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The Hishikari Au-Ag Epithermal Deposit, Japan: Oxygen and Hydrogen Isotope Evidence in Determining the Source of Paleohydrothermal Fluids

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Abstract

Quartz, adularia, and clay minerals from low-sulfidation epithermal veins at Hishikari (1.3–0.7 Ma) were analyzed for their oxygen and hydrogen stable isotope compositions to establish the source of paleohydrothermal waters. Veins consist predominantly of adularia and quartz, are banded, and exhibit a range of recrystallization and replacement textures indicative of precursor silica polymorphs and platy calcite. Adularia/quartz ratios decrease progressively from older, sulfide-mineral–bearing, outer bands to late-stage, drusy, barren quartz in the central portions of veins. Gold and silver occur predominantly as electrum, but smectite and vermiculite that occur as disseminated zones or thin bands (<2 mm) in early adularia-rich stages of veins are in some cases impregnated with micrometer-size native gold. High gold (>500 ppm) and silver (>150 ppm) concentrations in veins occur within bonanza zones (<50 m vertical and up to 600 m horizontal extent), and values (<60 ppm Au) sharply decrease outside those zones. These zones characteristically have relatively high adularia/quartz ratios (>0.5). Positive correlation between Au-Ag and the adularia/quartz ratio, the presence of platy calcite, Au-bearing smectite and vermiculite, and constant vertical elevation of ore zones are permissive evidence that boiling controlled ore deposition.

Quartz and adularia in gold- and silver-bearing parts of veins have $\delta^{18}O$ values that range from 7 to 9 per mil and 5 to 6 per mil, respectively. Late-stage drusy quartz usually has lower $\delta^{18}O$ values of 6 to 7 per mil. Gold-bearing smectite and vermiculite have $\delta^{18}O$ values that range from 8 to 13 per mil and δD values that range from –55 to –85 per mil. Late-stage clay (smectite and kaolinite), a common alteration product of adularia in veins, has $\delta^{18}O$ values (4–11‰) similar to those from early-stage clay but δD values that are distinctly lower (–90 to –130‰) than early-stage clay. Oxygen isotope equilibrium temperatures between quartz and adularia are 220° to 250°C and 170°C. Average homogenization temperatures of fluid inclusions from early quartz and adularia are about 180° to 220°C. Quartz and adularia results indicate that the ore-forming hydrothermal fluids at Hishikari had $\delta^{18}O_{H_2O}$ values that range from about –4 to 0 per mil, ^{18}O enriched compared with present-day meteoric water (–7‰). The Au-bearing smectite and vermiculite have calculated $\delta^{18}O_{H_2O}$ and δD_{H_2O} values of 1 to 4 per mil (at temperatures of 200°C) and –65 to –40 per mil, respectively. Calculation of $\delta^{18}O_{H_2O}$ variation as a consequence of boiling indicates that closed-system boiling was more likely than open-system boiling. Assuming isotopic equilibrium between columnar adularia and adjacent fine-grained quartz, then the lower calculated equilibrium temperatures of 170°C are consistent with a decrease in pressure causing steam loss and the formation of amorphous silica from fluids that were silica supersaturated. The calculated $\delta^{18}O_{H_2O}$ and δD_{H_2O} values (from quartz, adularia, and early smectite) suggest that mineralizing solutions were a mixture of magmatic and meteoric waters. Alternatively, water-rock calculations indicate that these values could derive from heated modern meteoric water that had undergone isotope exchange during circulation through basement rock (water/rock ratio 0.1–3). The overlap in δD values of magmatic water (–30 to –70‰) and meteoric water (–50‰) at Hishikari makes it impossible to clearly differentiate between these two processes. $\delta^{18}O_{quartz}$ values of veins have a north-south zonation, and values increase to the north, possibly reflecting a source or fluid flow direction.

The latest-stage drusy quartz from the central portions of veins has calculated $\delta^{18}O_{H_2O}$ values between –4 and –6 per mil, close to values (–7‰) of present-day meteoric water. Late-stage clays (smectite and kaolinite) have low δD_{H_2O} values (–110 to –75‰) compared with present-day meteoric water (–50‰) that cannot be adequately explained by fluid mixing or water-rock interaction. δD values of water extracted from fluid inclusions in adularia (–110‰) and quartz (–70‰) at Hishikari are not considered to be reliable for estimating δD_{H_2O} values of paleohydrothermal waters.