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Top-down fractional crystallization of a sulfide liquid during formation of largest ore-body from the Noril'sk-Talnakh PGE–Cu–Ni deposits, Russia

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The world-class Noril'sk–Talnakh PGE–Cu–Ni sulfide deposits are related to Siberian flood basalt province. The largest massive sulfide ore-body associated with the Oktyabr'sky deposit occurs at the base and in the immediate footwall of 100-260 m thick sill-like mafic-ultramafic Kharaelakh intrusion. This sheet-like sulfide body occupies an area of 4.6 km x 1.8 km, reaching a maximum thickness of 50 m. The dominant portion of this body is composed of pyrrhotite-rich ores. The most popular conduit model interprets this ore-body as a large sulfide liquid pool accumulated at the bottom of the plumbing magma chamber. The location of the sulfide pool between cold, underlying sedimentary rocks and the hot overlying Kharaelakh intrusion implies its bottom-up crystallization. However, our study shows that the main pyrrhotite-rich portion of the ore-body reveals a systematic upward increase in compatible elements (e.g. Ru, Rh, Os, Ir) and a decrease in incompatible elements (e.g. Cu, Pd, Pt). This compositional pattern indicates that the sulfide ore-body crystallized largely downwards from the top. There are three possible ways to explain this compositional pattern: (1) top-down solidification due to floating of early monosulfide solid solution (mss) crystals towards the roof; (2) bottom-up solidification with a progressive decrease in the amount of trapped residual liquid; (3) top-down solidification from cold roof rocks.

(1) Flotation of mss is not possible because the density of pyrrhotite group minerals (former mss) (4.55 to 4.87 g/cm3) is higher than that of coexisting sulfide liquid (3.88 g/cm3 at 1200°C).

(2) Bottom-up solidification with a progressive decrease in the amount of trapped residual liquid implies that the earlier-formed mss should occur at the base of the ore-body. However, pyrrhotite composition and distribution of compatible for mss elements (Rh, Ru, Ir, and Os) show that the most primitive mss was located at the top rather than at the bottom of the ore-body.

(3) Top-down crystallization from relatively cold roof rocks towards hotter floor rocks appears to be the only mechanism that remains to explain the observed zoning. The heating of floor rocks can be attributed to the hot underlying Lower Talnakh intrusion. However, this intrusion can hardly provide sufficient heating to prevent mss crystallization at the lower contact of the ore-body.

This leaves us with two possible options: (a) either top-down fractional crystallization of the ore-body was made possible by a thermal gradient that was strongly augmented by some other, unspecified, processes or (b) the mechanism responsible for top-down crystallization was not a temperature gradient and the explanation should be searched for in other directions.