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Mg isotopic evidence for subseafloor hydrothermal replacement in the Shimokawa massive sulfide deposit, Hokkaido, Japan

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The Shimokawa Cu-Zn massive sulfide ore deposit in the northern Hokkaido, Japan may have been formed by sub-seafloor replacement whereas most volcanogenic massive sulfide (VMS) deposits have been thought to form on the seafloor as exhalative and strata-bound deposits. However, geochemical processes that control the formation of massive sulfide ores in sub-seafloor have been poorly understood. Two main stages of hydrothermal alteration/mineralization have been recognized in the Nakanosawa ore body of the Shimokawa deposit. Whereas pyrite was the main sulfide mineral precipitated in the early stage, chalcopyrite and sphalerite were mostly mineralized together with pyrrhotite in the late stage. In this study, we focus on alterations of the host rocks, which are mostly slate, to (1) clarify the alteration patterns of the host rocks and (2) understand the genetic relationship between the early- and late-alteration/mineralization stages via Mg isotope analysis of the bulk samples. Microscopic observation and XRD analysis of the host rock samples show that most hanging walls and footwalls in the Nakanosawa ore body contain chlorite and illite, suggesting that the overlying sediments were also affected by the hydrothermal activity. However, samples exhibiting only early-stage hydrothermal activity (disseminated ores) contain talc and dolomite as the main gangue minerals. Some disseminated and laminated ores samples exhibiting overlapping the early- to late-stage hydrothermal stages, which are most significantly mineralized, contain talc and Mg-Fe chlorite with high Mg# (Mg/(Mg+Fe) = ~0.8), but no dolomite. The Mg isotope analysis demonstrated that both laminated and disseminated ores are isotopically lighter (δ^{26}Mg = -2.23 – -1.09‰) than typical silicate minerals. Whereas carbonate minerals (i.e., dolomite) were responsible for the negative δ^{26}Mg values of the early-stage disseminated ores, ores affected by the late hydrothermal stages do not contain detectable amounts of dolomite. These δ^{26}Mg values suggest that the formation of Mg-Fe chlorite with a high Mg# was associated with the dissolution of talc and dolomite formed in the early stage and inherit is Mg isotope compositions, which may be a key process for the formation of sub-seafloor replacement-type VMS deposit.