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Secondary dispersion from gold deposits in west Turkey

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Abstract

Orientation studies over the Sarpdağ prospect in the Biga peninsula and the Arapdaği deposit near Izmir have provided clear evidence for elemental dispersion around west Turkish gold prospects. Although these deposits are of different types, silicification associated with the deposits results in the main part of both deposits forming topographic highs.

At Sarpdağ gold mineralisation is relatively weak compared with nearby prospects and associated with a silicified cap on the main hill. Comparison of coarse and fine fractions, based on a 190 μm size split of 8 kg of −2 mm material, suggests that gold disperses clastically on the steep slopes, probably within silica, but coarse grains break down giving Au concentrations in the finer fractions at the base of the main slope. Discrete gold grains, that can be panned, only occur 1–2 km downstream within the streams and heavy mineral concentrations are very limited. This interpretation of Au dispersion is consistent with the data from 1 kg samples collected at the higher primary grade, but more contaminated, Arapdaği prospect.

Antimony is the most consistent pathfinder both for the silicified cap at Sarpdağ and for gold-rich veins at Arpadaği. It gives high contrast anomalies. Arsenic is useful being more mobile than Sb, although contrast may be low. High resolution Ag data can be useful but base metal enrichments are also often associated with Ag anomalies. Most prospects have some base metal enrichments although they can be displaced from the main gold-rich parts of the deposit and anomalies may be weak. Lead and Cu are the more consistently useful elements.

The use of large (> 8 kg of −2 mm material) samples produces consistent stream sediment data that can be used to reliably interpret single samples and quantify Au anomalies. A survey around the Halíköy Hg and Emirli Sb mines, using these large samples, confirmed the extension of the known gold-bearing Emirli structure. In contrast the major Hg-bearing Halíköy Fault is gold poor although a structure parallel to it is auriferous.

1. Introduction

West Turkey is a focus for continuing exploration for gold deposits. However little information is available on the dispersion of elements from these deposits to plan geochemical surveys which form a major part of most companies' strategies. This study reports on two detailed orientation studies and one exploration survey around gold prospects in West Turkey. It provides general guidelines on elemental dispersion for use in exploration. The study also provides data on two more general issues in gold exploration: a comparison of the use of large and small samples as well as coarse and fine particle size in stream sediment sampling, and the relation of the distribution of pathfinder elements to gold.

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West Turkey has been known as a gold province for considerable time. Gold was probably mined in West Turkey in Trojan times and the Roman historian Strabo reported (then) old gold mines that were equated by Schliemann, excavator of Troy, with operations at Madenköy and Kartaldaği near Çanakkale (De Jesus, 1980). Legendary figures in western Turkey include King Midas, who turned everything to gold with a simple touch, and the proverbially wealthy King Croesus of Lydia who had the first coins made from gold about 650 B.C. Croesus's wealth was based on the placer deposits of the Sart Çayi area (modern day Sardis, east of Izmir) (Brinkmann, 1976; Larson, 1989).

In Ottoman times gold was extracted from the Arapdaği (near Izmir) and Madendaği (near Çanakkale) areas. However there was almost no exploration activity for gold in the twentieth century due to restrictions in land tenure and political uncertainty. This changed in 1985 after the Turkish government changed the investments law to encourage foreign participation and eased the land tenure system as well as permitting majority foreign share holdings (Dickson, 1986). A number of multi-national companies have been actively involved in exploration that has resulted in a number of discoveries, the most important of which are at Ovacík and near Havran (Fig. 1). Diluted reserves at the Ovacík deposit of Eurogold Madencilik (ACM Gold (now La Source)/Metall Mining) near the town of Dikili were put at 0.8 Mt at 9.5 g/t Au open pittable and 0.33 Mt at 20 g/t Au underground in April 1991 (Mining Journal, 1991). The deposit near Havran is reported to contain 1.5 Mt at 5.6 g/t Au and 11 g/t Ag. In addition to their involvement at Havran, Gencor have stated that they have an interest in a potential open pit heap leach operation with resources of 9.0 Mt at 1.25 g/t in-situ Au (Gencor, 1990).

The two detailed orientation studies were carried out over two known deposits in June 1989. The first is the well described Arapdaği deposit, 6 km NNW of Izmir and the second, the Sarpdağ prospect, in the Biga Peninsula, 30 Km south-east of Çanakkale (Fig. 1). In these orientation studies sediment samples were collected at 100–200 m intervals downstream from the known mineralisation. A survey based on the findings of these orientation studies was undertaken in June 1990 in an area surrounding the Halíköy Hg and Emirli Sb mines, 20 km S of Ödemís, an area of known gold potential. In addition limited rock and soil samples were collected, as were panned concentrates.

2. Regional geological and tectonic setting

The present geology of western Turkey results from the early to middle Tertiary convergence of three distinct provinces which have subsequently been modified by extension and magmatism during the late Tertiary. The three major provinces are the western extension of the Pontide island arc or Pontides, the Anatolides and the Tauride fold belt or Taurides. The Pontides and Anatolides are separated by the Izmir–Ankara ophiolitic belt (Sengör et al., 1985). Within the Anatolian province there are a number of high-grade metamorphic complexes, the most important of which is the Menderes Massif (Fig. 1). The mechanisms of formation of these complexes are controversial; they appear to have been metamorphosed during Mesozoic–early Tertiary compression but recent work suggests that their present crustal position may result from later, post-Miocene extension (Bozkurt and Park, 1994; Hetzel et al., 1995).

Early stages of the magmatism occurred under a compressional regime in Oligocene–Early Miocene times and was of calc-alkaline character (Seyitoğlu and Scott, 1991). Intrusives are in the form of acidic rocks such as granitic stocks and dykes, and extrusives, andesites, latites and dacites, which cover most of the NW part of the region (Fig. 1). Post-early Miocene extension was accompanied by widespead volcanic activity throughout the entire region that continued until the very Recent. This volcanism evolved from early acidic volcanism to the late Miocene alkaline volcanism of basalts with subordinate hawaiites and mugearites.

The most prominent structural and morphological features in Western Turkey are the approximately E–W trending graben bounding and related fault systems that are believed to be of listric character (Sengör, 1987). This together with the volcanism is one of the analogies of Western Turkey to the Basin and Range Province of Nevada (Silberman et al., 1976).

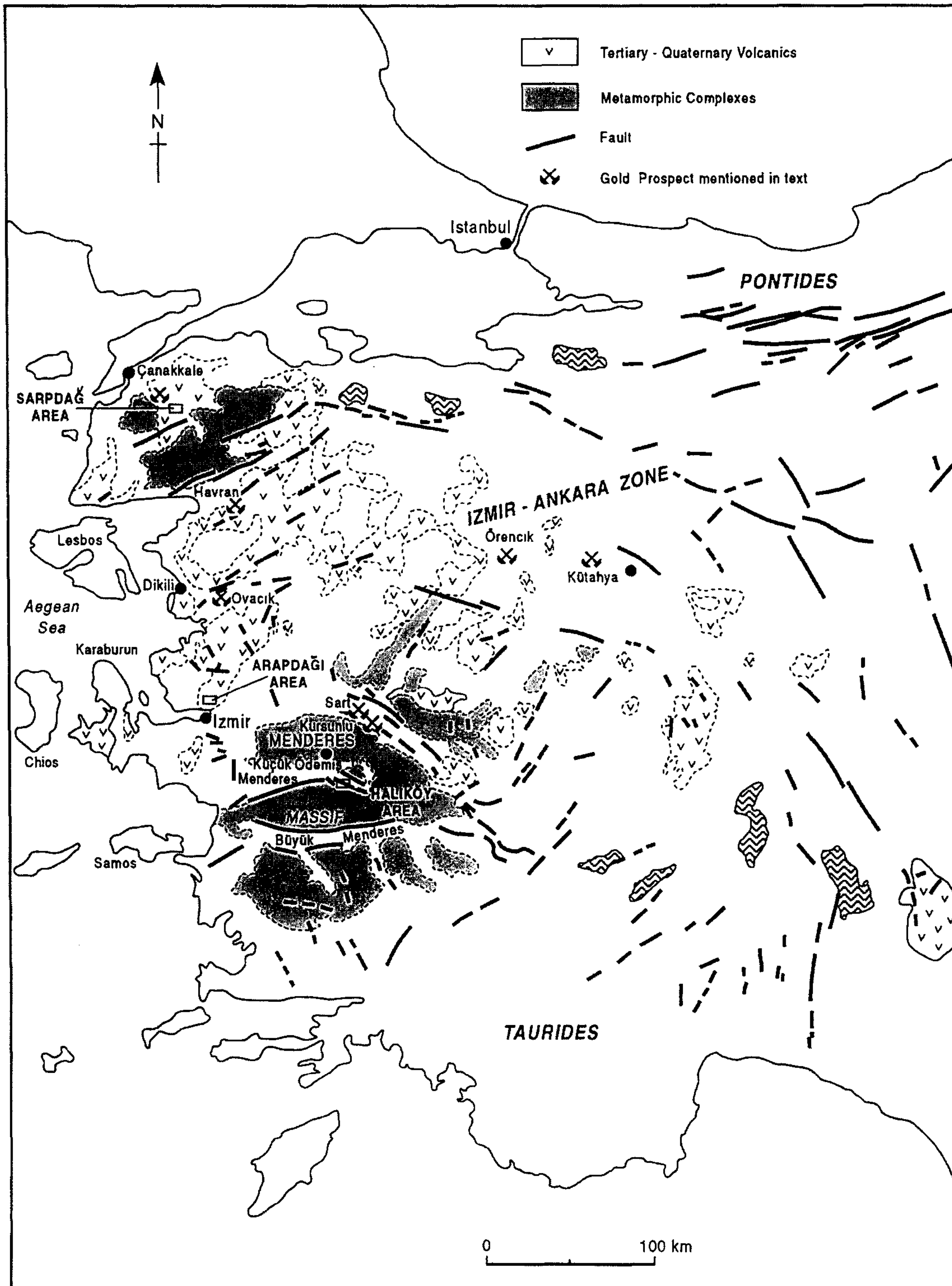

Fig. 1. Summary geological map and location of areas. Geology from Bingöl (1989).

