An Empirical Relation Between the Lunar Prospector Gamma-ray and Soil Sample Th Abundances. Jeffrey J. Gillis[1], Brad L. Jolliff[1], Randy L. Korotev[1], and David J. Lawrence[2]. 1. Washington University, Department of Earth and Planetary Sciences, St. Louis MO, 63130, Gillis@levee.wustl.edu. 2. Los Alamos National Laboratory, Los Alamos, NM.

The low altitude portion of the Lunar Prospector mission yielded a global map of thorium distribution at an impressive 2° resolution [1,2]. The high resolution Th map provides the ability to correlate Th concentrations with specific geologic units [e.g., 3], revealing information about local and regional geologic processes. This information is critical for examining petrologic models of the lunar crust [4,5], investigating regolith mixing caused by impacts [6,7,8], and providing improved regional context for samples [9].

Here we compare the most recent Th abundance calibration by [2], which is based on processes that are involved with creating and detecting γ-rays in the spectral region of the main ^{232}Th γ-ray (2.6 MeV) [1], with the composition of soils at the Apollo sites [9,10] and the lunar meteorites [11] (Figure 1a). The comparison yields an empirical relation which is then used to recalibrate the Prospector Th abundances. These rederived Th concentrations are then compared with Th abundances derived from the Apollo γ-ray data calibration [12] and a good correlation is observed between the two methods (Figure 1b).

Both methods for calculating Th abundance (theoretical [2] and ground-truth) are an interim substitute until a rigorous determination of the detector efficiency and the 2.6 MeV γ-ray flux can be performed (e.g., spectral fitting and deconvolution analysis that takes into account contributions from higher energy γ-ray lines, and detector composition and geometry). These preliminary calibrations are possible because Th γ-rays are produced by radioactive decay and hence do not depend on the neutron flux, have a large variation over the lunar surface, and few interfering γ-ray lines from other elements. Both calibration methods are relatively less precise where Th concentrations are low because the overall count rate in the 2.5 to 2.7 MeV range is mainly from background, and deviations from the average background, whatever their cause, are interpreted as contributions to the Th concentration.

Data: For this ground-truth comparison we used the Lunar Prospector absolute Th abundance data from the low-altitude portion of the mission (the global Th data set contains 11306 equal-area pixels, 2°×2° at the lunar equator [14]). The absolute Th abundance is based on total counts per 32 seconds in the spectral region of the main ^{232}Th γ-ray (2.61±0.1 MeV) [2]. The data have been corrected for gain, dead time, cosmic-ray variations, and non-symmetric response of the instrument. Because the Apollo 12 and 14 regions are compositionally heterogeneous at the 2° scale, we have rebinned the Th data into one and two degree equal-area pixels that more accurately represent the geology

