Hybrid Carlin gold and core complex exhumation sulphide mineralization: the Asimotrypes deposit of submicroscopic gold, Rhodope Massif, N. Greece

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ABSTRACT: The Asimotrypes deposit of submicroscopic Au, NE Greece, is hosted by marbles of the Rhodope Metamorphic Core Complex in the vicinity of the regional Neogene SW dipping low-angle Strymon Valley Detachment system. Based on geological and geochemical characteristics, the Asimotrypes Au deposit may be interpreted as an orogenic collapse-related hybrid system, bearing similarities to both Carlin-type Au deposits and base–metal sulphide deposits associated with metamorphic core complex exhumation and detachment faults. Extensional structures like the Strymon Valley Detachment fault system may have played a critical role for Au mineralization by providing feeder structures that concentrated ore fluids, driven by uplift, high heat flow and increased fracture permeability resulting from crustal extension, at the intersections with permeable and chemically favourable carbonate strata (*i.e.* marbles).

KEYWORDS: hybrid, Rhodope metamorphic core-complex, Carlin Au, carbonate-hosted Au

1 INTRODUCTION

A genetic link between hydrothermal base- and precious-metal mineralization and fluid circulation driven by high heat flow associated with metamorphic core complex exhumation and uplift along extensional low–angle detachment fault systems (mainly of Oligocene age), has been recently recognized in the Rhodope Massif (Blundell *et al.* 2005; Marchev *et al.* 2005). This relationship is well known from precious and base metal ore districts in Canada and the western USA (Spencer & Welty 1985; Beaudoin *et al.* 1991; 1992), and it has been recently suggested in the Ada Tepe syndetachment sediment-hosted epithermal Au deposit (Marchev *et al.* 2004), and the Madan core-complex Pb-Zn sulphide replacement and vein-type deposit (Kaiser-Rohrmeier *et al.* 2004). The carbonate-hosted Asimotrypes Au deposit occurs in the footwall of a large Neogene low-angle extensional fault system, the Strymon valley detachment (SVD) System (Dinter & Royden 1993; Dinter 1998). The SVD has been associated with the unroofing of the Rhodope Metamorphic Core Complex (RMCC) (Dinter & Royden 1993; Sokoutis *et al.* 1993; Dinter 1998) that represents core complex exhumation of basement rocks, during late Oligocene (30 Ma) (Lips *et al.* 2000) or early-Middle Miocene [26 Ma (Krohe & Mposkos 2001) or 21 Ma (Dinter 1998)]–early Pliocene (Dinter 1998) NE-SW extension of the Alpine collisional orogen in NE Greece. Therefore, it offers a very good opportunity to study the origin of Au mineralization in relation to extension and core complex formation, in the framework of the recent genetic hypotheses on hydrothermal mineralization and late-orogenic evolution of the Rhodope Massif (Blundell *et al.* 2005; Marchev *et al.* 2005).

2 GEOLOGICAL SETTING AND MINERALIZATION

The Asimotrypes submicroscopic Au deposit is hosted by marbles of the “Transitional Unit” of the Pangeon Mountain, Rhodope Massif, NE Greece that belongs to the Rhodope Metamorphic Core Complex (RMCC). The Pangeon Mountain forms a domed structure consisting from top to bottom of: (1) a “carbonate unit” of ~500m thickness comprising sheared white coarse-grained calcitic marble with intercalations of dolomite lenses and ribonned-crystalline siliceous marble at its lower part. (2)

a “transitional unit” ~600m thick: an early Miocene regional ductile shear zone consisting of alternating layers of albite-gneiss (20-25m thick) and mica-schists (5-15m thick) and lenses or blocks of mylonitized ribonned and foliated siliceous marble (a few to 100m thick) and actinolite-plagioclase amphibolite; (3) the “Pangeon gneiss”, ~1500m thick, and consists of plagioclase-rich paragneiss and mica schist. Calc-alkaline late kinematic granitoids were emplaced into the crustal sequence and underlie the entire Pangeon Mountain. These rocks are medium-grained to locally porphyritic granodiorite and are known as the Pangeon granodiorites. (Mesolakia, Mesoropi, and Nikisiani plutons). These bodies have been dated at 13-15 Ma (Harre *et al*. 1968), and have been reinterpreted by Dinter & Royden (1993) as cooling ages related to the unroofing of the Symvolon pluton in the footwall of the Strymon Valley Detachment.