3. Mineralisation

Western Turkey contains a variety of mineral deposits, the most important of which are the world class borate deposits, chromite and lignite (Erseçen, 1989). It is a metallogenic As–Sb–Hg province with significant production of stibnite and cinnabar and some current production of silver from a deposit near Kutahya (Gümüs, 1970, Jankovic, 1982). The majority of the Sb production has come from the margins of the Menderes Massif core complex whereas past Hg production was from the volcanic and fault associated areas, in particular, the Karaburun peninsula, west of Izmir, and the Halíköy area, investigated in this study (Yildiz and Bailey, 1978).

Gold production and prospects in western Turkey can be divided into five end-member types:

(1) volcanic associated deposits of both high and low sulphidation types;

(2) deposits associated with Neogene major, usually graben bounding faults, that are the locus for present day hot spring activity;

(3) listwanites;

(4) veins within the metamorphic complexes of the Menderes Massif;

(5) alluvial placers and paleoplacers.

Mineralisation associated with the Tertiary volcanics is the most commercially significant of these types to date. The Ovacík discovery of Eurogold is a series of andesite hosted gold bearing quartz veins with minimal sulphide at a graben margin. Gold prospects in the Biga peninsula are associated with silicified breccia pipes, stockworks and veins within volcanics and at the contact with underlying metamorphic basement (Pirajno, 1995). According to him the systems show strong vertical zonation and are of the high sulphidation type. The tops of the systems, as exposed at Sarpdağ, are silica rich and sulphur poor. In contrast, the Arapdaği deposit, discussed in detail below, is a high sulphidation vein system also hosted in volcanics.

4. Climate, topography and drainage

Western Turkey has a semi-arid type of climate with dry summers and cool and wet winters dominant. Only the high peaks of the mountains receive regular snow during winter. July and August are the hottest months with average temperatures around 30°C whereas January and February are the coldest with temperatures around 10°C. Annual rainfall is about 600 mm.

The landscape in Western Anatolia is dominated by E–W trending river valleys, which are the surface representation of the graben structures. Mountains in the Menderes Massif reach 2500 m. Further north the topography is smoother and gentler with a maximum altitude of 1710 m at Kazdağ in the Biga peninsula.

Major perennial rivers such as the Küçük Menderes, Büyük Menderes, Gediz and Simav Çayi flow within the major grabens; however the majority of the streams are ephemeral. Hills in western Anatolia are mainly covered by indigenous 1–1.5 m tall bushes and more locally by pine forests. In contrast, valleys and gentle slopes of the hills are very fertile permitting intensive agriculture. Further north in the Biga Peninsula cultivation is restricted to wheat and fruit because of lack of large valleys.

5. Overburden and soil

Both residual and transported overburden are present in the region. Residual overburden is mainly observed on the high plateaux and is composed of thick mature soil formation. In the Biga area these are luvisols of in the FAO/UNESCO (1978) classification scheme, more commonly known as brown Mediterranean soils and eutric cambisols or brown earths at Halíköy. Due to the rough topography scree development with limited immature soil formation is very widely seen on the slopes of the mountains; the soils are classified as lithosols. As the rate of erosion is very pronounced in deep valleys, the major rivers form wide and thick alluvial deposits that are parent rock to fluviosols.

6. Previous geochemical studies

Although many geochemical studies have been undertaken, notably by the Turkish Mining Research and Exploration Institute (MTA), very few have been formally published. Perhaps the first major study in the area was that of Köksoy (1967) who conducted orientation studies around the Halíköy Hg and Ivrindi

Sb deposits. Orientation studies at Halíköy investigated both primary concentration (Bradshaw and Köksoy, 1968) and secondary dispersion, mainly by soil sampling, over the deposit (Köksoy and Bradshaw, 1969). Their soil sampling studies demonstrated that Hg gave maximum contrast in the −80 mesh soil fraction and Sb and Hg in stream sediments up to 3 km downstream were useful in indicating deposits.

A more comprehensive survey, concentrating on Hg, Sb and As, was undertaken in part of the Menderes Massif by a U.N. sponsored team (Egger, 1974) in the south of the Küçük Menderes graben area (Fig. 2). This study, that used a sample spacing of about 1 sample per km on major rivers, resulted in the delineation of 4 strong Sb anomalies on the south side of the graben as well as 8 areas of Hg anomalies. Most of the Hg and Sb anomalies were along the major graben bounding faults and the contact between schists and gneissic units. The Hg anomalies range from 1 to 210 ppm and Sb values from 5 to 2200 ppm. The maximum Sb concentrations are possibly caused by contaminated samples taken downstream of the main Sb producing adits at Emirli. A lack of significant correlation between Hg and Sb suggests that these two types of mineralisation are the products of different mineralising episodes. Arsenic anomalies (not shown) were used by Dilek and Kayhan (1987) to indicate possible Gold bearing arsenopyrite veins.

One of the few published studies of gold potential is that of Larson and Erler (1993) who undertook a rock chip programme at two prospects, Kursunlu and Örencik (Fig. 1). The Kursunlu prospect is on the northern margin of the Menderes massif and associated with a detachment, possibly graben bounding fault similar to Halíköy discussed below, whereas Örencik is a melange type prospect. Örencik is Sb-rich and associated with silica–carbonate alteration whereas Kursunlu is siliceous and more enriched in arsenic. Pirajno (1995) provided a summary of trace element concentration around prospects in the Biga peninsula. He determined mineralising and alteration factors consisting of combinations of Cu–Au–Pb–Zn–Hg–Sb–Ba and Zr–Rb–Nb–Y coupled with depletion in Na and K based on XRF rock analyses.

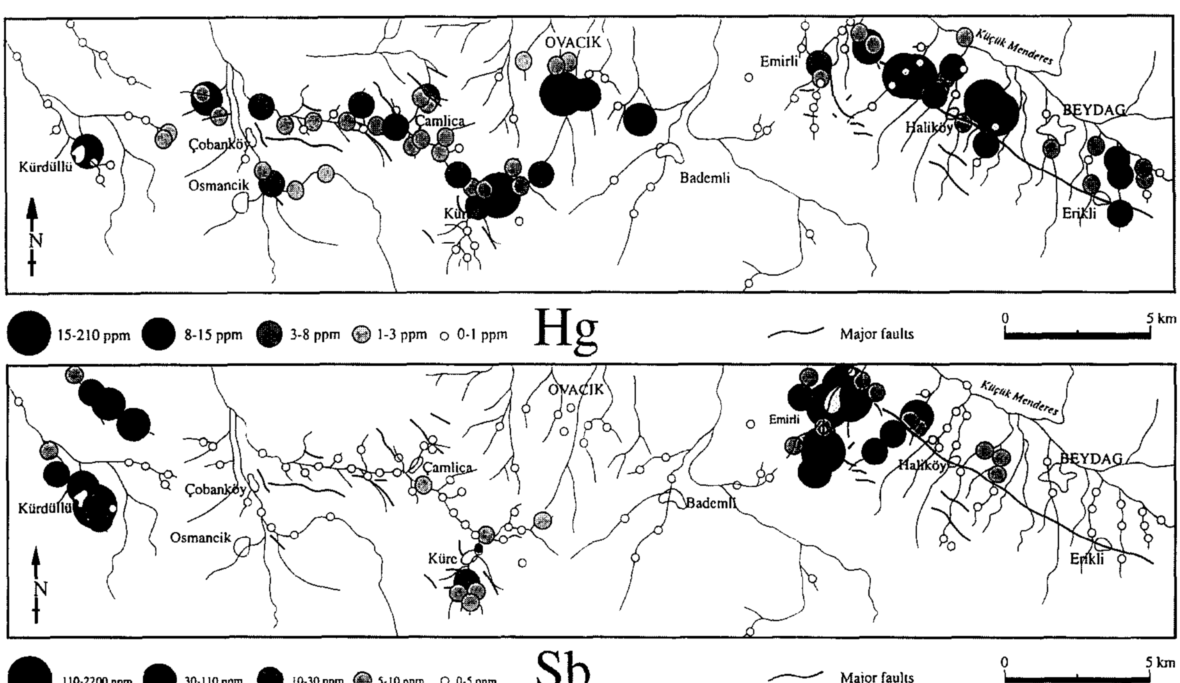

Fig. 2. Regional geochemical survey of the area south of Ödemís. Note the strong anomalies reflecting known minerlisation at Emirli and Halíköy. This is the area resampled for gold. Redrawn from data in Egger (1974).

Bulk leach extractable Au (BLEG) sediment sampling has been widely used in Turkey with success, including the indication on a regional scale of the Ovacík deposit (personal communication to C.J.M.). No published details are available as to sampling techniques or interpretation.

7. Sample collection, preparation and analyses

7.1. Sample collection

One of the objectives of the study was to compare the efficacy of different sample masses. The samples taken at the Arapdaği area were conventional grab stream sediment samples as collected for base metal exploration, i.e. around 1 kg, whereas those collected in the Sarpdağ area were designed to minimise the nugget effect seen when determining Au (Harris, 1982; Nichol et al., 1989). The size of the samples was based on the nonograms contained in Clifton et al. (1969) so that, based on 190 μm particle size and expected anomalies of 100 ppb Au, a mass of approximately 8 kg of −2 mm material was chosen, as also used by Gunn (1989). The 8 kg samples were collected by sieving large volumes of sediment through a nylon screen in the field and collecting the fine fraction in polyethylene bags. A large oven was used to dry the samples in Çanakkale area whereas they were air-dried in the Arapdaği and Halíköy areas due to unavailability of ovens. All samples were sieved to − 190 μm (approx. BS 80 mesh size) and approximately 300–400 g fine fraction was obtained from the 8 kg samples. The coarse fraction (−2 mm + 190 μm) of the sediment samples was only analysed in the Çanakkale area, where 300 g portions were sub-sampled using a splitter.

At a distance from the known mineralised areas, stream sediment samples were collected at 200 m intervals but near mineralisation at 100 m intervals. In total, 358 samples were collected: 102 fine fraction from Arapdaği; 90 fine fraction and 90 coarse fraction from Çanakkale; and 76 fine fraction from Halíköy area.

