Genesis of Polymetallic Vein Mineralization in the Paleoproterozoic Cobalt Embayment, Northern Ontario: Implications for Metallogenesis and Regional Exploration

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Summary

The Cobalt Embayment is an irregular domain of Paleoproterozoic (2.45 - 2.22 Ga) siliciclastic sedimentary rocks (*i.e.* the Huronian Supergroup) that unconformably overlies Archean basement rocks of the Abitibi Greenstone Belt. The Nipissing Diabase, a regionally-distributed complex of mafic sills and dikes, intruded the Huronian sedimentary rocks *ca.* 2.22 Ga. The sedimentary rocks were subsequently affected by a poorly constrained subgreenschist-facies metamorphism (Easton, 2000) and by a regionally-distributed, K- and Na-metasomatic event at *ca.* 1.7 Ga Ma, likely related to the waning stages of the Penokean orogeny (Fedo *et al.,* 1997). Although best known for the economically important Ag-Co veins of the Cobalt mining camp, the Cobalt Embayment also hosts numerous other regionally-distributed, polymetallic (Fe, Cu, Ni, Co, As, Au, Ag, Bi ± U) calcite-quartz vein systems.

Radiogenic and stable isotope results confirm the occurrence of at least two, basin-wide hydrothermal (mineralizing) events in the Early Proterozoic (*ca.* 2.2 and 1.7 Ga; Potter & Taylor, 2009). In addition, our integrated field and geochemical data suggest a petrogenetic model for polymetallic vein mineralization in which oxidized basin fluids reacted with localized reductants along major regional fault systems that were reactivated both during and post-intrusion of the Nipissing Diabase. Such features are suggestive of larger-scale hydrothermal systems in which the polymetallic veins may represent a peripheral element of previously unrecognized unconformity-associated mineralization at depth. These observations thus form the basis of a new mineral exploration model for the Proterozoic rocks of the Cobalt Embayment.

Introduction

The recent discoveries of Au-rich and U-bearing, polymetallic mineralization in a geological setting akin to that of the historical Cobalt Ag-Co veins have: (*i*) Clearly demonstrated the potential of the Cobalt Embayment to host hydrothermal mineral deposits enriched in economic metals other than Ag; and (*ii*) Prompted a re-evaluation of the metallogeny of this important Paleoproterozoic basin, located in northern Ontario. This re-evaluation has integrated field mapping, ore mineralogy, petrography, and stable and radiogenic isotope studies in order to assess the petrogenetic similarities of the regionally-distributed hydrothermal mineralization whose main characteristics are its:

1) Occurrence in steeply-dipping, discordant calcite-quartz vein systems hosted in Nipissing Diabase and adjacent Huronian metasedimentary rocks;
2) Spatial association with periodically reactivated, regional fault systems rooted in the Archean basement; and
3) Polymetallic, precious-metal-bearing (Cu, Co, Ni, Fe, As, Au, Ag, ± U) ore assemblage.

When fully developed, the regionally-distributed polymetallic vein systems exhibit a common paragenetic sequence and internal zoning with:

i) Narrow silicate selvages (chlorite + quartz ± epidote ± K-feldspar ± albite) with sporadic "early-stage" sulphides (pyrite ± chalcopyrite);

ii) A transition to calcite gangue and precipitation of hematite followed by the "main-stage" polymetallic mineralization (chalcopyrite + pyrite + cobaltite ± precious-metal minerals ± pitchblende ± Bi-bearing sulphides ± galena);

iii) "Late-stage" massive calcite ± galena.

Stable and Radiogenic Isotope Data

Carbon and oxygen isotopic data from the major gangue mineral (calcite) support a common hydrothermal origin for the polymetallic vein systems involving mixing of meteoric-dominated fluids with basin brines (Fig. 1). Local variations in $\delta^{13}C$ values likely reflect the degree of hydrothermal fluid interaction with organic matter in the immediate country rocks. Despite local variations in $\delta^{13}C$ values, the majority of the calcite from the polymetallic veins plot within a narrow range of $^{87}Sr/^{86}Sr$ values similar to the Huronian metasedimentary rocks.

