‘T’-type mineralisation – a pseudo-epithermal style of VHMS associated gold mineralisation, Cyprus

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Abstract. A recent investigation of five VHMS prospects located in the Troodos ophiolite, Cyprus (Tourounjia, Alestos, Papoutsi, Kokkinovounaros and Agrokipia B), has indicated the possible presence of a pseudo-epithermal style of mineralisation. This is based on the presence of anomalous Au concentrations and hydrothermal brecciation. Short wavelength infrared (SWIR) analysis using a portable infrared mineral analyser (PIMA) was carried out to investigate the alteration mineralogy of these deposits and compare them with Cyprus-type mineralisation. Three distinct styles of alteration are present, two represent typical Cyprus-type VHMS alteration, with acidic alteration, not previously documented in Cyprus-type VHMS deposits, being the third. A process of sub-seafloor boiling, as inferred to be occurring presently in the Lau basin, most easily explains the formation and spatial link between acidic alteration and the zones of explosive hydrothermal brecciation present in the Tourounjia and Alestos deposits. It also provides a model to account for the high Au content found in the boreholes from Tourounjia.

Keywords. VHMS, epithermal, Troodos ophiolite, gold

1 Introduction

Cypriot copper deposits are considered to be a type example of a massive sulphide deposit produced at an oceanic spreading ridge (e.g. Hannington et al 1998). These deposits, formed at the seawater-lava interface and underlain by a mineralised stockwork zone are derived from metal-bearing exhalative fluids. Modern analogues are black smokers, as seen in mid-ocean and supra subduction zone ridge settings today (e.g. the TAG mound on the Mid-Atlantic Ridge, and the Lau Basin).

Recent investigation of the Kokkinovounaros, Papoutsi, Alestos and Tourounjia prospects (Figure 1) located in the Troodos ophiolite, Cyprus, has led to the proposal of a possible pseudo-epithermal style of mineralisation on account of high Au grades and explosive hydrothermal brecciation (Maliotis and Herzig 2000). Short wavelength infrared (SWIR) analysis of core and chippings from each of these deposits was undertaken using a portable infrared mineral analyser (PIMA-SP) with a total of over 500 analyses. The project aimed to evaluate the alteration mineralogy of these deposits and to compare them with a typical Cyprus-type VHMS deposit, Agrokipia B (Cyprus Crustal

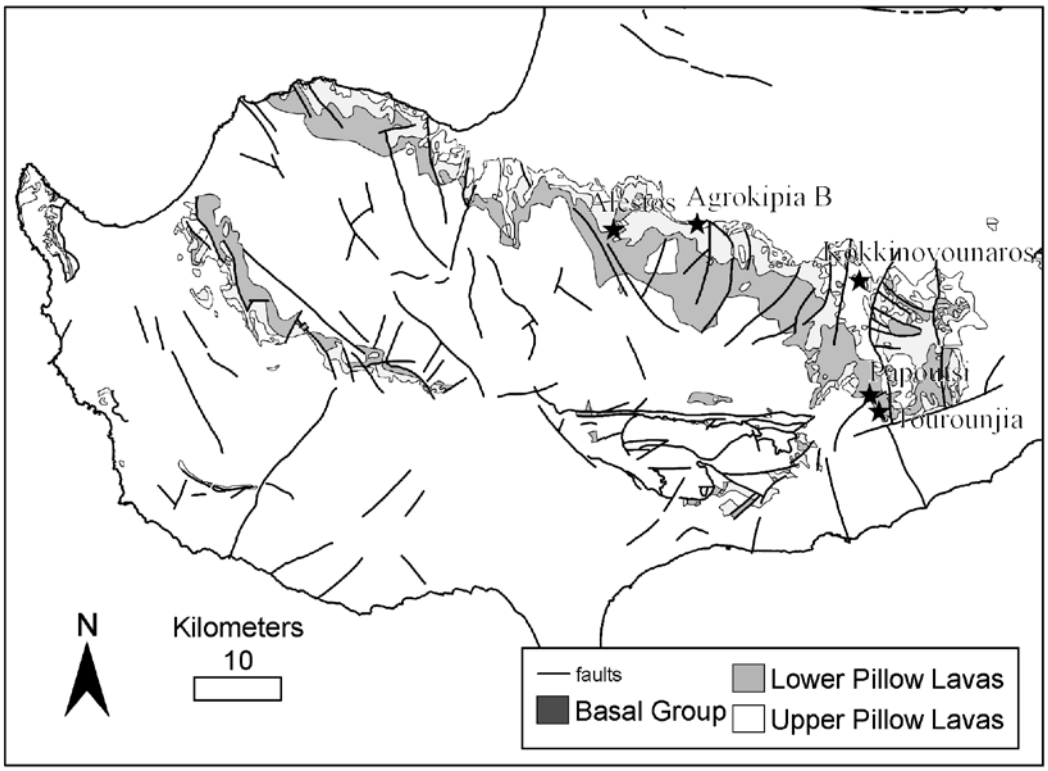

Figure 1. A map of the Troodos ophiolite showing the locations of the five deposits studied in relation to host rock lithologies.

