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The Werner Lake Co-Cu-Au Deposit of the English River Subprovince, Ontario, Canada: Evidence for an Exhalative Origin and Effects of Granulite Facies Metamorphism

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Abstract

The Werner Lake Co-Cu-Au deposit is confined to a mixed unit of orthopyroxene-bearing amphibolites, ultramafic rocks, garnetiferous biotite schists, calc-silicate rocks, and garnet-rich quartzites. Mineralization includes disseminated sulfides in the garnetiferous biotite schists and semimassive-massive cobaltite-rich orebodies. Field relationships and geochemical data suggest that the garnetiferous biotite schists were most likely derived from amphibolites, whereas the calc-silicate rocks and garnet-rich quartzites probably represent metamorphosed exhalites. Mass changes for the formation of the garnetiferous biotite schists include gains in Fe, Mn, and K but loses in Ca and Na. The garnetiferous biotite schists are also characterized by depletion in whole-rock $\delta^{18}O$ values (4–6.5‰ V-SMOW) relative to the associated amphibolites (6.8–8.3‰) and ultramafic rocks (5.6–6.6‰), which is interpreted as an indication of high- temperature interactions with seawater. Near zero $\delta^{34}S$ values of cobaltite and sulfides indicate a juvenile source for S. These data and similarities to strata-bound Co-Cu and Cu-Co deposits suggest that the Werner Lake deposit most likely formed from syngenetic exhalative processes.

The granulite facies metamorphism (680°–780°C, 4.5–6.6 kbars, and a_{H_2O} of 0.12–0.25) at the Werner Lake deposit was accompanied by penetrative deformation and was followed by retrogression and late hydrothermal alteration. However, high-grade metamorphism and deformation did not obliterate the primary metal and alteration zonation in the Werner Lake deposit. We attribute this preservation of primary features to the dry character of the granulite facies metamorphism. This is supported by the preservation of contrasting oxygen isotope signatures in the ores and associated lithologies. Localized, solid-state remobilization of cobaltite-rich ores is indicated by the presence of durchbewegung textures, the alignment of cobaltite porphyroblasts parallel to the S_2 foliation and thickening of cobaltite-rich orebodies close to F_2 fold hinges. Chalcopyrite-rich veins with biotite-rich selvages suggest a local, fluid- facilitated remobilization during retrogression. Granulite facies metamorphism, deformation, and subsequent retrogression might have locally upgraded the cobaltite-rich ores. Late hydrothermal alteration did not significantly affect the Co mineralization in the Werner Lake deposit.