

LUNAR PROSPECTOR NEUTRON MEASUREMENTS AND CONSTRAINTS ON FeO AND TiO₂. R. C. Elphic¹, D. J. Lawrence¹, S. Maurice², W. C. Feldman¹, B. L. Barraclough¹, O. M. Gasnault¹, A. B. Binder³, and P. G. Lucey⁴, ¹Space and Atmospheric Sciences, MS D466, Los Alamos National Laboratory, Los Alamos, NM 87545 USA (relphic@lanl.gov), ²Observatoire Midi-Pyrénées, 31400 Toulouse, FRANCE, ³Lunar Research Institute, Ste 2360, 9040 South Rita Rd., Tucson, AZ, 85747, ⁴Hawai'i Institute of Geophysics and Planetology, University of Hawai'i, Manoa, HI USA.

Introduction: Lunar Prospector neutron spectrometer (NS) observations have previously been combined with spectral reflectance estimates of FeO and TiO₂ [1, 2, 3, 4] to infer the distribution of the rare earth elements (REEs) gadolinium and samarium on the lunar surface [5]. This is possible because Fe, Ti, Gd and Sm are the most important thermal neutron absorbers in lunar materials. Here the Fe contributions are removed using preliminary gamma ray spectrometer data. Analysis of Clementine spectral reflectance (CSR) data provides the nominal Ti-contributions to the NS data, and GRS thorium can be used as a proxy for the Gd and Sm. However, some deviations from a good Th-REE correlation are apparently related to overestimates and underestimates of the CSR-derived FeO and TiO₂ abundance values.

Here we use Prospector NS and GRS data to help constrain FeO and TiO₂. We find evidence suggesting that CSR TiO₂ values are too high in several of the nearside maria.

Approach: In previous work we have relied on CSR FeO and TiO₂ estimates to derive REE abundances from the NS data. Here we will use preliminary estimates of FeO abundance derived from the Prospector GRS to determine the degree of neutron absorption due to Fe, and we will use GRS estimates of thorium to calculate the REE contribution to absorption. The latter comes from a well-documented correlation of Th and REEs in returned samples of KREEP. We use the GRS FeO and CSR TiO₂ abundance estimates to calculate ϵ_{eff} , the macroscopic absorption cross section. In turn, ϵ_{eff} is directly related to the ratio of the epithermal neutron flux to the thermal neutron flux.

We can then relate part of the deviations from the ideal flux ratio relationship with ϵ_{eff} to the presence of REEs, and remove this effect by using GRS Th as a proxy. Whatever deviations remain must then be due primarily to errors in the assumed TiO₂ abundance.

Results: Figure 1 is a map of ϵ_{eff} , the deviation of the calculated ϵ_{eff} from the ideal flux ratio relationship. This map delineates high positive values (yellow-red) that are associated with concentrations of REEs in KREEPY terrains. Negative values (purple-magenta) that reflect the apparent overestimate in major element neutron absorber, namely FeO, TiO₂ or both.

Figure 2 is a scatter plot of GRS Th vs ϵ_{eff} . Blue points correspond to low-Ti, where errors in estimated TiO₂ have a small effect on ϵ_{eff} . This illustrates the trend between the REEs gadolinium and sa-

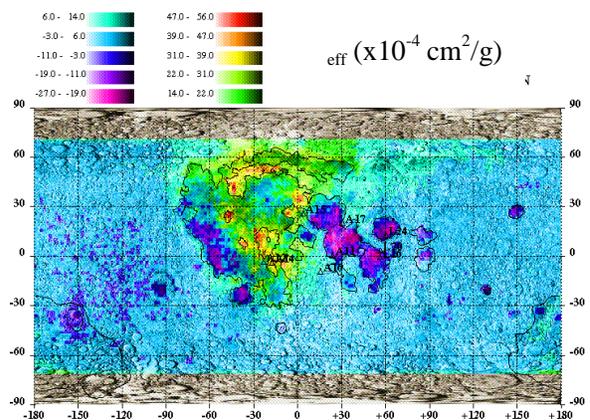


Fig. 1. Distribution of ϵ_{eff} across the lunar surface.

marium, and thorium. Red points correspond to high-Ti locations; many of these lie to the left of the Th-REE trend, indicating that ϵ_{eff} is pulled to lower values by overestimates of FeO, TiO₂ or both.

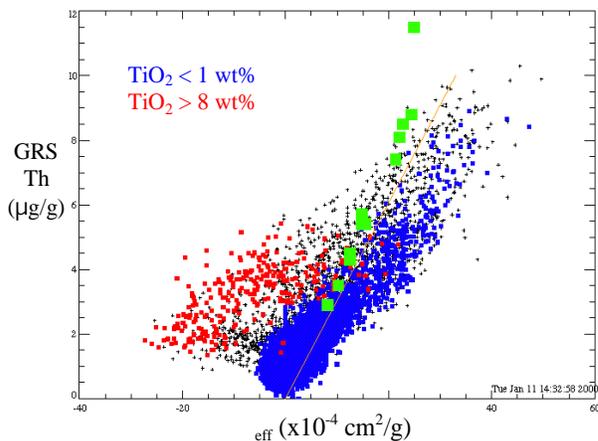


Fig. 2. LP GRS Thorium vs macroscopic absorption cross section. Blue points have TiO₂ < 1 wt%, red points TiO₂ > 8 wt%.

