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Mineral Deposits: Processes to Processing

Edited by
C.J. Stanley et al.
Department of Mineralogy, Natural History Museum, London, UK

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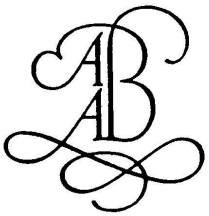

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Fluid inclusion and stable isotope (O, H) evidence for the formation of the Asimotrypes mesothermal gold deposit, N. Greece

D.G. Eliopoulos
Institute of Geology and Mineral Exploration, Athens, Greece

J. Naden
British Geological Survey, Keyworth, UK

S. P. Kilias
Geology Department, Athens University, Greece

ABSTRACT: Microthermometric studies in gangue quartz from the Asimotrypes mesothermal gold deposit indicate early ore deposition at P-T conditions of 275°C-310°C and 2.7-3.1 kb during unmixing of the mineralizing fluids. This was followed by deposition at temperatures down to 130°C and low near-surface pressures. Whole rock O ($\delta^{18}O$: 15.79 to 16.48 per mil) and H (δD: -105 to -125 per mil) isotope data suggest that mineralizing fluids are of meteoric origin perhaps incorporating a metamorphic fluid component. Fluid inclusion and stable isotope data of the Asimotrypes gold mineralization are consistent with genesis from deeply convecting meteoric water driven by regional uplift through rocks undergoing retrogressive greenschist facies metamorphism.

1 GEOLOGICAL SETTING

The Asimotrypes mesothermal gold deposit is located in the Pangeon Mt. (E. Macedonia, N. Greece) which geologically is part of the western Rhodope metamorphic province (RMP). The rocks of the western part of the RMP that crop out between the Strymon and Nestos Rivers, and include Pangeon Mt). They represent the metamorphic core complex of an Alpine collisional orogen, that was extended and tectonically unroofed in the footwall of the Strymon Valley detachment system beginning in Middle Miocene time (Dinter, 1994, 1998). These rocks comprise mainly marbles, gneisses, and schists of Paleozoic to Mesozoic age intruded by Oligocene granodiorites. Alpine metamorphism (Upper Cretaceous-Middle Eocene) reached upper greenschist to lower amphibolite conditions (T=550°-600°C, P=13.5-15 bar). A low pressure, greenschist facies (T=350°-400°C, P=3-5 bar) retrograde overprint during uplift marked the end of Alpine metamorphism in Miocene (Mposkos, 1994). Post-metamorphic Miocene uplift has been recognized in the Pangeon Mt and it was ascribed to Late Cenozoic extensional tectonics (Wawrzenitz et al., 1994).

2 MINERALIZATION

Mineralization occurs in irregular quartzite pods or lenses developed in marble along the contact with schists (replacement style), and quartz veins cross-cutting the marble (shear-zone style). The Asimotrypes ore consists mainly of arsenopyrite, pyrite and gold, with subordinate sphalerite, galena, chalcopyrite, pyrrhotite, tetrahydrite-tennantite, marcasite, covellite and malachite. Gold is either refractory occurring mainly in arsenopyrite and to a lesser extent in As-pyrite, or free in the oxide minerals. Gangue minerals include dominantly quartz and lesser muscovite-sericite. Mineralization bears evidence of ductile deformation followed by brittle fracturing, cataclasis and recrystallization. Quartz exhibits wavy extinction and suture margins (quartz A). Sub-grains of quartz (quartz B) locally surround quartz A. Cataclastic arsenopyrite is also of local development. Textural observations suggest that quartz A and gold-bearing arsenopyrite have coprecipitated.

3 FLUID INCLUSIONS

All the fluid inclusions studied are hosted by quartz A and healed microfractures. No workable inclusions were found in quartz B. Three types of fluid inclusions (with subtypes) were recognized based on constituent phases at room temperature and microthermometric behavior.

Type I. H_2O-CO_2 3-phase inclusions: L_1 (H_2O)+L_2 (CO_2)+V (CO_2). They are characterized by highly variable CO_2/H_2O volumetric ratios. Type I are subdivided into Type Ia, H_2O-rich inclusions (10-40 volume % CO_2) which homogenize to the liquid (aqueous) phase, and Type Ib, CO_2-rich inclusions (70-90.

Table 1. Microthermometric data and ore-fluid properties of Types I and II fluid inclusions from the Asimotrypes mesothermal gold deposit.

