Economic Geology
Vol 94, 1999, pp. 1007-1028

Origin of Black Shales and the Serpentinite-Associated Cu-Zn-Co Ores at Outokumpu, Finland

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Abstract

The Outokumpu Cu-Zn-Co deposits are associated with serpentinites, interpreted as ophiolitic. The serpentinites are surrounded by dolomite-rich rocks, calc-silicate rocks, fine-grained quartz rocks, metamorphosed black shales (black schists), and mica schists. The ore is hosted mainly by quartz rocks, but also by calc-silicate rocks and black schists. Calc-silicate and quartz rocks are anomalously enriched with respect to Ni and Cr. The original reserves in the Outokumpu area were 50 million tonnes (Mt) sulfide ore grading 1.2 to 3.8 percent Cu, 0.6 to 1 percent Zn, 0.1 to 0.2 percent Co, 0.1 percent Ni, 0.1 to 0.8 g/t Au, and 1 to 9 g/t Ag.

Black schists in the serpentinite-associated prospects and mines in the Kainuu-Outokumpu area were compared by studying more than 100 drill cores and over 800 samples. The black schists over the entire area exhibit many features in common: an average of 7 percent S and graphitic C, formation thicknesses commonly exceeding 50 m, and textures such as fine-grained laminae rich in spheroidal pyrite and locally veined by quartz and sulfides. The uniform distribution of S and heavy metals in the thick and widespread black shale formations provides evidence for influx of hydrothermal fluids to seawater during the sedimentation of the organic-rich mud.

Carbon isotope $\delta^{13}C$ values in the Kainuu-Outokumpu black schists grade from –30 to –19 per mil. Values of about –20 per mil are probably the result of isotope exchange reactions between organic and carbonate C during metamorphic processes. Fine-grained (<0.01 mm) spheroidal pyrite exhibits $\delta^{34}S$ values from –12.7 to –6.4 per mil, with those of coarse-grained pyrite ranging from –5.9 to +1.4 per mil in the Kainuu-Outokumpu black schists. $\delta^{34}S$ values in the Outokumpu Cu-Zn-Co ores are comparable to those in the black schists. These $\delta^{34}S$ values suggest bacterial reduction of seawater sulfate, with addition of hydrothermal S. Nickel concentrations in pyrite, as high as 0.7 percent, occur in black schists from the Talvivaara black schist-hosted occurrence (300 Mt, grading 0.26% Ni, 0.14% Cu, and 0.53% Zn). Cobalt concentrations in pyrite in black schists (0.3% maximum) and the Outokumpu ores (average 1.1%) differ. Cobalt concentrations also vary widely in the Outokumpu ore pyrites. This suggests that the composition of the ore-forming fluids was not constant; rather, the Co, Cu, and Zn concentrations differed in the successive fluids.

The Kainuu-Outokumpu thick (>20 m) black shale formations were deposited in basins where the bottom waters were enriched by hydrothermal fluids. According to the genetic model now presented, the black shale formed a cap, enabling pulses of Cu-Zn-Co-rich fluids to precipitate metals beneath the cap. Subsequently, tectonic metaperidotites intruded the black shale–ore association. Alteration of the serpentinite released Ca- and Si-rich material that precipitated between the black shale and the serpentinite. During tectonic and metamorphic processes, continued concentration of Cu, Co, and Zn in the silica-rich host rocks resulted in massive orebodies. Serpentinite-associated Cu-Zn-Co ores are rare because the close association of the Cu-Zn-Co ores with the serpentinites is coincidental.

The feasibility of using characteristics of black shales as an exploration tool was tested in the Hammaslahti Cu-Zn-Au and the Vihanti Zn-Cu-Pb ore provinces in Finland, as well as in the Kainuu-Outokumpu area. At both Hammaslahti and Vihanti, black shale could have served as a cap rock under which the ore precipitated.