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Titanium Isotopes in Magnetite as Tracers of Ore-Forming Processes in Iron Oxide Apatite (IOA) and Iron Oxide Copper Gold (IOCG) Systems

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Iron oxide apatite (IOA) and iron oxide copper gold (IOCG) deposits collectively are major sources of Fe and Cu and minor or potential sources of Au and the rare earth elements (REE)—resources crucial for modern and emerging technologies and whose demand is expected to increase significantly in the next few decades. IOA and IOCG deposits occur globally and comprise structurally controlled Fe oxide (± Cu sulfide in IOCG systems) bodies hosted within highly metasomatized country rocks and exhibiting characteristic element enrichment suites. Mounting evidence suggests that IOA deposits represent deeper portions of IOCG systems, however, a universal connection remains tenuous. These deposits are geologically diverse in their ages, petrologic associations, mineralization styles, and particular elemental enrichments but are believed to represent a common set of respective processes. Additional uncertainties as to the source of their metallic resources have posed difficulties in establishing consensus for a holistic formation model. Here, we present Ti isotope compositions for magnetite, an oxide phase common in both IOA and IOCG deposits, and apply these results to better understand the formation of Fe oxide resources in these and other magnetite-bearing mineralized systems including Fe-rich skarns, layered mafic intrusions, and Cu-Au porphyries. The utility of Ti isotopes in deconvolving ore-forming processes is premised in the suggested exclusivity of Ti isotopic variations in crustal materials reflecting the precipitation of primary magmatic Ti-bearing oxide phases while resisting hydrothermal overprinting.

Ti isotope compositions were determined via multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS). Ranges in δ^{49}Ti of magnetite from IOAs (5.55‰), IOCGs (5.49‰), and layered mafic intrusions (3.78‰) each eclipse the variation of bulk rock δ^{49}Ti observed in terrestrial igneous rocks (c. 0–0.19‰) and in meteorites (c. 0–0.3‰), and variation within individual deposits (e.g., 2.43‰ variation at El Laco IOA in Chile) far exceeds the $\Delta^{49}Ti_{oxide\text{-}melt}$ (0.39‰) predicted from earlier work by Johnson et al. (2019) for magnetite monotonically precipitating (i.e., not resorbed) from a fractionating magmatic reservoir (Figure 1). The large overlap (from c. -2 to 3‰) and similar range in δ^{49}Ti observed in IOA and IOCG magnetite strongly suggests that similar processes occur in the formation of magnetite in both of these deposit types and is consistent with models suggesting a genetic relationship between them. Further work is necessary to understand the mechanism responsible for such large degrees of Ti isotope fractionation in individual ore deposits and to better characterize the ranges of δ^{49}Ti in magnetite from different types of iron oxide ore deposits.

Figure 1. Measured $\delta^{49}Ti$ compositions for banded iron formation (BIF), Cu-Au porphyry, Fe-Ti-V deposit, iron oxide apatite (IOA) deposit, iron oxide copper gold (IOCG) deposit, layered mafic intrusion (LMI), and Fe skarn magnetite. Analytical uncertainties are smaller than the symbol size.