Paper Number: 3058

Sm-Nd isotopic evidence for sampling of multiple sources during the emplacement of the Upper Critical Zone, Bushveld Complex, South Africa

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The origins of PGE-sulphide bearing reefs, many of which include chromitite layers, in layered intrusions remains a lively subject for research and for speculation, in spite of decades of concerted research. The congruence of the sulphide and oxide mineralization has promoted models involving one or the other or a combination of crustal contamination and magma mixing, most often attributed to in-situ Upper Crustal processes. There is evidence to support the presence of an evolved component intimately associated with chromitite layers, e.g., radiogenic isotopic enrichments within the basal parts or immediate footwall, alkali-rich inclusions in early crystallised phases (chromite, olivine). The 2.055 Ma-old Bushveld Complex is a well-studied layered intrusion in which variations in strontium isotopic compositions have been used to support a model of “within chamber” contamination of incoming magmas by Upper Crustal host rocks.

New Sm-Nd isotopic data have been obtained from two drill-holes (WH14 and WH31) that transect the Merensky Reef in the Winnaarshoek section, Eastern Limb. The Merensky Reef comprises a 2 m-thick unit of feldspathic orthopyroxenite in which a 1-5mm-thick chromitite stringer occurs 0.4 m from the upper contact with a thin layer of leuconorite that in turn is overlain by 8-12 m of anorthosite. The basal part of the Reef may include an irregular layer of pegmatoidal pyroxenite capped by a thin, discontinuous stringer of chromitite. The footwall succession is a complexly interlayered sequence of leuconorite, norite, and pyroxenite. The Sm-Nd data reveal a distinct increase in radiogenic component within the reef pyroxenite, with the most radiogenic samples ($\varepsilon_{Nd}^{2.06}$ of around -8.0) found about 1 m below the uppermost chromitite stringer. In comparison to Sr isotopic variations, which cannot readily distinguish between contributions from large volumes of relatively young (ca. 2.7-2.1 Ga) Crust or smaller volumes of older Mesoarchaean crust, $\varepsilon_{Nd}^{2.06}$ of -8.0 demonstrably require wholesale re-melting of younger crust such as the Rooiberg and Dullstroom lavas which might correspond to roof rocks for the Bushveld magmas. Since the Upper Critical Zone rocks are otherwise consistent with more modest amounts of contamination (up to 40% crust has been proposed for parts of the Bushveld based on oxygen isotopic compositions), older more radiogenic crust is required as a contaminant. Depending on the choice of mantle melt composition (i.e., a basaltic or komatiitic composition), between 5 and 10% contamination by Mesoarchaean (3.5-3.1 Ga) tonalite-trondhjemite-granite crust is sufficient to explain the normal variation in Bushveld magmas, with another 5% required to account for the sporadic enrichments associated with oxide and sulphide mineralization. The isotopic composition of the footwall and hangingwall rocks to the Reef is consistent, with an average value of $\varepsilon_{Nd}^{2.06}$ of approximately -5.5 ± 1.0. In comparison, Sr isotope systematics show a marked step in the initial ratio above the Merensky Reef.

The Sm-Nd isotopic profile requires that the Reef pyroxenite crystallized from a parental magma that was contaminated by more radiogenic, older crust at depth, in comparison to the footwall and hangingwall which could be accounted for by either similar amounts of less radiogenic (i.e., younger) contaminant or lesser (5%) amounts of the same ancient contaminant. This requires a distinct provenance for the Reef pyroxenite relative to its host rocks. The simplest explanation is one wherein the same source is tapped at different times in a thermally and mechanically evolving system, such that earlier crystallized but more crustally-contaminated material was emplaced into an existing, less contaminated sequence. This is consistent with the hypothesis of Mitchell and Scoon [1] wherein it was suggested the ultramafic-mafic components of the Merensky Reef at Winnaarshoek were emplaced as a sill within an earlier-formed sequence dominated by leuconorite and anorthosite.

Reference:

[1] Mitchell A A and Scoon R N (2007) Economic Geology 102: 971-1009