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High *P-T* phase relations of Al-bearing magnetite: Post-spinel phases as indicators for *P-T* conditions of formation of natural samples

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Abstract

The phase relations of Al-bearing magnetite were investigated between 6–22 GPa and 1000–1550 °C using a multi-anvil apparatus. This study demonstrates that the spinel-structured phase persists up to ~9–10 GPa at 1100–1400 °C irrespective of the amount of hercynite ($FeAl_2O_4$) component present (20, 40, or 60 mol%). At ~10 GPa, the assemblage $Fe_2(Al,Fe)_2O_5$ + $(Al,Fe)_2O_3$ forms and remains stable up to 16–20 GPa and 1200–1550 °C. $Fe_2(Al,Fe)_2O_5$ adopts the $CaFe_3O_5$-type structure with the *Cmcm* space group. At 18–22 GPa and T>1300 °C the assemblage $Fe_3(Fe,Al)_4O_9$ + $(Al,Fe)_2O_3$ becomes stable. $Fe_3(Fe,Al)_4O_9$ is isostructural with Fe_7O_9, having the monoclinic structure of the *C*2/*m* space group. At T <1300 °C, $Fe_3(Fe,Al)_4O_9$ + $(Al,Fe)_2O_3$ gives way to the assemblage of a hp-$Fe(Fe,Al)_2O_4$ + $(Al,Fe)_2O_3$. This hp-$Fe(Fe,Al)_2O_4$ phase is unquenchable; a defect-bearing spinel-structured phase was recovered instead, and it contained numerous lamellae parallel to {100} or {113} planes and notably less Al than the initial starting composition. While low-pressure spinel can have a complete solid solution between Fe^{3+}-Al, the post-spinel phases have only very limited Al solubility, with a maximum of ~0.1 cpfu Al in hp-$Fe(Fe,Al)_2O_4$, ~0.3 cpfu in $Fe_2(Fe,Al)_2O_5$, and ~0.4 cpfu in $Fe_3(Fe,Al)_4O_9$, respectively. As a result, the phase relations of $Fe(Fe_{0.8}Al_{0.2})_2O_4$ can also be applied to bulk compositions richer in Al with the only difference being that larger amounts of an $(Al,Fe)_2O_3$ phase are present.

Coexisting rhombohedral-structured phases demonstrate that the binary miscibility gap established at low pressure between hematite and corundum is still valid up to 20 GPa. Since iron oxides (e.g., magnetite) with variable Al contents are found in extraterrestrial rocks or as inclusions in diamond, constraints on their high-P-T-f_{O_2} stability might help unravel their formation conditions.

Keywords: Magnetite, hercynite, iron oxides, Fe_4O_5, Fe_7O_9, Earth's mantle, phase relations, inclusion in diamond, shock metamorphism