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REVIEW ARTICLE

Comparative planetary mineralogy: Valence state partitioning of Cr, Fe, Ti, and V among crystallographic sites in olivine, pyroxene, and spinel from planetary basalts

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ABSTRACT

This is a comparative planetary mineralogy study emphasizing the valence-state partitioning of Cr, Fe, Ti, and V over crystallographic sites in olivine, pyroxene, and spinel from planetary basalts. The sites that accommodate these cations are the M2 site (6 to 8-coordinated) and M1 site (6-coordinated) in pyroxene, the M2 site (6- to 8-coordinated) and M1 (6-coordinated site) in olivine, and the tetrahedral and octahedral sites in spinel. The samples we studied are basalts from Earth, Moon, and Mars, and range in oxygen fugacity conditions from IW-2 (Moon) to IW+6 (Earth), with Mars somewhere in between (IW to IW+2). The significant elemental valence-states at these f_{O_2} conditions are (from low to high f_{O_2}): Ti^{4+}, V^{3+}, Fe^{2+}, Cr^{2+}, Cr^{3+}, V^{4+}, and Fe^{3+}. V^{2+} and Ti^{3+} play a minor role in the phases considered for the Moon, and are found in very low concentrations. V^{5+} plays a minor role in these phases in oxidized terrestrial basalts because it is probably lower in abundance than V^{4+}, and has an ionic radius that is so small (0.054 nm, 6-coordinated), that it is almost at the lower limit for octahedral coordination, and can even be tetrahedrally coordinated. The role of Cr^{2+} in the Moon is significant, as Cr^{2+} predominates in basaltic melts at f_{O_2} less than IW-1. Lunar olivine has been found to contain mostly Cr^{2+}, whereas coexisting pyroxene contains mostly Cr^{3+}. Fe^{3+} is very important in Earth, less so in Mars, and nonexistent in the Moon. The importance of the Fe^{2+} to Fe^{3+} transition cannot be overstated and, indeed, their crystal-chemical differences, in terms of behavior (based on size and charge), are similar to the differences between Mg and Al. We note that for pyroxene in six of the seven terrestrial suites we studied, Fe^{3+} (in the M1 site) coupled with Al (in the tetrahedral site) is one of the two most important charge-balance substitutions. This substitution is of lesser importance in Mars and does not exist in lunar basalts.