Mineral Exploration and Sustainable Development, Eliopoulos et al. (eds)
© 2003 Millpress, Rotterdam, ISBN 90 77017 77 1

Preliminary study of the low-sulphidation epithermal Ovacık gold-silver deposit, western Turkey

A.K. Şener
KSPM Associates Ltd, 3 Dulas Close, Didcot, Oxfordshire, OX11 7UA, United Kingdom

Keywords: Ovacık, gold, silver, low-sulphidation, epithermal, Turkey

ABSTRACT: The Ovacık gold-silver deposit is centred on two major low-sulphidation epithermal quartz veins hosted by partly silicified and extensively clay-altered, andesitic to latitic, porphyritic volcanic rock of Early Miocene age. The veins dip steeply to the north, and strike E-W and WNW-ESE. Economic gold mineralisation in these veins extends for a strike length of 400m for the M-vein and 280m for the S-vein. Gold occurs freely in micro-fissures within quartz with an average diameter of 5µm; sulphide minerals are rare and dominated by pyrite. Base-metal contents are low (generally <40ppm for any given base-metal) and the ratios between Cu-Pb-Zn are approximately equal. The gold-silver ratio is 1:1 and gold occurs typically as electrum with a fineness of ~600-800, while silver occurs in acanthite, freibergite and pyrargyrite, and more rarely as the native metal. The depth of formation of the deposit is interpreted to be <350m based on vein textures and the temperature of formation constrained to <176°C based on the presence of prismatic acanthite. The deposit is probably Late Miocene in age and hosted by faults that are related to bounding normal faults of the Bergama Graben.

1 INTRODUCTION

The Ovacık deposit is located at 39° 4' N and 27° 4' E in western Turkey, approximately 72km due north of the regional capital of Izmir and 11km WSW of the town of Bergama (Fig. 1). Pottery from shallow pits, shafts and drives provide evidence that the deposit was mined in Roman times, but mining activity was not extensive and work appears to have halted due to difficulty of processing the ore.

The deposit contains a total reserve (proven + possible + probable) of 4.19Mt @ 7.6g/t for 31.87 tonnes (1.02Moz) of contained gold, of which 2.4Mt @ 10g/t (24 tonnes) is mineable. Since 2001, the mine has been operated by Normandy Madencilik A.Ş., a subsidiary of Newmont Mining Corporation. The deposit is mined by a combination of open-pit and underground methods and is the first modern gold mine to operate in Turkey.

2 EXPLORATION HISTORY

Eurogold Madencilik A.Ş. rediscovered the deposit in 1989 during a regional BLEG stream-sediment sampling programme. The geochemical programme was initiated after Landsat TM satellite data interpretation had indicated that the region near Ovacık had undergone significant hydrothermal alteration, characteristic of the epithermal systems targeted by the company.

A 3ppb Au BLEG anomaly was followed up with reconnaissance work, and an epithermal quartz vein system was discovered along the crest of Ayıkayası Hill, some 0.5km north of Ovacık village and 0.7km north of the Bergama-Dikili road.

The epithermal character of the veining was recognised and rock-chip sampling returned high-grade Au values. Follow-up diamond drilling in late 1989 confirmed the existence of a potentially economic gold resource. Since 1989, approximately 15,000 m of drilling has been undertaken on and around the deposit area during definition of the ore bodies.

3 REGIONAL GEOLOGY

The Ovacık deposit (Fig. 1) is located on the periphery of the Kozak Igneous Complex (KIC), which was emplaced during the Late Oligocene to Early Miocene (Altunkaynak & Yılmaz, 1998) into regionally and subsequently contact-metamorphosed sedimentary rocks of Permian to Triassic age (Dubertret *et al.* 1973; Kaya & Mostler 1992). The age of these basement rocks is well constrained from a granodioritic gneiss in the Kozak Dağ, which has a mean age of 293±8 Ma (Özmen & Reischmann 1999).