Significant, inter-deposit variation in $\delta^{34}S$ values of sulphides (pyrite, chalcopyrite, and galena) from the polymetallic vein occurrences suggests that localized sources of sulphur existed in the Huronian and/or Archean rocks. The positive values ($\delta^{34}S$ >0‰) in a number of the vein systems examined in this study likely reflect the introduction of sulphur remobilized from the basement, as a result of the conversion of pyrite to pyrrhotite in the underlying Archean rocks, as originally proposed by Goodz *et al.* (1986) for the Cobalt Ag-Co veins. Interpretation of the isotopic data and textural features suggests that metals were transported in oxidized fluids and precipitation occurred as a result of oxidation-reduction reactions along reactivated fault systems rooted in the Archean basement, which facilitated fluid mixing. A broad hematite-bearing alteration halo present at the 'type locality' (the Merico-Ethel property, Elk Lake) supports the presence of oxidizing fluids within the sedimentary units overlying the Archean basement at the time of hydrothermal mineralization.

The Pb isotope compositions of pyrite and chalcopyrite from nine, widely-separated, polymetallic vein systems yield a Pb-Pb errorchron age of 2236 ±180 Ma (*Fig. 2a*), whereas late-stage galena (*Fig. 2b*) from six, regionally-distributed vein systems produce a Pb-Pb secondary isochron age of *circa* 1675 Ma (Potter & Taylor, 2009). These Pb isotope data for the vein systems: *i*) Confirm the occurrence of at least two major episodes of hydrothermal fluid activity throughout the Cobalt Embayment *ca.* 2.2 and 1.7Ga; *ii*) Indicate that the emplacement of the Nipissing Diabase was the most likely driver of regional hydrothermal fluid circulation at *ca.* 2.2 Ga; and *iii*) Provide supporting evidence for the basin-wide extent of the regional K- and Na-metasomatic events at *ca.* 1.7 Ga, most likely related to waning stages of the Penokean orogeny (Fedo *et al.,* 1997).

Conclusions

A genetic model that encompasses all of the observed isotopic, mineralogical, and textural features of the polymetallic vein systems involves: (*i*) Regional flow of oxidized, hydrothermal fluids focused along the Huronian-Archean unconformity, driven by sedimentary loading and the heat released by the Nipissing Diabase intrusive event *ca.* 2.2 Ga; (*ii*) Genesis of regionally-distributed, discordant, polymetallic vein mineralization through the interaction of the oxidized basin fluids with both fluid- and solid-reducing components of the basement, facilitated by localized displacement of the Huronian-Archean unconformity along reactivated faults; and (*iii*) Hydrothermal remobilization of at least some of the vein components, notably Pb, in association with regional Na- and K-metasomatic events *ca.* 1.7 Ga. This new model for the genesis of the polymetallic vein mineralization in the Cobalt Embayment (Fig. 3) also introduces the intriguing possibility that other styles of polymetallic mineralization, notably "unconformity-associated", could have formed as a result of the two regional hydrothermal fluid circulation events.

