

NEW ESTIMATES OF THE GLOBAL DISTRIBUTION OF TITANIUM, RARE EARTHS, THORIUM/SAMARIUM RATIO AND MG-NUMBER FROM INTEGRATING LUNAR PROSPECTOR NEUTRON AND GAMMA RAY SPECTROMETER AND CLEMENTINE MINERAL MAPS. S. T. Crites^{1*}, P. Englert¹, M. A. Riner¹ and P. G. Lucey¹, ¹Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, 1680 East West Road, POST 602, Honolulu, HI 96822, *scrites@hawaii.edu

Introduction: Lunar Prospector (LP) gamma-ray (GRS) and neutron spectrometer (NS) measurements and Clementine multispectral imaging are highly complementary data sets that together allow more refined estimates of geochemistry than is possible separately. Elphic et al. [1] pioneered the utilization of the complementary nature of the data sets by deriving the distribution of the rare earths Sm and Gd from thermal and epithermal neutron data corrected for the effects of iron and titanium, initially using Clementine multispectral maps of those elements, then later incorporating Lunar Prospector GRS measurements of iron and titanium.

Mineral maps of the Moon offer insights into the abundances of elements not measured by the LP GRS, but to which the LP NS is sensitive. For example, the high plagioclase abundance of much of the Moon causes the fast neutron signal to be nearly entirely dominated by elements that LP GRS did not measure: aluminum, calcium and silicon (and oxygen). Even in the maria the contribution by these elements is significant, with the contribution to the fast neutron signal by FeO, MgO and TiO₂ being less than 50% even when weighted for the higher average masses of iron and titanium (Table 1).

These elements can be derived from Clementine mineral maps by converting the stoichiometric composition of the minerals and their relative abundances to oxides but the mineral maps themselves suffer from difficulties in validation. The two neutron spectrometer measurements (thermal to epithermal ratio and fast neutron flux) offer a way to validate the mineral map data and directly compare the elements derived from mineral maps to measurements by the LP GRS. Our ultimate goal is to produce a self-consistent set of elemental and mineral maps that incorporate all these data sets.

In this work we bring together data from the LP GRS [2], LP neutron spectrometer thermal, epithermal and fast neutron measurements [3], and mineral maps derived from Clementine data [4]. In this abstract we will present the correlation of LP fast neutron signal derived from elements calculated from Clementine mineral maps, a new TiO₂ map derived by difference between the fast neutron distribution (that is sensitive to all the major elements) and Clementine-predicted fast neutron signal excluding titanium. We will use the major element maps, reconciled with the LP fast neutron data, to produce a refined estimate of the distribution of Sm and Gd, where the improvement over Elphic et al [1] is that we use explicit mineralogy-derived, and fast neutron validated, maps of CaO, SiO₂, and Al₂O₃, elements not measured by the LP GRS.

Methods and Results: The fast neutron data captured by the Lunar Prospector Neutron Spectrometer is sensitive to the average atomic mass of the surface and as such is dominated by the major element chemistry

of the surface.

After Gasnault et al. [5] the fast neutron flux is related to the average atomic mass of the surface by:

$$\langle A \rangle = \sum_n f_n A_n = \frac{1}{\sum_n w_n / A_n}$$

We computed a predicted total fast neutron flux using oxides from mineral maps (except TiO₂ where LP GRS was used). The mineral map calculation also requires an Mg-number to be assigned each mafic mineral. We used Mg-number data that falls out of the mineral map derivation.

Oxide	Average Mass
SiO ₂	20.0
Al ₂ O ₃	20.4
FeO	35.9
MgO	20.1
TiO ₂	26.6
CaO	28.0

Figure 1 shows the relationship between the predicted average atomic mass from Clementine mineralogy and LP fast neutron data. The LP fast neutron data was converted to average atomic mass using the equations of Gasnault et al. [5]. To produce this correlation

we found that dropping the olivine Mg-number by ten units relative to the values derived by Lucey et al. [4] improved the fit in the olivine and titanium-rich Procellarum region where the atomic mass estimates from the fast neutrons are highest.

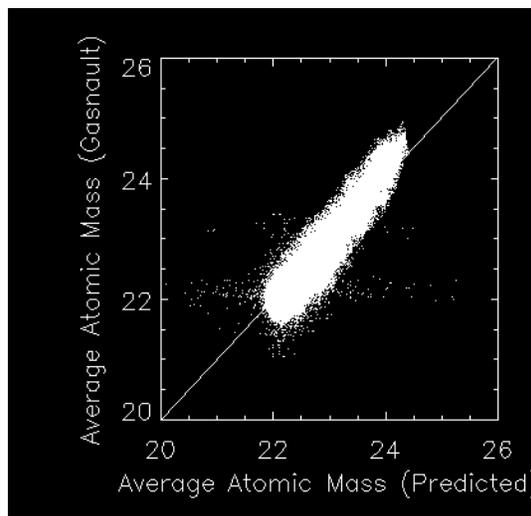


Figure 1. Predicted vs. measured fast neutron response. The measured value is the fast neutron flux converted to average atomic mass. The predicted value uses oxides derived from Clementine mineral maps with the exception of TiO₂, which is derived from LP GRS.

