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On the Physical Transport of Magmatic Sulfides: Insights from the Trace-Element and Isotope Signature of Sulfide Globule Halos

Maria Cherdantseva[1], Marco L. Fiorentini[1], Christopher M. Fisher[1], Antony I. Kemp[1], Laure A. Martin[2], Matvei Aleshin[2], Malcolm P. Roberts[2]
1. Centre of Exploration Targeting, School of Earth Sciences, The University of Western Australia, Perth, WA, Australia, 2. Centre for Microscopy, Characterisation and Analysis, The University of Western Australia, Perth, WA, Australia

The origin of volatile-rich minerals such as calcite, apatite, amphibole, and mica, as well as incompatible element-enriched minerals such as baddeleyite and zircon, which are commonly associated with magmatic sulfides in layered intrusions, mafic-ultramafic intrusions, and komatiites, has been debated for decades. Based on mineralogical and petrological studies, it was recently suggested that these minerals may form due to interaction between three immiscible liquids: silicate, carbonate, and sulfide. This hypothesis was confirmed by experimental data revealing the systematic envelopment of sulfide globules by carbonate melt, indicating their mutual affinity.

However, the source of the volatile-rich carbonate melt involved in this process remains unknown. To address this knowledge gap, we present data on isotopic signatures and trace element distributions of three minerals commonly found in spatial association with sulfides—calcite, apatite, and zircon—in selected samples from three mineralized intrusions. These are the Rudniy intrusion within the Torgalyk Complex surrounding the Tuva depression, Mongolia; the Valmaggia intrusion in the Ivrea Zone, Italy; and the Norilsk-Talnakh camp associated with the Siberian Traps Large Igneous Province, Russia. The rationale for the selection of these deposits is that these intrusions span in age, size, geodynamic setting, metal endowment, and emplacement depth, displaying a comprehensive series of characteristics that can be applied to deposits globally.

Our findings from the three selected localities indicate that both mantle and crustal sources play a role in the formation of these mineral phases, correlating with sulfur isotope systematics in magmatic sulfides. This relationship confirms the shared origin of sulfide, carbonate melts, and fluids during ore-forming processes. The trace element signatures underscore the complexity of apatite and zircon formation, reflecting a mixture of different melts over the intricate evolutionary history of magmatic sulfide systems in different settings and with diverse petrogenetic histories.