

On the hydrothermal origin of platinum-group element deposits in layered intrusions

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There are a number of lines of evidence suggesting that volatile-rich magmatic fluids have played a dominant role in the petrogenesis of platinum-group element (PGE) deposits in layered intrusions. These include footwall sections that are unusually enriched in Cl in the higher grade deposits, potholes and other fluid-escape structures, pegmatoidal textures, relatively abundant hydrous minerals, and the ease by which sulphur can be moved in hydrothermal systems.

Models of a solidifying and degassing crystal pile illustrate how magmatic fluids can give rise to zones of PGE-enrichment in layered intrusions. Cooling through the base of a crystal + liquid column leads to solidification and eventual fluid saturation in interstitial silicate liquids. A zone of "cryptic" degassing (so named as evidence of a former fluid phases is preserved largely in compositional trends in minor element such as the halogens and S) migrates upward as volatiles degassed from underlying interstitial liquid enriches overlying, fluid-under-saturated interstitial liquids. Sulphur and sulphide is resorbed from the degassing regions and is re-precipitated in the vapor-undersaturated interstitial liquids, producing a zone of relatively high modal sulphide that also migrates upward with time. This sulphide-enriched front can mimic a conventional sulphide-in horizon and appear as the stratigraphic level at which the magma became S-saturated, but it is secondary and hydromagmatic in origin.

Owing to their strong preference for sulphide, the PGE are not significantly mobile until all sulphide is resorbed. In addition, fluid migration can result in significant chromatographic separations of ore elements. These stratigraphic "offsets" are characterized by a lower, typically S-poor, Pt- and Pd-enriched zone overlain by a zone enriched in the base metals, S and Au. The process can also produce high PGE/S ratios that mimic values conventionally interpreted as the result of high "R" values.

The fluid front and ore element transport may remain fully within the pile or it may reach the top of the pile where it can affect crystallization of the main magma body. For the former, metals may be trapped at compaction-induced porosity/composition discontinuities in the crystal pile (e.g., Great Dyke-type PGE deposits). The latter may result in significant degrees of incongruent melting of the solid assemblage due to volatile fluxing and form unconformity-type deposits (e.g., J-M Reef of the Stillwater Complex).

Tracing geochemical evolution of the Bushveld Complex with lead isotopes analyzed by LA-MC-ICP-MS

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A new investigation of Pb isotopic compositions of plagioclase and sulfide in the Bushveld Complex has been conducted to evaluate results of an earlier study, extend observations to the UG2 chromitite as well as Merensky reef, and characterize better the Pb components in the rocks. The PGE-rich UG2, like the Merensky reef, displays evidence of magmatic metasomatism and recrystallization. Analyses were obtained with the NuPlasma multicollector ICP-MS coupled with a NewWave DUV193 ArF Excimer laser. Helium was used as the carrier gas, spot sizes ranged from 80 to 150 μm and pulse rates 5 to 20 Hz, and isotopic fractionation was controlled by external normalization.

Most plagioclase and sulfide analyses fall on the $^{207}\text{Pb}/^{204}\text{Pb}$ vs $^{206}\text{Pb}/^{204}\text{Pb}$ geochron of 2.06 Ga, which is the solidification age. This indicates that most measured ratios are equivalent to initial ones. Of the 28 samples studied, only two contain phases contaminated by young Pb. Plagioclase possesses a single composition, interpreted to represent that of the parent magma, of $^{208}\text{Pb}/^{204}\text{Pb} \approx 34.80$, $^{207}\text{Pb}/^{204}\text{Pb} \approx 15.25$, $^{206}\text{Pb}/^{204}\text{Pb} \approx 15.00$. The $^{238}\text{U}/^{204}\text{Pb}$ and $^{232}\text{Th}/^{204}\text{Pb}$ ratios of the source were 9.2 and 38.3, respectively. Sulfide compositions are commonly different than that of plagioclase in the same thin section, confirming the original results of Mathez and Waight (2003) and their interpretation that material with a Pb isotopic composition different from that of the original magma was introduced into the rocks under conditions under which sulfide but not the plagioclase compositions could be modified. The sulfides contain Pb from two different, old sources. Some possess $^{208}\text{Pb}/^{206}\text{Pb}$ and $^{207}\text{Pb}/^{206}\text{Pb}$ ratios distinctly lower than those of coexisting plagioclase. The Bushveld rocks are cut by a set of late magmatic veins, the plagioclase of which also displays anomalously low $^{208}\text{Pb}/^{206}\text{Pb}$ and $^{207}\text{Pb}/^{206}\text{Pb}$ ratios. Other sulfides contain Pb characterized by high $^{208}\text{Pb}/^{206}\text{Pb}$ and $^{207}\text{Pb}/^{206}\text{Pb}$ ratios, suggesting introduction of material from a Th-rich source substantially older than the Bushveld. The variability of Pb isotopes reflects a long and complex magmatic to subsolidus cooling history involving several episodes of melt/fluid infiltration.

Reference

Mathez, E.A., and Waight, T.E. (2003) *Geochim. Cosmochim. Acta* **67**, 1875-1888.