Incl. type		Tm $_{CO2}$ ^{0}C	Tm $_{Clath}$ ^{0}C	Th $_{CO2}$ ^{0}C	Th ^{0}C	D.fill. %	Salinity * wt% NaCl equiv.	D Bulk* gr.cm^{-3}	NaCl mol %	CO_2 mol %	H_2O mol %
Ia	Min.	-56.2	6.1	25.5 (V)	275 (L)	10	2.61	0.88	0.80	3.05	81.85
H_2O-rich	Max.	-56.9	8.7	27.5 (V)	335 (L)	40	7.31	0.99	1.99	16.16	96.15
	n	35	35	35	35	35	35	35	35	35	35
	Mean	-56.6	7.9	26.5 (V)	302 (L)	25	4.41	0.94	1.39	9.65	88.50
Ib	Min.	-56.2	8.9	26.5 (V)	308 (V)	70	0.61	0.37	0.09	22.38	45.35
CO_2-rich	Max.	-56.9	9.7	29.4 (V)	340 (V)	90	2.22	0.52	0.50	54.57	77.08
	n	30	30	30	30	30	30	30	30	30	30
	Mean	-56.6	9.3	27.9 (V)	322 (V)	80	1.63	0.47	0.32	38.47	61.21
II	Min.	-3.5			135(L)	10	5.62	0.84			
	Max.	-5.9			256(L)	20	9.05	0.98			
	n	19			25	25	25	25			
	Mean	-4.7			190(L)	15	7.33	0.91			

Tm $_{CO2}$: CO_2 melting temperature ; Tm $_{Clath}$: Clathrate melting temperature; Th $_{CO2}$: Partial CO_2 homogenization; Th: Total homogenization temperature; X: Bulk inclusion composition.
*Calculated using FLINCOR (Brown, 1989), Bodnar (1983) and Brown and Lamp(1989) Equation of State.

volume % CO_2) which homogenize to the vapor (carbonic) phase

Type II. Aqueous 2-phase inclusions: L+V. These contain an aqueous liquid and an aqueous vapor phase occupying 10-20 % of the inclusion volume. They always homogenize to the liquid phase.

Type III. Naturally decrepitated and/or leaked inclusions: V or L+V. Decrepitated inclusions are either empty or contain a vapor phase, whereas leaked varieties exhibit inconsistent vapor/liquid ratios.

Type I inclusions occur in clear domains of the quartz matrix. Type II occupy healed trans-granular microfractures, and Type III inclusions occur either isolated in quartz A or at the interfaces of quartz B. Type III inclusions have been swept to the quartz grain boundaries as they migrated through the strained crystal, and represent early ruptured inclusions. This disruption was caused by internal overpressures. The shape of inclusion Types I and II is elliptical to sub-rounded with smooth boundaries. Their sizes vary from <5 to 20 μm. Type III inclusions are up to 50 μm in size and range from irregular through elongate to ovoid in shape.

Textural relationships suggest that the fluids represented by Types I and II are related to the ore-forming event, and Type III related to syn-depositional decompression of the host quartz during uplift.

4 FLUID IMMISCIBILITY AND P-T CONDITIONS OF MINERALIZATION

Homogenization temperatures range between 275^{0}C and 335^{0}C for Type Ia inclusions, and between 308^{0}C and 340^{0}C for Type Ib inclusions. Coexisting Types Ia and Ib inclusions homogenizing over the same temperature range and producing different phases indicate the existence of a fluid that has undergone phase separation prior to or during entrapment as fluid inclusions (Ramboz et al., 1982). The variable phase ratios of Type I inclusions is probably a result of mixed entrapment of variable physical proportions of immiscible H_2O-rich and CO_2-rich components. Considering that for coeval inclusions, the minimum temperatures for inclusion homogenization into the aqueous and into the carbonic phases are provided by inclusions trapping pure end-members. In the studied inclusions minimum homogenization P and T conditions of 275^0-310^{0}C at calculated pressures between 2.7 and 3.1 kb can be considered as conditions of phase unmixing and deposition of the majority of the mineralization.

Estimated salinities of Type Ia inclusions (2.6-7.3 wt % NaCl equiv.) increase with decreasing temperature while salinities of Type Ib inclusions (0.61-2.2 wt % NaCl equiv.) show opposite trend. This is a result of preferential partitioning of salt into the H_2O-rich liquid phase rather than into the CO_2-rich vapor phase during unmixing (Fig. 1) (Bowers and Helgeson, 1983). Type II inclusions show a trend of decreasing salinity (5.6-9 wt % NaCl equiv.) with homogenization temperature (135^0-256^{0}C) (Fig.1). This

