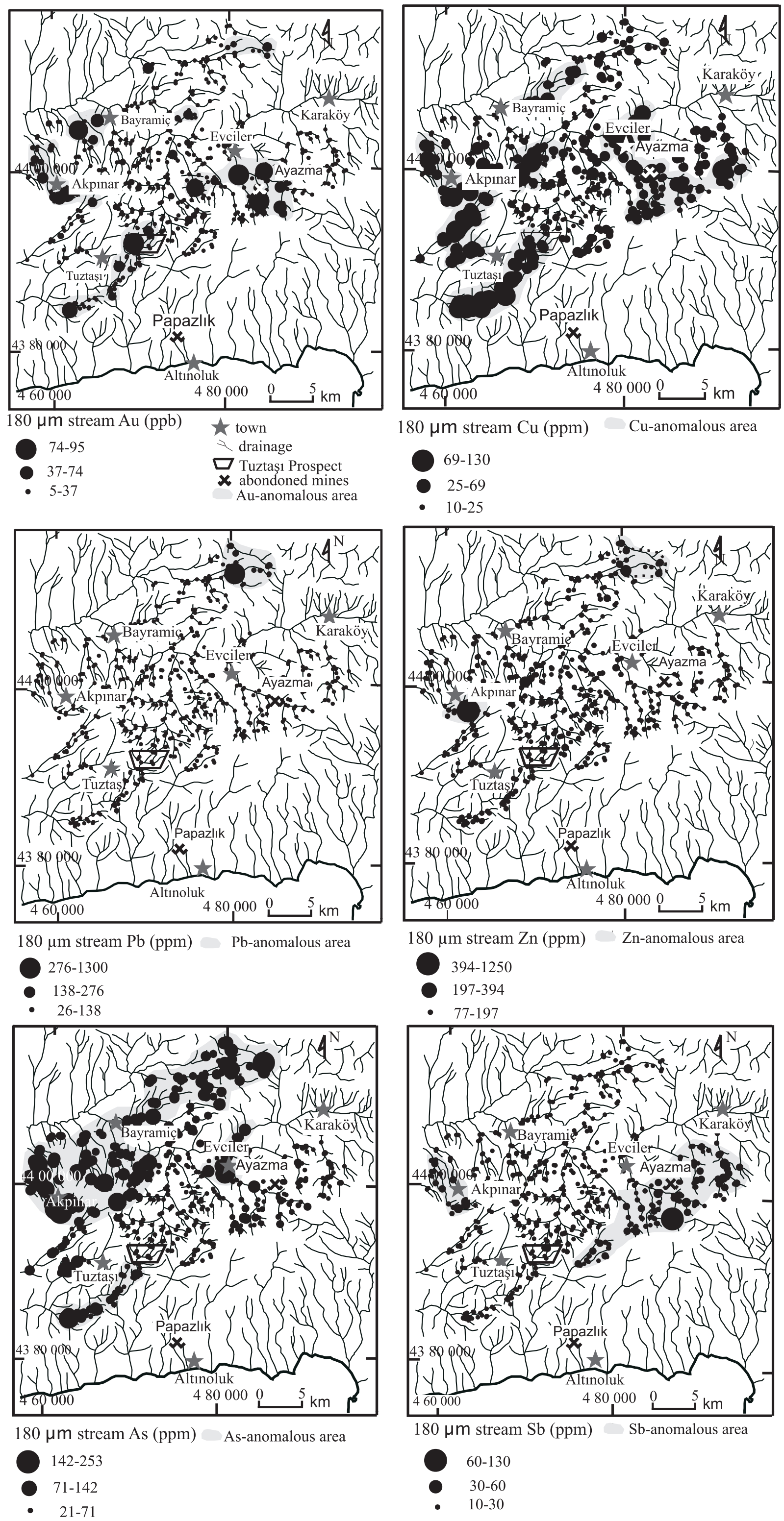

Figure 5. Stream sediment geochemistry of Au, Cu, Pb, Zn, As, Sb at the AYALE area.

Table 3. Statistical values for the rockchip geochemical data set of the AYALE area.

Elements	Au	Ag	Cu	Pb	Zn	As	Sb	Mo	W	Bi	Tl	Au	Ag	Cu	Pb	Zn	As	Sb	Mo	W	Bi	Tl
Data	Raw											Log10-trransformed										
Minimum	<1	<0,5	<1	<1	<1	<1	<1	<1	<1	<1	<1	0.00	-0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	5400	130.00	23000	57000	46000	11200	2791	8	737	303	29	3.73	2.10	4.36	4.76	4.66	4.05	3.45	1.66	3.42	2.48	1.46
Mean	315	7.00	397	863	737	325	50	2	14	16	5	1.19	0.06	1.6	1.18	1.47	1.87	0.9	0.25	0.37	0.55	0.46
Median	12	0.50	20	11	21	80	8	1	1	1	1	1.08	-0.30	1.30	1.04	1.32	1.90	0.90	0.00	0.00	0.00	0.00
Mode	1	0.50	17	1	1	1	1	1	1	1	1	0.00	-0.30	1.23	0.06	1.04	0.00	0.00	0.00	0.00	0.00	0.00
S.D	754	18.00	1927	5789	5029	888	258	2	81	39	6	1.19	0.67	0.72	0.91	0.71	0.80	0.76	0.40	0.64	0.60	0.41
Q_1	1	0.50	13	6	12	23	1	1	1	1	1	0.00	-0.30	1.11	0.74	1.08	1.36	0.00	1.00	0.00	0.00	0.00
Q_3	115	1.00	39	40	44	285	25	4	5	11	3	2.06	0.01	1.60	1.60	1.65	2.45	1.39	0.55	0.69	1.03	0.42
95^{th} percentile	1915	39.00	1608	482	1076	1834	124	8	32	30	14	3.28	1.59	3.21	2.68	3.03	3.26	2.09	0.90	1.51	1.47	1.13
Skewness	3	4.00	8	8	8	9	10	5	8	7	2	0.50	1.63	1.64	1.19	1.97	-0.22	0.46	1.43	2.32	1.01	1.40
Kurtosis	14	17.00	84	66	62	96	106	27	69	55	18	-1.40	1.23	3.74	2.63	6.12	-0.08	-0.31	1.26	6.48	0.02	0.68
N	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240
BG_1	315	7.00	397	863	737	325	50	2	14	16	5	16.0	0.06	1.60	1.18	1.47	1.87	0.89	0.25	0.37	0.55	0.46
$Threshold_1$	1823	43.00	4251	12441	10792	2101	566	6	176	94	17	48.0	11.00	53.0	32.0	41.0	91.0	20.0	8.0	13.0	11.0	9.0
BG_2	12	0.50	20	11	21	80	8	1	1	1	1	12.0	0.0	20.0	11.0	21.0	80.0	8.0	1.0	1.0	1.0	1.0
$Threshold_2$	1520	37.00	3874	11589	10079	1856	596	5	163	79	13	44.0	10.0	30.0	32.0	41.0	91.0	20.0	7.0	11.0	9.0	7.0
C	2.4	2.60	5	7	7	3	5	1	5.7	2.4	1	1.0	4.5	0.2	0.2	0.2	0.0	0.9	1.5	1.5	1.0	1.0

