

A Fresh Look at the World-Class “Five-Element” Vein Deposit, Cobalt, ON, Canada: Constraints from Fluid Inclusion and Stable Isotope Systematics and Mineral Paragenesis

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The world-class “five-element” (Ag-Co-Ni-As±Bi) vein deposits of the Cobalt-Gowganda district (Ontario, Canada) have not been rigorously studied for decades. We present results of a fully integrated study involving mineralogical and mineral chemical, fluid inclusion (FI), and in situ O-isotope data to reassess fluid and metal sources relevant to ore-forming processes in this high-tenor, five-element vein setting. Our ongoing work uses fluid inclusion assemblage (FIA) protocol and a range of analytical methods (microthermometry, cathodoluminescence imaging, Raman spectroscopy), in situ (SIMS) $\delta^{18}\text{O}$ quartz analysis, and Fe-sulphide trace element mapping (LA-ICP-MS).

Early-stage (pre-Co-Ni-Ag-As-Bi ore) and late-stage (syn- to post-ore) vein quartz preserves two dominant fluid types in both homogeneously and heterogeneously trapped FIAs. These comprise (at room T) single-phase carbonic fluid ($\text{CH}_4\pm\text{N}_2$), single-, two-, or three-phase aqueous fluids (liquid±vapour±halite), and coentrapped carbonic and aqueous fluids. Salinity of aqueous FI varies between 0.2 and 50 wt.% ($\text{NaCl}_{\text{equiv.}}$) but with minimal variation within FIAs. The FIAs are of secondary and pseudosecondary origin and preserve numerous episodes of brine and carbonic fluid interaction and mixing with a more dilute aqueous phase.

Cathodoluminescence imaging of early- and late-stage quartz shows pronounced primary growth zonation and basal-terminated fracture plumes, indicating pervasive dissolution-recrystallization related to incursion of the aqueous-carbonic fluid mixtures. In situ $\delta^{18}\text{O}$ analyses of primary growth zones (early-stage quartz 11.9-14.8%; late-stage quartz 14.5-15.3%) and secondary features hosting fluid inclusions (early-stage quartz 12.2-16.1%; late-stage quartz 14.7-15.8%) suggest $<100^\circ\text{C}$ of cooling throughout early vein mineralization. This, in tandem with fluid mixing, was a major control on mineralization.

Elemental mapping of accessory Fe-sulphides reveals complex enrichment/depletion patterns across primary zones and discordant overprints, indicating highly variable fluid enrichments in metals, decoupling of Ag from Ni-Co-As, and oscillations between arsenide/sulpharsenide-dominant (Ni-Co-As), Ag, and base metal (Cu-Zn-Pb) sulphide mineralization stages. This is inconsistent with traditionally documented geochemical paragenesis for five-element vein-type mineralization.