We can examine this question in another way. Figure 3 plots ϵ_{eff} versus CSR-derived TiO₂ abundance, with ϵ_{eff} now in units of the TiO₂ weight percent needed to give the observed value of ϵ_{eff} . Once again there is considerable scatter, partly due to the offsetting effects of positive absorption due to Gd and Sm, and apparent overestimates of TiO₂ abundance. To help distinguish these competing effects, we

make a subset of points, selected for $\text{Th} < 2 \mu\text{g/g}$ so that the contributions of Gd and Sm should be small, less than the equivalent of 2 wt% of TiO_2 . This subset reveals that there is a systematic negative trend of σ_{eff} (in equivalent TiO_2 wt%) with CSR-derived TiO_2 abundance. In other words, these data suggest that some of the CSR TiO_2 abundance values have been overestimated; the magnitude of this effect is equivalent to about a -5 wt% correction for an estimated 10 wt% and above of TiO_2 .

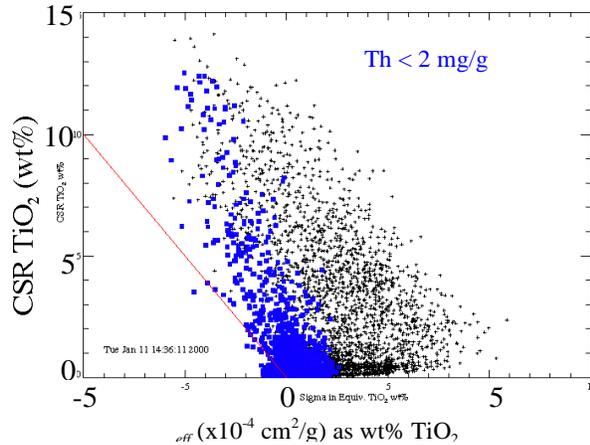


Fig. 3. CSR TiO_2 abundance versus σ_{eff} expressed as wt% of TiO_2 . Blue points are for $\text{Th} < 2 \mu\text{g/g}$, hence where REEs have little effect on σ_{eff} .

The focus here is on CSR-derived TiO_2 to explain these effects because we believe that the effects due to Fe, REEs, and other elements have been properly accounted for. We note that a preliminary comparison of CSR FeO and Lunar Prospector GRS FeO suggests that the CSR FeO values may also be too high in some locations [7], by as much as 3 or 4 wt% within some of the nearside maria. These discrepancies are removed here since we are using GRS data for FeO. The results in Figures 2 and 3 suggest that better agreement would be obtained if the CSR TiO_2 abundances in these regions were reduced by 3 – 5 wt%. The disagreement would still be present if other spectral techniques were used to infer TiO_2 abundances. Figure 4 illustrates a preliminary “revised” TiO_2 map based on the foregoing analysis.

We also note that the results of nuclear simulations and comparisons of the fast neutron data with CSR FeO and TiO_2 appear to suggest a similar discrepancy. These indicate that the Lunar Prospector fast (0.5 – 8 MeV) neutron data also suggest that the CSR estimates of TiO_2 may be too high to explain their fluxes [8,9]. The fast neutron results come from a completely different sensor (the gamma ray spectrometer) than the epithermal and thermal neutron results. Thus, the TiO_2 implications here and in fast neutron analyses are completely independent, but both reflect a similar apparent disagreement with TiO_2 abundance estimates

obtained through UV/VIS spectral reflectance techniques.

Conclusions: The major assumptions concerning the CSR method of *Blewett et al.*, [1997] and *Lucey et al.* [1999] for mapping titanium are that: 1) variations in opaque mineral abundance overwhelmingly dominate variations in the UV/VIS color because of their nature as dark, spectrally neutral absorbers; 2) opaque minerals are the principle carriers of TiO_2 . The empirical nature of the calibration is such that if the abundance of other minerals or soil components with important UV/VIS properties are correlated with either TiO_2 abundance, or soil maturity, the technique will include these color variations in the calibration from spectral parameter to elemental abundance, and at the same time will suppress maturity effects. The results reported here suggest that some of the spectral reflectance assumptions may not hold globally. At present, this apparent disagreement in TiO_2 abundances remains an area of active analysis, with no obvious resolution.

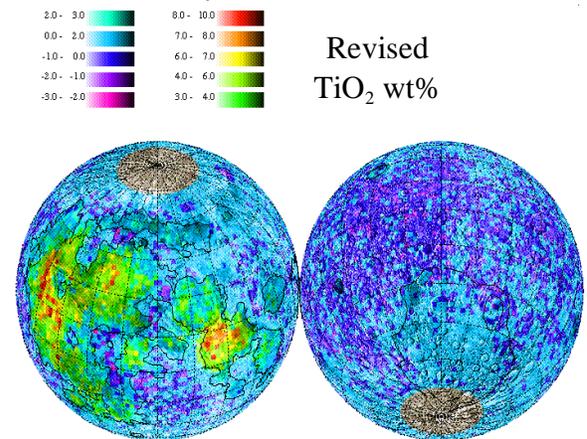


Fig. 4. Preliminary revised distribution of TiO_2 based on LP NS data.

References: [1] Lucey P. G., Taylor G. J., and Malaret E. (1995), *Science*, 268, 1150. [2] Lucey, P. G., et al. (1996), *LPS XXVII*, 781. [3] Blewett D. T., et al. (1997), *JGR*, 102, 16,319. [4] Lucey P. G., et al. (1998), *JGR*, 103, 3679 (1998). [5] Elphic, R. C., et al. (1998), *Science*, 281, 1493. [6] Korotev, R. L. (2000), *JGR*, in press. [7] Lawrence, D. J., et al. (1999), *Workshop on New Views of the Moon II: Understanding the Moon Throughout the Integration of Diverse Datasets*. LPI Contribution No. 980, Lunar and Planetary Institute, Houston, 1999a. [8] Maurice, S. et al. (2000), *JGR*, in press. [9] Gasnault, O. M. et al. (2000), *JGR*, in press.