The high and 1:1 correlation of the predicted fast neutron model with the fast neutron data lends confidence to the major element model.

Titanium From Fast Neutrons. The LP GRS TiO₂ used to generate the correlation in Figure 1 has low

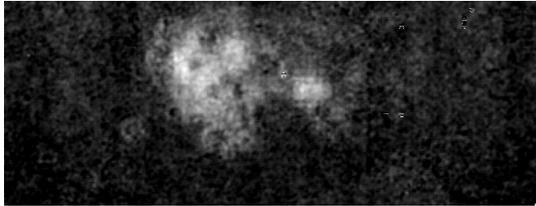


Figure 2. Distribution of titanium derived from LP fast neutron data by subtracting the contribution from the major elements other than titanium using estimates from Clementine mineral maps

resolution relative to the neutron data ([2],[3]) so we derive a new TiO₂ map using the difference between the predicted average atomic mass (excepting Ti) and the fast neutron data converted to average atomic mass.

Estimated Sm and Gd Distribution. With the validated suite of elements, we can now derive a new estimate of the abundance of Sm and Gd. The ratio of the thermal and epithermal neutron fluxes are governed by the neutron absorption efficiency of the elements present, and their relative abundances. The cross sections of these elements are not well correlated with their masses, with the complication that the isotopes Gd¹⁵⁷, Gd¹⁵⁵, Sm¹⁴⁹ have cross sections so large that they have a strong influence on the thermal neutron signal (previously exploited by Elphic et al. to show the distribution of these elements [1]). While iron and titanium have the largest thermal neutron absorption cross sections of the major elements, the remaining major elements are so abundant that their contribution cannot be neglected (see Riner et al. [6]).

Using the validated major element distribution maps, we produce a model of the thermal absorption due to the major elements and subtract this model from the measured LP epithermal/thermal ratio to produce a new estimate of the distribution of Sm and Gd using the methodology of Elphic et al. [1].

Of special interest is the ratio of Sm to Th. In lunar samples where Th is abundant, the ratio is about 2.5. Using our estimates of Sm, with a small correction for an apparent pedestal of about 10 ppm, ratios with LP GRS-derived Th in the Procellarum area are about 4, and in the South Pole Aitken terrane are slightly smaller, but still substantially above Apollo sample values. At this early stage of analysis we draw no special conclusions from these results, except to suggest that the Sm/Th of SPA is probably within a factor of two of the Procellarum region values sampled by Apollo.

Conclusions: To first order, the estimated major element oxides derived from Clementine mineral maps are consistent with the Lunar Prospector fast neutron data that are sensitive to the presence of the major elements. We used this validation to produce a new estimates of the distribution of TiO₂ from fast neutron

flux, and Sm and Gd from epithermal/thermal neutron ratios. However, the inferred ratio of Sm to Th substantially exceeds Apollo values. Sm/Th ratios of the Procellarum region and South Pole Aitken appear similar within a factor of two.

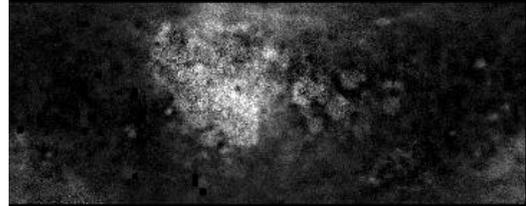


Figure 3. Distribution of Sm+Gd derived from LP thermal neutron data by subtracting the contribution of the major elements using estimates from Clementine mineral maps, validated with fast neutron data.

The next phase of analysis is to simultaneously reconcile the mineral maps, LP GRS and LP NS data to produce a self-consistent estimate of major element, Th- and REE abundances, major mineral abundances, and expose inconsistencies among the data sets.

References: [1] Elphic, R. C. et al., (2000), Determination of lunar global rare earth element abundances using Lunar Prospector neutron spectrometer observations, *JGR*, 105(E8), 20,333– 20,346. [2] Prettyman, T.H et al. (2006b), Elemental composition of the Lunar surface: Analysis of gamma ray spectroscopy data from Lunar Prospector, *JGR*, 111(E12007). [3] Maurice, S. et al., (2004) Reduction of neutron data from Lunar Prospector, *JGR*, 109(E07S04). [4] Lucey, P.G., Mineral maps of the moon (2004). *Geophys. Res. Lett.*, 31(L08701). [5] Gasnault, O. et al. (2001), Composition from fast neutrons: application to the Moon, *Geophys. Res. Lett.*, 28(19), 3797-3800. [6] Riner, M.A. et al., Constraints on Mercury's surface composition from MESSENGER Neutron Spectrometer data, EPSL (submitted).