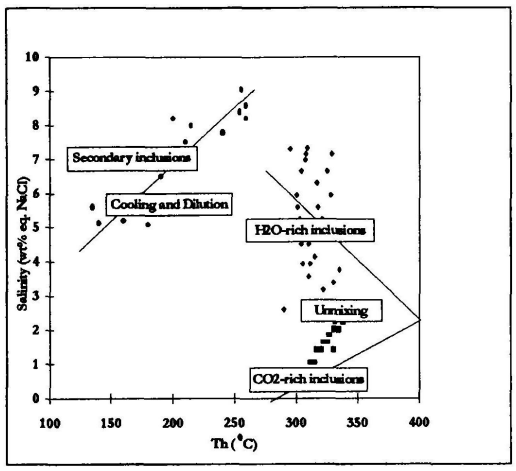

Figure 1. Total homogenization temperatures versus salinity diagram for fluid inclusions from the Asimotrypes ore. CO_2-rich and H_2O-rich inclusions represent unmixing of a low salinity H_2O-CO_2 fluid, whereas secondary fluids record later fluid incursion of more dilute waters.

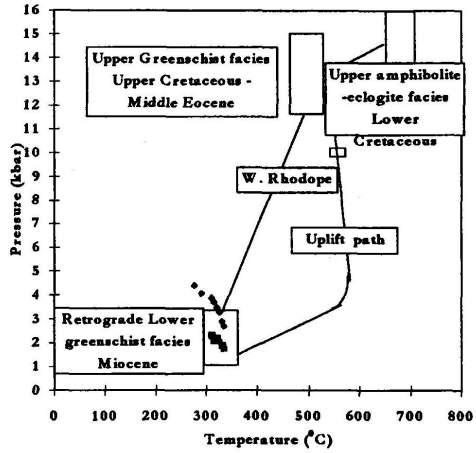

Figure 2. Pressure-temperature diagram showing calculated homogenization conditions for Type I and II inclusions, showing the their relationship to regional metamorphic conditions in the Rhodope Massif.

trend in conjunction with their occurrence along late healed fractures and stable isotope data (see below) indicate flashing of cooler meteoric waters into the mineralizing system during brittle fracturing induced by syn-to post-metamorphic uplift. Mineralizing fluid temperatures and pressures approach closely those of regional retrogressive greenschist facies metamorphism (T=350^0-400^{0}C, P=3-5 kb) (Fig. 2), and attest to the conditions of syn-to post-metamorphic cooling.

5 WHOLE ROCK OXYGEN AND HYDRO- GEN ISOTOPES

Whole rock $\delta^{18}O$ values for the Asimotrypes ore lie within a narrow range from 15.79-16.48 per mil with a median value of 16.15 ± 0.26 (1σ). It is apparent that these values are consistent with values of metamorphic fluids. δD values are in the range of -105 to -125 per mil with a median value of -117±7.5 (1σ). These values imply that all fluids contained in the Asimotrypes ore represent evolved meteoric waters (Shelton et al., 1988; Nesbitt et al., 1989).

Figure 3 shows that the area in δD- $\delta^{18}O$ space occupied by the Asimotrypes fluids lie outside the metamorphic and magmatic water fields and could be only derived from these fluids through a significant negative shift in the δD_{fluid} values. It is suggested therefore, that the Asimotrypes mineralizing fluids are of meteoric origin, perhaps incorporating a metamorphic fluid component, and that the observed fluid composition was derived by substantial interaction of this fluid with the rock mass.

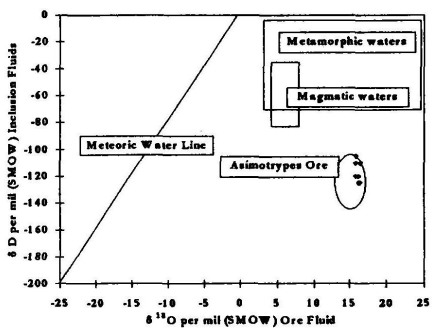

Figure 3. Plot of δD inclusion fluids versus $\delta^{18}O$ fluids of the Asimotrypes mesothermal gold deposit. The isotopic composition of the Asimotrypes clearly lies outside of the metamorphic and magmatic water fields.

6 CONCLUSIONS

1. Mineralizing fluid pressures and temperatures indicate early ore deposition during phase separation at temperatures between 275^0 and 310^{0}C at calculated pressures between 2.7 and 3.1 kb followed by late deposition at temperatures down to 130^{0}C and very low near-surface pressures.

2. The Asimotrypes mineralizing fluids are of meteoric origin, perhaps incorporating a metamorphic fluid component.

3. Combined with geological evidence, the fluid inclusion and stable isotope data of the Asimotrypes gold mineralization are consistent with genesis from deeply convecting meteoric water driven by regional

uplift through rocks undergoing retrogressive greenschist facies metamorphism.

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