Ag, Cu, Pb, Zn, As, Sb, Mo, Cd, W, Bi and S data in ppm; data for Au in ppb. SD– standard deviation, C– coefficient of variation, Q_1 and Q_3: first and third quartiles N– number of samples. Mean– background (BG_1), $Threshold_1$– BG_1 + 2 standard deviation. Median: background (BG_1), Threshold1: BG_1+ 2 standard deviation. Detection limits: Au: 1 ppb, Ag: 0,5 ppm, Cu. 1ppm, Pb: 1 ppm Zn: 1 ppm, As: 1ppm, Sb: 1 ppm, Mo: 1 ppm, W: 1ppm, Bi: 1ppm.

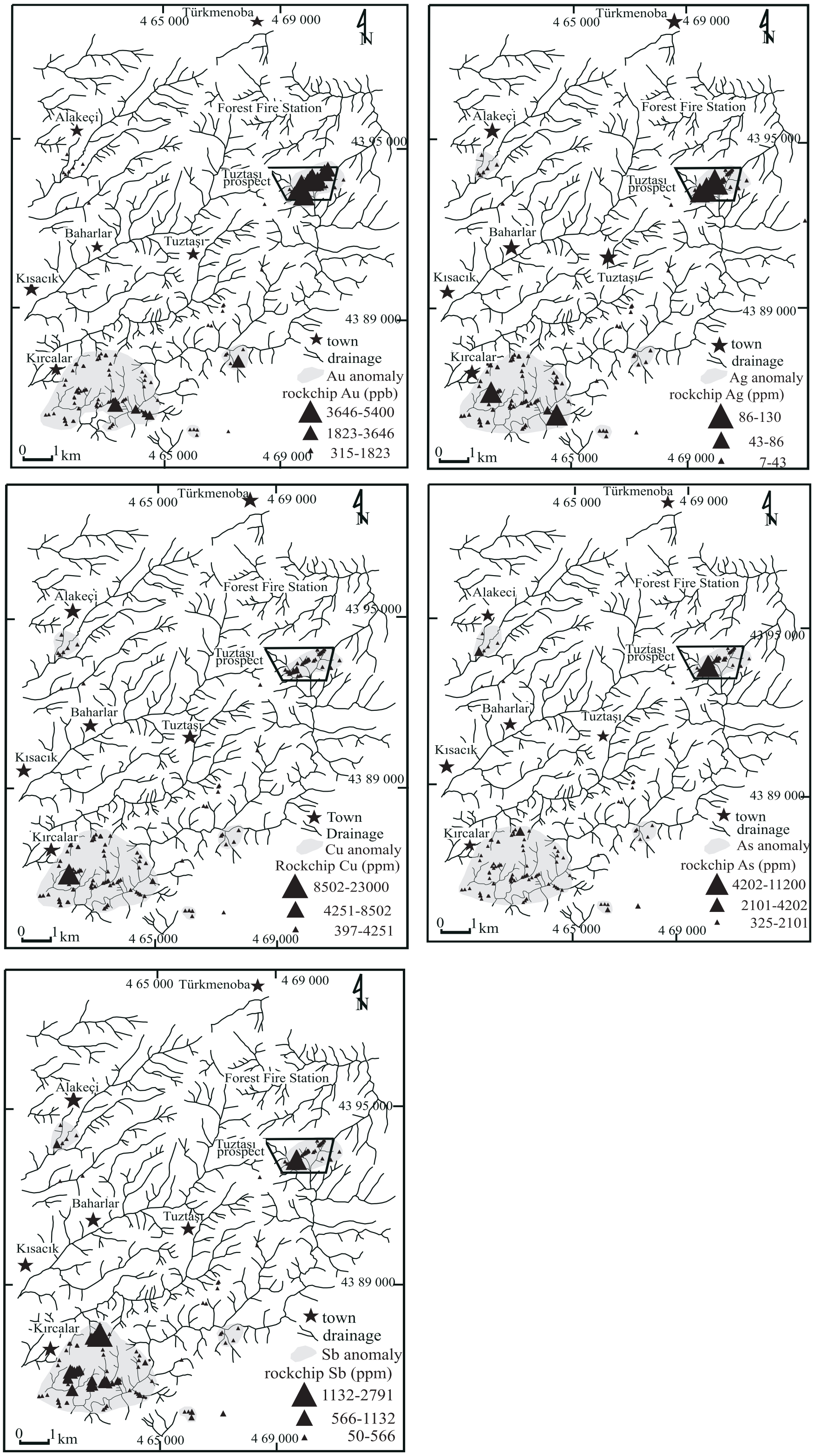

Figure 6. Rock chip geochemistry of Au, Ag, Cu, As and Sb at the Tuztaşı area.

Table 4. Statistical values for the 180-µm soil geochemical data set of the AYALE area.