Intrusion of the KIC occurred at 24 to 15 Ma along approximately N-S striking oblique slip faults (Yılmaz *et al.* 2000) that were contemporaneous with regional E-W extension (Altunkaynak & Yılmaz 1998). This structural regime is considered by Seyitoğlu & Scott (1996) to be the result of orogenic collapse of overthickened crust (Şengör *et al.* 1985), which formed during Palaeogene compression.

The Kozak igneous complex is composed of differentiated granodiorite, granite and microgranite, with subordinate quartz-diorites and quartz monzonites (Altunkaynak & Yılmaz 1998). Like many other magmatic rocks in the region, the pluton is a high-K, calc-alkaline suite of predominantly intermediate to felsic composition. Geochemical data indicate that the magmas are hybrid, and were formed from mantle-derived melts, contaminated by crustal rocks (intermediate between I- and S-types). The pluton was emplaced at shallow crustal levels as a caldera-type or subvolcanic pluton (Altunkaynak & Yılmaz 1998). Volcanic rocks, contemporaneous with the emplacement of the plutonic rocks, surround the pluton.

Calc-alkaline magmatic activity waned during the Middle Miocene, although volcanism was rejuvenated briefly during the Late Miocene-Pliocene, when alkaline basalt fissure-eruptions occurred (Altunkaynak & Yılmaz 1998). At the same time, a north-south extensional regime initiated the formation of approximately east-west trending grabens across western Turkey (Yılmaz *et al.* 2000). The deposit is situated on the northern margin of the east-west trending Bergama Graben, the formation of which was initiated during the Plio-Pleistocene and continues to the present (Yılmaz *et al.* 2000).

4 DEPOSIT GEOLOGY

4.1 *Host rocks*

The Ovacık deposit is situated within fine- to coarse-grained variably porphyritic andesitic volcanic rocks related to the intrusion of the KIC. Rocks related to similar calc-alkaline magmatic activity are known locally as the South West Anatolian Porphyry (SWAP) and are regionally extensive in western Turkey. Around the KIC, these rocks consist of An_{35-40} plagioclase (55-85%), hornblende (3-15%), biotite (5-10%) and sanidine (1-40%) phenocrysts (Altunkaynak & Yılmaz 1998). In the mine area, the rocks are latitic in composition. The matrix is microcrystalline and devitrified with apatite, haematite, rutile, titanite and zircon as common accessories. The age of similar rocks in the vicinity vary between 20.8 to 15 Ma in age (Altunkaynak & Yılmaz 1998), corresponding to a Late Oligocene-Middle Miocene age determined from regional studies (Seyitoğlu *et al.* 1997).

Based on the stratigraphic reconstructions of Altunkaynak & Yılmaz (1998), the andesitic volcanic rocks in the vicinity of the mine are of probable Lower Miocene age. These rocks are overlain by Quaternary alluvium to the immediate west and south of the Ovacık mine.

4.2 *Structural geology*

Gold mineralisation at Ovacık is confined to four epithermal quartz veins of which two host the majority of the economic gold resource. The veins are subvertical near the surface but dip steeply (60-70°) to the north at depth and strike WNW-ESE and approximately E-W (Fig. 2). Normal faulting provides the critical structural control to the vein systems.

The two major easterly striking veins, known as the ‘M’ and ‘S’ veins, contain economic resources over an average width of 8m (locally up to 20m) and strike lengths of 400m and 280m, respectively. The veins extend down dip to the north for at least 250m, as defined by drilling to date. The ore bodies plunge steeply to the west, and are controlled by local flexures along the faults hosting the veins. East-northeast striking, post-mineralisation brittle faults, marked by clay-rich fault gouge, offset the veins in places.

The faults hosting the epithermal veins are interpreted as antithetic extensional faults that are related to major east-trending normal faults responsible for the formation of the Bergama Graben. A major graben-bounding normal fault occurs approximately 0.5-1km south of the Ovacık deposit.