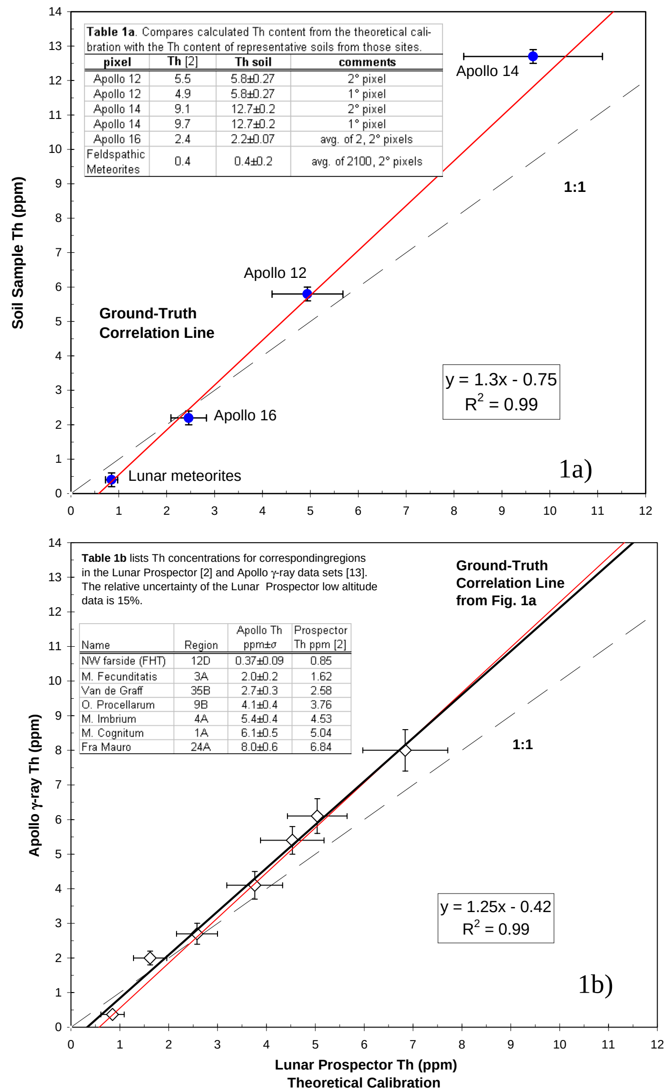

Table 1a. Compares calculated Th content from the theoretical calibration with the Th content of representative soils from those sites.

pixel	Th [2]	Th soil	comments
Apollo 12	5.5	5.8±0.27	2° pixel
Apollo 12	4.9	5.8±0.27	1° pixel
Apollo 14	9.1	12.7±0.2	2° pixel
Apollo 14	9.7	12.7±0.2	1° pixel
Apollo 16	2.4	2.2±0.07	avg. of 2, 2° pixels
Feldspathic Meteorites	0.4	0.4±0.2	avg. of 2100, 2° pixels

Table 1b lists Th concentrations for correspondingregions in the Lunar Prospector [2] and Apollo γ-ray data sets [13]. The relative uncertainty of the Lunar Prospector low altitude data is 15%.

Name	Region	Apollo Th ppm±σ	Prospector Th ppm [2]
NW farside (FHT)	12D	0.37±0.09	0.85
M. Fecunditatis	3A	2.0±0.2	1.62
Van de Graff	35B	2.7±0.3	2.58
O. Procellarum	9B	4.1±0.4	3.76
M. Imbrium	4A	5.4±0.4	4.53
M. Cognitum	1A	6.1±0.5	5.04
Fra Mauro	24A	8.0±0.6	6.84

Figure 1 (a) shows a comparison between Th abundances for soil samples and pixels in the Prospector γ-ray data that cover these regions. The subsequent regression line (red) is used to recalibrate the Prospector data. (b) compares Th concentration for corresponding regions in the Apollo and Prospector γ-ray data sets [2] (Table 1b). The regression line from Figure 1a (red) is translated onto Figure1b to illustrate the correlation between the Th concentrations calculated from the sample suite and the Apollo γ-ray data. The dashed line represents a 1:1 correlation which is anticipated if both calibration methods calculated similar Th abundances.

of the landing sites and adjacent areas (Table 1a).

Method and Results: The ground-truth comparison is based on soil compositions at the Apollo 12 [10], 14 [9], and 16 [9] landing sites as well as the mean compositions of the feldspathic lunar meteorites (Figure 1a), which represent highlands regolith distant from the Apollo sites [11]. These 4 sampling sites were chosen because they are compositionally uniform at the 1° scale and span the range of Th concentrations observed on the lunar surface (Figure 2). For the lunar meteorites we plot the median Th concentration from the Lunar Prospector calibration for an area within the Feldspathic Highlands Terrane (0-90°N and 120°-260°; Table 1a). For the Apollo sites we plot the Lunar Prospector Th composition calculated [2] for pixels that include the Apollo 12, 14, and 16 landing sites, against mean Th concentrations of typical soil samples from those sites [9,10] (Table 1a). The regression line of Figure 1a is derived from a least-squares linear regression weighted by uncertainties in the X and Y values.

Using this relation we observe a 20% discrepancy in the estimated Th abundance between the ground-truth and Lunar Prospector theoretical calibration at high Th concentrations (Figure 1a), which is close to the uncertainty limits of the theoretical calibration (~15% [2]). In addition, the ground-truth Th calculation predicts lower Th values at concentrations <2 ppm. While not fully evaluated yet, a possible explanation of some of the discrepance in Figure 1a may be related to the large area over which the Prospector gamma-ray spectrometer acquires counts.