Panned concentrate samples were not collected at every stream sediment sample site as little placer development had previously been reported and many disseminated gold deposits have a poor response. However, panned concentrates were taken at 400 m intervals along the main river in the Sarpdağ area as it was flowing and in the Arapdaği area from stream sediment sample locations with running water. In both cases the minus 2 mm fraction of sediment was carefully washed and panned to produce a clay-free heavy mineral concentrate and the samples, weighing 100–150 g, were stored in Kraft paper bags.

A limited number of soil samples were collected from B horizons of the soil profiles, by digging 30–50 cm deep small pits. At Sarpdağ a limited 750 m line was traversed whereas at Arapdaği, samples were collected at 25 m intervals along two 700 m long traverses, which were 120 m apart. At each sampling site, a 400–500 g sample of −2 mm size fraction was obtained. Rock chips were taken from various obviously mineralised parts of the study areas.

7.2. Sample preparation and analyses

The samples were prepared at Leicester University. Coarse stream sediments and soil samples were disaggregated by ceramic mortars; rock chips and panned concentrates were pulverised in an agate Tema mill.

All samples were analysed, following a $HNO_3/HClO_4$ digestion by ICP-ES at Leicester using a Philips 8060 simultaneous spectrometer for Ba, Co, Cr, Cu, Li, Mo, Ni, Pb, Sn, Sr, V, Zn, Al, Ca, Fe, K, Mg, Mn, Na, and Ti. Precision was better than 10% at the 95% confidence level using the method of Thompson and Howarth (1978). Silver was determined on the same solutions for the orientation studies using a graphite furnace AAS with background correction. Arsenic and Sb for the orientation samples were determined (precision < 5%) by hydride generation AAS after the sample pulp was wet-ashed with magnesium nitrate at 450°C, taken up in concentrated HCl and reduced with KI. Arsenic, Sb and Ag in the Halíköy samples were determined by ICP-ES with off-line correction for major element interferences. While the detection limits are higher than for the hydride method and GFAAS, they are adequate to detect anomalous areas.

Gold for the orientation areas, and a subset of the Halíköy samples, was determined by GFAAS at Leicester after a 3:2:4 $HCl/HNO_3/HF$ attack and dissolution with HBr followed by an uptake in MIBK (Meier, 1980; Fletcher and Horskey, 1988). This method is precise (< 10% precision) but the attack may not be total (Hall et al., 1989). The full set of Halíköy samples were fire assayed with good precision and accuracy at Acme Laboratories in Vancouver as determined by duplicates using the Thompson and Howarth (1978) method and international reference materials. Comparison of the subset determined by MIBK extraction and the full set determined by fire assay shows similar patterns but the absolute concentrations are higher in the fire assayed data.

8. Case histories

8.1. Arapdaği gold deposit

8.1.1. Local geology and structure

The Arapdaği gold deposit is situated on the western slopes of the Yamanlar Daği in the township of Karsíyaka and within sight to the NE of the city of Izmir (Fig. 1).

The area is underlain by calc-alkaline volcanics of Oligocene–Early Miocene age of dacitic and andesitic composition (Dora, 1969; Sayílí et al., 1990; Fig. 3). The andesitic volcanism consists of tuffs, agglomerates and lavas and is generally older than the dacitic volcanics. Andesitic lavas show flow textures and are composed of large plagioclase phenocrysts, hornblende, pyroxene and biotites, with much plagioclase altered to kaolinite, sericite, chlorite and zeolite. Dacitic tuffs consist of quartz fragments, feldspars, biotites, pieces of flysch of probable upper Cretaceous age, rare tourmaline and augite. These tuffs are overlain by the dacitic lavas with porphyritic texture and microcrystalline groundmass, composed of large quartz phenocrysts, biotite, hornblende and plagioclase, with the plagioclase often sericitised, carbonatised and albitised. The total thickness of the dacitic volcanics is in the range

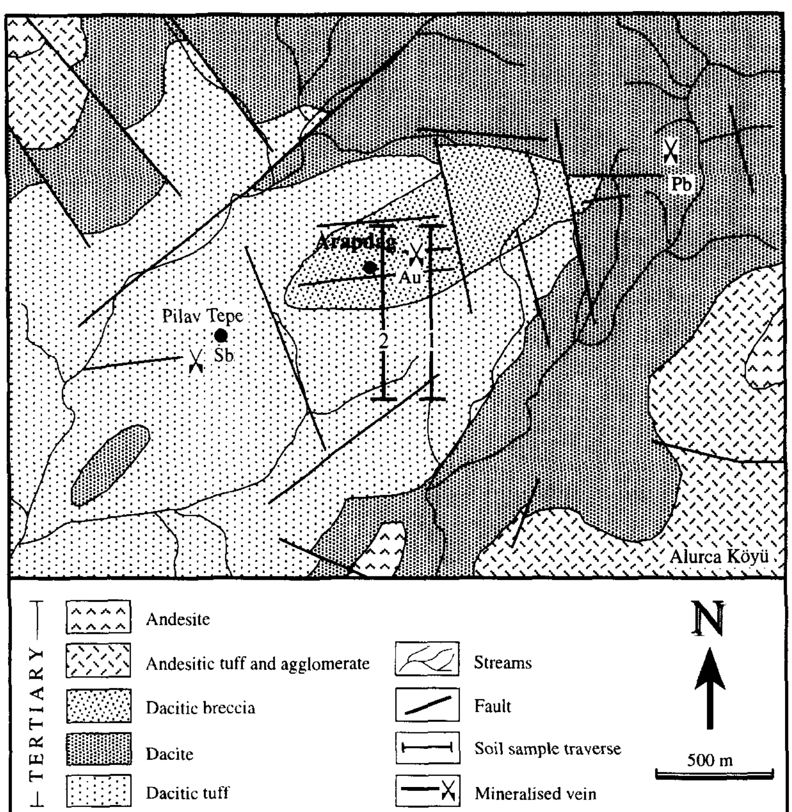

Fig. 3. Summary geological map of the Arapdaği prospect (largely based on Dora, 1969).

600–800 m. A younger dacitic breccia underlies the area around the peak of Arapdaği and is intensively propylitically altered with quartz veining and idiomorphic pyrite. Younger andesitic dykes cut through all these lithologies.

8.1.2. Mineralisation

The deposit has been intermittently mined since ancient times with previous workings concentrated on veins mainly located around the top of Arapdaği (Fig. 3). These show a distinct lateral zonation with an Sb-rich (stibnite) vein in the west of the area near Pilav Tepe and a lead-rich (galena) and arsenic-rich (enargite and arsenopyrite) vein on the eastern slopes of Arapdaği, both within dacitic tuffs and lavas. Gold-rich quartz veins occur along the fracture systems in volcanic breccias around the central peak of Arapdaği.

The approximately E–W trending fractures, along which the main gold–quartz veins occur, are tensional joints and are offset by younger faults trending 120° and 170° (Dora, 1969). Three gold-bearing veins occur over an area 1 km long E–W and 100–150 m N–S. One of these, the main gold bearing vein, along which most of the previous work was carried out, is about 300 m long, 0.3–3 m thick and dips 65–70° N. The other two smaller veins parallel the main vein, are up to 80 m long and 40 cm thick with steeper dips of 75–80° N.

Reported Au grades vary from less than 1 ppm to more than 20 ppm in the richest zones with a mean Au concentrations along the main vein of 6 ppm (Dora, 1969). He estimated a resource of more than 100 000 t in the main vein. More recent exploration by MTA has delineated a resource of 0.357 Mt of 3.4 g/t Au and 42.8 g/t Ag in this vein as well as a resource of 1.4 Mt of 1.3 g/t Au disseminated in silicified dacitic tuff at Cilektepe (Sayílí et al., 1990).

The veins of Arapdaği area contain gold in the form of electrum (up to 30% Ag), accompanied by pyrite, arsenopyrite, marcasite, hematite, sphalerite, galena, chalcopyrite, sulphosalts, Pb–Sb sulphides and Ag minerals. Quartz, barite, calcite and siderite are the gangue minerals. Gold occurs up to a depth of 160 m below the surface as delineated by drilling. Arsenopyrite is present at depths of greater than 60 m, but, unlike pyrite, base metals increase with depth. Silver minerals and sulphosalts remain constant through the known depth of the veins.

Secondary quartz veins, that are the most obvious alteration products, are observed in a 0.5–1 m wide zone around the main gold–quartz veins and the wall rock. Sericite, tourmaline and prehnite accompany the quartz veins. Peripheral to the mineralised veins is a kaolinitic zone composed of quartz, sericite, epidote, chlorite and kaolinite.

The mineralogy, vertical and lateral variation of alteration, temperature of formation and alteration, suggest that Arapdaği gold mineralisation is an acid sulphate type epithermal deposit (Bonham, 1985; Boyle, 1979).

8.1.3. Contamination

Although there has been mining in the area over a long period contamination is apparently limited to minor dumps, one at the foot of Arapdaği and the others localised around the mined veins.

8.1.4. Stream sediment samples

Sampling (1 kg) at 100 m intervals clearly delineated the known mineralised veins (Figs. 4 and 5) and generally confirms the lateral zonation previously reported. Tributary A drains the Sb vein, tributary B the gold veins, and tributaries D and E the lead vein.

In spite of its erratic dispersion in the 1 kg samples, gold has concentrations up to 110 ppb Au in stream sediments immediately downstream from the main veins and is effective in delineating the Arapdaği gold veins. In addition possible unknown sources can be seen to the SE of the Pb vein. Gold has weak correlation with other elements perhaps due to the unrepresentative nature of the 1 kg samples but also due to its clastic dispersion.

Silver is, by far, the most consistent indicator of the gold-rich veins, although 60% of Ag values are below the detection limit (0.1 ppm). Unlike Au, Ag is only detectable in the tributaries and is rapidly diluted in the main river. Silver shows some correlation with manganese at higher Mn concentrations indicating adsorption.

