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Title:

LUNAR PROSPECTOR MEASUREMENTS OF THE DISTRIBUTION OF INCOMPATIBLE ELEMENTS GADOLINIUM, SAMARIUM, AND THORIUM

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LUNAR PROSPECTOR MEASUREMENTS OF THE DISTRIBUTION OF INCOMPATIBLE ELEMENTS GADOLINIUM, SAMARIUM AND THORIUM.

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Introduction: Lunar Prospector neutron spectrometer (NS) and gamma ray spectrometer (GRS) observations have been used to map out the distribution of incompatible elements on the lunar surface. Specifically, the GRS data provide maps of the distribution of thorium and potassium while the NS data provide information on the distribution of iron and titanium, and the rare earth elements gadolinium and samarium. Using results of analysis of Clementine spectral reflectance (CSR) data [1, 2, 3, 4], the Fe- and Ti-contributions to the NS data can be removed, leaving primarily rare earth element contributions from Gd and Sm. The Th and K maps correlate with the inferred Gd and Sm maps (r ~ 0.93), but there are regions of significant disagreement. One of these is in the KREEP-rich circum-Imbrium ring. No clear explanation has emerged for this disagreement, though Th, K, Gd and Sm have differing degrees of incompatibility.

These results clearly are important to discussions of the geochemistry of the Procellarum-Imbrium Th-rich Terrane and the South-Pole-AitkenTerrane.

Approach: The LPNS footprint on the lunar surface is estimated to be about 350 km FWHM from 100-km orbit for fast neutrons (~500 keV - 8 MeV), and about 700 km FWHM from 100 km for thermal neutrons (0 - 0.3 eV). In order to remove the effects of Fe and Ti using CSR data at 0.25° resolution, we convolve the CSR data with the LPNS footprints.

We compare the resulting CSR Fe and Ti maps with both the fast and thermal neutron observations, as each reflects different aspects of lunar surface composition. Fast neutrons are derived from the primary interaction of galactic cosmic rays (GCR) with the nuclei in the regolith - more fast neutrons are produced in regolith rich in the massive nuclei, Fe and Ti [6]. Thermal neutron fluxes are sensitive to a combination of fast neutron production, moderation, and absorption by nuclei. Both Fe and Ti have large cross sections for thermal neutron absorption, so regions rich in these elements have a dearth of thermal neutrons.

Results: Figure 1 shows the predicted relative fast neutron flux variation based on CSR estimates of Fe and Ti. Highs are found in Oceanus Procellarum and within Mare Tranquillitatis. This can be compared with the LPNS results discussed below.

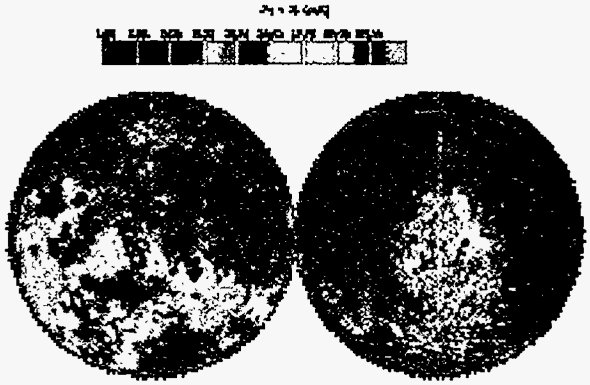

Fig. 1. Predicted fast neutron flux based on Clemetine spectral reflectance estimates of Fe and Ti. The data are mapped at 2° resolution.

LP Fast Neutrons and CSR Fe/Ti. Figure 2 shows the LP fast neutron flux [9] mapped in the same way. There is a very clear correlation with CSR Fe and Ti content. The global correlation coefficient between wt% Fe+Ti and the LP fast neutron flux is 0.811. In a more restricted latitude range, ±60°, the correlation improves to 0.887. For a region including nearside maria and farside highlands (40° to 180° E longitude, ±60° latitude), the correlation coefficient is 0.930. It appears that the fast neutron flux correlates with the CSR Fe and Ti determinations at the ~90% level.

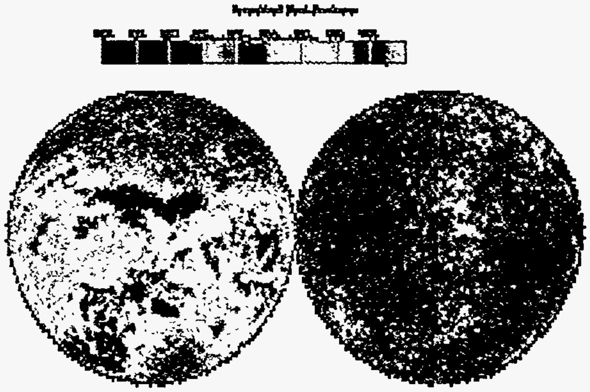

Fig. 2. LP neutron spectrometer map of fast neutron fluxes. The scale ranges from about 250 to 350 counts per 32 seconds.

