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Siderophile and Chalcophile Metal Variations in Flood Basalts from the Siberian Trap, Noril'sk Region: Implications for the Origin of the Ni-Cu-PGE Sulfide Ores

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Abstract

The Talnakh, Kharaelakh, and Noril'sk I intrusions of the Noril'sk region are coeval with the Permo-Triassic Siberian trap flood basalt and contain one of the largest known resources of Ni-, Cu-, and platinum group element (PGE)-enriched sulfide mineralization. The ~3.5-km-thick stratigraphy of the basalts consists of a Lower sequence of high Ti alkalic, subalkalic, and picritic basalts, and an Upper sequence of low Ti basalts. The stratigraphy of the Upper sequence consists of a group of picritic and tholeiitic basalts assigned to the Tuklonsky Formation, overlain by the Nadezhdinsky Formation which is represented by a sequence of contaminated tholeiites that show an upward decline in the degree of contamination into the overlying Morongovsky and Mokulaevasky Formations. The Nadezhdinsky Formation is depleted in Ni, Cu, and PGE, with the most depleted basalts having concentrations below the analytical determination limits of 0.06 ppb for Pd and 0.1 ppb for Pt and a factor of at least 100 less than the Pd and Pt concentrations of the rest of the Upper sequence. The greatest PGE depletion occurs a short distance above the base of the Nadezhdinsky, and these flows are overlain by basalts that exhibit a gradual recovery in PGE concentration toward values typical of the Mokulaevsky Formation and the overlying basalts (~6.8–12.1 ppb Pt and ~7.2–16.5 ppb Pd). Within the Nadezhdinsky Formation, there is a strong correlation between Pd/Zr and La/Sm ratios that indicates that the magmas with the largest contribution from crustal material are also the most PGE depleted. Moreover, the contribution of crust to the magma and the degree of metal depletion decreased through time. The PGE-undepleted Upper sequence tholeiites have Pd/Pt of 0.45 to 2.0, and the ore-forming sulfides (Pd/Pt ~3–4) were probably formed from magmas with Pd/Pt ratios at the upper limit of this range; the metal-depleted basalts have lower values (Pd/Pt ~0.3). The high Pd/Pt ratio of the ores and the low Pd/Pt ratio of the basalts indicate that the processes of ore formation and flood basalt magmatism were important because they indicate that the basalts have the Pd/Pt ratio of a magma that has segregated sulfide with the same Pd/Pt ratio as the Noril'sk ores. Moreover, the ore deposits are located in the region where the metal-depleted Nadezhdinsky Formation is ~500 m thick and forms a >5,000-km^3 volcanic center.

The continuous changes in basalt chemistry through the stratigraphy of the Upper sequence are consistent with processes that took place in a very large staging chamber rather than within multiple ~5- to 10-km^3 discrete high-level magma chambers on the scale of the mineralized intrusions. In the staging chamber, Tuklonksy-type magmas interacted with crust to produce the contaminated basalts of the Nadezhdinsky Formation. The staging chamber containing the crustally contaminated magma was then replenished with PGE-undepleted magma. Initially, the replenishing magma became sulfide saturated, thereby producing the ore-forming sulfides, and the magma in the staging chamber remained sulfide-saturated. As further injections of PGE-undepleted magma entered the staging chamber, the melt became sulfide undersaturated and magmas tapped from it were progressively less PGE depleted. The deposits of the Noril'sk, Talnakh, and Kharaelakh intrusions were formed by injection of olivine-bearing melts containing immiscible sulfide that were produced in the staging chamber. The ores inherited a heavy sulfide isotope composition possibly by reaction with evaporite-laden country rocks. The unradiogenic composition of the Os in the ores is consistent with interaction between the crustally contaminated magma (which had become depleted in the PGE and radiogenic Os) in the staging chamber with later pulses of uncontaminated mantle-derived magma. The high PGE contents of PGE-undepleted Siberian trap are due to interaction of plume-generated picritic magmas with lithosphere that had been depleted in sulfide by previous melt extraction.

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