Elements	Au	Ag	Cu	Pb	Zn	As	Sb	Mo	W	Bi	S	Au	Ag	Cu	Pb	Zn	As	Sb	Mo	W	Bi	S
Data	Raw											Log10-trransformed										
Minimum	<1	<0,5	<1	<1	<1	<1	<1	<1	<1	<1	17	0.00	-0.30	0.00	0.00	1.04	0.00	0.00	0.00	0.00	0.00	1.20
Maximum	2100	20	435	949	418	521	2029	10	34	13	1617	3.32	1.31	2.64	2.98	2.62	2.72	3.31	1.01	1.53	1.11	3.21
Mean	42	0.60	50	21	94	27	20	3	3	2	188	0.62	-0.29	1.62	1.15	1.92	1.13	0.94	0.39	0.21	0.14	2.21
Median	1	0.50	41	17	83	15	11	2	1	1	160	0.00	-0.30	1.61	1.22	1.92	1.18	1.04	0.37	0.00	0.00	2.20
Mode	1	0.50	37	1	70	1	1	1	1	1	172	0.00	-0.30	1.56	0.00	2.07	0.00	0.00	0.00	0.00	0.00	0.00
S.D	166	1.00	40	44	47	44	108	0.4	4	1	133	0.82	0.12	0.26	0.38	0.21	0.54	0.47	0.37	0.37	0.30	0.23
Q_1	1	0.50	30	10	65	9	5	1	1	1	114	0.00	-0.03	1.48	0.99	1.81	0.93	1.00	0.00	0.00	0.00	2.06
Q_3	16	0.50	58	24	116	25	18	6	2	1	223	1.20	-0.30	1.76	1.37	2.06	1.39	2.39	0.77	0.38	0.00	2.35
95^{th} percentile	178	0.50	103	41	184	104	29	8	10	7	369	2.25	-0.30	2.01	1.61	2.26	2.02	1.47	0.89	1.00	0.84	2.57
Skewness	8	15	5	18	2	5	17	0.5	3.2	2.4	4.5	1.09	11.50	-0.22	-0.85	-0.14	-0.58	-0.22	0.13	1.46	1.76	0.38
Kurtosis	75	234.00	35	380	7.2	43	285	-1.2	15	5.3	33	0.14	137	4.00	2.73	0.72	1.20	1.75	-1.77	0.70	1.42	1.62
N	533	533	533	533	533	533	533	533	533	533	533	533	533	533	533	533	533	533	533	533	533	533
BG_1	42	0.60	50	21	94	27	20	3	3	2	188	4.0	0.0	43.0	15.0	82.0	12.0	9.0	3.0	1.0	1.4	165.0
$Threhold_1$	374	2.60	130	109	188	115	236	3.8	11	4	454	16.0	0.0	45.0	21.0	84.0	18.0	15.0	9.0	7.0	5.4	167.0
BG_2	1	0.50	41	17	83	15	11	2	1	1	160	1.00	0.5	43.0	17.0	83.0	16.0	9.0	2.0	1.0	1.0	165.0
$Threshold_2$	337	2.50	121	105	177	103	227	2.8	9	3	426	13.0	2.0	45.0	23.0	85.0	22.0	17.0	8.0	7.0	5.0	2.7
C	3.9	1.70	0.8	2.1	0.5	1.6	5.4	0.1	1.3	0.5	0.7	1.50	0.00	0.00	0.20	0.00	0.30	0.20	1.00	1.50	2.00	0.00

Ag, Cu, Pb, Zn, As, Sb, Mo, Cd, W, Bi and S data in ppm; data for Au in ppb. SD– standard deviation, C– coefficient of variation, Q_1 and Q_3: first and third quartiles. N– number of samples. Mean– background (BG_1), $Threshold_1$– BG_1 + 2 standard deviation. Median– background (BG_2), $Threshold_1$– BG_2 + 2 standard deviation. Detection limits: Au: 1 ppb, Ag: 0,5 ppm, Cu. 1ppm, Pb: 1 ppm Zn: 1 ppm, As: 1ppm, Sb: 1 ppm, Mo: 1 ppm, W: 1ppm, Bi: 1ppm.

