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In situ laser ablation ICP-MS analyses of fluid inclusions, Serra Norte jaspilite-hosted high grade iron ore, Carajás Mineral Province, Brazil

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In situ laser ablation ICP-MS analyses conducted on fluid inclusions trapped in quartz and carbonate veins and breccias from Serra Norte Carajás iron ore deposits revealed a saline Ca-rich fluid evolving to low saline Na-rich fluid from early to advanced hydrothermal alteration stages. In order to better constrain and understand the hydrothermal processes that lead to the upgrade of protore jaspilite to form hard, high-grade iron ores in the Serra Norte deposits, we have investigated the composition of hydrothermal fluids from five major veins-breccias types of quartz ± carbonate ± oxide ± sulphide located in the distinct hydrothermal alteration zones: V1 from distal; V2 and V3 from intermediate; and V4 and V5 from proximal hydrothermal alteration zones.

The elements Na, Ca, K, Mg, Fe, Mn, Li, Sr, Ba, Cu, Zn and Pb were identified and quantified in all vein-breccia types. With respect to the contents of the cations Na, Ca, K and Mg, V1 veins display slightly higher content when compared to V2b and V3 veins (Figs. 1A to C), and fluid inclusions from the latter two are compositionally similar. In V5 veins the trace element contents is significantly lower when compared to all other vein types (Fig. 1D). The majority of the analyzed fluid inclusions in all vein types are Na-rich, followed by Ca and K. Exception are fluid inclusions in V3 veins, where Na is followed by K (Fig. 1C). Magnesium contents are higher in V2b veins than in all other veins. Lithium and Sr contents are similar in all vein types (Fig. 1), except in V1 veins that display slightly higher Li contents than the other veins, with Sr concentration higher than Li. The V2b and V5 veins display the lowest Sr contents, and Li is only detected in two inclusions of V5 veins. Figure 1 shows that Fe is present in most fluid inclusions from all vein types, with proximal V5 displaying the lowest concentrations when compared to early (distal) and intermediate stages V1, V2 and V3 quartz veins. Fluid inclusions in V1a and V2 veins have higher Fe and Mn contents when compared to other vein types, but only slightly higher concentrations than V3 veins. Among the base metals, Cu is the main element in V1 veins, followed by V3 veins. The next most important is Zn, in both distal V1 and intermediate V2 and V3 veins. Copper, Zn and Pb decrease slightly from V2b to V5 veins (Fig. 1), and somewhat higher in overall values in V1a and V2a veins (Fig. 1). There is a significant decrease in Cu concentrations from V1a to V2a veins, and the lowest contents are observed in V2b and V5 veins. Copper is detected only in some inclusions of V1 veins.

Fluid inclusions trapped in calcite from V1b vein breccias and kutnahorite from V4 ore breccias have also been analyzed, although Ca, Mn and Fe were not considered since these elements are part of carbonate composition. In carbonate samples the sequence is Na > K > Zn > Li > Cu > As > Pb > Ag > Cs. The most outstanding depiction from Figure 1 is the significant decrease in all elements from the distal V1 to the proximal V5 veins. A decrease in Fe in the fluid is accompanied by the advanced hematite precipitation in the proximal alteration zone, which is compatible with iron having been extracted from the fluid to form hematite (Fig. 1D). The overall decrease in all elements analyzed in V5 veins, in conjunction with the decrease in the total fluid salinity, suggests the significant influx of meteoric water causing dilution of the original fluid in the high-grade ore zone. Calcite is widely distributed in V1 veins, mainly in the N4E deposit, but is not in present in V2 veins. This supports the assertion that the high contents of this element, as shown in Figure 1, must reflect the high Ca concentration in the fluids, suggesting an original Ca-rich fluid, in accordance with the low eutectic temperature of –50 °C. Of note is the presence of Li in the studied fluid inclusions, mainly from the early hydrothermal stage V1 type, which likely suggests a magmatic component in the hydrothermal fluids. According to Seitz and Woodland (2000), Li may be used as an indicator of magmatic processes such as partial melting, crystal fractionation and accumulation.

