

Stable Isotope (O, H, S, C, and N) Systematics of Quartz Vein Systems in the Turbidite-Hosted Central and North Deborah Gold Deposits of the Bendigo Gold Field, Central Victoria, Australia: Constraints on the Origin of Ore-Forming Fluids

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Abstract

The Central and North Deborah gold deposits are located in one of 15 mining centers of the Bendigo gold field, central Victoria, Australia, a major world-class gold province developed in a turbidite terrane. Gold mineralization occurs primarily within domes and reverse-fault systems in multiply deformed Lower Ordovician metaturbidites. Deformation and thrusting occurred between 450 and 420 Ma coevally with regional metamorphism at zeolite to greenschist facies. In the Central and North Deborah deposits six stages of quartz veining, each with characteristic geometry and mineral paragenesis, developed sequentially: stages 1, 2, and 4 are gold-bearing, whereas stages 3, 5, and 6 are barren.

Gold-related quartz veins were deposited at temperatures of $350^{\circ} \pm 25^{\circ}\text{C}$ based on oxygen isotope geothermometry of silicate phases (quartz-muscovite) and sulfur isotope compositions of coexisting sulfide mineral pairs (sphalerite-galena). This result is consistent with temperatures inferred from fluid inclusions. The $\delta^{18}\text{O}$ values of gold-bearing vein quartz and coexisting hydrothermal muscovite are uniform within and between the six vein stages ranging from 15.9 to 17.2 per mil and 11.6 to 12.8 per mil, respectively. The δD values of hydrothermal muscovites are also uniform at -68 to -55 per mil. Ore fluids have calculated $\delta^{18}\text{O}$ values of 8 to 11 per mil and δD values of -37 to -17 per mil.

Pyrite of syndimentary-diagenetic origin in slate and sandstone displays sulfur isotope compositions of -23.5 to -8.0 per mil and -0.1 to $+11.9$ per mil, respectively. Sulfides from gold-bearing quartz veins have a range of -7.4 to $+8.1$ per mil (median ca. $+2.5\%$). The relatively uniform vein pyrites indicate a large, uniform sulfur source, most likely from desulfidation reactions of sulfide minerals; interaction of the ore-forming fluid with depleted sulfides at the site of deposition may have shifted the sulfur isotope signatures of source sulfides to more negative values. Carbon isotope compositions of carbonates range from -5.1 to -9.0 per mil (median ca. -6.5%). Nitrogen concentrations and nitrogen isotope compositions of hydrothermal muscovite from quartz veins are 652 to 895 ppm and 2.84 to 4.49 per mil, respectively. Collectively, the data define a band in N content versus $\delta^{15}\text{N}$ coordinate space from higher N and lower $\delta^{15}\text{N}$ in the Phanerozoic metasedimentary-hosted Central and North Deborah gold deposits to lower N and higher $\delta^{15}\text{N}$ in predominantly meta-igneous-hosted Neoproterozoic gold provinces.

Collectively, the H, O, S, C, and N isotope compositions of ore-related hydrothermal minerals indicate that the dilute, aqueous carbonic and N-bearing ore-forming fluids were generated from metamorphic dehydration reactions at deeper crustal levels and were variably influenced by exchange with wall rocks during transport to the site of deposition. This genetic model for the Central and North Deborah gold deposits is consistent with other turbidite-hosted lode gold deposits and counterparts in volcanic-plutonic terranes. In contrast, these data are not consistent with either mantle-derived fluids or magmatic fluids, nor do they support a deeply circulated meteoric surface water model for vein formation.