4.3 *Mineralisation and alteration*

Gold mineralisation at Ovacık is confined exclusively to the veins and very low-grade enrichment caused by veinlets and microveining in the immediate wallrocks. Multiple generations of quartz and chalcedony veins are commonly accompanied by adularia and calcite, in addition to baryte, sericite and supergene haematite.

The veins show a variety of textures including, colloform-banded and crustiform quartz and chalcedony, and lattice-textured quartz pseudomorphs after calcite. Lesser fine-grained adularia, calcite and minor sulphosalts occur in association with the crustiform quartz. Such textures and mineralogy are characteristic of low-sulphidation epithermal systems that formed at shallow levels and probably less than 200-350m from the palaeosurface (Cooke & Simmons, 2000

Silicification and brecciation are observed in places along the margins of the veins. Some breccias are, in places, bound by a matrix of microcrystalline black silica. Distinct jasperoidal breccias occur in the central parts of the vein systems and are generally associated with lower Au grades. A silicic to argillic envelope characterises the alteration of the immediate country rocks. A quartz-adularia-illite-nontronite assemblage flanks pervasive silicification and a high-density of extension fracture-veinlets in the selvages of the main veins.

Gold occurs as free grains with a diameter of 1-8μm (avg. of 5μm) within micro-fractures in quartz and as micro-clusters associated with iron-oxides, alumino-silicates and rare pyromorphite (Fig. 3). Sulphide minerals are nearly absent (<0.15%) and are dominated by pyrite, which tends to occur as isolated euhedral to subhedral crystals (<30-100μm), with occasional sub-micron inclusions of an unidentified Mo-Pb bearing mineral. Accessory sulphides include prismatic acanthite, non-pseudomorphic after argentite (5-20μm), stibnite (1-10μm), tetrahedrite/freibergite (5-10μm) and rare phases of galena and pyrargyrite.

A 1:1 gold to silver ratio in the deposit is evident from the tenor of the *doré* produced (Newmont fact sheet). However, SEM analysis shows that gold occurs as electrum with a fineness of about 600-800, indicating that a significant amount of silver must occur in other minerals. Mercury and cinnabar are absent from the ore assemblage (mean concentration of Hg in the ore = 0.83ppm), indicating that the veins do not represent the uppermost part of an epithermal mineral system. The ore contains low base-metal contents (usually <40ppm for any given base metal) and the ratios between Cu-Pb-Zn are about equal.

Apart from quartz, gangue minerals include baryte, which is the second most common mineral after pyrite in the ore and occurs as isolated grains (10-100μm) or irregular clusters. Rare phases of apatite, haematite, rutile and zircon were identified. Near-surface weathering has created extensively bleached and clay-altered zones that flank the vein systems.

4.4 *Timing of mineralisation*

The relative timing of gold mineralisation at Ovacık is constrained by the age of the host rocks. Many epithermal precious-metal deposits in western Turkey are hosted by volcanic rocks of Late Oligocene to Middle Miocene age (Oygur, 1997; Sayılı & Gonca, 1999) and gold mineralisation is well-constrained to the Middle Miocene for the genetically similar Karşıyaka gold occurrences that occur just north of Izmir, (Sayılı & Gonca, 1999), about 65km south of Ovacık.

Gold mineralisation at Ovacık is clearly associated with ~E-W structures that formed during N-S extensional tectonism. In western Turkey, earliest N-S extension occurred during the Late Miocene and the second phase occurred during rejuvenated extension that initiated in the Plio-Pleistocene (Yılmaz *et al.*, 2000). Consequently, the age of gold mineralisation at Ovacık is equivocal and could be either Late Miocene or Plio-Pleistocene in age (i.e., <12Ma), although the Late Miocene is the most likely age of formation for this deposit.