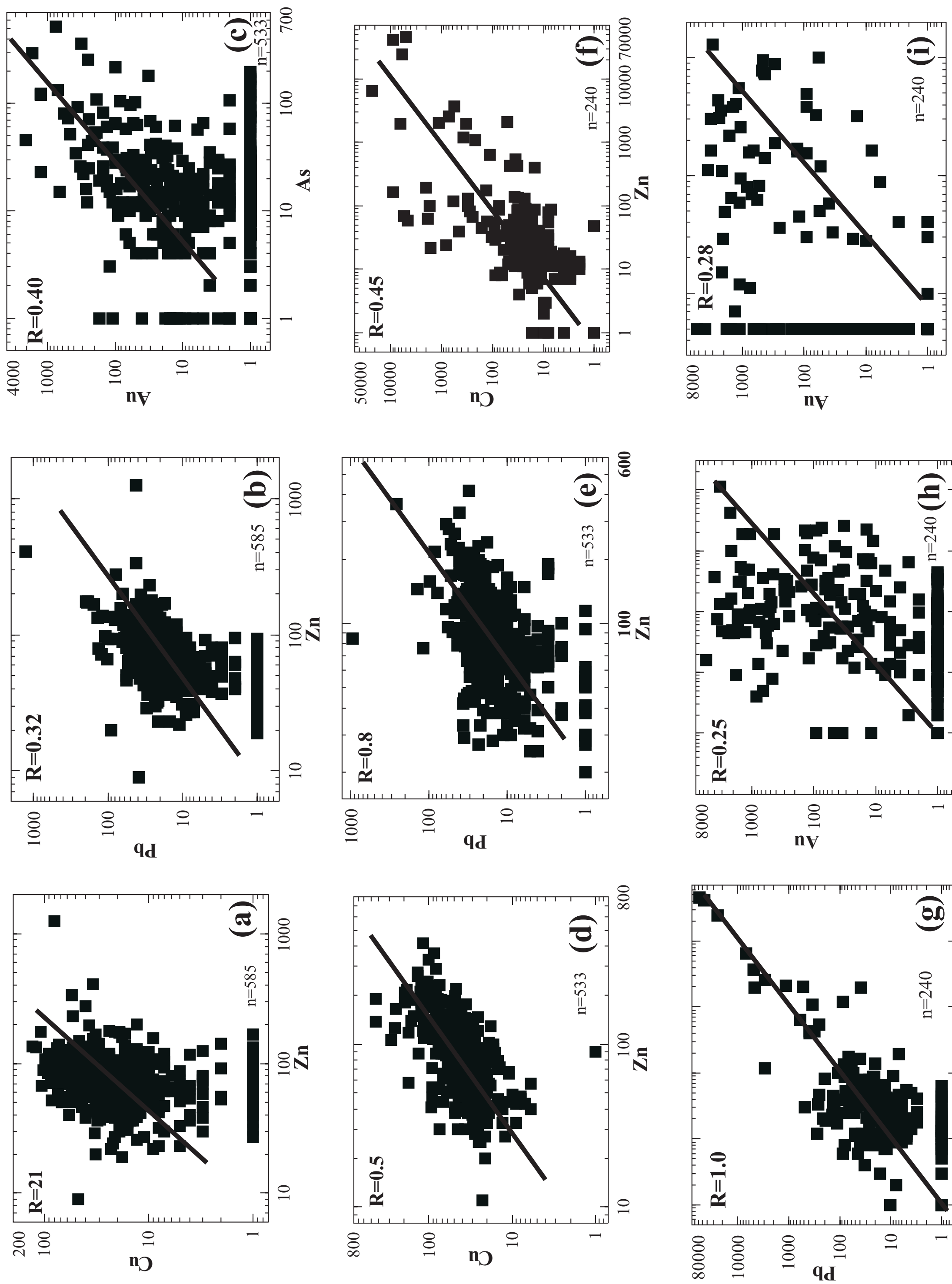

Figure 7. Log-Log concentrations of: (a) Cu versus Zn and (b) Pb versus Zn in 180-µm stream sediment; (c) Au versus As, (d) Cu versus Zn and (e) Pb versus Zn in 180-µm soil; (f) Cu versus Zn, (g) Pb versus Zn, (h) Au versus As and (i) Au versus Ag in rock chip at the AYALE area.

Discussion of Results

Arsenic exhibits a nearly universal enrichment in most types of hypogene gold deposits (Boyle 1979). Gold-bearing polymetallic deposits and certain skarns are invariably enriched in arsenic, as are the typical quartz veins at Fortitude Mine in Nevada, USA. In these types of deposit the arsenic content ranges from a few tens of parts per million to percentage amounts in the ore. Because the gold is so intimately associated with arsenopyrite- and arsenic-bearing sulfosalts in some deposits the element appears to be a lattice constituent of these minerals. The disseminated gold deposits of north central Nevada are all enriched in arsenic (Berger & Bethke 1984). However, the element is not only bound in As minerals and As-bearing pyrite, which are commonly associated with Au mineralization (Yang & Blum 1999), but also forms widespread geochemical haloes around Au deposits, so that the element is commonly used as a pathfinder in noble metal exploration. In the northwestern part of Hunan Province (China) many Au–Sb (or Au–W) deposits occur in low-grade metamorphic rocks of Neoproterozoic age. Here, arsenopyrite is the only As-bearing mineral, occurring in minor quantities. Arsenic concentrations in these slate belt deposits range from 0.10 to 2.36 wt% (mainly between 0.4 and 1.0%). However, As has never been considered as pathfinder for Au-exploration in the earlier work (Yang & Blum 1999). A similar geochemical signature to that of northwestern Hunan is recognized in low-grade metamorphic rocks of western Turkey (Yılmaz 2003). Mesothermal gold mineralization closely associated with As is widespread in Upper Mesozoic metagreywackes deposited in a collisional setting in the Southern Alps of New Zealand (Craw 2001). Arsenic is present in solid solution in many of the sulfides, and in accessory As minerals in mesothermal deposits (Craw 2001). It is readily mobilized from these deposits at neutral to alkaline pH. In contrast to As behavior, Cu, Pb, Zn and Cd are dissolved and passed into soil under highly acidic conditions. Arsenic is most stable in an oxidizing environment, being a constituent of basic sulfate arsenates. Oxidation of native As, arsenopyrite and various other arsenides and sulfarsenides yields a variety of supergene arsenates and basic arsenate-sulfates, the most common being scorodite, $Fe(AsO_4).H_2O$, and Co-, Ni-, Pb-, Zn-, and Cu-arsenates (Boyle 1979). Of these, the most important in gold deposits is scorodite; the others occur only where there are high contents of Ni, Co, Cu, Pb or Zn. All these minerals, in particular scorodite, tend to concentrate gold (Boyle 1979). Oxidation of primary As minerals yield arsenic acid H_3AsO_4. In these forms, arsenic is relatively mobile, and under certain conditions considerable amounts of the element may be removed from the deposits during oxidation.

Under oxidizing conditions, and in the presence of iron, inorganic arsenic species are predominantly retained in the solid phase through interaction with iron oxy-hydroxide coatings on soil particles (Bose & Sharma 2002). These authors described several types of interactions, i.e., adsorption on amorphous iron hydroxide and adsorption on ferrihydrite and co-precipitation of arsenic (III) and arsenic (V) with iron oxy-hydroxide occurring in an oxidizing environment.

No linear correlation occurs between Au and Ag, As, Sb, Cu, Pb, Zn in BLEG and 180-μm stream sediment geochemical and rock chip data (Table 5a & b; Figure 7) from the AYALE area. The critical value for t with 238 degrees of freedom and 10% level of significance is t= 1.645. Because most of the test statistics fall into upper critical region, it is concluded that there are true correlations ($r > 0.1$) between the element variables particularly in the rock chip (Table 5b) data set (Davis 1986). Nevertheless, weak correlations occur between Cu-Zn and Pb-Zn in 180-μm (Figure 7). All these may be caused by different dissolution and transport characteristics of these metals in secondary environment as well as their emplacement into the host rock at different levels and phases (Boyle 1979; Craw 2001; Bose & Sharma 2002). On the other hand, very weak correlations between Au and Ag and As in rocks (Table 5a & b; Figure 7), as in 180-μm stream-sediment samples, at AYALE suggests that they may be related to different mineralizing events, thereby indicating possible introduction of Au, Ag and As in three different phases of mineralization within the same structural zone. Although not always, anomalous gold zones are usually accompanied by anomalous As zones (Figure 5). Relatively higher correlations occurring between Cu and Pb, Zn; Pb and W; Zn and Sb, W and, Mo and W (Table 5a & b; Figure 6) in the same mineralized rock-chip samples may also indicate two distinct phases of mineralization at least two different times because these elements would be expected to be found associated within

Table 5. Matrix of correlations between measured variables for Tuztaşı prospect rock chip data set (a) and calculation of *t* values (b) using the corresponding correlation coefficiecients in (a).