The dispersion of arsenic and Sb are similar. Both elements show high concentrations near the stibnite mineralisation (tributary A), reflecting the primary association of arsenic and Sb in the stibnite vein

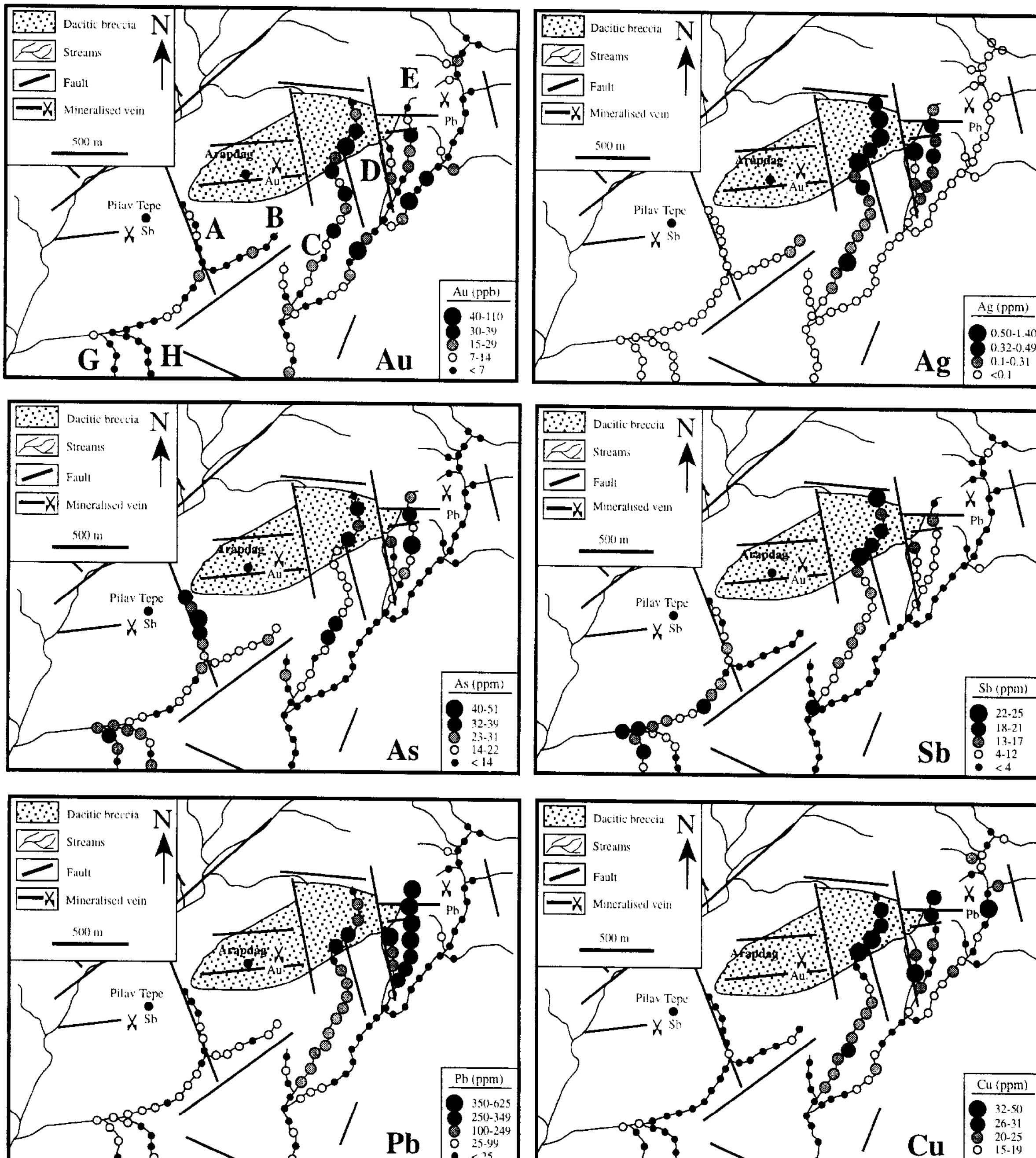

Fig. 4. Results of stream sediment sampling at Arapdaği for Au, Ag, Sb, As, Pb Cu. Data were mainly subdivided on 50, 75, 90, 95 percentiles except Ag (detection limit, 90, 95).

although Sb anomalies are best developed further downstream. In addition, As and Sb sources of unknown origin can be seen in tributaries G and H (Fig. 4). Both elements indicate the gold-rich veins with Sb having a coherent dispersion train. Arsenic concentrations are relatively low, reaching 50 ppm As.

Zinc and lead show similar dispersion with high

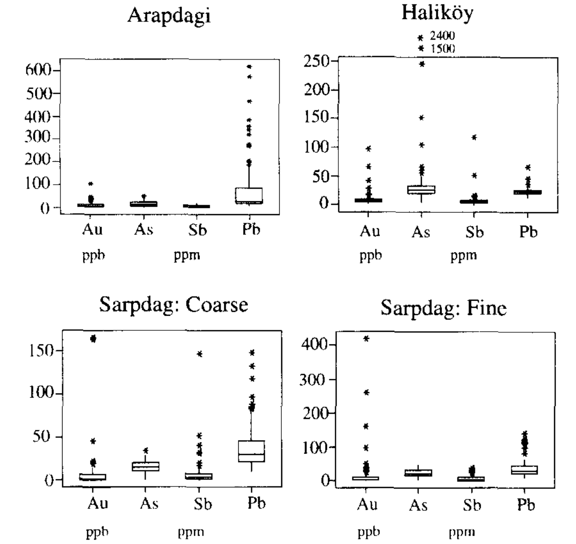

Fig. 5. Box plots comparing stream sediment results from Arapdaği, Sarpdağ, Halíköy. Note that the two highest As samples at Halíköy have been omitted from the main part of the plot.

contrast anomalies downstream from the lead-rich vein and the gold-rich veins to a lesser degree. Scatterplots show that zinc is, however, strongly correlated to and probably scavenged by manganese. Copper has only weak contrast, reflecting its relatively low primary concentration at Arapdaği.

Potassium and aluminium can be used as indicators of altered dacitic tuffs. In contrast, strontium, vanadium, titanium and calcium indicate the outcrops of andesitic volcanics.

8.1.5. Panned concentrates

Results of panned concentrates (Fig. 6) are not encouraging, in part due to the poor sampling conditions. Gold in panned concentrates is only slightly higher than stream sediments, only two samples which were more than 2 km from the gold-rich veins had concentrations above 100 ppb Au. Silver in panned concentrates is much lower than in stream sediments although there is some indication of mineralisation. Base metals give erratic results and no firm conclusions can be drawn.

8.1.6. Soil sampling

Two soil sample traverses were designed to test the downslope dispersion from two outcropping gold veins; Traverse 1 cuts two veins and Traverse 2 one. Both traverses were made down the steep slopes from the dacitic neck.

Both traverses detected the known gold veins although the intensity of the response differed between traverses. In Traverse 1 (Fig. 7) Au values up to 530 ppb were observed whereas the maximum response in Traverse 2 was only 50 ppb. The erratic results suggest that dispersion is clastic within scree developed on the steep slopes. Gold values decrease to background about 400 m away from the veins at the base of the slope. In contrast, Ag dispersion is much more consistent than Au. Concentrations of Ag are similar in both traverses with a maximum of about 4 ppm Ag immediately downslope from the main gold vein. Both Au and Ag indicate a further source at the northern end (700 m) of the traverse.

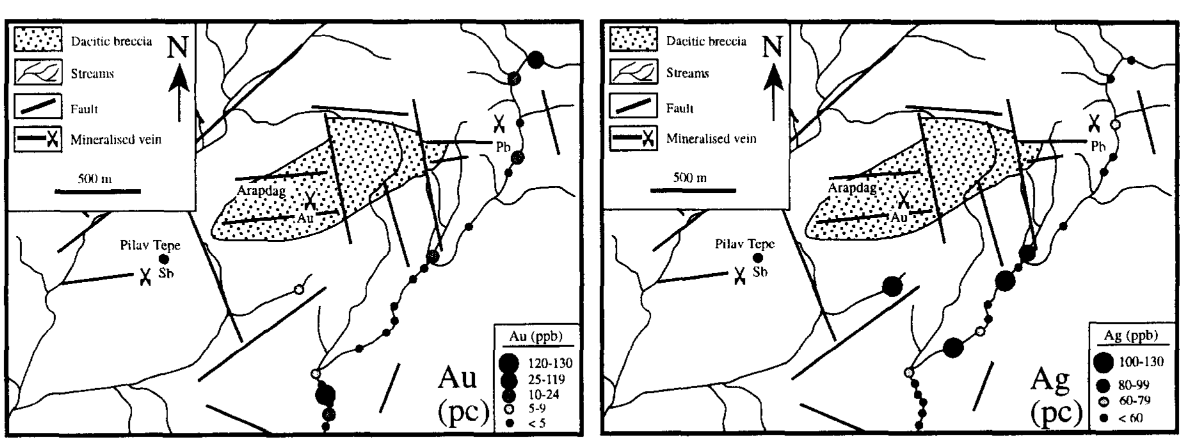

Fig. 6. Panned concentrate results for Au and Ag, Arapdaği prospect.

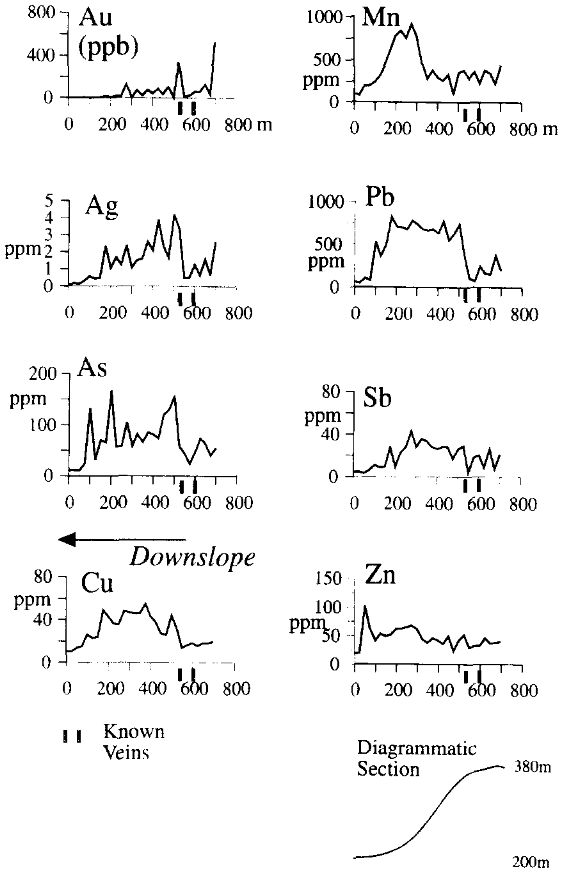

Fig. 7. Soil Traverse 1, Arapdaği prospect: Au, Ag, As, Sb, Pb, Zn, Cu, Mn.