Project, Borehole CY-2A—Herzig and Friedrich, 1987).

2 Discussion

The data obtained show three distinct styles of alteration. Two of these, named P and M-type alteration (Richards 1989), are typical of Troodos VHMS deposits. They have similar external alteration zones, but different internal zones. P-type (named after the Pitharokhoma deposit) alteration is generally characterised by a chlorite-illite facies with a leached core. Conversely, M-type (from the Mathiati deposit) alteration shows no illite or rectorite in the core of the alteration halo and possesses a central zone with a chlorite, quartz, pyrite and anatase assemblage, referred to as chlorite-quartz-pyrite facies alteration. Chlorite in the chlorite-illite-pyrite facies is more Fe-rich. The third type (discussed below) shows the presence of possible hypogene acidic alteration minerals—dickite and nacrite.

The boreholes from the Agrokipia B, Kokkinovounaros and Papoutsi deposits are associated with alteration minerals typical of Cyprus-type VHMS deposits. The Agrokipia B and Kokkinovounaros deposits contain P-type alteration with abundant chlorite and illite in addition to epidote and minerals of a supergene origin. Illite was not recorded in the Papoutsi prospect alteration assemblage implying an M-type alteration style, although the chlorites exhibited Mg-rich spectral characteristics more consistent with P-type alteration. No sign of hydrothermal brecciation was found in these deposits and it is likely that the brecciation present is tectonic in origin.

Analysis of drill core from Alestos revealed a predominately P-type alteration with chlorite and illite being identified. Dickite was identified in three samples taken from minor zones of hydrothermal brecciation, identified by the presence of sub-angular to rounded clasts supported by a silicic matrix. Field observations at Tourounjia also suggest the brecciation present is also of hydrothermal origin. PIMA analysis of two boreholes from Tourounjia showed that the kaolin group minerals are dominant with the frequent identification of kaolinite, nacrite and dickite as well as supergene minerals. Kaolinite was the most commonly identified mineral in the Tourounjia boreholes, although nacrite was also common, present in around 40% of analyses of borehole material, and dickite subsidiary. The spatial link between the occurrences of the kaolin group

minerals to zones of hydraulic brecciation implies that their genesis is related and, as nacrite is a relatively high temperature mineral, is most likely to have occurred at a similar time. Though supergene processes cannot be discounted, the presence of relatively abundant high-temperature kaolinite polymorphs (nacrite and dickite) suggests that at least some of the elevated gold, silver and arsenic values are the result of hypogene mineralisation. In one of the Tourounjia boreholes chlorite, illite and epidote were also identified. Advanced argillic-style alteration, which formed the kaolin group minerals, has not hitherto been identified in Cyprus-type VHMS deposits and is named here T-type alteration (after Tourounjia).

Au grades are at least an order of magnitude greater than in other VHMS deposits on Cyprus, with As grades ~20 times higher and Ag grades five times higher. It is considered unlikely that supergene enrichment alone could have increased the content of Au, Ag or As within the Tourounjia deposit as the increase in grades, compared to levels seen in other deposits both affected and unaffected by supergene enrichment, is too high to reflect merely supergene enrichment. This implies that the grades of these deposits reflect the primary mineralisation processes within the deposit rather than later supergene enrichment of a typical VHMS deposit. Mineralisation at Tourounjia is hosted by silicified breccia units, and consists of dominant pyrite, with subsidiary covellite, chalcopyrite and sphalerite. Minor amounts of arsenopyrite and cinnabar, minerals rarely associated with VHMS deposits but common in epithermal deposits, are present as overgrowths on pyrite, sphalerite and copper sulphides. Chalcopyrite and sphalerite are seen as early phases with covellite replacing and coating pyrite, chalcopyrite and sphalerite. Small amounts of galena were also identified through the use of scanning electron microscopy, although no gold was identified.

