

In-situ magnetite and apatite chemistry from the Carajás iron oxide-copper-gold and hydrothermal nickel deposits: A new perspective for regional fluid circulation, metal transportation and mineral exploration

Dutra, L.F.¹; Monteiro, L.V.S.¹; Dare, S.²; Ferreira Filho, C.F.³; Mansur, E.T.⁴; Barbosa, N.A.¹; Montresor G.⁵; Araújo, J.⁶; Matos, F.M.⁶

¹Universidade de São Paulo. ²Université du Québec à Chicoutimi. ³Universidade de Brasília. ⁴Norges Geologiske Undersøkelse. ⁵Centaurus Metals Limited. ⁶Vale S.A.

Magnetite and apatite are commonly associated with ore zones in hydrothermal deposits, where their trace element composition provides insights into several metallogenic processes and can be used as proxies in mineral exploration. In this study, we utilized petrographic observations, in-situ high-resolution electron microprobe and laser ablation inductively coupled mass spectroscopy (LA-ICP-MS) analysis to examine the major, minor and trace element compositions of magnetite and apatite from several deposits in the Southern Copper Belt, Carajás Province. These deposits include IOCG (Sossego and Sequeirinho orebodies), Ni-rich IOCG (Castanha and Jatobá deposits), and hydrothermal nickel (GT-34 deposit, and Jaguar South and Onça Preta orebodies) deposits. Our goal was to investigate the factors contributing to the formation of these deposits, understand the relationship among them, and discuss the key elements for discriminating the different deposit types. Despite differences in the principal metal endowment of these deposits, our findings indicate a complex evolution of ore-forming fluids. The compositions of magnetite and apatite depend on the hydrothermal fluid, interactions with the host and regional rocks and subsequent dissolution-reprecipitation processes. The IOCG and Ni-rich IOCG deposits were formed by a high-temperature (>400°C), hypersaline, F-Cl-bearing fluid that evolved from reduced to moderate oxidized conditions. This evolution is evidenced by the increasing Eu/Eu* ratio in apatite and the decrease of Cr and V concentrations in magnetite from early to later generations. On the other hand, hydrothermal nickel mineralization was formed by distinct F-(Cl)-bearing fluids in oxidized conditions and low to high temperatures. The composition of the magnetite from these deposits reveals low V, Co, Zn, Ti contents in GT-34 magnetite and higher Ga, V, and moderate Ta, Nb and Zn contents in Jaguar South and Onça Preta magnetite. Regarding rock buffering, the host rock of the hydrothermal nickel deposits shows moderate to intense chemical assimilation ($Ti + V \leq 0.2\%$ in magnetite) with a significant mafic contribution (high Mg + Co + Ni in magnetite; Sr/Y > 0.67 in apatite). In contrast, the Ni-rich IOCG deposits exhibit a magmatic alkaline felsic signature (high Σ LREE content in apatite). In IOCG deposits, the magnetite and apatite reveal a predominance of fluid-assisted processes without significant fluid-rock interaction. Based on our results, we propose that the best elements for classifying the deposit types in the Carajás Province are Ni, V, Al, Co, Ti, and Mg in magnetite, and Th, Lu, Gd, U, Sr, Y, and As in apatite. We also propose an approach using multi-element diagrams to enhance mineral exploration classification.