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A Fresh Look at the World-Class “Five-Element” Vein Deposits, Cobalt Embayment, ON (Canada): Fluid and Metal Sources and Systematics, and Mineralization Ages

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The world-class “five-element” (Ag-Co-Ni-As±Bi) Paleoproterozoic vein deposits of the Cobalt Embayment (Ontario, Canada) have not been rigorously studied for decades. Here we present the results of a fully integrated approach that employs Re-Os dating, mineral-chemical constraints (EDS, XRF, LA-ICP-MS), and fluid inclusion (FI) measurements (microthermometry, laser Raman, cathodoluminescence (CL), and in-situ $\delta^{18}O_{quartz}$ SIMS), which has important implications for fluid and metal sources, process systematics, and ore system initiation that collectively impact the conventional genetic model for this high-tenor ore setting.

Early- (pre-Co-Ni-Ag-As-Bi ore) and late- (syn- to post-ore) stage vein quartz preserves two dominant fluid types as homogeneously and heterogeneously trapped FI assemblages (FIAs). The FI types are single-phase carbonic FIs (CH_4±N_2) and aqueous FIs (liquid±vapour±halite) of variable salinity (0.2 to 50 wt. $\%_{NaCl\ eq.}$). The secondary and pseudosecondary timing of FIAs record numerous episodes of interaction between methane-dominant fluids with aqueous fluids.

CL imaging of early- and late-stage quartz shows pronounced primary growth zones and basal-terminated fracture plumes, indicating pervasive dissolution-recrystallization during and after vein formation. In-situ $\delta^{18}O_{quartz}$ data reflects a steady increase of values between primary growth zones and secondary features hosting FIs with <100°C of cooling during 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 with discordant zones overprinting primary growth features. Metal distribution indicates variable enrichment, decoupling of Ag from Ni-Co-As, and oscillations among Ni-Co-As, Ag, and base metal (Cu-Zn-Pb) mineralization stages. These observations are inconsistent with the traditionally documented paragenesis for five-element vein mineralization.

Re-Os radiometric dating constrains Ni-Co-As arsenide/sulpharsenide, and Cu sulphide mineralization to ~2232Mya, pre-intrusion age for the modelled heat-source (Nipissing Diabase intrusions) by ~13Ma, thus precluding the latter as a source of localized heat and/or metal, and necessitating a full-scale reevaluation of the deposit model.