3 Formation of 'T' type mineralisation

The kaolin minerals present in the Tourounjia deposit may have been formed by three hypogene processes: (i) the genesis of acidic fluids through oxidation of H_2S; (ii) magmatic input or (iii) by boiling. The last two methods are analogous to the genesis of terrestrial high or low sulphidation epithermal deposits. Oxidation of H_2S requires a sulphur content higher than the S_2:Fe ratio and more oxidising conditions than those in which the other Cyprus VHMS deposits formed. The input of magmatic fluids to create acidic fluids is another possible method, as proposed by Sillitoe et al (1996) to explain acidic alteration within shallow Kuroko-type VHMS deposits and the presently active Hine Hina hydrothermal field of the Lau Basin, a supra-subduction zone spreading centre analogous to the possible setting of the Troodos ophiolite. However, it is questionable whether the magmas that formed the Troodos ophiolite are sufficiently rich in magmatic volatiles to provide the necessary input to form the Au-rich zones seen in the Tourounjia deposit.

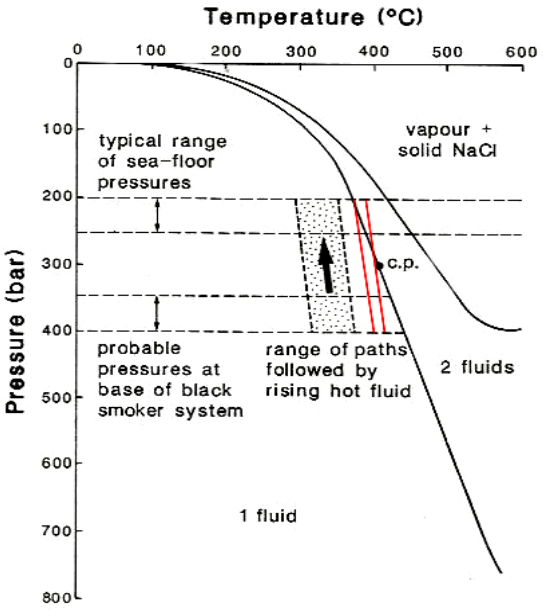

Figure 2. A P-T diagram for a NaCl-H_2O solution of seawater salinity (3.2wt%). c.p is the critical point for seawater. The typical range of seafloor pressures corresponds to normal mid-ocean ridge depths of 2000 to 2500 m. The probable pressures at the base of the hydrothermal system correspond to hydrostatic pressure 1500 to 2000 m below the seafloor. The path of normal Cyprus type mineralising fluids rising from the base of the system to the seafloor is plotted in the stippled region. The path of the raised temperature fluids needed to produce boiling is outlined. (Adapted from Cowan and Cann, 1988)

Our preferred process for acidic fluid generation at Tourounjia is one of sub-seafloor boiling, as inferred to be occurring presently in the Lau basin. This most easily explains the formation and spatial link between acidic style alteration and zones of explosive hydrothermal brecciation in the Tourounjia and Alestos deposits. It also provides a model to account for the high Au content found in the boreholes from Tourounjia. Boiling has been well documented in Kuroko-type systems, but has not been encountered in VHMS deposits in the Troodos ophiolite as the depths inferred from

overlying sediments and modern analogues implied that at these depths (2000-2500m) mineralising fluids of up to 350°C would not boil.

As the phase diagram in Figure 2 indicates, decreasing pressure (e.g. uplift of the hydrothermal field by ~500m) or increasing the temperature of the hydrothermal fluids could cause subcritical phase separation and boiling. These conditions are encountered in modern-day hydrothermal black smokers – such as the Vai Lili hydrothermal field in the Lau Basin (Herzig et al. 1993) and the Northern Fiji basin (Luders et al 2002). This boiling also allows the deposition of Au, not commonly encountered in the Troodos VHMS deposits, as the typical temperatures encountered inhibit the precipitation of Au (from Au(HS)) until after the fluids have been vented from the black smoker. However, boiling of the hydrothermal fluids beneath the seafloor would allow the precipitation of Au, Ag and As seen in the Tourounjia prospect.

Further work currently being undertaken using XRD analyses will clarify the alteration assemblages and mineralisation processes within these atypical Au-rich Cyprus-style VHMS deposits. Stable isotope studies of samples taken from Tourounjia may allow the source of the hydrothermal fluids to be determined.

Acknowledgements:

This work is part of a collaborative research programme between the Geological Survey Department, Cyprus and the British Geological Survey and is funded by the Government of the Republic of Cyprus. The Hellenic Mining Company Ltd, Eastern Mediterranean Minerals (Cyprus) Ltd. and Oxiana Resources NL are also thanked for access to a variety of proprietary information. Permission to publish for JN, & AGG is by the Director, BGS, NERC, UK and for SN by the Director, GSD, Cyprus.

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