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Visible-infrared spectral properties of iron-bearing aluminate spinel under lunar-like redox conditions†

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Abstract

Remote sensing observations have identified aluminate spinel, in the absence of measureable olivine and pyroxene, as a globally distributed component of the lunar crust. Earlier remote sensing observations and returned samples did not indicate the presence of this component, leaving its geologic significance unclear. Here, we report visible to mid-infrared (V-IR) reflectance (300–25 000 nm) and Mössbauer spectra of aluminate spinels, synthesized at lunar-like oxygen fugacity (f_{O_2}), that vary systematically in Fe abundance. Reflectance spectra of particulate (<45 μm), nominally stoichiometric aluminate spinels display systematic behavior, with bands at 700, 1000, 2000, and 2800 nm increasing in strength with increasing bulk Fe content. The especially strong bands at 2000 and 2800 are discernible for all spinel compositions and saturate at <15 Fe# [Fe/(Mg+Fe)×100, molar]. Absorption bands at 700 and 1000 nm, collectively referred to as the 1000 nm bands, are weaker and become observable at >6 Fe#. Although the 2000 and 2800 nm bands are assigned to Fe^{2+}_{IV} electronic transitions, spectra of aluminate spinels with excess Al_2O_3 demonstrate that the strengths of the 1000 nm bands are related to the abundance of Fe^{2+}_{VI}. The abundance of Fe^{2+}_{VI} depends on bulk Fe content as well as factors that control the degree of structural order-disorder, such as cooling rate. Consequently the strength of the 1000 nm bands are useful for constraining the Fe content and cooling rate of remotely sensed spinel. Controlling for cooling rate, particle size, and f_{O_2}, we conclude that spinels with >12 Fe# (<88 Mg#) have observable 1000 nm bands under ambient lunar conditions and that only very Mg-rich spinels lack 1000 nm bands in their spectra. This links remote observations of spinel anorthosite to Mg-Suite magmatism. The combined effects of Fe oxidation state, abundance of coexisting plagioclase, and space weathering have not been explored here, and may add additional constraints. The relative strengths of the distinctive 1000 and 2000 nm bands of the spinels associated with pyroclastic deposits at Sinus Aestuum suggest fast cooling rates, possibly in the absence of an extensive vapor cloud.

Keywords: Spinel, visible to mid-infrared spectroscopy, spinel anorthosite, lunar highlands, dark mantle deposits