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Crystallization of spinel from coexisting silicate and sulfide immiscible liquids: An equilibrium case with postcumulus reactions

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Abstract

Spinel minerals occur as inclusions in both silicates and sulfides in the Kalatongke magmatic Ni-Cu deposit in NW. China, showing textural and compositional variations. The spinel enclosed in olivine and other silicates (orthopyroxene, clinopyroxene, and hornblende) is predominantly Cr-magnetite with minor Cr-spinel, having wide variations in MgO (0.1–8.0 wt%), Al_2O_3 (1–25 wt%), Cr_2O_3 (3–20 wt%), and TiO_2 (0.5–6.2 wt%) contents. Such continuous variations suggest that Cr-magnetite in silicates was crystallized from residual melts and experienced extensive reaction with trapped liquid undergoing a typical tholeiitic trend of increasing Fe and Ti concentrations. Crystals of Cr-magnetite enclosed in disseminated sulfides have similar Mg, Al, Cr, Ti, V, Sc, Ga, Mo, Zr, and Nb concentrations to the Cr-magnetite in silicates. Such compositional similarity, which is explained by the simultaneous equilibrium crystallization of Cr-magnetite from the silicate and sulfide melts, shows that the Kalatongke deposit is a typical example of where the same mineral phase is formed from two coexisting immiscible liquids. However, the Cr-magnetite in disseminated sulfide and that in silicates show distinctly different crystal size distribution patterns, illustrating that the chemical equilibrium was attained despite contrasting growth rates. Nevertheless, the Cr-magnetite in disseminated sulfides shows significantly lower Ni, Co, and Zn contents (median value of 845, 22, and 319 ppm) than that in silicates (median value of 1428, 160, and 1039 ppm). This cannot be the result of sulfide fractionation because there is little compositional variation between Cr-magnetite included in pyrrhotite (early crystallized phase) and that immersed in chalcopyrite (late crystallized phase). Such Ni, Co, and Zn depletions, combined with the relatively constrained Fe/Ni, Fe/Co, and Fe/Zn ratios in those Cr-magnetite, are attributed to postcumulus reactions between Cr-magnetite and sulfide melts. The spinel hosted by massive sulfides is magnetite, which has distinctly different compositional variations and crystal size distribution patterns compared with those of the silicate-hosted Cr-magnetite, although the magnetite in massive ore generally has similar contents in some lithophile elements (Zr, Ta, Mo, Sn, Mn) to the silicate-hosted Cr-magnetite. This could be taken as evidence for a mixture of early accumulated sulfide pools with a component of drained sulfide from the cumulates above. This study shows a detailed textural and compositional investigation of spinel is useful to decode the sulfide evolution processes during the formation of magmatic Ni-Cu deposits and highlights that equilibrium crystallization and postcumulus reactions play critical roles in controlling the spinel/magnetite composition.

Keywords: Spinel, magnetite, equilibrium crystallization, postcumulus reactions, immiscible liquids, Kalatongke, magmatic Ni-Cu deposit