5 DISCUSSION AND CONCLUSIONS

The Ovacık deposit is interpreted to represent part of a low-sulphidation epithermal mineral system, which was active during the Late Miocene. The presence of lattice-textured quartz and adularia suggest that the deposit formed from a boiling fluid of low to moderate salinity (0-13wt% NaCl equiv.) at near-neutral pH (Henley 1993; Cooke & Simmons 2000). Gold in this system is interpreted to be transported by a reduced fluid carrying $Au(HS)_2^-$ complexes (Cooke & Simmons 2000). The existence of chalcedony indicates that rapid cooling resulted in deposition within a temperature range of 100-190°C, at a depth of less than 100m below the palaeo-watertable (White & Hedenquist 1990). More specifically, the identification of prismatic crystals of acanthite indicates that the temperature of vein formation was less than 176°C (Kracek 1946), also suggesting a shallow depth of formation. This temperature of vein formation constrains the palaeo-depth to <100m using hydrostatic vapour-saturated (boiling point) P-T curves for pure water. This range of depth is further constrained by the vein textures and alteration that are characteristic of shallow-depth deposits, which formed less than 350m from surface (ref?).

ACKNOWLEDGEMENTS

This preliminary study was the result of three short visits to the Ovacık mine in the summers of 1997, 2001 and 2002. Zafer Kara and Hasan Çiftehan, mine geologists at Ovacık, are thanked for their time during the last two visits and in providing the samples necessary for this study. The Centre for Microscopy and Microanalysis at the University of W.A.

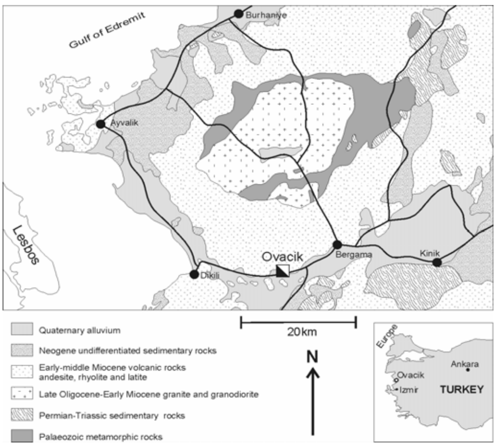

Fig. 1: Location of the Ovacık deposit and regional geology of the Kozak Igneous Complex.

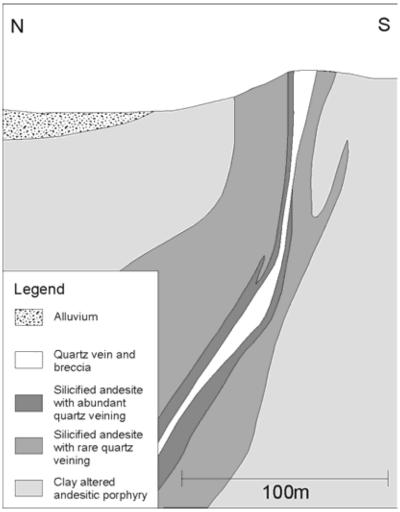

Fig. 2: Cross-section through the M-vein, facing east. Courtesy of Normandy Madencilik A.Ş.

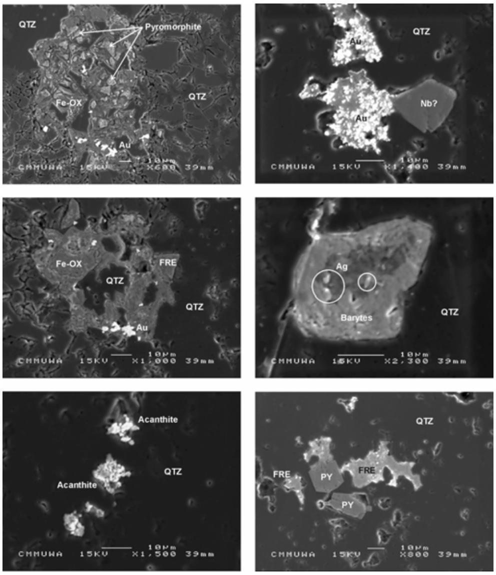

Fig. 3: Scanning electron-microscope images of mineralisation at Ovacık. Annotations: Gold (Au); silver (Ag); quartz (QTZ); pyrite (PY); freibergite (FRE); iron oxides (Fe-OX); niobium-bearing mineral (Nb?). Note prismatic acanthite in lower left image.