Var*	Au	Ag	Cu	Pb	Zn	As	Sb	Mo	W	Bi
Tl	-0.09	0.05	0.36	0.06	0.07	-0.01	-0.02	0.12	0.01	0.22
Bi	0.21	0.01	0.20	0.07	0.05	0.07	-0.01	0.05	0.02	
W	-0.04	0.22	0.37	**0.97**	**0.96**	0.18	**0.61**	0.39		
Mo	0.01	0.33	0.18	0.32	0.34	0.05	**0.56**			
Sb	-0.02	0.11	0.29	**0.57**	**0.60**	0.31				
As	0.25	0.13	0.07	0.19	0.18					(a)
Zn	-0.04	0.27	0.45	**1.00**						
Pb	-0.04	0.27	0.44							
Cu	0.05	0.18								
Ag	0.28									
Var**	**Au**	**Ag**	**Cu**	**Pb**	**Zn**	**As**	**Sb**	**Mo**	**W**	**Bi**
Tl	-1.39	0.77	**5.95**	0.93	1.08	-0.15	-0.31	**1.86**	0.15	**3.48**
Bi	**3.31**	0.15	**3.15**	1.08	0.77	1.08	-0.15	0.77	0.31	
W	-0.62	**3.48**	**6.14**	**61.56**	**52.89**	**2.82**	**11.88**	**6.53**		
Mo	0.15	**5.39**	**2.82**	**5.21**	**5.58**	0.77	**10.43**			
Sb	-0.31	**1.71**	**4.67**	**10.70**	**11.57**	**5.03**				
As	**3.98**	**2.02**	1.08	**2.99**	**2.82**					(b)
Zn	-0.62	**4.33**	**7.77**	**1090.79**						
Pb	-0.62	**4.33**	**7.56**							
Cu	0.77	**2.82**								
Ag	**4.50**									

Var* - variable; high-lighted values refer to relatively higher correlations between elements, n= 238.
Var** - variable; critical value *t*= 1,645 for 238 samples. High-lighted values suggest that there is a real correlation between variables.

intrusive-centred porphyry or skarn systems. The presence of weak to moderate correlations between Cu and Pb, Zn as well as W and Pb, Zn, Sb, Mo in rock-chip samples may suggest that 180-μm stream-sediment samples should also be analyzed for Mo and W during further exploration in the AYALE area. Elements commonly found enriched in mesothermal lode gold deposits in metamorphic terrains include Au, Ag, As, Sb, Hg, W, Bi and Mo (Pirajno 1992). Less commonly, Pb, Zn and Cu may be present. Therefore, the AYALE area, more specifically the Tuztaşı area, may be a significant target for some of the above-mentioned mineralization hosted by metamorphic rocks.

Much of the arsenic in the Tuztaşı area might have been co-precipitated and/or adsorbed by hydrous iron and other oxides or have reacted with cations such as Fe and Cu to give a variety of insoluble arsenates during various hydrolytic and colloidal reactions in oxidized zones as suggested by Boyle (1979), Craw (2001) and Bose & Sharma (2002) elsewhere. These reactions take place mainly between pH from 4 to 7 (Bose & Sharma 2002), and this may also be so in the Tuztaşı area where some of the illite and chlorite formed possibly by weathering indicate weakly acidic to neutral conditions. The wall rocks and gangue also contain abundant carbonate minerals such as calcite to neutralize the downward moving solutions. Arsenic concentration is variable and clearly not exclusively related to Au enrichment except for their coexistence within the same structure (Table 6a & b; Figures 5–7). A similar situation exists for the silver as well. Positive correlation coefficients between Au and Ag and, Au and As, are weak to moderate (r< 0.5) in the180-μm in soil data set. The critical value for t with 531 (samples) degrees of freedom and 10% level of significance is *t*= 1.645. It is concluded that there are true correlations (r > 0.1) between the significant numbers of element variables within the soil (Table 6b) data set (Davis 1986). These metal associations can only be encountered in epithermal and to a certain extent in mesothermal precious metal deposits. A close association of Au with As and Ag in soil as well as a very close association of W with Sb, Pb, Zn and Mo in rock chip samples indicate two distinct geochemical signatures that are possibly related to the epi- to meso-thermal precious and base metal skarn mineralization systems in the AYALE area.

Table 6. Matrix of correlations between measured variables for Tuztaşı prospect soil data set (a) and calculation of *t* values (b) using the corresponding correlation coefficiecients in (a).

Var*	Au	Ag	Cu	Pb	Zn	As	Sb	Mo	W	Bi
S	0.00	0.05	0.23	0.08	**0.44**	0.24	-0.04	-0.36	-0.07	-0.20
Bi	0.15	-0.03	0.07	-0.03	-0.04	-0.01	-0.01	**0.45**	0.04	
W	0.01	-0.04	0.05	0.01	0.06	-0.08	0.05	-0.02		
Mo	0.15	0.09	0.06	-0.03	-0.13	-0.10	0.13			
Sb	0.03	0.01	0.02	-0.02	-0.03	-0.01				
As	**0.40**	0.11	0.08	0.08	0.07					(a)
Zn	-0.02	0.01	**0.51**	0.18						
Pb	0.05	0.02	0.05							
Cu	0.08	0.02								
Ag	**0.43**									
Var**	**Au**	**Ag**	**Cu**	**Pb**	**Zn**	**As**	**Sb**	**Mo**	**W**	**Bi**
S	0.00	1.15	**5.44**	**1.85**	**11.27**	**5.69**	-0.92	**-8.88**	**-1.61**	**-4.69**
Bi	**3.49**	-0.69	**1.61**	-0.69	-0.92	-0.23	-0.23	**11.59**	0.92	
W	0.23	-0.92	1.15	0.23	1.38	**-1.85**	1.15	-0.46		
Mo	**3.49**	**2.08**	1.38	-0.69	**-3.02**	**-2.31**	**3.02**			
Sb	0.69	0.23	0.46	-0.46	-0.69	-0.23				
As	**10.04**	**2.55**	**1.85**	**1.85**	**1.61**					(b)
Zn	-0.46	0.23	**13.64**	**4.21**						
Pb	1.15	0.46	1.15							
Cu	**1.85**	0.46								
Ag	**10.95**									

Var* - variable; high-lighted value refer to relatively higher correlations between elements, n= 531.
Var** - variable; Critical value *t*= 1,645 for 531 samples. High-lighted values suggest that there is a real correlation between vaiables.