The mineralization has been developed in the vicinity of the regional SW dipping low-angle Strymon Valley Detachment system. Mineralization is clearly post-metamorphic and related to syndeformational fluid flow in a complex and dynamic environment linked to extension, decompressive uplift through the ductile-brittle transition, and concurrent exhumation of the RMCC.

The main Asimotrypes mineralization occurs in the form of parallel to the shear planes elongate discontinuous replacive sulphide-bearing orebodies that consist mainly of quartz, and sericite-clay minerals, as well as rare calcite- and dolomite-relics; sulphides may constitute up to 35 % by volume. These orebodies are 1-2m wide, ~1 m thick and ~5m long; they contain, or are separated by, complex mixtures of phyllonitic, variably silicified, sulphidized, argillized and locally dedolomitized wall rock. They occur at the intersections of steep NW-trending feeder quartz-veins with several marble/micaschist horizons within shear planes parallel to the Strymon Valley Detachment system. Sulphide ore is dominated by arsenopyrite and As-pyrite with subordinate sphalerite, galena, chalcopyrite, pyrrhotite, Bi-Pb± Sb sulphosalts, and marcasite. Gold is invisible in arsenopyrite and As-pyrite.

3 FLUID INCLUSIONS

Quartz that hosts the auriferous sulphides is characterized by ductile strain textures overprinted by brittle fractures; it contains Type I carbonic CO_2 ($\pm H_2O$) and Type II aqueous-carbonic H_2O-CO_2-NaCl inclusions with low to moderate salinity (0.6-7.3 mass% NaCl equiv.) randomly coexisting with Type III naturally decrepitated/leaked type IV, and rare Type III aqueous H_2O-NaCl ($\pm CO_2$) inclusions· most type III inclusions occur in crosscutting brittle fractures. Natural decrepitation, and leakage, textures of type IV inclusions are attributed to internal overpressures due to decompression. A wide range in types I and II fluid inclusion CO_2:H_2O phase ratios, calculated bulk densities and apparent P-T trapping conditions indicate heterogeneous fluid state due to a combination of CO_2-H_2O immiscibility, fluid mixing, and post-entrapment modifications accompanying decompression.

The Au-bearing fluids were probably trapped at 250-300^{o}C at pressures between 1 and 3 kbar under transitional conditions from near-lithostatic (*i.e.* 12 to 4 km) to hydrostatic conditions (*i.e.* 5 to <1 km) where deep hot (> 300^{o}C) CO_2-rich near-lithostatic (over pressured) fluids come to contact with shallow aqueous low salinity and cooler hydrostatic fluids. Decompression probably occurred at rather constant temperatures between 250 and 300^{o}C implying sustained heat flow due to rapid uplift, and may have caused CO_2-H_2O fluid unmixing of the deep fluid, as well as mixing of the two fluids.

4 STABLE ISOTOPES

$\delta^{13}C$ values in marble calcite range between 1. 9 to 2.9 ‰ and are indicative of a marine environment of deposition.$\delta^{18}O$ values of the gold-bearing quartz range between 20.8 and 22.6 ‰. The estimated $\delta^{18}O_{fluid}$ values at the inferred temperatures of mineralization range from 11.8 to 16 ‰ and overlap with the measured $\delta^{18}O$ values of fluid inclusion water extracted from mineralized quartz (15.8 -16.5 ‰) suggesting a highly exchanged crust-equilibrated meteoric fluid (Goldfarb *et al.* 2004; Kuehn & Rose 1995). Measured δD values for inclusion fluids from auriferous quartz, range between -125 and -105 ‰, indicate variably exchanged meteoric water (*e.g.* Cline *et al*. 2005). Gold-associated hydrothermal sulphides are characterized by $\delta^{34}S$ values between +2.2 to +3.1 ‰, with the sulphur derived through leaching of metamorphic rocks (*e.g.* (Ohmoto & Goldhaber 1997).