Arsenic, Sb, Pb (and Cu and Fe) show similar dispersion patterns (Fig. 7). Although they show maxima near the veins, they have anomalous concentrations down the slope giving rise to broad anomalies. This is probably the result of both clastic and hydromorphic dispersion on the slopes of the hill with As the most mobile of these elements. The dispersion of Zn is different and displays a typical hydromorphic distribution pattern with the highest values near the base of the steep slope evidenced by a strong correlation with Mn, although no seepage zones were observed during summer visits. Arsenic, Sb and Cu are significantly higher over the Au rich portion of the vein (Traverse 1) than in Traverse 2. Silver and Pb are more consistent between the traverses.

8.2. Sarpdağ

This orientation study was undertaken in an area 30 km to SE of Çanakkale. The reason the area was selected was that it was known to be weakly mineralised but, unlike more intensely mineralised areas nearby, it was not contaminated by ancient or nineteenth century workings. The general geology is of andesitic volcanics (tuffs, lavas and agglomerates) of Eocene or younger age overlying a metamorphic basement of Paleozoic age. From analysis of Landsat images, the survey area is believed to be located in or at the edge of a volcanic caldera that is approximately 10 km in diameter.

Within the study area there are three volcanic related lithological units: (1) epiclastic conglomerates; (2) pyroxene andesites and andesites; (3) silicification and quartz veins.

Gold mineralisation in the study area is related spatially to a silicified breccia pipe that cuts andesitic host rocks and is expressed at surface as a silica cap. Two different stages of silicification can be recognised. The first is grey and barren in Au whereas the second generation is milky white and contains Au. Besides silicification the main alteration is sericitisation, which forms a halo around the silica cap. The matrix of the brecciated material is coated by manganese.

A few minor trenches of unknown, but ancient, age were opened along these milky quartz zones. The study area is covered in pine trees and is essentially uncultivated.

8.2.1. Stream sediment survey

Stream sediment samples, of approximately 8 kg of −2 mm material, were collected from streams draining from the mineralised area which forms the top of the approximately 500 m high hill (Fig. 8). The two sample size fractions, make it possible to deduce the nature of element transport.

Examination of the distribution patterns shows that > 25 ppb Au in the coarse fraction is erratically restricted to stream sections immediately down slope from the known mineralisation (streams A, B, C, D, E). Limited rock sampling shows values of 100–300 ppb Au in the silicified areas. In the fine fraction, > 25 ppb Au is present in stream D, particularly at the base of the main slope, and downstream from

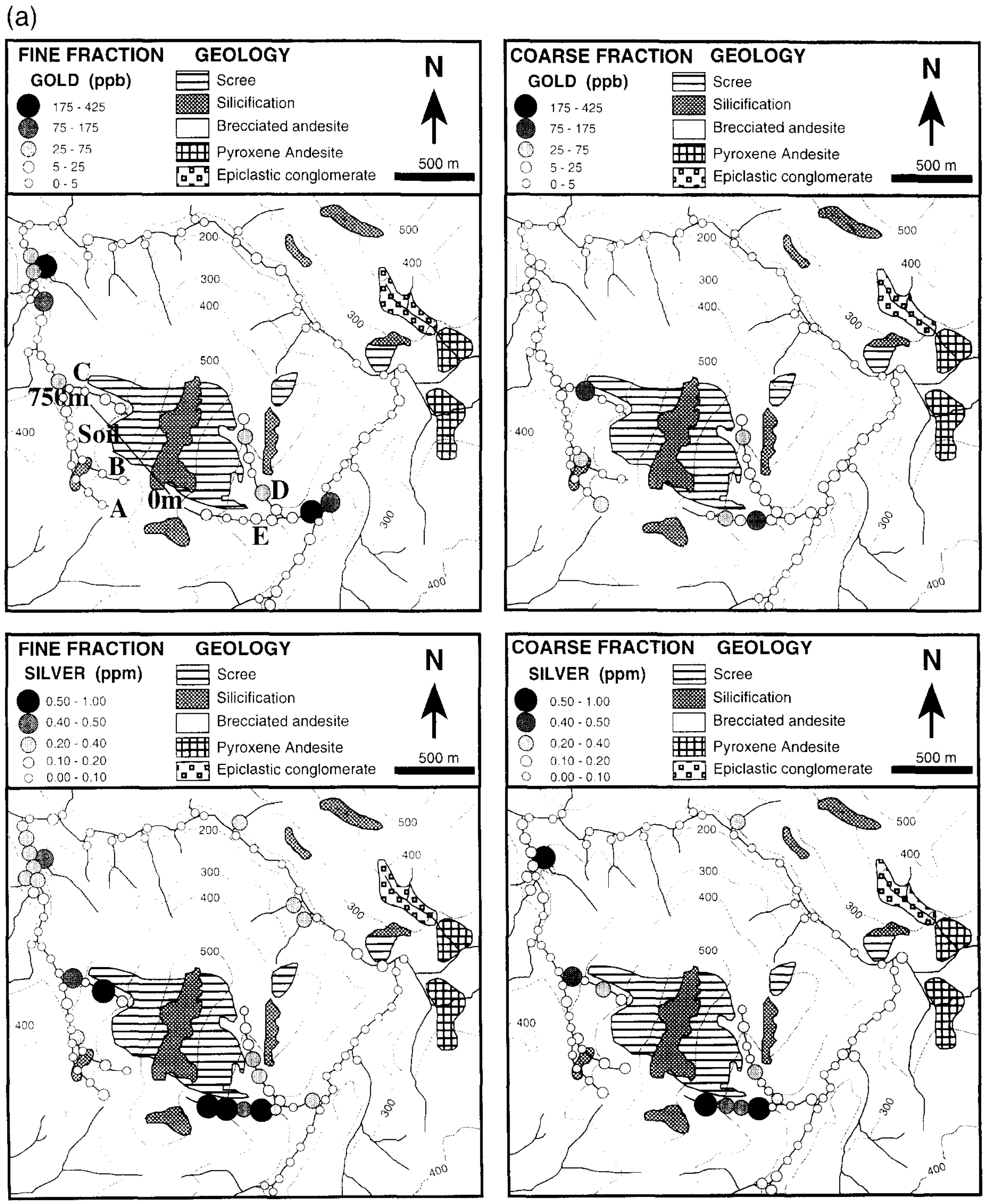

Fig. 8. Stream sediments 8 kg −2 mm samples. Sarpdağ prospect, coarse (> 190 μm) and fine (< 190 μm) fractions: Au, Ag (a); Sb, As (b); Pb, Cu (c). Data were sub-divided on rounded 50, 75, 90, 95 percentiles for coarse fraction.

(b)

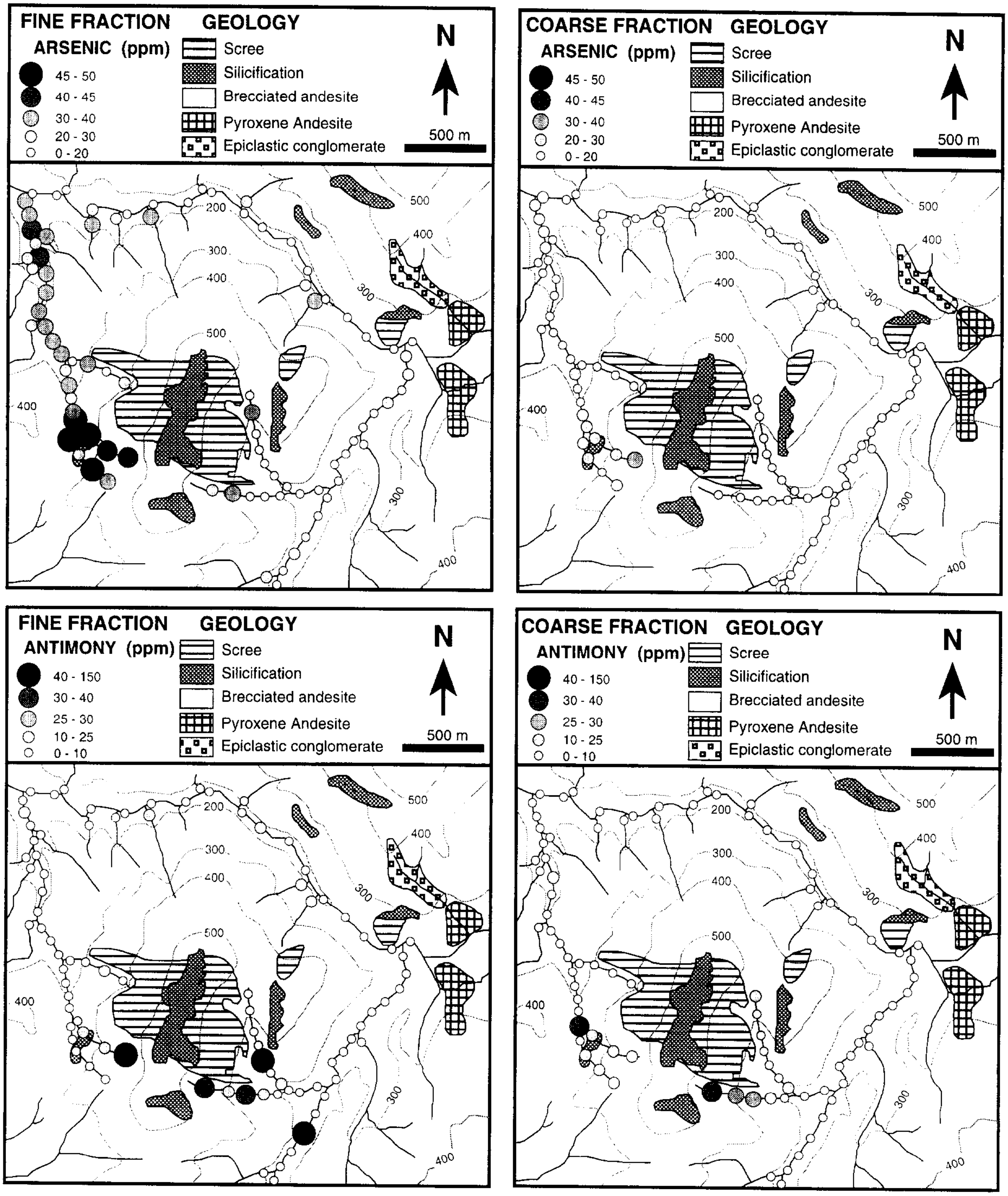

Fig. 8 (continued).