Although the Akpınar-Evciler south area stretching from Tuztaşı to Karaköy hosts gold-Ag-As-rich quartz veins/breccia zones, a major, coherent 180-μm stream sediment As anomaly appears to be confined to a structural divide, where Upper Cretaceous–Palaeocene mélange, Upper Oligocene granitoids and Miocene volcanic rocks, overlie the exposed metamorphic core. This may be caused by the erosion of possible As-bearing high-level mineralization zones during exhumation of the metamorphic rocks from ~14-km to ~7-km along a northward-dipping ductile shear zone (Figures 1, 2 & 5; Okay *et al.* 1991; Okay & Satır 2000).

BLEG, 180-μm stream-sediment and soil sampling techniques appear to be an effective reconnaissance tool in the AYALE area in west Turkey. The persistence of 180-μm Au anomalies for less than 1000 m downstream from the Tuztaşı Prospect (from 90 ppb to 7 ppb) suggests that 180-μm stream-sediment sampling is not as efficient as BLEG on <1.2 mm in locating Au and Ag anomalies and associated mineralization in regional-scale surveying because the BLEG anomalies are detectable as far as 6 km downstream from the Tuztaşı Prospect.

Silver in BLEG samples is a very useful indicator element at regional-scale exploration although ICP data obtained from commercial laboratories generally has too high a detection limit for more subtle anomalies such as in the Tuztaşı area. The persistence of BLEG-Ag anomalies over a distance of 9 km downstream from the source area (Tuztaşı Prospect) suggests that the BLEG stream-sediment sampling is highly efficient in locating Ag (>212 ppb) anomalies.

At the initial stage of regional reconnaissance, BLEG anomalies indicated that Ag in the Tuztaşı area might occur as electrum or sulfosalts (log-transformed Ag/Au: 4.6). This was further supported by high Ag contents (130 ppm) and log-transformed Ag/Au ratios (3). Arsenic-Sb and Ag are the most reliable pathfinder elements for Au in the study area.

Conclusions

BLEG stream sediment geochemical sampling is a time- and cost-efficient method in assessing large areas of rugged terrains (1350 km^2 in this case). The re-discovery

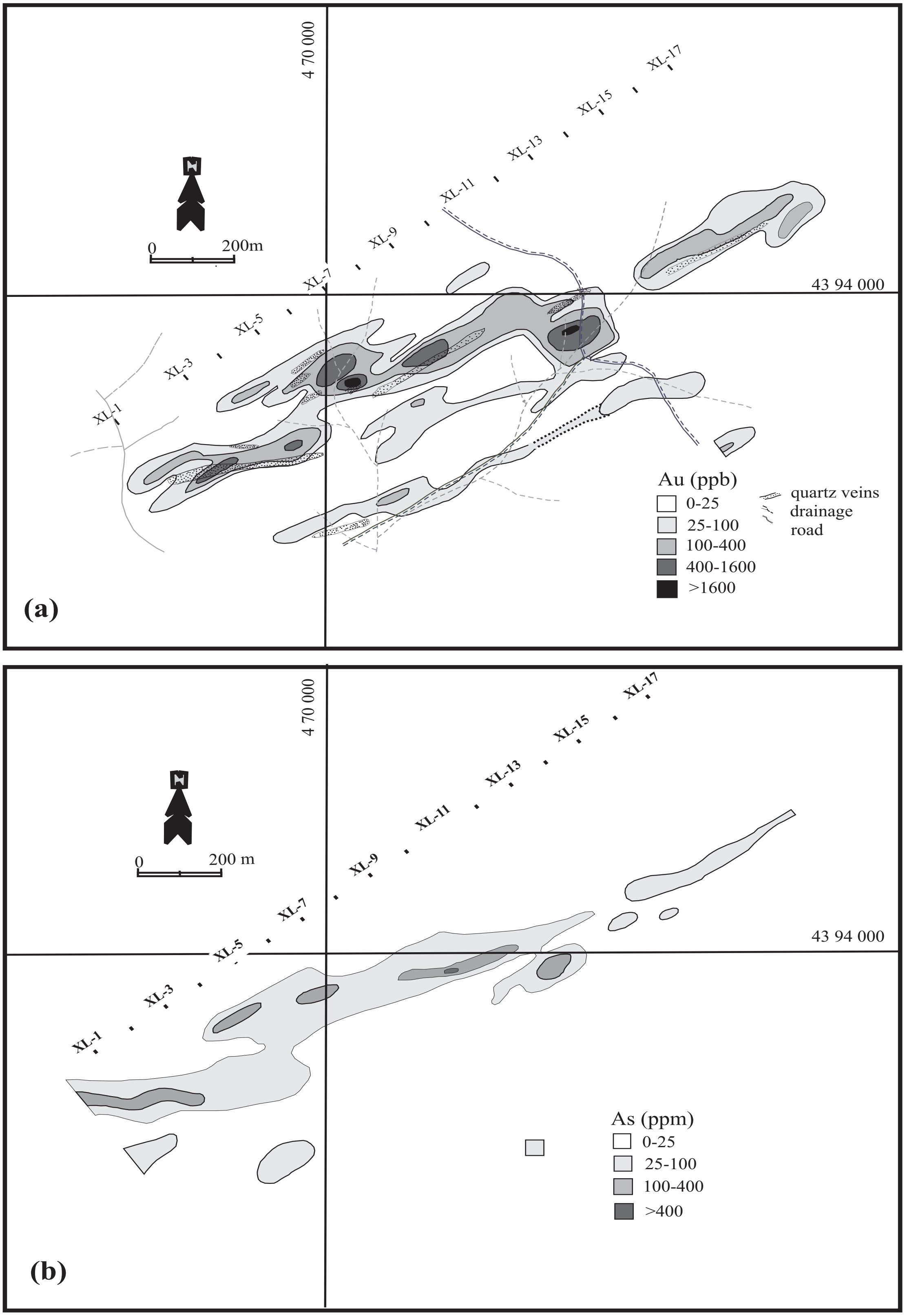

Figure 8. Distribution of (a) Au and (b) As in 180-μm soil at the Tuztaşı Prospect.

