**The Formation of Magmatic Ore Deposits**

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The formation of magmatic Ni-Cu sulfide deposits is directly linked to interaction between mafic-ultramafic magma and rocks of the continental crust. This interaction decreases the solubility of sulfide in the magma and/or adds sulfur to generate an immiscible sulfide liquid. Strongly chalcophile Ni, Cu and PGE become concentrated in the sulfide and if this phase accumulates in sufficient quantity and with sufficient tenor, an ore deposit is formed.

Most models propose that sulfide droplets segregate and accumulate from magma that flows rapidly through conduits. These 'high-flux' models are at odds, however, with the following observations. Many ores appear to have been emplaced as magmatic breccias (Norilsk-Talnakh, Russia; Aguablanca, Spain) or crystal mushes (Jinchuan, China) that contain a high proportion of sulfide. Such mixtures are very dense and could not have migrated upwards through the crust from a deeper staging chamber. In the Uitkomst and Platreef deposits (South Africa), screens of sedimentary rock maintaining the same orientation as adjacent sedimentary strata separate layers of ultramafic cumulates, some containing abundant sulfide ore. This geometry suggests that ultramafic mush and ore sulfides oozed into the sedimentary sequence, replacing less resistant strata.

These features can be explained if sulfide-rich masses of magma accumulated higher in the magmatic plumbing system then slumped downwards. Most mafic-ultramafic intrusions do not differentiate in place but grow through the injection of magmas of differing compositions and crystallinities. Highly mafic magmas, particularly those charged with ferromagnesian crystals and sulfide, have high densities and they are injected into the lower parts of growing intrusions while less-dense, more evolved and/or plagioclase-rich magmas are injected at higher levels. Many ore-bearing intrusions are hosted in conduits with sloping margins. As magma flows up along these margins, the denser sulfide/inclusion/crystal-rich mush accumulates near the lower border while a sulfide-crystal-poor silicate liquid ascends along the upper part. This process differentiates the magma, producing evolved decanted liquids that flow upwards and erupt, and a sulfide-rich slurry that periodically becomes unstable and slumps down the conduit. The magma interacts with the slumping sulfide in the lower part of the conduit, enriching the sulfide in chalcophile metals. This interpretation, if correct, requires re-evaluation of the geological criteria used to locate ore deposits in magmatic systems. High fluxes are associated with decanted magma flowing upwards through the system but ore formation results from intermittent downward flow of sulfide mushes. To understand these processes requires detailed 3D mapping of magma conduits.

Density also plays an important role, but at a larger scale, during the formation of the Cr and platinum-group-element deposits (PGE) in the Bushveld Complex in South Africa. This is the world’s biggest mafic-ultramafic intrusion and one of the richest repositories of magmatic ores. Despite decades of study, many aspects of the emplacement of the intrusion continue to pose problems. Foremost are mismatches between the volume of magma required to account for the major deposits of Cr and PGE and the volume of mafic rock preserved in the complex. A large volume of magma is missing, but the most obvious explanation - that the missing magma erupted - is contradicted by the small volumes of mafic lava at the surface. The recent discovery of highly magnesian rocks at the periphery of the complex exacerbates the situation because these would have produced large volumes of ultramafic cumulates. Geophysical data are also problematic. The centre of the complex, where a large mass of dense rock should be present if the intrusion had the funnel shape that is normal for large mafic-ultramafic intrusions, displays negative gravity anomalies.

A solution is offered by recent analogue and numerical modelling of the emplacement of mafic magma into crustal magma chambers. This modelling shows that the dense lower mafic-ultramafic cumulates of an intrusion with the form, size and geological context of the Bushveld Complex would founder and descend deeper in the crust. It is proposed that the complex, as currently exposed at the surface, represents only a small portion of an initially much larger intrusion.