C10
Game Changers in Understanding and Exploring for Magmatic Ni-Cu-PGE Deposits

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Ni-Cu-PGE sulfides are the type example of orthomagmatic mineralization. Although the origins of magmatic Cr, Fe-Ti-V, and PGE deposits and their exploration implications are still hotly debated with no consensus yet in sight, our better understanding of the genesis of magmatic Ni-Cu-PGE deposits was transformed by several game-changing discoveries in the late 1970s and 1980s. During the first half of the 20th century, most models involved sulfide exsolution with no explanation for the very high abundances of sulfides in some deposits. In the 1960s and 1970s, the first evidence for crustal S appeared, but as late as the mid-1970s, the leading model involved formation of sulfides in sulfide-rich parts of the mantle with transport to the surface in olivine-rich magmas. In the late 1970s, it was discovered that the partitioning of platinum-group metals between immiscible sulfide and silicate melts is orders of magnitude stronger than previously assumed and that the metal tenors of immiscible sulfide melts are strongly dependent on the effective magma:sulfide ratio. In the early 1980s, this led to the revelation that high-tenor magmatic Ni-Cu-PGE deposits cannot form from sulfide-saturated magmas, but must form from sulfide-undersaturated magmas. In the mid-1980s, it was shown that magmatic Ni-Cu-PGE deposits do not form from magmas containing intratelluric olivine phenocrysts, but that the host units represent dynamic lava/magma conduits, in which olivine crystallized in situ, that were capable of thermomechanically eroding wall rocks. This, increasing S-isotope evidence for non-mantle S in a wider range of deposits, and new geological and fluid dynamic constraints led to models in which sulfide melts do not come from the mantle, but S is incorporated during thermomechanical erosion of crustal rocks. The 1990s and 2000s provided additional geological, stratigraphic, mineralogical, geochemical, isotopic, fluid dynamic, and thermodynamic evidence for crustal incorporation models. These developments fundamentally and forever changed how we explore for magmatic sulfide deposits, a process that now involves exploring for magma conduits (lava channels, channelized sills, chonoliths, channelized dikes) that were able to access crustal S (sulfidic sediments, sulfidic volcanic rocks, evaporites). The debate in the 2010s turned to if and how sulfides can be transported vertically, with some models suggesting significant upward transport of sulfide droplets from the mantle or deeper “staging chambers” and other models requiring generation at more-or-less the same stratigraphic levels and only subhorizontal transport (see Figure: 1 = prospective channels with access to S, 2 = non-prospective channels without access to S, 3 = non-prospective, access to S but not channelized). During the next 10 years, we will develop more sophisticated fluid dynamic models of multiphase transport of silicate melt – sulfide melt ± phenocrysts ± xenoliths ± xenocrysts ± xenovolatiles, leading to advances in our understanding of how sulfides are localized in geometrically complex dynamic magmatic systems. We will also determine how to more precisely target mineralized magmatic plumbing systems by integrating more sophisticated understanding of tectonomagmatic controls with high-resolution seismic, magnetotelluric, and gravity data. MERC contribution number 2020-002.