of the Tuztaşı prospect during the follow up of an already delineated BLEG anomaly is an exploration success using 180-µm stream sediment and soil geochemistry. Moreover, the BLEG sampling technique proved to be a very sensitive exploration tool even in discovering small-scale mineralization in areas with well-developed drainage as in the Tuztaşı area. Identification and sampling of altered and mineralized rock float in streams was critical in ranking the regional geochemical results. Soil sampling effectively delineated Au and As geochemical zonings. The BLEG geochemical technique should not be used in isolation and should be accompanied by a compilation study of recent, old and ancient workings, and known mineralization since the Tuztaşı deposit had been mined on a small-scale mine during ancient times. Two distinct 180-µm Au and As geochemical signatures in the Tuztaşı area appear to be confined to medium- to high-grade metamorphic rocks forming the footwall and crustal hanging-wall accretionary mélange of a major detachment fault, respectively.

Acknowledgement

I would like to express my appreciation to Eurogold Madencilik/Normandy Mining Ltd., Turkey for generous financial support to the project during my tenure as Eurogold Exploration Manager. Reviewers Robert B. Cook and anonymous are thanked for their invaluable comments in improving the quality of this paper. John A. Winchester helped with English of the final text.

References

ALDANMAZ, E. 2006. Mineral-chemical constraints on the Miocene calc-alkaline and shoshonitic volcanic rocks of western Turkey: disequilibrium phenocryst assemblages as indicators of magma storage and mixing conditions. *Turkish Journal of Earth Sciences* **15**, 47–73.

AYDAL, D., VURAL, A. & POLAT, O. 2004. Definition the base metal- and gold-bearing hydrothermally-altered areas in volcanic rocks using Landsat 7 Tm imagery: case study from Bayramiç (Çanakkale). 57th *Geological Congress of Turkey, Ankara, Abstracts,* p. 90.

BECCALETTO, L. & JENNY, C. 2004. Geology and correlation of the Ezine Zone: A Rhodope fragment in NW Turkey. *Turkish Journal of Earth Sciences* **13**, 145–176.

BECCALETTO, L. & STENER C. 2005. Evidences of two-stage extensional tectonics from the northern edge of the Edremit Graben, NW Turkey. *Geodinamica Acta* **18/3**, 225–239.

BEESON, R. 1995. A drainage sediment geochemical orientation study at Boddington, Western Australia. *Journal of Geochemical Exploration* **54**, 63–71.

BERGER, B.G. & BETHKE, P.M. 1984. Geology and geochemistry of epithermal systems. *Reviews in Economic Geology* **2**, 169–202.

BEUS, A.A. & GRIGORIAN, S.V. 1977. *Geochemical Exploration Methods for Mineral Deposits.* Applied Publishing Ltd., Illinois, USA.

BİNGÖL, E. 1969. Geology of the central and southeastern parts of the Kazdağ Massif. *Maden Tetkik ve Arama (MTA) Dergisi* **72**, 110–23 [in Turkish with English abstract].

BOSE, P. & SHARMA, A. 2002. Role of iron in controlling speciation and mobilization of arsenic in subsurface environment. *Water Researches* **36**, 4916–4926.

BOYLE, R.W. 1979. The geochemistry of gold and its deposits. *Bulletin Geological Survey Canada* **280**, 1–584.

COHEN, D.R., DUNLOP, A.C. & ROSE, T. 2005. Contrasting dispersion patterns for gold in stream sediments in Timbarra, NSW, Australia. *Journal of Geochemical Exploration* **85**, 1–16.

CRAW, D. 2001. Tectonic controls on gold deposits and their environmental impact, New Zealand. *Journal of Geochemical Exploration* **73**, 43–56.

DAVIS, J.C. 1986. *Statistics and Data Analysis in Geology.* John Willey & Sons, New York, USA.

DELALOYE, M. & BİNGÖL, E. 2000. Granitoids from western and northern Anatolia: Geochemistry and modeling of geodynamic evolution. *International Geological Review* **42**, 241–268.

DURU, M., PEHLİVAN, Ş., ŞENTÜRK, Y., YAVAŞ, F. & KAR, H. 2004. New results on the lithostratigraphy of the Kazdağ Massif in Northwest Turkey. *Turkish Journal of Earth Sciences* **13**, 177–186.

ELIOT, S.M. & TOWSY, C.A. 1989. *Regional Drainage Geochemical Exploration Techniques Used in Queensland, Australia. North Queensland Gold '89 Conference, Townsville, Australia, IMM Publication*, 51–61.

ERCAN, T., TÜRKECAN, A., AKYÜREK, B., GÜNAY, E., CEVİKBAŞ, A., ATEŞ, M., CAN, B., ERKAN, M. & ÖZKİRİŞÇİ, E. 1984. The geology of Dikili-Bergama-Çandarlı area (Western Anatolia) and petrology of the magmatic rocks. *Jeoloji Mühendisliği Dergisi* **20**, 47–60 [in Turkish with English abstract].

ERCAN, T., SATIR, M., STEINITZ, G., DORA, A., SARIFAKOĞLU, E., ADIS, C., WALTER, H.J., YILDIRIM, T. 1995. Biga yarımadası ile Gökçeada, Bozcaada ve Tavşan adalarındaki (KB Anadolu) Tersiyer volkanizmasının özellikleri [The characteristics of Tertiary volcanism in Biga Peninsula, Gökçeada, Bozcaada and Tavşan islands (NW Anatolia)]. *Maden Tetkik ve Arama (MTA) Dergisi* **117**, 55–86 [in Turkish with English abstract].

ERKÜL, F., HELVACI, C. & SÖZBİLİR, H. 2005. Stratigraphy and geochronology of the Early Miocene volcanic units in the Bigadiç borate basin, western Turkey. *Turkish Journal of Earth Sciences* **14**, 227–253.

GENÇ, Ş.C. 1998. Evolution of the Bayramiç magmatic complex, northwestern Anatolia. *Journal of Volcanology and Geothermal Research* 85, 233–49.