As an independent test we also compared Th concentrations calculated using the Lunar Prospector [2] and Apollo γ-ray analysis [13] for 7 overlapping regions (Figure 1b). The 7 regions within the Apollo γ-ray footprint were selected from a list of regions defined by [13] to have a homogeneous γ-ray spectrum and Th concentration. Regions in the Apollo γ-ray data were chosen as a reference to compare with corresponding regions in the Prospector data [2] because they have good counting statistics and cover a range in Th concentration (Table 1b). The comparison of the two methods offers an independent evaluation of the ground-truth method because the Apollo calibration, like the Prospector calibration, is theory based, involving no ground-truth normalization. A difference between the two techniques, however, is the γ-ray source function: The Apollo calculation [15] assumes the Moon is an infinite plane while the Prospector calibration assumes a sphere [2]. These two assumptions can cause the derived abundances to differ by up to 10%. In any event, we see that the comparison between the Apollo and Prospector Th abundances also reveals a 20% difference in the estimated Th abundance for areas of high Th concentrations. Moreover, we observe an excellent agreement in both the sample based regression line and the Apollo γ-ray regression line (Figure 1b).

We hope that future comprehensive comparisons of soil information and local geology with calibrated Lunar Prospector γ-ray data will aid in reducing error sources (e.g. detector efficiency (at high Th concentrations) and the need for better background subtraction (at low Th concentrations)) and provide us with the penultimate Th abundance calibration.

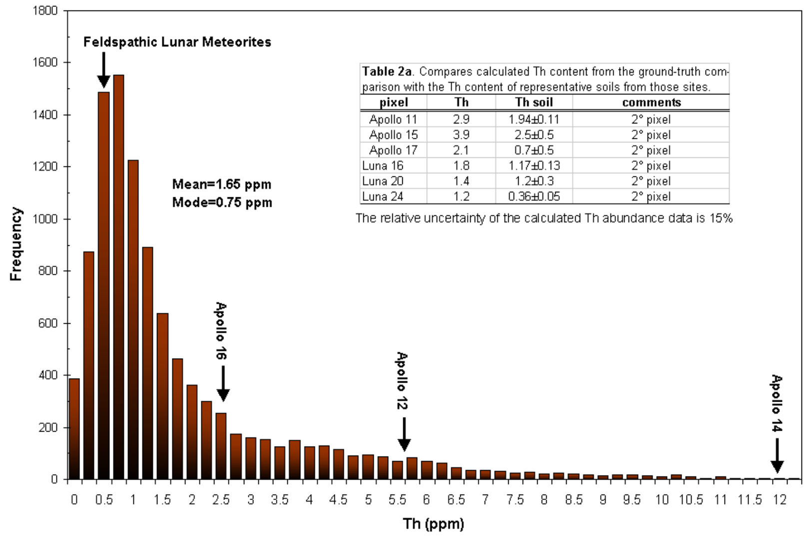

Table 2a. Compares calculated Th content from the ground-truth comparison with the Th content of representative soils from those sites.

pixel	Th	Th soil	comments
Apollo 11	2.9	1.94±0.11	2° pixel
Apollo 15	3.9	2.5±0.5	2° pixel
Apollo 17	2.1	0.7±0.5	2° pixel
Luna 16	1.8	1.17±0.13	2° pixel
Luna 20	1.4	1.2±0.3	2° pixel
Luna 24	1.2	0.36±0.05	2° pixel

Figure 2. A histogram of global Th concentrations calculated using the regression from figure 1a. Table 2a (inset), lists the Th concentrations for soils samples from landing sites not included in the ground-truth comparison and Th abundances as calculated using the regression from figure 1a for a 2° pixel that overlies that site.

Acknowledgements: This work was supported by NAG5-6784, NAG5-8609 and NAG5-4172. At Los Alamos, this work was supporte by NASA and conducted under the auspices of the US Department of Energy.

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