5 DISCUSSION

The Asimotrypes Au deposit shows affinities to three deposit types: (i) Base metal sulphide deposits associated with metamorphic core complex exhumation, (ii) Carlin-type Au and (iii) orogenic Au deposits. Asimotrypes shares a broadly similar extensional tectonic setting, metamorphic core complex host rocks, structural control, and possible mineralization timing with the Pb-Zn(-Ag)-dominated core complex vein and replacement deposits (CCVR) in the Bulgarian Rhodope (Marchev *et al* 2005), and as well as extensional core complex-related Ag-Pb-Zn vein and replacement deposits in Canada (Beaudoin *et al.* 1991; 1992). Moreover, ore and fluid geochemisty, and hydrothermal alteration show many features in common with Carlin-type Au deposits in Nevada (Hofstra & Cline 2000; Kuehn & Rose 1995) and China (Rui-Zong *et al.* 2002), although the host rocks are different. These are: (1) association with shear zones at the ductile-brittle transition; (2) localization of Au ore at intersections of extensional structures with permeable and reactive carbonate strata (i.e. marbles); (3) complete silicification and sulphidation of impure carbonate strata, and spatially coincident dedolomitization and argillization; (4) refractory gold in As-pyrite and arsenopyrite; (5) fluids that are CO_2-rich with evidence of CO_2-H_2O immiscibility and ^{18}O-enriched at the inferred temperatures of mineralization between 250 and 300°C (*i.e.* 12-13.5 $^{o}/_{oo}$ at 250°C); (6) $\delta^{18}O_{fluid}$ and δD_{fluid} composition showing the involvement of meteoric waters; and, (7) fluid inclusion and isotope evidence for interaction of deep- and shallow-level fluids. Some of the above features are also shared by CCVR ores in Canada that were formed during late stages of orogenic collapse (Beaudoin *et al.* 1991; 1992). Furthermore, the fluids of Asimotrypes have all the features that are typical of orogenic gold deposits in metamorphic belts (Goldfarb *et al.* 2005). However, Asimotrypes differs substantially from orogenic gold deposits because most of the latter are the products of fluids associated with major mantle–crustal devolatilization, magmatism and deformation associated with evolving collisional to transpretional orogeny (Goldfarb *et al* 2005); whereas Asimotrypes has been associated with mixing of deep-and shallow- level fluids during post-orogenic extension.

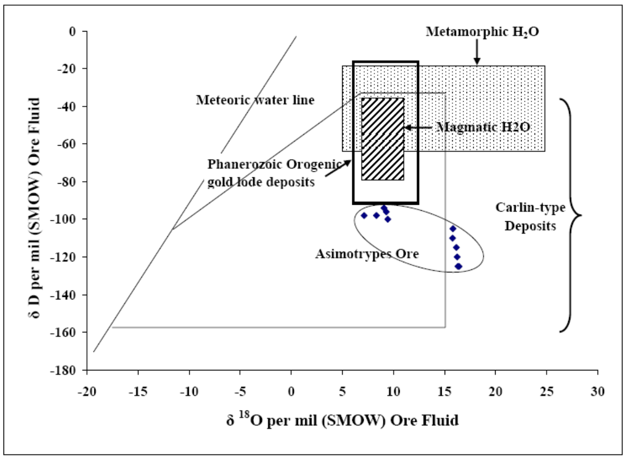

Figure 1. Plot of $\delta D_{inclusion\ fluids}$ versus $\delta^{18}O_{fluids}$ of the Asimotrypes gold deposit. The isotopic composition of the Asimotrypes fluids clearly lies outside of the metamorphic and magmatic water fields. Isotopic composition of the Asimotrypes hydrothermal fluids plots clearly within the range of values that characterize ore fluids associated with Carlin-type gold deposits in Nevada and SW China (Rui-Zhong *et al.* 2002; Hofstra & Cline 2000).

6 CONCLUSIONS

The classification of the Asimotrypes mineralization into conventional Au metallogenetic models is not clear-cut, and based on geological and geochemical characteristics it may be interpreted as an orogenic collapse-related hybrid system bearing similarities to both Carlin-type Au deposits and Pb+Zn+Ag deposits associated with metamorphic core complex exhumation and detachment faults. The Strymon Valley Detachment fault system may have played a critical role for Au mineralization by providing feeder structures that concentrated ore fluids, driven by uplift, high heat flow and increased fracture permeability resulting from crustal extension, at the intersections with permeable and chemically favorable strata (*i.e.* marbles).

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