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Magnetite-apatite ores formed as mushy hydrous Fe-P immiscible magma

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There is an unusual class of igneous rocks composed of iron oxides (magnetite ± ilmenite) and apatite as the major constituents, which includes nelsonites (Ti-rich) and Kiruna-type ores (Ti-poor). The mineralizing environment of these magnetite-apatite deposits remains controversial and the relative roles of magmatic vs. hydrothermal processes is also not fully identified. Nevertheless, there is a growing evidence that liquid immiscibility played a major role in the formation of these rocks. However, immiscible Fe-P liquids with very low Si concentrations similar to those of magnetite-apatite ores have never been produced in experiments nor observed in melt inclusions. To address this controversy, we conducted an experimental study in a multicomponent system (ferrobasalt-ferroandesite) at 1 kbar and 1000-1040˚C. We also varied the phosphorous and H_2O contents of our starting compositions. Liquid immiscibility occurs in experiments rich in phosphorous (>1.0 wt.% P_2O_5 in starting composition) at oxygen fugacity ranging from QFM to QFM+3.3, with QFM being the quartz-fayalite-magnetite solid buffer. In experiments where liquid immiscibility between Fe-P-rich silicate and rhyolitic melts developed, apatite and magnetite are the liquidus phases and are surrounded preferentially by Fe-P-rich liquids. The composition of Si-rich immiscible liquid is relatively constant in composition independently on experimental conditions (SiO_2: 67.63-72.89 wt.%; Al_2O_3: 9.65-11.26 wt.%, FeO_{tot}: 4.53-7.21 wt.%) and enriched in Na_2O and K_2O. The conjugate Fe-rich immiscible melts show a moderate compositional range, i.e. 22.69-32.61 wt.% SiO_2, 33.85-40.84 wt.% FeO_{tot} and 8.55-18.07 wt.% P_2O_5, and are enriched in MgO, CaO and TiO_2. With addition of water and increasing fO_2, very Fe-P-rich liquids (~33 wt.% FeO_{total} and ~39 wt.% P_2O_5, with minor Si, Ti, Al, Mg and Ca) are produced. In these samples, only magnetite crystals form clusters wetted by Fe-P liquid pockets. The composition of the Fe phosphate liquids is homogenous and contains 32.63-33.36 wt.% FeO_{tot}, and 39.02-39.40 wt.% P_2O_5, and minor SiO_2 (3.09-4.55 wt.%), TiO_2 (0.99-1.53 wt.%), Al_2O_3 (2.18-3.90 wt.%), MgO (4.87-5.22 wt.%) and CaO (5.13-5.74 wt.%). The Si-rich conjugates contain 70.77-73.71 wt.% SiO_2, 9.22-9.69 wt.% Al_2O_3, 2.48-3.19 wt.% FeO_{tot} and 4.23-4.77 wt.% K_2O.

Our experimental results show that addition of water and elevation of fO_2 in the system extend the two-liquid field and produce more contrasted compositions. Especially the addition of water could lead to the enrichment of Fe and P in the Fe-rich liquids and decrease the activity of silica. These very Fe-P-rich liquids wetting magnetite and/or apatite may form hydrous crystal mushes, with strong potential for complete segregation from the paired rhyolite and lead to formation of magnetite-apatite ores.