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Trace element composition of magnetite with different occurrences in orthomagmatic nickel-copper sulfide ores from Selebi-Phikwe complex, Botswana

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Orthomagmatic ore deposits are important sources of critical and base metals, such as nickel (Ni), copper (Cu), chromium (Cr), and Platinum Group Elements (PGE). To understand the formation processes, we focused on the trace element composition of magnetite, which has recently been used to discriminate various types of ore deposits. However, factors controlling magnetite chemistry are complex and require further investigation. This study investigated the relationship between trace element composition measured by LA-ICP-MS and formation processes of magnetite identified by petrographic observation in the Selebi-Phikwe Complex (Cu-Ni deposits), Botswana, compared to other major orthomagmatic ore deposits.

Different types of magnetite were observed under a microscope and divided into two types based on their morphology and occurrence: magmatic and hydrothermal magnetite. Some magmatic magnetite occurred together with pyrrhotite and pentlandite, which appeared to have been affected by the liquid immiscibility of sulfide. Euhedral magnetite was likely crystallized in the early stage of fractional crystallization, while interstitial magnetite crystallized between grains of pyroxene, and plagioclase seems to have been formed in a relatively late stage of crystallization. The coarse-grained may have experienced a long crystallization period. Among the hydrothermal magnetite, while veined magnetite precipitated from hydrothermal fluids, anhedral magnetite was likely hydrothermally altered magmatic magnetite. The chemical trends varied between magnetite types. Compared to hydrothermal magnetite, magmatic magnetite showed higher trace element concentrations, particularly in Ti, Al, V, and Cr, but was depleted in Si. Magnetite co-crystallized with ilmenite tends to be depleted in Ti, whereas magnetite co-crystallized with pentlandite or chromite tends to be enriched in Ni or Cr. While the (Ti+V) vs. (Al+Mn) diagram of magnetite showed high temperatures (~1000 °C) for magmatic magnetite, the Mg concentration indicated lower formation temperatures (~800 °C). These results suggest that the Mg concentration reflects re-equilibration during magma cooling, with a higher temperature in the center of the magma chamber where cooling is slower, and a lower temperature in the periphery where cooling is faster.

Keywords: Orthomagmatic ore deposits, fractional crystallization, immiscibility of sulfide, trace element composition, magnetite, LA-ICP-MS, formation temperature