Constraining hydrothermal and magmatic processes beneath the Merensky Reef and UG2 Chromitite, Bushveld Complex, RSA

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This thesis takes on a two-part study of late-stage pegmatite veins and pipes which cross-cut stratigraphic units within the Bushveld Complex, South Africa. The compositional evolution of a late magmatic to a hydrothermal system, via a comprehensive fluid and melt inclusion study, is constrained in addition to the thermochemical characterization of the system during pegmatite crystallization.

Quartz and andesine contain primary inclusions of magmatic origin, varying from early, low salinity, two-phase aqueous inclusions to late, nearly anhydrous, NaCl-$CaCl_2$-dominant halide melt inclusions. Silicate melt inclusions (high K and granitic) are also present, and are unambiguously coeval with the halide melt inclusions, demonstrating that the late-stage felsic liquid was saturated in this salt melt. Analyses of melt inclusions by LA-ICP-MS indicate high concentrations of precious metals such as Pd and Au (0.2–0.6 ppm range) at the time of their entrapment. Trace element modeling, using the silicate melt inclusions in conjunction with bulk pegmatite analysis, shows that the formation of the late-stage pegmatite units are by low degrees (~1 vol%) of fractional crystallization of the granitic melt.

SEM (scanning electron microscope) analysis of mineralized cores within the pegmatite veins show pyrrhotite and pentlandite as primary, vug-infilling metals with early inclusions of melonite [(Ni, Pd) Te_2]. Normative abundance patterns are most similar to those from the Bushveld Platreef, showing a marked enrichment in Pd relative to Pt (Pd/Pt > 8), Cu relative to Ni (Cu/Ni > 20) and significant depletion in Ir. Secondary chalcopyrite replacement of pyrrhotite and hessite fracture infill was also observed.

Radiometric $^{40}Ar/^{39}Ar$ dating of biotite (~2022–2044 Ma) indicates the crystallization age of the pegmatite is synchronous with the Bushveld Complex, (~2054 Ma) and disproves previous speculation that the crystallization of the pegmatite was related to the neighboring Pilannesburg Dyke Swarm (~1300 Ma). Mössbauer spectroscopy and EMP (electron microprobe) analyses show direct evidence that slightly oxidizing (within ~1 log unit of the FMQ redox buffer), halide melt-saturated silicate residues were ore metal-bearing during entrapment; therefore, metals at this time were carried via sulfide complexes. Ore/accessory metal ratios in the melt inclusions and pegmatite sulfide assemblages are consistent with the bulk rock metal ratios of pyroxenite cumulates below the Merensky Reef, suggesting that metals were scavenged from those cumulates. Quantitative modeling suggests that the residue melts significantly impacted metal tenor and ratios in the Upper Critical Zone magma.

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