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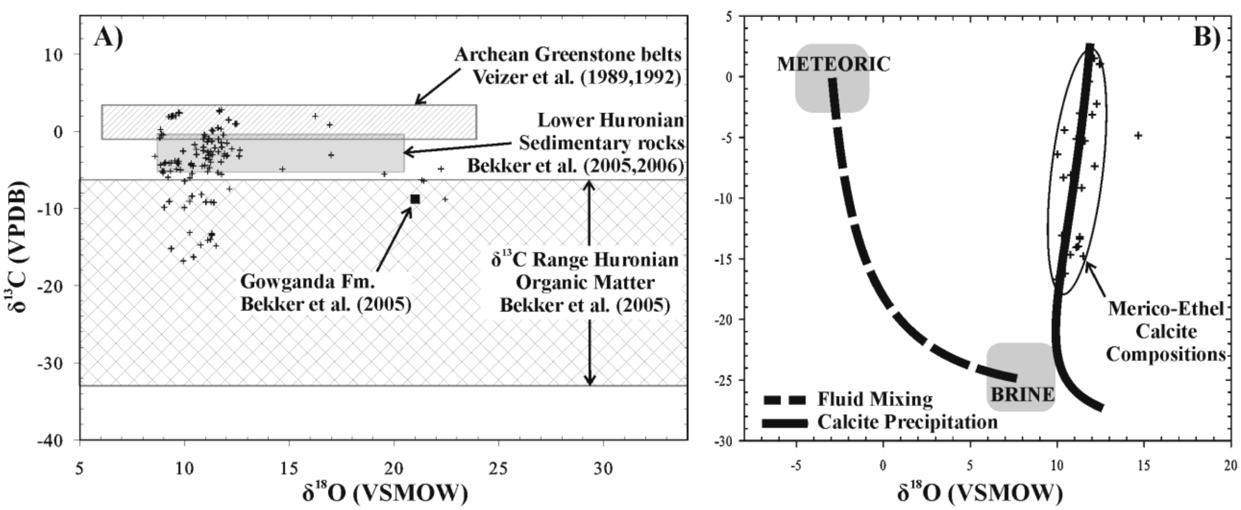

Fig.1 (A) Carbon and oxygen isotope data for calcite from the regionally-distributed polymetallic vein occurrences examined in this study (black crosses) plotted in reference to the major isotopic reservoirs present in the Cobalt Embayment. (B) Fluid-mixing model illustrating the potential interaction of meteoric-dominated fluids with basin brines in the formation of calcite from the Merico-Ethel polymetallic vein systems (black crosses) examined in this study. Fluid mixing and precipitation trends were generated using the procedures outlined by Schwinn et al. (2006).

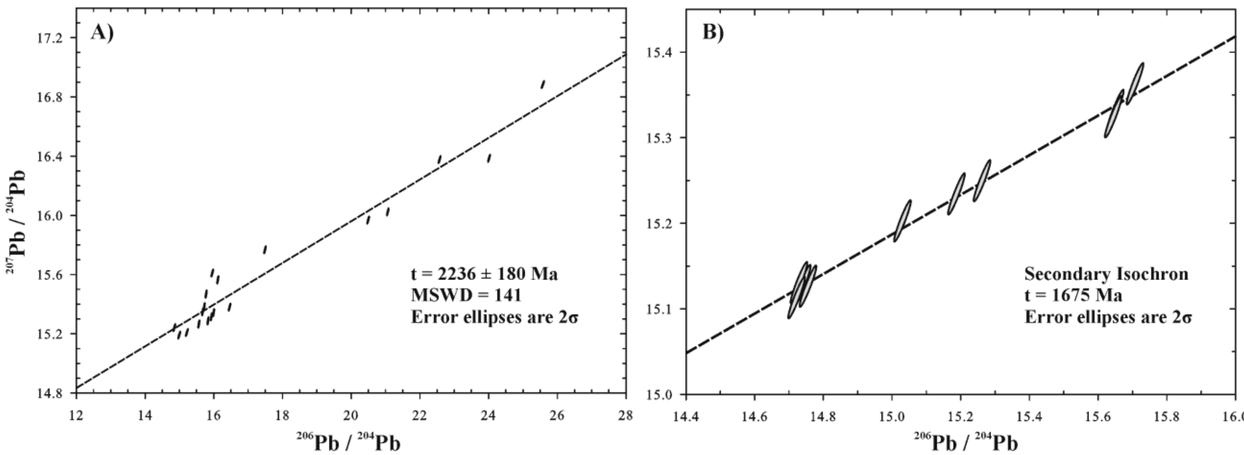

Fig. 2 (A) Lead isotope data of base-metal sulphides extracted from nine, widely-spaced polymetallic vein occurrences in the Cobalt Embayment. The Pb-Pb errorchron yields an age of 2236 ± 180 Ma. (B) Lead isotope data of galena crystals extracted from six polymetallic vein occurrences plot along a secondary Pb-Pb isochron whose slope corresponds to an age of 1675 Ma (After Potter & Taylor, 2009).