The presence of the base metals Cu-Pb-Zn in fluid inclusions, mainly Cu in V1, V2 and V3 veins from the distal and intermediate alteration zones, is compatible with a magmatic fluid. The lower concentration of these metals in the proximal V5 veins helps corroborate the LA-ICPMS analyses obtained on paragenetically different hematite types from high-grade iron ore, which also show low Zn, and some Pb and Cu (Figueiredo e Silva et al., 2009). The gradual dilution of the base metal signature in fluid inclusions from early to late stage veins and breccias also serves to support the influx of surface water into the high-grade ore zone.

Relative to the distal and proximal alteration zones, the laser ablation ICP-MS data of the intermediate-stage V2-V3 veins (Figs. 1B-C) display oscillating distribution patterns of most elements with concentrations that cover a much wider range than those elements observed for fluid inclusions from the distal alteration zone (Fig. 1A). Furthermore, various other characteristics of the intermediate alteration zone, including mineral assemblages, microthermometric fluid inclusion data including low to high salinity values, and variation of eutectic temperatures, together strongly suggest mixing of magmatic fluid and meteoric water. This results in the dilution of fluid composition, including the magmatic trace element Li. Some of the more abundant elements (mainly Na, K, Ca, Fe, and Mg) maintain their initial concentration in the fluid, as they likely were transported through the vein and breccias system without significant mass transfer via fluid-rock reactions or mineral precipitation.

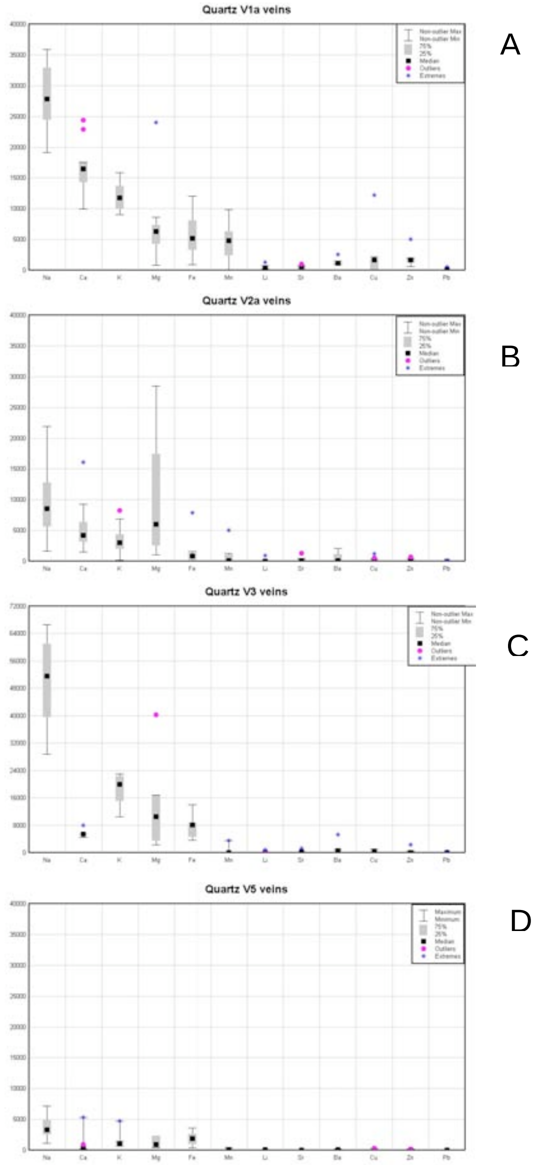

Fig. 1. *Metal concentrations obtained from LA-ICPMS analyses of fluid inclusion assemblages and individual fluid inclusions: A. quartz from V1a vein-breccias; B. quartz from V2a veins; C. quartz from V3 veins; D. quartz from V5 veins located in high grade hard iron ore. Error bars show 1σ variability within an assemblage of similar inclusions.*

REFERENCES

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