Geological Controls on Critical Metal Endowment in Sedimentary-Hosted Zn-Pb Deposits: Insights from the Canadian Cordillera

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Sediment-hosted massive sulfide (SHMS) Zn-Pb deposits are increasingly recognized as potential secondary sources of critical metals, including germanium (Ge), gallium (Ga), indium (In), and tin (Sn). These elements are commonly incorporated into sphalerite and can be recovered as by-products during zinc smelting. The Canadian Cordillera hosts several major SHMS districts - including Howard's Pass and Macmillan Pass (Selwyn basin), the Gataga district (Kechika Trough), and the Purcell district - formed within Mesoproterozoic to Devonian-aged sedimentary sequences.

Trace element analysis of sphalerite from several ore bodies across the four districts reveal significant variability in critical metal concentrations, reflecting a combination of the original hydrothermal fluid compositions and the effect of post-depositional chemical modifications. The Macmillan Pass district exhibits the highest Ge contents of the region, with sphalerite from the Boundary Zone and Tom deposits reaching up to 320 ppm Ge. At the Tom deposit, Ge shows a strong correlation with Cu that is consistent with the coupled substitution mechanism ($2\ Zn^{2+} \leftrightarrow Cu^{+} + Ge^{4+}$). In contrast, elevated Ge at the Boundary Zone appears to reside in micro-inclusions, likely linked to localized post-depositional processes. In the Purcell basin, sphalerite from the amphibolite-facies metamorphosed Sullivan deposit is chemically homogeneous and depleted in most critical metals except In. Elevated whole-rock Sn concentrations reported for the Sullivan deposit are hosted entirely in cassiterite rather than sphalerite. Across the four districts, Ga concentrations in sphalerite are consistently low (<15 ppm), probably reflecting a Ga-poor signature of the mineralizing fluids.

These findings highlight the important role of post-depositional processes in controlling the redistribution and retention of trace metals within the SHMS deposits. Advancing our understanding of trace metal mobility in these settings is essential to unlocking the largely untapped critical metal potential of sedimentary-hosted Zn-Pb systems.