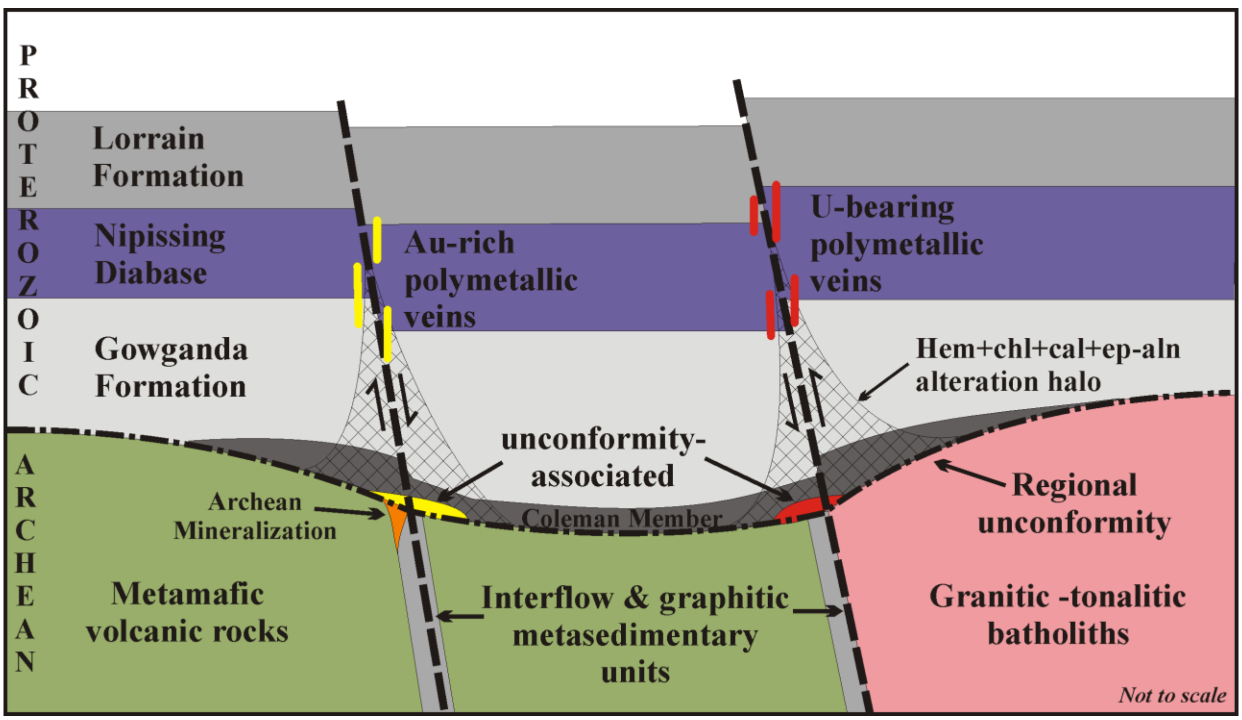

Fig. 3 Simplified exploration model for the genesis of regionally-distributed, polymetallic vein mineralization in the Cobalt Embayment. The polymetallic veins are interpreted as a shallow, peripheral component of large-scale, hydrothermal systems where flow was focussed along both the regional unconformity and reactivated faults that offset the unconformity. The dominant source of the basal Huronian sedimentary rocks (mafic *versus* felsic basement rocks) is believed to have been a primary control on metal endowment (*i.e.* Au *versus* U) in the polymetallic veins.