

Fluids in high-sulphidation gold deposits: Insights from *in situ* stable isotopes and noble gas analyses

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In the past, the origin of fluids in high-sulphidation gold deposits has been based on stable isotopes (D, O and S) using the temperature of homogenisation of co-existing fluid inclusions (typically <300 °C).

We have separated euhedral quartz crystals from sulphosalt ore from the El Indio Au-Ag-Cu deposit, Chile; and the Summitville Au-Ag-Cu deposit, Colorado in order to investigate their isotopic composition. These euhedral ~200 µm crystals either grow into vugs in the sulphosalt ore, or are encased by sulphosalts.

All the high-density fluid inclusions found in these crystals are secondary, occurring in multiple generations of healed fractures. Low-density vapour inclusions are present as both primary and secondary inclusions. Often their paragenesis is unclear due to their small size (<1 µm), or isolation.

Sulphosalt-melt inclusions are abundant in quartz crystals from both deposits. They are mostly primary sulphosalt-melt inclusions, restricted to certain growth bands within the crystal (Fig. 1) - but rare secondary sulphosalt-melt inclusions have been identified.

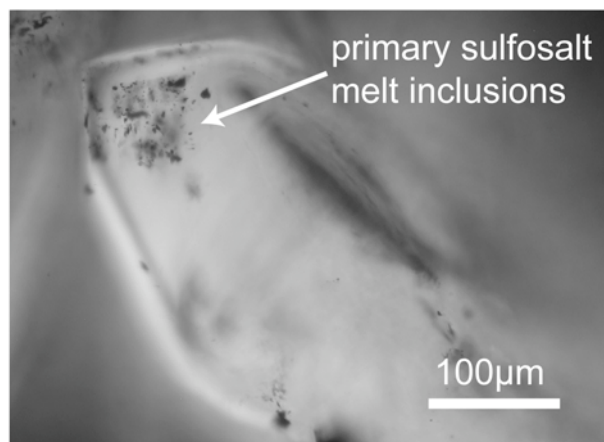


Fig. 1. Primary sulphosalt-melt inclusions restricted to distinct growth bands in euhedral quartz from the El Indio Au-Ag-Cu deposit, Chile.

Recent work has shown that sulphosalt melt assemblages co-existing with quartz crystals in high-sulphidation deposits are quenched at high temperatures ~675 °C (Mavrogenes et al., 2010; Henley and Mavrogenes, in review); suggesting that the quartz was sourced from a magmatic vapour.

In order to test this hypothesis, *in situ* stable isotopes were used to see whether the quartz had a magmatic ($\delta^{18}\text{O} \sim 5\text{-}10\text{‰}$) or low-T hydrothermal ($\delta^{18}\text{O} \sim 5\text{-}10\text{‰}$) signature. The noble gas chemistry of crushed quartz was also measured to test whether the fluid inclusions contain a crustal (He R/Ra <1) or magmatic (He R/Ra ~8) signature.

Cathodoluminescence (CL) imaging and Al-mapping using the electron microprobe (EMP) revealed that most quartz crystals displayed intricate euhedral growth bands (ranging from 1-40 µm thick), while a few samples displayed intricate sinter-like banding.

Oxygen isotopes were analysed using SHRIMP II at the Australian National University. The primary beam was ~25 µm in diameter, so many isotopic analyses within individual quartz crystals still provide a mix of isotopic compositions across two distinct growth zones (Fig. 2).

The isotopic composition of quartz from these deposits shows a wide range in isotopic compositions (3.7 - 17.1 ‰); with up to 11 ‰ variation within an individual crystal.

These data are compatible with published data from other high-sulphidation gold deposits. The $\delta^{18}\text{O}$ of whole quartz crystals from the Summitville deposit has been found to range between ~9.8 - 14.2 ‰ (Bethke et al., 2005). The $\delta^{18}\text{O}$ of one quartz crystal from the Pierina high sulphidation gold deposit was found to be ~17 ‰ (Fifarek and Rye, 2005).

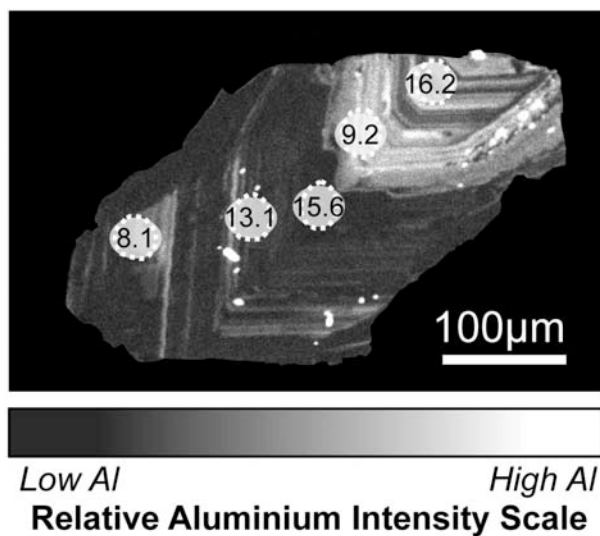


Fig. 2. Aluminium zoning in euhedral quartz from the El Indio Au-Ag-Cu deposit, Chile. The numbers show the measured variation in $\delta^{18}\text{O}$ (‰) within the crystal.

Such heavy and variable $\delta^{18}\text{O}$ compositions could suggest one of either two possibilities:

- a) the range in $\delta^{18}\text{O}$ values may be explained by *equilibrium* Rayleigh fractionation of a low-temperature fluid in a closed system with episodic pulses of fresh fluid; or
- b) the heavy oxygen may be explained by *kinetic* fractionation during progressive dehydration of a Si-O-OH-rich volcanic gas condensate. The range in $\delta^{18}\text{O}$ can therefore be explained by various degrees of dehydration from various Si-phases.

We do not consider option (a) to be plausible, as the entrapment of so many sulphosalt melt inclusions is not possible at low-temperatures.

Hypothesis (b) may also explain the origin of sinter-like banding evident in CL and EMP imagery – as residual evidence of an opaline phase.

Given that the isotopic composition of the quartz is controlled by kinetic, rather than equilibrium fractionation; and the fluid inclusions are not derived from the same fluid as the host mineral, isotopic calculations of the ore-bearing fluid cannot be made.

Noble gas analyses of 1g of crushed quartz from the El Indio Au deposit reveal that the fluid inclusions within the quartz have a crustal He signature ($R/R_a < 0.26$). However, this contradicts the Ne isotopes, which suggest a more magmatic source ($\text{Ne}/\text{Ne} = 9.27$). The He and Ne values founding El Indio quartz are remarkably similar to vapour inclusions measured in alunite from other high-sulphidation deposits (Landis and Rye, 2005). These noble gas analyses suggest that the quartz preserves a fingerprint of both magmatic and crustal fluids.

These results show that the majority of fluid inclusions in quartz from the El Indio deposit are secondary and record evidence of a low-temperature, crustal-derived fluid.

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Zoologisch-Botanische Datenbank/Zoological-Botanical Database

Digitale Literatur/Digital Literature

Zeitschrift/Journal: [Berichte der Geologischen Bundesanstalt](#)

Jahr/Year: 2011

Band/Volume: [87](#)

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