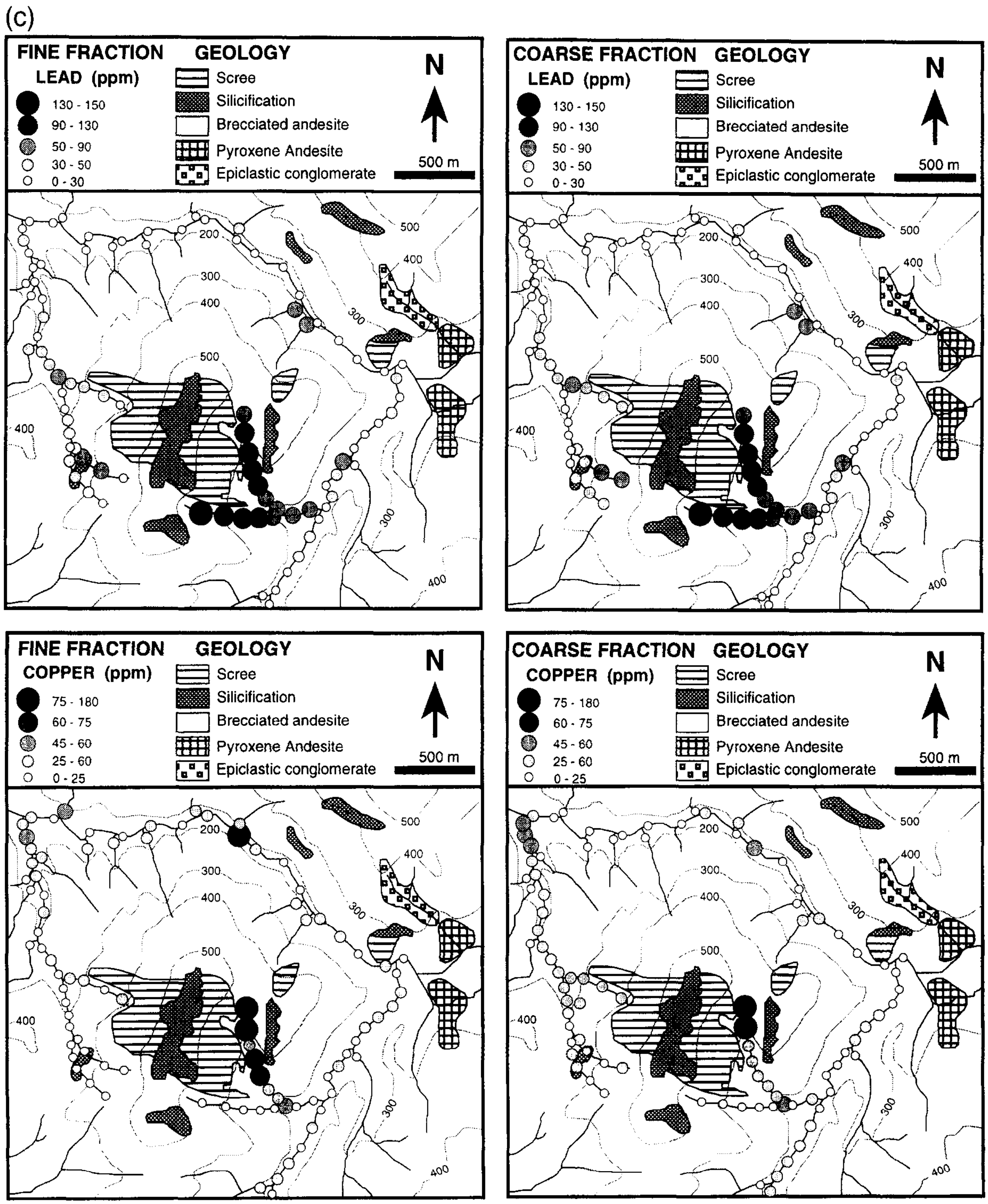

Fig. 8 (continued).

streams A, B, and C where minor placers were previously known. The occurrence of placers was confirmed by concentrations of up to 1200 ppb Au in panned concentrates.

Silver (determined by GFAAS) in the coarse fraction shows erratic dispersion in streams C and D but is distinctly anomalous in stream E, with a maximum of 0.8 ppm reflecting rock concentrations of up to 4 ppm. Stream E also shows a highly coherent anomaly in the fine fraction which highlights base of slope anomalies as well as the minor placer development

Antimony shows high contrast anomalies with more consistent patterns in the coarse fraction of streams A, B and E. One rock sample at the source of stream B reported 0.2% Sb with no Au enrichment, suggesting that this silicified zone is Sb rich. Streams A and B have coherent though weak, fine fraction As anomalies. Stream D shows a strong Cu and Pb anomaly whereas stream E is high in only Pb, which is also weakly anomalous in streams A, B and C. Although these elements all indicate the mineralised area, only Pb correlates spatially with coarse fraction Au anomalies. The limited response in the fine fraction for Sb suggests that it is best used at the follow-up stage whereas weak anomalies of more mobile As and Cu are useful for regional surveys.

Potassium and Al in stream sediments (not shown) are useful indicators of sericitic alteration.

8.2.2. Soil samples

A short soil profile in a NW direction down the western slope of the hill (Fig. 8a and Fig. 9) provided information about the mechanisms of element transport down the western slope of Sarpdağ. Gold anomalies occur over the subcrop of silicified breccia and at the base of slope. In contrast Ag shows distinct base of scree anomalies. Antimony shows a wide general enrichment (15–25 ppm) both around the silicified zone and at the base of slope. Lead behaves similarly although anomalies are weak (50–80 ppm). Arsenic and Cu (not shown) are weakly (2 × background) anomalous over the main siliceous outcrop and at the base of slope.

8.2.3. Panned concentrate samples

Limited (13) panned concentrates were collected where the rivers were flowing. Samples at the site of the main fine fraction Au anomaly gave 200–1200 ppb Au and 0.2–0.4 ppm Ag reflecting minor placer formation, as did a sample (2360 ppb Au) from the north side of Sarpdağ on the main river. Results from other samples were background reflecting the very limited heavy mineral concentrations.

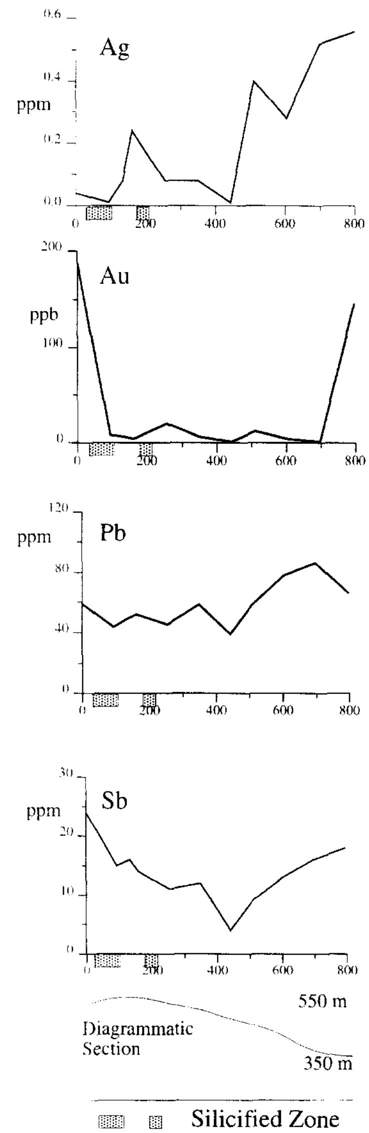

Fig. 9. Soil traverse, Sarpdağ prospect: Au, Ag, Sb, Pb.

8.3. Discussion of orientation studies: Arapdaği and Sarpdağ

Both sediment surveys show similar results in spite of the dissimilar geology. Gold and Ag are the most dependable indicators of precious metal mineralisation. Gold dispersion at the uncontaminated Sarpdağ prospect is probably a more reliable guide than at the partly contaminated Arapdaği area. In both cases the Au rich lithologies mainly occur on the crests of hills. The soil surveys in both areas, and the coarse fraction stream sediments at Sarpdağ, suggest that Au initially disperses as clastic grains, probably mainly as inclusions in silica, from the mineralisation and accumulates at the base of slopes. Base of slope samples have a much stronger fine Au signal than those on the slopes, probably because of limited time for weathering on slopes and the breakdown of coarse grains at the base of slopes. The Au signal in the fine fraction is best developed at the base of slopes but extends into the major rivers. Both the fine fraction sediment studies show that there is limited release of discrete Au grains and placer development in streams, and where heavy mineral concentrates occur they are present only after 1–2 km of transport.

Comparison of the 1 kg (at Arapdaği) and 8 kg (at Sarpdağ) sediment samples shows clearly that 1 kg samples give very irregular patterns whereas the more representative 8 kg samples give more consistent and therefore easily interpretable results. If patterns are more consistent then more reliance can be placed on a single sample and the necessity of analysing or sampling in duplicate (Harris, 1982) can be avoided.

Pathfinder element data is useful although anomalies may be displaced from the Au rich sources.

Based on these conclusions a survey was conducted over the Halíköy area on the southern edge of the Küçük Menderes graben, known to be prospective for Au.

8.4. Halíköy area

The survey area is on the southern side of the Küçük Menderes graben within the Menderes massif and includes the extension of the operating Emirli Sb mine and the defunct Halíköy Hg mine. The area was chosen as the Emirli mine was known to contain anomalous Au concentrations (Larson, 1989) although a deliberate decision was made to exclude the mine area to avoid contamination from current and old workings.

