THE SECOND CONFERENCE ON THE LUNAR HIGHLANDS CRUST AND NEW DIRECTIONS

Revised mineral and Mg# maps of the Moon from integrating results from the Lunar Prospector neutron and gamma-ray spectrometers with Clementine spectroscopy†

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ABSTRACT

Mineralogical measurements from spectral remote sensing and remote geochemical measurements from gamma-ray and neutron spectrometers are complementary data sets that have been used together successfully to study the distributions of iron, titanium, and rare earth elements on the Moon. We compare neutron and gamma-ray data sets from Lunar Prospector and find them in good agreement with each other within the errors of previously developed equations that relate neutron flux with geochemistry, but find small adjustments to the nominal values are warranted. We used the neutron-validated LP GRS oxides to improve Clementine-based global mineral maps. The comparison was enabled by converting the minerals of Lucey (2004) to oxides using stoichiometry and assumptions about Mg#, calcium content of clinopyroxenes, and An#. We find that FeO and Al2O3 derived from the maps of Lucey (2004) do not follow the expected negative correlation seen in lunar samples, but can be brought into agreement with samples and with LP GRS oxides by increasing plagioclase in proportion with orthopyroxene abundance, while simultaneously decreasing Mg#. We interpreted this to mean that plagioclase and orthopyroxene exist in rocks together (as in a noritic rock) with the spectrally difficult to detect plagioclase being masked by the strong spectral signature of the orthopyroxene. We generated revised sets of maps of the major lunar minerals and a map of Mg# for the mafic minerals that are consistent with Lunar Prospector neutron and gamma-ray spectrometer results and show greatly improved agreement with lunar soil samples over previous global mineral maps from Clementine.

Keywords: Remote sensing, mineralogy, lunar magma ocean, neutron spectroscopy, gamma-ray spectroscopy, visible spectroscopy

INTRODUCTION

Visible and near-infrared spectroscopy of the Moon provides a tool that is sensitive to both the major minerals and chemistry of the lunar surface. Minerals detected through spectroscopy help constrain their spatial distribution and the distribution of interpreted rock types that make up the Moon, with the high-calcium pyroxene-rich maria distinct from the plagioclase-rich highlands (e.g., McCord et al. 1981). Spectrally derived mineralogy can play an important role in deciphering the history and evolution of the Moon. For example, the “purest anorthosite” (PAN) detections of Ohtake et al. (2009) and Pieters et al. (2009) with <2 vol% mafic minerals suggest that the lunar magma ocean may have concentrated plagioclase to a high degree in many locations across the Moon. Orbital neutron and gamma-ray measurements (e.g., Feldman et al. 2000; Prettyman et al. 2006) provide geochemical measurements of the same geologic truth that, because of the Moon’s comparatively simple mineralogy, can be compared with spectrally derived mineralogy using relatively few assumptions to draw robust conclusions about lunar surface mineralogy.

Lucey (2004) produced global maps for the major lunar minerals olivine, orthopyroxene, clinopyroxene, and plagioclase from the Clementine mission’s spectral reflectance measurements. However, these maps were not validated against other data sets or by comparison with lunar samples. The Lunar Prospector mission (Binder 1998) followed Clementine with a gamma-ray spectrometer (GRS) that directly measured elemental abundance (Prettyman et al. 2006) and a neutron spectrometer (NS) to provide a measurement of the weighted sum of the components present in the surface (e.g., Feldman et al. 2000). The Lunar Prospector measurements are independently sensitive to composition, so we perform a direct comparison, achieved through modeling and empirical relationships, to improve understanding of uncertainties in both measurements. We then compare the neutron-validated Lunar Prospector gamma-ray measurements against mineral maps from spectral reflectance using simple stoichiometry. We use independent and complementary measurements by the Lunar Prospector gamma-ray spectrometers to validate and improve the mineral maps, using lunar sample compositional trends as an additional constraint.

METHOD

Lunar prospector neutron and gamma-ray spectrometer reconciliation

The Lunar Prospector mission carried a gamma-ray spectrometer and a neutron spectrometer to study the composition of the lunar surface (Feldman et al. 1999). The gamma-ray spectrometer measured gamma rays emitted from the lunar surface...