(Perth) are thanked for use of the SEM. Steve Garwin is thanked for reviewing this paper and providing some helpful comments. Newmont are thanked for providing permission to publish.

REFERENCES

Altunkaynak, S. & Yılmaz, Y. 1998. The Mount Kozak magmatic complex, Western Anatolia. *Journal of Volcanology and Geothermal Research* 85: 211–231.

Cooke, D.R. & Simmons, S.F. 200. Characteristics and genesis of epithermal gold deposits. *Reviews in Economic Geology* 13: 221–244.

Henley, R.W. 1993. Epithermal gold deposits in volcanic terranes. In: *Gold Metallogeny and Exploration*, 133–164.

Kaya, O. & Mostler, H. 1992. A Middle Triassic age for low-grade greenschist facies metamorphic sequence in Bergama (Izmir), western Turkey: the first paleontological age assignment and structural-stratigraphic implications. *Newsletter for Stratigraphy* 26: 1–17.

Kracek, F.C. 1946. Phase relations in the system silver-sulfur and the transitions in silver sulfide. *Transactions of the American Geophysical Union* Vol. 27: 367–374.

Dubertret, L., Kalafatçıoğlu, A., Pamir, H.N. & Erentöz, C. 1973. *1:500,000 Ölcekli Türkiye Jeoloji Haritası: Explanatory Text of the Geological Map of Turkey*. Maden Tetkik ve Arama Enstitüsü, Ankara.

Oygur, V. 1997. Anatomy of an epithermal mineralization; Mumcu (Balikesir-Sindirgi), inner-western Anatolia, Turkey. *Bulletin of the Mineral Research and Exploration Institute of Turkey*. 119: 29–39.

Özmen, F. & Reischmann, T.J. 1999. The age of the Sakarya Continent in W Anatolia: implications for the evolution of the Aegean Region. *Journal of Conference Abstracts* Vol. 4: 36.

Sayılı, I.S. & Gonca, S. 1999. Geology, petrography and precious metal mineralizations of Altintepe and Cilektepe sectors of Karsiyaka ore occurrences, Izmir, Turkey. *Bulletin of the Mineral Research and Exploration Institute of Turkey* 121: 33–49.

Seyitoğlu, G. & Scott, B.C. 1996. The cause of N-S extensional tectonics in Western Turkey: Tectonic escape vs back-arc spreading vs orogenic collapse. *Journal of Geodynamics* 22: 145–153.

Seyitoğlu, G., Anderson, D., Nowell, G. & Scott, B. 1997. The evolution from Miocene potassic to Quaternary sodic magmatism in western Turkey: implication for enrichment processes in the lithospheric mantle. *Journal of Volcanology and Geothermal Research* 76: 127–147.

Şengör, A.M.C., Görür, N. & Şaroğlu, F. 1985. Strike-slip deformation basin formation and sedimentation: strike-slip faulting and related basin formation in zones of tectonic escape: Turkey as a case study. In: *Strike-slip Faulting and Basin Formation. Society of Economic Paleontologists and Mineralogist Special Publicatio*. 37: 227–264.

Yılmaz, Y., Genc, S.C., Gürer, F., Bozcu, M., Yılmaz, K., Karacık, Z., Altunkaynak, S. & Elmas, A. 2000. When did the western Anatolian grabens begin to develop? In: *Tectonics and Magmatism in Turkey and the Surrounding Area. Geological Society Special Publications* 173: 353–384.

White, N.C. & Hedenquist, J.W. 1990. Epithermal environments and styles of mineralisation: variations and their causes, and guidelines for exploration. *Journal of Geochemical Exploratio*. 36: 445–474.