8.4.1. Local geology and structure

The area (Fig. 10) is situated on the Halíköy Fault that appears to be a major graben bounding fault on the south side of the Küçük Menderes graben and which is the controlling structure of the Hg mineralisation at Halíköy. To the north of the fault the area is largely covered by post-Miocene alluvial deposits, whereas The area to the south of the fault is underlain by muscovite, sericite and quartz schist while to the north of the fault metamorphic rocks consist of augen gneiss with lesser biotite schist, marble and quartzite. The area more than 1 km north of the fault is largely covered by post-Miocene alluvium.

The exact nature of the Halíköy Fault is in doubt. In the survey area it is relatively linear, strikes 110–140° and dips 45–65° NE, forming the topographic boundary of the graben but elsewhere has the overall outcrop pattern of a thrust fault (Yildiz and Bailey, 1978). A plausible solution is that it was a thrust zone partially reactivated during extension as a normal fault. Near the Halíköy mine the Halíköy Fault forms a 35 m wide clay alteration zone between augen gneiss and schists. There are a number of small faults which are parallel to the Halíköy Fault further in the south of the survey area. The structure that hosts the main mineralisation at Emirli, known as the Emirli Fault, strikes approximately 110–150° with a 50–70° dip NE, and is sub-parallel to the Halíköy Fault.

8.4.2. Mineralisation

Three main deposit types are known in this sector of the Küçük Menderes graben area:

(1) fault hosted and stratabound stibnite in the Emirli area;

(2) cinnabar mineralisation along the Halíköy Fault;

(3) gold rich arsenopyrite vein deposits within metamorphic rocks.

Stibnite deposits are confined to areas around the Emirli Fault and splays off it. In contrast, the Hg deposits are located as pods along the Halíköy Fault. The Emirli mine, which is active on a small scale, is producing arsenic-rich stibnite concentrates from underground workings of vein hosted and stratabound, graphitic, deposits. Detailed studies by H.M.O. suggest that the stibnite was deposited over a wide range of (fluid inclusion homogenisation) temperatures

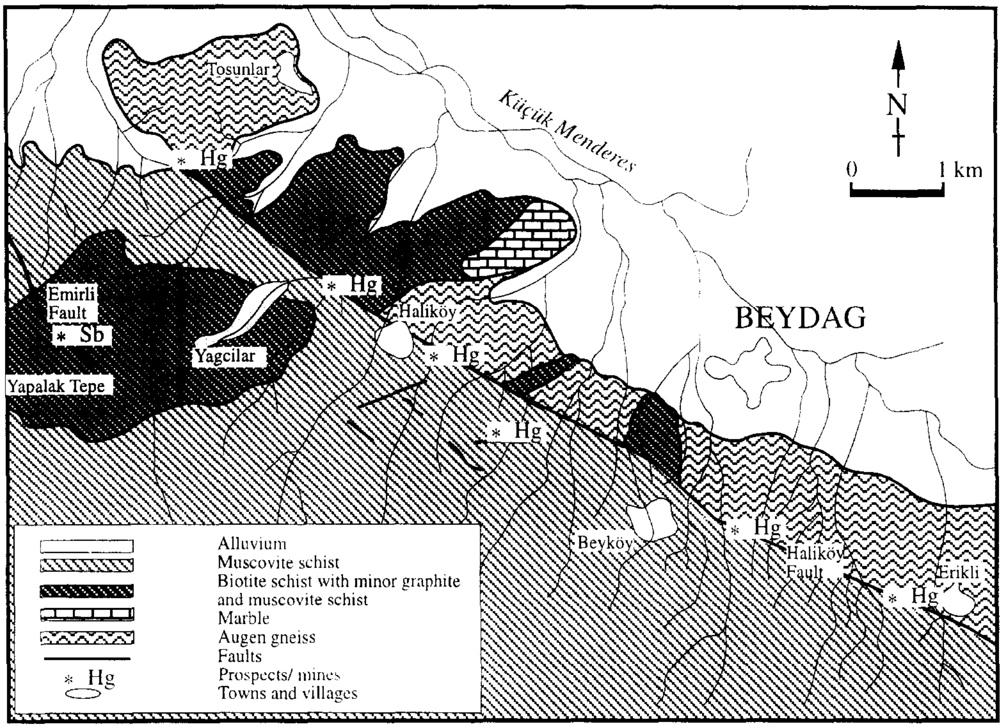

Fig. 10. Haliköy area: sketch geology (from unpublished ETIBANK mapping).

from 290–160°C as observed in co-genetic quartz (Özkan et al., 1993). Arsenopyrite, pyrite, minor sphalerite, chalcopyrite and tetrahedrite were deposited with stibnite at higher temperatures, whereas the later phases of stibnite deposition were coeval with minor Au deposition. Orpiment, realgar and cinnabar constitute a final stage of mineralisation. Alteration is intense, mainly argillic with some secondary dolomite, but restricted to about 20 m around the fault. Geochemical sampling of underground workings and drillcore confirms a strong enrichment in As, Sb, Ag with lesser Pb and Zn. Gold mineralisation at Emirli, generally ranges from 0.5 to 1.0 ppm Au, but with areas associated with silicification and brecciation reaching 10 ppm.

The Halíköy Hg mine operated from 1962 to 1990 at an average grade of 0.3% Hg. Economic Hg mineralisation is restricted to the pods along the Halíköy Fault, the most important of which is immediately to the E of Halíköy village. Mineralisation occurs as disseminations and veinlets in the clay zone within 30 m of the main fault surface (Yildiz and Bailey, 1978). Cinnabar, the main ore mineral, and minor metacinnabar, are accompanied by quartz, pyrite, minor chalcopyrite and marcasite. Underground samples taken along a cross-cut at the Halíköy mine show weak enrichment in Au, generally in the 20–70 ppb Au range with a maximum of 1150 ppb Au. The clay alteration zone shows strong enrichment in As (500–2000 ppm As) with lesser Cu (50–500 ppm Cu), Pb (50–300 ppm Pb) and localised Ag (10–200 ppm). Antimony is at background levels. Wider alteration around the deposit is expressed as kaolinisation in gneisses and sericitisation in schists.

Although not observed, it is possible within the geochemical survey area that small (20×0.2 m) Au-bearing arsenopyrite ± stibnite veins of the type investigated by MTA (1970) to the west and north of the area might occur. Besides arsenopyrite and stibnite, pyrite, minor sphalerite and galena, as well as sulphosalts and scheelite, the veins are Au rich (often > 30 g/t) and contain significant (typically 2000 ppm Co) cobalt. Fluid inclusion studies on these give uncorrected homogenisation temperatures of 300–390°C with a mode of 320°C, suggesting that they

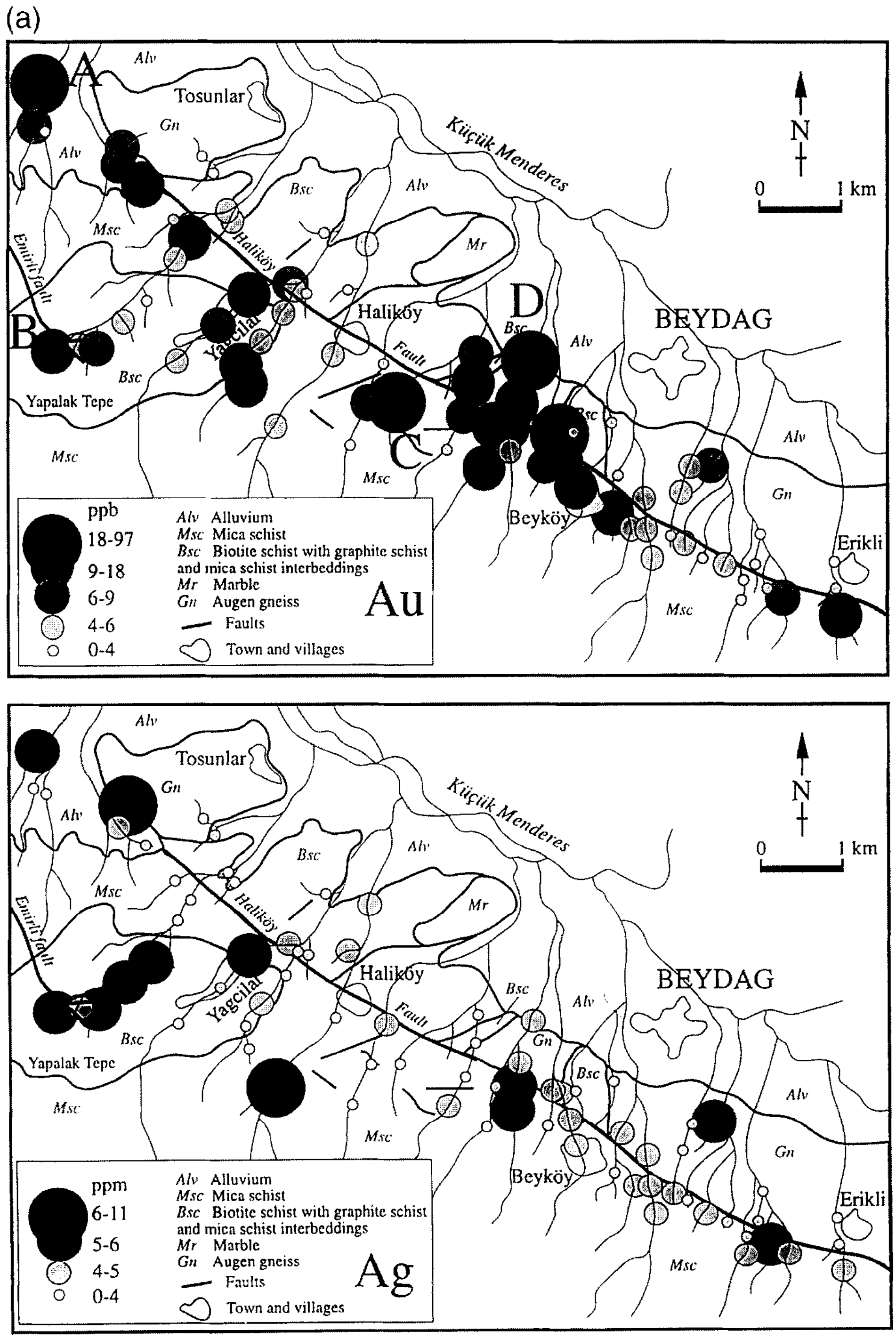

Fig. 11. Halíköy area stream sediments, 8 kg −2 mm material: Au, Ag (a); Sb, As (b). Sub-division based on 50, 75, 90, 95 percentiles as appropriate. Geological units from Fig. 10 are shown in outline.