The overall good correlation between CSR estimates of Fe and Ti and LP fast neutron fluxes suggests that the CSR values can be used to approximate the absorbing effect of these elements on thermal neutrons. This we discuss next.

LP Thermal Neutrons and REEs. A macroscopic absorption cross section Σ_{eff} derived from the CSR Fe and Ti estimates (with effects due to Ca included) correlates with the fast-to-thermal neutron flux ratio: r = 0.849. A limited region covering only eastern maria and farside highlands but not including KREEP-rich terrains, 20° E to 180° E longitude and ±30° latitude, yields a correlation coefficient of 0.978. Thus our calculations of Σ_{eff} based on CSR Fe and Ti abundances agrees with the results of the ratio of fast to thermal count rates in regions where contributions from KREEP are likely to be minor.

The highlands immediately surrounding Mare Imbrium have the poorest correlation between the LP neutron flux ratio and Σ_{eff}. We assert that this is due to the effect of not including the contributions of rare-earth elements such as gadolinium and samarium, which have anomalously large cross sections for thermal neutron absorption. While Gd and Sm are trace elements even in KREEP-rich materials, the effect of their cross sections can be comparable to that of Fe in the maria. Consequently, it is possible to map the incompatible elements using these absorptions as proxies, once the Fe and Ti effects are removed using the CSR data. Figure 3 shows the effective weight fraction of Gd based on these residuals.

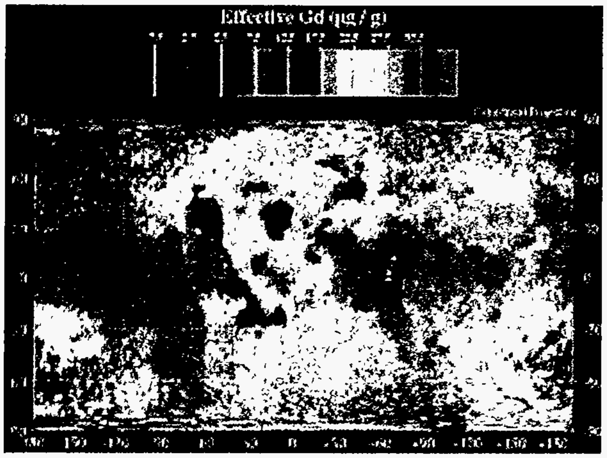

Fig. 3. Approximate concentrations of the REE Gd, in μg/g. The scale ranges from about -7 to +35 μg/g. Also shown are Apollo and Luna landing sites.

The Gd variations seen in Figure 3 should correlate with those of Th as determined by the LP GRS. Figure 4 is a map of the Th gamma ray flux; it is quite similar to Figure 3. There are, however, regions where they disagree. One is the circum-Imbrium ring of KREEP-rich terrains, where the northwestern province appears to be much richer in Gd and Sm than would be expected based on Th. The same is true of the Aristarchus Plateau. The high in Gd within the South Pole-Aitken Basin is partly due to a systematic effect in the LPNS data, and should be treated with caution.

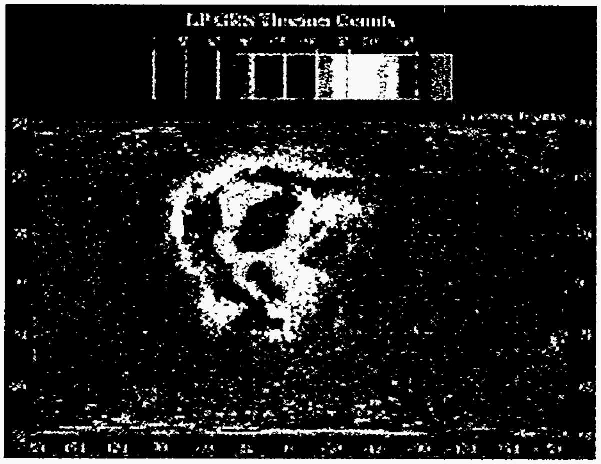

Fig. 4. Distribution of Th based on LP GRS data [10].

Conclusions: The LPNS turns out to be a useful tool not only for mapping hydrogren, iron and titanium, but apparently the rare earth elements Gd and Sm as well. If data on Fe and Ti abundances are available either using spectral reflection techniques or from the GRS, these data can be used to remove the influence of Fe and Ti on the neutrons. The remaining effects in thermal neutrons must be due other elemental absorbers, and Gd and Sm are the likeliest candidates.

Our LPNS mapping of Gd and Sm agrees for the most part with that of Th from the GRS. However, there are disagreements in the circum-Imbrium ring. If real, these differences could help us understand the mineralogy of the Procellarum-Imbrium Th-rich Terrane.

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