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Crystal chemistry of lunar merrillite and comparison to other meteoritic and planetary suites of whitlockite and merrillite

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Abstract

Merrillite, also known as "whitlockite," is one of the main phosphate minerals, along with apatite, that occur in lunar rocks, martian meteorites, and in many other groups of meteorites. Significant structural differences between terrestrial whitlockite and lunar (and meteoritic) varieties warrant the use of "merrillite" for the H-free extraterrestrial material, and the systematic enrichment of REE in lunar merrillite warrants the use of "RE-merrillite." Laser Raman spectroscopy of extraterrestrial merrillite and terrestrial whitlockite confirms the absence of H in the former and presence of H in the latter. Lunar merrillite, ideally $(Mg, Fe^{2+}, Mn^{2+})_2[Ca_{18-x}(Y,REE)_x](Na_{2-x})(P,Si)_{14}O_{56}$, contains high concentrations of Y+REE, reaching just over 3 atoms per 56 O atoms, or up to ~18 wt% as $(Y,RE)_2O_3$. In the absence of extensive Si↔P substitution, the "availability" of the Na site limits Y+REE substitution to ~2 atoms per 56 O atoms. Higher concentrations of Y+REE, with coupled substitution of Si for P to balance charge are possible, but rare in lunar material. Intrinsically low Na concentrations in lunar rocks, combined with the typical formation of merrillite in late-stage basaltic mesostasis or residual, intercumulus melt pockets, produce these high REE concentrations. Lunar merrillite typically contains 0.1–0.4 Na atoms per 56 O atoms. For comparison, martian merrillite contains significantly higher Na concentrations (up to 1.7 Na atoms per 56 O atoms) and much lower REE concentrations. Meteoritic merrillite has relatively low REE contents, but exists in both Ca-rich and Na-rich varieties. Concentrations of Fe and Mg in all varieties sum to near 2 atoms per 56 O atoms. Merrillite in lunar crustal lithologies typically has Mg >> Fe; however, Fe-rich mare basalts contain up to 1.8 Fe^{2+} per 56 O. The structure of merrillite accommodates a variety of substitutions, and the compositional characteristics reflect conditions and processes specific to the parent planet.

Keywords: Merrillite, whitlockite, Moon, Mars, electron microprobe, ion microprobe, Raman spectroscopy, rare earth elements