(b)

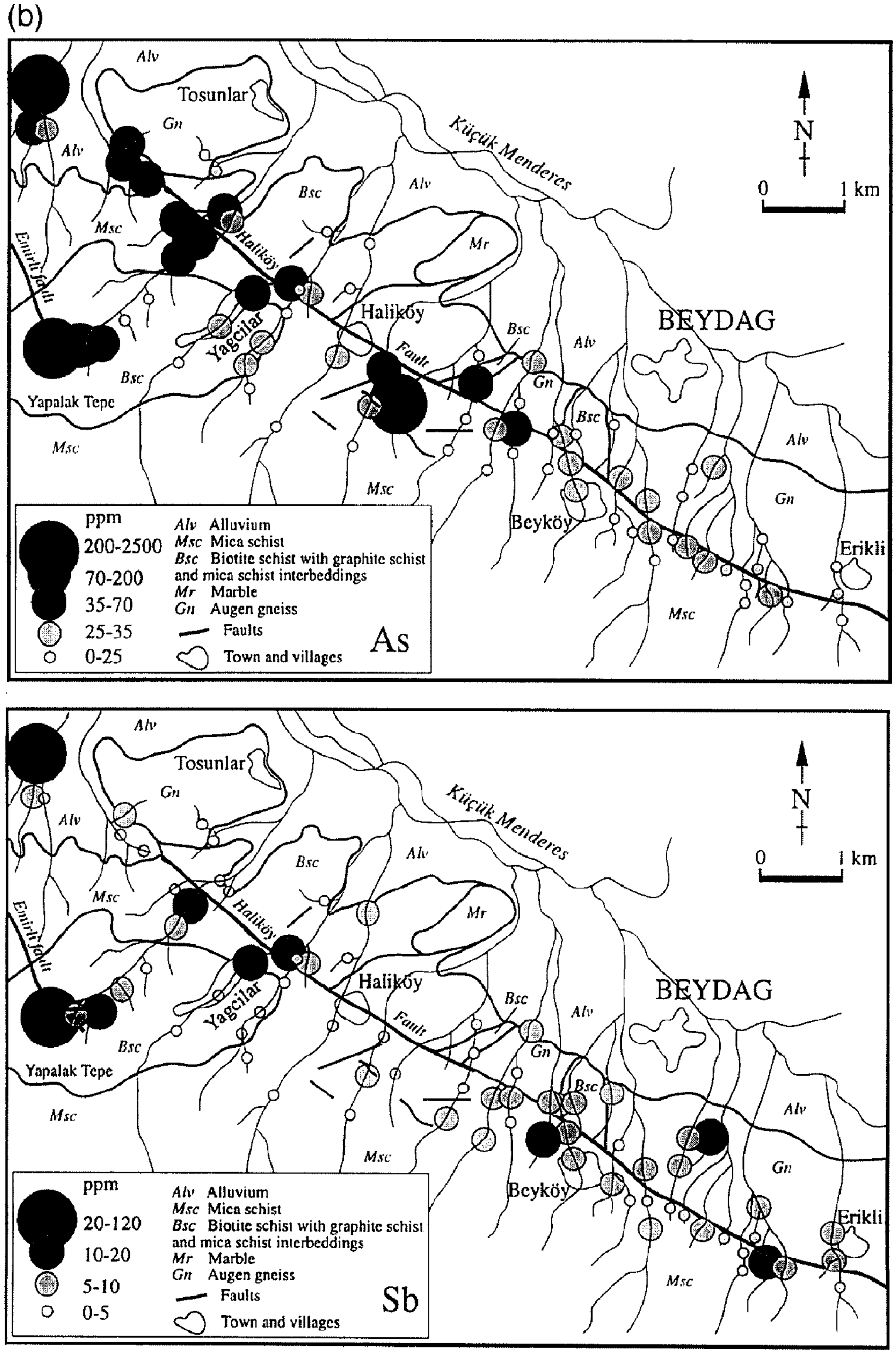

Fig. 11 (continued).

have an origin different to the mineralisation at Emirli.

8.4.3. Stream sediments

Samples of 8–10 kg of −2 mm material were collected at 500 m intervals (Fig. 11) based on the results of the orientation studies at Sarpdağ and Arapdaği.

The extensions of the Emirli structure (A and B, Fig. 11) are detected in the Sb, As, and to some extent in Ag concentration of samples contaminated from trial workings. Fire assayed Au data indicates the NE extension of mineralisation at Emirli with a sample with 66 ppb Au. The southward extension at Yapalak Tepe has a much weaker Au expression. The other Au anomalies reflect gossanous material derived from an As-enriched, Hg-mineralised fault zone (C, Fig. 11) sub-parallel to the Halíköy Fault that had been tested for Hg and an anomaly of unknown source to the north of the Fault (D). The Halíköy Fault and the sericitic alteration zone to the south of it are best shown in the As data, with stronger anomalies to the west of Halíköy.

Base metal data (not shown) shows little contrast with only weak Pb (2–3 × background) and Zn anomalies downstream from the SW extension of the Emirli structure. Sericitic alteration within the area immediately south of the Halíköy Fault is detected in the Al data.

9. Discussion of results from Halíkõy, Emirli, Arapdaği and Sarpdağ

9.1. Elemental associations

Both the data from the orientation areas at Sarpdağ and Arapdaği as well as those from Halíköy confirm the well established association of Au with Sb, As and, on circumstantial evidence, Hg. However the Au prospects examined in this study appear to be relatively Sb-rich compared to those reported elsewhere, reflecting west Turkey's status as an Sb-rich province (Jankovic, 1982). Silver is variable and clearly not exclusively related to Au mineralisation, but also related to base metal-rich parts of the deposits, particularly, as at Emirli, where the deposits have complex parageneses.

The overall occurrence of base metals is variable. All the prospects have some base metal mineralisation but concentrations may be weak. In addition these concentrations may be displaced from the Au-rich parts of the deposits by some hundreds of metres, either laterally or vertically, as shown at Arapdaği. A more extensive study of primary concentration in the Biga area by Pirajno (1995) confirms the vertical zonation suggested by the surficial data at Sarpdağ and he proposed a vertical zonation of Ba–As–Ag–Pb ± Sb in the upper levels to Ba–Au–Cu in the middle to Pb–Zn ± Au in the lower levels, with Sarpdağ being at the upper level. Gold deposition is generally a late phase in deposits with complex parageneses, and as at Emirli, an overprint on pre-existing mineralisation and related to brecciated and silicified parts of the deposit.

9.2. Size of primary targets

Although Emirli and Arapdaği are mainly vein or vein-like deposits they are accompanied by stratabound or disseminated mineralisation that enlarges the primary target size. Halíköy appears to be a simpler case and ore metals and metalloids appear to be confined to the mineralised zone.

The mineralisation at Sarpdağ although disseminated appears also to be a discrete target.

9.3. Secondary dispersion mechanisms and size of trains

Silicification associated with mineralisation at Sarpdağ and Arapdaği has resulted in the main parts of the deposit occurring on present day topographic highs. The dominant mechanism of dispersion of all but the most mobile elements appears to be clastic movement down the steep slopes. The soil traverse data and base of slope stream sediment samples suggest that base of slope sampling is an effective reconnaissance tool in west Turkey as also recommended by Hoffman (1977) and Reimann (1988). Coarse fraction stream sediment anomalies at Sarpdağ do not extend beyond the base of slope. In contrast, anomalies in fine fraction of stream sediment samples extends beyond the base of slope although dilution in larger streams is rapid.

9.4. Secondary dispersion of gold and sample mass

Soil data from both Sarpdağ and Halíköy suggest that Au disperses as clastic grains. As both the deposits are siliceous it is suggested that little free Au is available for placer formation and that the Au is encased in rock matrix. Minor placer development and its detection in panned concentrates shows that release of discrete Au appears to take place after 1–2 km transport. As heavy mineral concentration is limited bulk sediment sampling of fines is a more effective reconnaissance tool than panned concentrate sampling. Comparison of the Arapdaği and Sarpdağ data show the effects of increasing the sample size from 1 to 8 kg. Individual dispersion trains become more coherent, single samples can be more reliably used for the presence or absence of Au and quantitative maps can be made of Au potential. Dispersion trains in the fine fraction appear limited in size and 500 m spacing of second and third order streams coupled with base of slope sampling of first and second order streams are recommended geochemical strategy, as is coarse fraction follow-up to source.

9.5. Usefulness of pathfinder elements in reconnaissance exploration

Although all the prospects discussed have pathfinders (Fig. 5) associated with them there is lateral and vertical primary displacement of some of the more commonly used pathfinder elements from Au, as discussed above. Arsenic and Sb are probably the most useful pathfinders although As anomalies are weak and dispersion trains for Sb are short. In addition both elements are associated with early phase base metal rich mineralisation in more complex deposits such as Emirli. Silver is a useful indicator on both a local and regional scale although ICP-ES data obtained from commercial laboratories generally has too high a detection limit for more subtle anomalies, such as at Sarpdağ. In addition sulphosalt rich mineralisation may give a much stronger Ag response than Au-rich parts of deposits.

All the prospects, except Halíköy, have a base metal response, although their signal is often weak and restricted to parts of the deposit. Lead is the most reliable pathfinder although Cu is also useful. The correlation of Zn with Mn indicates scavenging of Zn by Mn, reducing that zinc's effectiveness and residuals from regression, rather than raw Zn data, should be used to correct for background scavenging. Alteration detectable from multi-element data includes sericitic alteration from acid leach Al data.

Although the pathfinders provide much useful extra data they should only be used as additions to effective Au sampling.

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