

Trace element fractionation in magnetite as a function of Fe depletion from ore fluids at the Baijian Fe-(Co) skarn deposit, eastern China: Implications for Co mineralization in Fe skarns

GUANG WEN^{1,2}, JIAN-WEI LI^{1,2,*†}, ALBERT H. HOFSTRA³, DANIEL E. HARLOV^{2,5,6,‡}, XIN-FU ZHAO^{1,2}, HEATHER A. LOWERS³, AND ALAN E. KOENIG⁴

¹State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Wuhan 430074, China

²School of Earth Resources, China University of Geosciences, Wuhan 430074, China

³U.S. Geological Survey, DFC, MS-963, P.O. Box 25046, Denver, Colorado 80225, U.S.A.

⁴Newmont, Technical Services, 10101 East Dry Creek Road, Englewood, Colorado 80112, U.S.A.

⁵Deutsches GeoForschungsZentrum–GFZ, Telegrafenberg, 14473 Potsdam, Germany

⁶Department of Geology, University of Johannesburg, P.O. Box 524, Auckland Park 2006, South Africa

ABSTRACT

Magnetite is common in various magmatic and hydrothermal ore deposit types, and its trace element geochemistry has become increasingly used in ore genesis studies and mineral exploration. While fractional crystallization has been shown to influence the chemistry of igneous magnetite, the extent to which this process regulates the trace element composition of hydrothermal magnetite remains poorly understood. In this study, we analyzed trace elements in hydrothermal magnetite from the Baijian Fe-(Co) skarn deposit in eastern China and used Rayleigh and equilibrium fractionation modeling to demonstrate the importance of magnetite precipitation in controlling fluid and magnetite chemistry during Fe skarn mineralization.

The Baijian Fe-(Co) skarn deposit has three stages of magnetite. From early Mag-1 to later Mag-2 and Mag-3, the concentrations of compatible elements (Ni and V) decrease, whereas those of incompatible elements (Zn, Mn, and Co) increase. There are obvious trends of increasing incompatible/compatible element ratios (e.g., Co/Ni, Zn/V, and Zn/Ni) and decreasing compatible/incompatible element ratios (e.g., V/Mn, Ni/Mn, and V/Co) from Mag-1 to Mag-3, with strong correlations between each of these ratios. Such systematic trace element variations in successive stages of magnetite can be best explained by increasing degrees of fractional crystallization with time. The wide range of incompatible/compatible element ratios (spanning 2–4 orders of magnitude) in Mag-2 and Mag-3 suggests that magnetite crystallization follows a process akin to Rayleigh fractionation.

Results from this study highlight the significant role that magnetite crystallization during skarn formation has on the trace element chemistry of this mineral. Moreover, as the crystallization of magnetite progresses, the Co/Fe ratio of residual hydrothermal fluids is elevated, which favors the precipitation of Co in late-stage sulfides. This process helps to explain why some Fe skarn deposits, as well as magnetite-rich iron oxide-apatite and iron oxide-copper-gold deposits, are potentially important economic sources for Co, currently necessary as one component in Li-ion batteries.

Keywords: Magnetite geochemistry, Rayleigh fractionation, cobalt mineralization, iron skarn; Critical Minerals for a Sustainable Future