Re-Os Isotope Systematics of the Voisey's Bay Ni-Cu-Co Magmatic Sulfide System, Labrador, Canada: II. Implications for Parental Magma Chemistry, Ore Genesis, and Metal Redistribution

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Abstract

Re-Os isotope data have been obtained for sulfide samples from five environments within the 1333 Ma Voisey's Bay intrusion (Ovoid, Eastern Deeps, Discovery Hill zone, Reid Brook zone, and Basal Breccia sequence) and the 1313 Ma Mushuau intrusion (Sarah prospect), as well as unmineralized gabbroic and troctolitic intrusions, Archean Nain orthogneiss, and Proterozoic Tasiuyak paragneiss, in order to assess the role of crustal contamination in the genesis of this large Cu-Ni-Co sulfide deposit. Massive sulfide samples have high Re concentrations (148–288 ppb) compared to their Os concentrations (4.8–28 ppb), yielding high Re/Os ratios (2.9–38) that are similar to those for massive sulfides from Sudbury and the Duluth Complex. Whole-rock Re-Os isotope data exhibit a large spread in $^{187}Re/^{188}Os$ (14–157) but do not define a precise isochron, most likely the result of R factor variations within this dynamic ore system (R factor = effective mass of silicate magma with which a given mass of sulfide magma has equilibrated). Large whole-rock sulfide samples from the Ovoid yield an imprecise 1320 Ma isochron age that is consistent with baddeleyite U-Pb ages from the magmatic system. However, data for sulfide (chalcopyrite, pyrrhotite, pentlandite) and oxide (magnetite, ilmenite) mineral separates from the Ovoid and a troctolite from the Eastern Deeps yield an isochron with an age of 1004 ± 20 Ma, consistent with Re-Os T_{CHUR} model ages for some low Os troctolites and olivine gabbros from the magmatic system. These data suggest that the Re-Os system may have been reset at the mineral scale and metals redistributed during a heating-hydrothermal alteration event which coincided temporally with the Grenville orogeny.

The high initial γ_{Os} values (200–1,100 = percent deviation in calculated initial $^{187}Os/^{188}Os$ from mantle of the same age) for sulfide-rich samples from the Voisey's Bay intrusion document significant magma interactions with older Nain-Churchill province crust as there are no known mantle reservoirs with these extreme geochemical characteristics. Re-Os isotope modeling suggests that a reasonable fit to the sulfide data may be obtained via contamination of basaltic magma similar to fine-grained feeder zone olivine gabbros and troctolites with sulfidic-graphitic Proterozoic Tasiuyak paragneiss (γ_{Os} = 1,900), followed by an R factor process (300–>5,000) that improved the tenor (metal concentration in 100% sulfide) of the sulfide liquid during transport in the active Voisey's Bay magma conduit or after deposition in the active-replenished Eastern Deeps magma chamber. However, R factors of this magnitude (>5,000) are not supported by Cu, Ni, and PGE data for the mineralization. Thus, chalcophile element-depleted feeder olivine gabbros and troctolites from the Voisey's Bay intrusion may represent frozen magmas that were the end product of sulfide saturation and segregation during the early stages of mineralization. More internally consistent R factors (50–500) are obtained if the

immiscible sulfide magma interacted with a second, chalcophile element-undepleted (>150 ppt Os) magma. Compelling evidence for the presence of more fertile magmas in the Voisey's Bay system comes from the geochemical and Re-Os isotope data for unmineralized melatroctolite inclusions within the Basal Breccia sequence. These inclusions contain olivine with high MgO and Ni concentrations and low La/Sm and Th/Nb ratios, a high Os concentration, and an enriched (but near-chondritic) initial Os isotope composition (γ_{Os} = 9), geochemical features that are consistent with high MgO basaltic or picritic, plume-type magmas. These inclusions may document magmatic processes in the early stages of development of the Voisey's Bay intrusion, prior to significant fractional crystallization and crustal contamination in the deep crust.

Based on our Re-Os isotope studies of the Voisey's Bay and surrounding intrusions, and on the geochemical and isotopic data presented elsewhere, we postulate that there are at least two staging areas within the crust where contamination of primitive magmas occurred prior to entering the upper Voisey's Bay chamber. This is consistent with other models in which plume-derived, high MgO basaltic magmas were first contaminated in the lower to middle crust to yield sulfide-undersaturated basaltic magmas parental to the Voisey's Bay intrusion. Simple two-component mixing models suggest that contamination of a fertile high MgO basalt with Os isotope characteristics like those of the melatroctolite inclusions with ca. 1 percent lower to middle crust similar to Nain mafic orthogneiss is sufficient to yield the Os isotope characteristics of the feeder olivine gabbro from the Voisey's Bay intrusion and two unmineralized leucotroctolites from the Mushuau intrusion (γ_{Os} = 59–84). These Os isotope results are also broadly consistent with trace element and Sr, Nd, and Pb isotope data for proposed Voisey's Bay intrusion parental magmas as well as for the 1.28 Ga Nain basaltic dikes.

Re-Os data from the mineralized portions of the Voisey's Bay intrusion suggest that these contaminated basaltic magmas underwent more extensive contamination in the upper crust when they encountered the sulfidic-graphitic Tasiuyak gneiss in magma conduits and/or in the Reid Brook subchamber. The fact that this secondary contamination process has not perturbed the relatively homogeneous but enriched Sr, Nd, and Pb isotope geochemistry of the Voisey's Bay intrusion suggests that the contamination process was selective in nature, involving melting-devolatilization of the crustal sulfide and carbon component from the Tasiuyak gneiss. This selective contamination process decoupled the chalcophilic Os isotope system from the lithophilic Sr, Nd, and Pb isotope systems in mineralized rocks from Voisey's Bay. The 1313 Ma Mushuau intrusion may not have undergone a second phase of upper crustal contamination where excess sulfide, in the form of sulfide liquid of crustal origin, can be acquired by the parental magma. Thus, a multistage model of ore genesis, involving at least two stages of crustal contamination, two magma chambers, and multiple pulses of geochemically distinct magma, is entirely consistent with the Re-Os isotope data from Voisey's Bay.