KILIÇ, M., KÜÇÜKEFE, Ş., AVŞAR, M., SARI, R., VURAL, A. & PEHLİVAN, N. 2004. Preliminary geological and geochemical data on Kısacık (Ayvacık-Çanakkale) Au mineralization. 57th *Geological Congress of Turkey, Ankara, Abstracts,* p. 101.

LEVINSON, A.A. 1974. *Introduction to Exploration Geochemistry.* Applied Publishing Ltd., Wilmette, IL.

MAZZUCCHELLI, R.H. 1990. *Advanced Exploration Geochemistry.* Workshop course 704/90, Australian Mineral Foundation, Publication 550.84, Australia.

MAZZUCCHELLI, R.H. 1994. Drainage geochemistry in gold exploration. *In*: HALE, M. & PLANT, J.A. (eds), *Drainage Geochemistry, Handbook of Exploration Geochemistry* 6. Elsevier, Amsterdam, 379–414.

MEIER, A.L. 1980. Flameless atomic-absorbtion determination of gold in geological materials. *Journal of Geohemical Exploration* 13, 77–85.

MTA (Maden Tetkik ve Arama Enstitüsü) 1966. *Copper, Lead and Zinc Deposits of Turkey.* MTA Publications 133, Ankara.

MTA (Maden Tetkik ve Arama Enstitüsü) 1993. *Lead and Zinc Deposits of Turkey.* MTA Publications 199, Ankara.

NICHOLS, I., HALE, M. & FLETCHER, W.K. 1994. Drainage geochemistry in gold exploration. *In*: HALE, M. & PLANT, J.A. (eds), *Drainage Geochemistry, Handbook of Exploration Geochemistry* 6. Elsevier, Amsterdam, 499–557.

OKAY, A.İ, SIYAKO, M. & BÜRKAN, K.A. 1991. Geology and tectonic evolution of the Biga Peninsula, northwest Turkey. *Bulletin of the Technical University of İstanbul* 44, 191–256.

OKAY, A.İ., SATIR, M., MALUSKI, H., SIYAKO, M., MONIE, P., METZGER, R. & AKYÜZ, S. 1996. Paleo- and Neo-Tethyan events in northwest Turkey: geological and geochronological constraints. *In*: YIN, A. & HARRISON, M. (eds), *Tectonics of Asia.* Cambridge University Press, 420–441.

OKAY, A.İ. & SATIR, M. 2000. Coeval plutonism and metamorphism in a latest Oligocene metamorphic core complex in northwest Turkey. *Geological Magazine* 137, 495–516.

ÖNGEN, S. 1978. Petrographie und Petrochemie des Çavuslu-Karaköy Granitoid Massivs, *İstanbul Üniversitesi FenFakültesi Mecmuası* B43, 93–115.

ÖNGEN, S. 1994. Le pluton calco-alcalin d'Evciler (peninsula de Biga, Turquie-NW): age, geochemie et signification geodynamique. *Comptes Rendus de l'Académie des Sciences, Paris* 319, 1033–1039.

OTTESEN, R.T. & THEOBALD, P.K. 1994. Stream sediments in mineral exploration. *In*: HALE, M. & PLANT, J.A. (eds), *Drainage Geochemistry, Handbook of Exploration Geochemistry* 6. Elsevier, Amsterdam, 147–184.

PIRAJNO, F. 1992. *Hyhdrothermal Mineral Deposits.* Springer-Verlag. New York, Berlin Heidelberg.

RADFORD, N. 1996. BLEG sampling in gold exploration: an Australian View. *Explore* 92, 8–10.

ROSE, A.W., HAWKS, H.E. & WEBB, J.H. 1979. *Geochemistry in Mineral Exploration.* Academic Press, NY, USA.

SCHUILING, R.D. 1959. Über eine prä-herzynische Faltungsphase im Kazdağ Kristallin. *Maden Tetkik ve Arama (MTA) Dergisi* 53, 89–93.

TAYLOR, S.R. 1966. The application of trace element data to problems in petrology. *Physics and Chemistry Earth* 6, 133–213.

THOMPSON, M. & HOWARTH, R.J. 1978. A new approach to the estimation of analytical precision. *Journal of Geochemical Exploration* 9, 23–30.

TOKÇAER, M., AGOSTINI, S. & SAVAŞÇIN, M.Y. 2005. Geotectonic setting and origin of the youngest Kula volcanics (western Anatolia), with a new emplacement model. *Turkish Journal of Earth Sciences* 14, 143–166.

XUEQIU, W., XUEJING, X., ZHIZHONG, C. & DAWEN, L. 1999. Delineation of regional geochemical anomalies penetrating through thick cover in concealed terrains – a case history from the Olympic Dam deposit, Australia. *Journal of Geochemical Exploration* 66, 85–97.

WILHELM, E. & ARTIGNAN, D. 1994. Drainage geochemistry in gold exploration. *In*: HALE, M. & PLANT, J.A. (eds), *Drainage Geochemistry, Handbook of Exploration Geochemistry* 6. Elsevier, Amsterdam, 415–444.

WOOD, D.G., PORTER, R.G. & WHITE, N.C. 1990. Geological features of some Paleozoic epithermal gold occurrences in northeastern Queensland, Australia. *Journal of Geochemical Exploration* 36, 413–443.

YANG, S.X. & BLUM, N. 1999. A fossil hydrothermal system or a source bed in the Madiyi Formation near the Xiangxi Au-Sb-W deposit, NW Hunan, PR of China. *Chemical Geology* 155, 151–169.

YILMAZ, H. 2003. Geochemical exploration for gold in western Turkey: success and failure. *Journal of Geochemical Exploration* 80, 117–135.

YILMAZ, H. & KARA, Z. 1996. *Kazdağ Project.* Eurogold, Turkey Company Report, 1–20 [unpublished].

YÜCEL-ÖZTÜRK, Y., HELVACI, C. & SATIR, M. 2005. Genetic relations between skarn mineralization and petrogenesis of the Evciler granitoid, Kazdağ, Çanakkale, Turkey and comparison with world skarn granitoids. *Turkish Journal of Earth Sciences* 14, 255–280.

Received 03 August 2005; revised typescript received 29 June 2006; accepted 13 October 2006