

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

Tanner, Dominique, Mavrogenes, John A. and Henley, Richard W.

The Research School of Earth Sciences, Australian National University, Building 61, Mills Rd., Canberra, Australia

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.

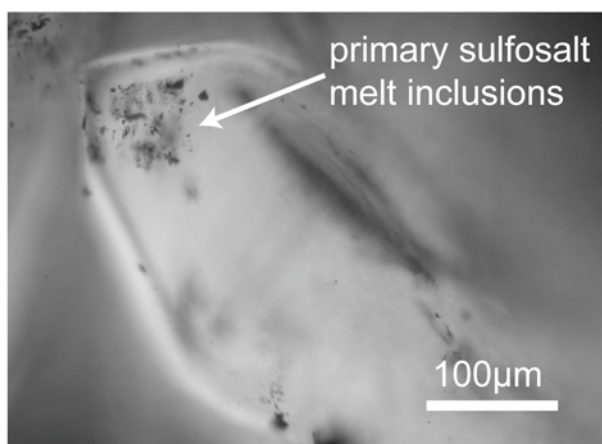


Fig. 1. Primary sulphosalt-melt inclusions restricted to distinct growth bands in euhedral quartz from the El Indio Au-Ag-Cu deposit, Chile.

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).

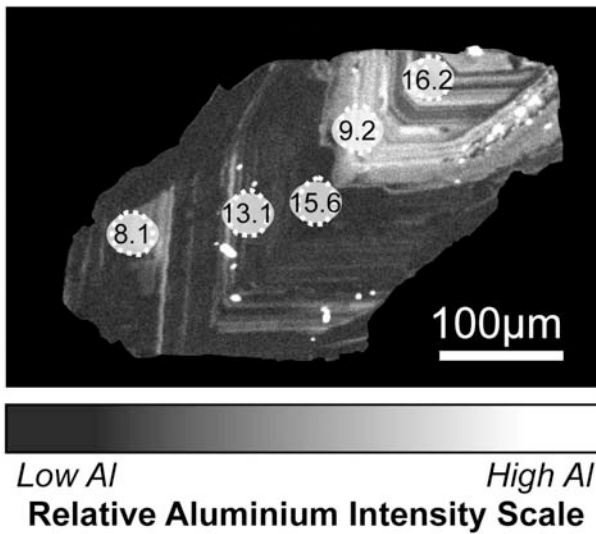


Fig. 2. Aluminium zoning in euhedral quartz from the El Indio Au-Ag-Cu deposit, Chile. The numbers show the measured variation in $\delta^{18}\text{O}$ (‰) within the crystal.

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.

REFERENCES

- Berger B.R. (2010) *Econ. Geol.* 105: 257-262.
Bethke P.M., Rye R.O., Stoffregen R.E., Vikre P.G. (2005) *Chem. Geol.* 215: 281-315.
Fifarek R.H., Rye R.O. (2005) *Chem. Geol.* 215: 253-279.
Henley R.W. and Mavrogenes J.A. (2011) *Geofluids (in review)*.
Landis G.P. and Rye R.O. (2005) *Chem. Geol.* 215: 155-184.
Mavrogenes J.A., Henley R.W., Reyes A.G., (2010) *Econ. Geol.* 105: 257-262.