DISTRIBUTION OF IRON AND TITANIUM ON THE LUNAR SURFACE FROM LUNAR PROSPECTOR GAMMA RAY SPECTRA.

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Introduction: Gamma ray pulse height spectra acquired by the Lunar Prospector (LP) Gamma-Ray Spectrometer (GRS) contain information on the abundance of major elements in the lunar surface, including O, Si, Ti, Al, Fe, Mg, Ca, K, and Th. With the exception of Th and K, prompt gamma rays produced by cosmic ray interactions with surface materials are used to determine elemental abundance. Most of these gamma rays are produced by inelastic scattering of fast neutrons and by neutron capture. The production of neutron-induced gamma rays reaches a maximum deep below the surface (e.g. ~140 g/cm^2 for inelastic scattering and ~50 g/cm^2 for capture). Consequently, gamma rays sense the bulk composition of lunar materials, in contrast to optical methods [e.g. Clementine Spectral Reflectance (CSR)], which only sample the top few microns.

Because most of the gamma rays are produced deep beneath the surface, few escape unscattered and the continuum of scattered gamma rays dominates the spectrum. In addition, due to the resolution of the spectrometer, there are few well-isolated peaks and peak fitting algorithms must be used to deconvolve the spectrum in order to determine the contribution of individual elements.

Spectrum Analysis: We have carried out a preliminary analysis of GRS pulse height spectra at high energy, where the continuum is smallest and the number of gamma ray lines is relatively low. The region from 5400 keV to 9000 keV primarily contains gamma rays from neutron interactions with O, Fe, Ti [1]. Reactions with Ca, Al, and Si also contribute gamma rays to this region. However, because their production rate is relatively small, they were not included in the analysis. The dominant peaks in this region are from inelastic scattering with O (at 6130-, 6917-, and 7117-keV). Capture of neutrons by Fe and Ti produce several prominent gamma rays (7631.2- and 7645.6-keV for Fe and 6760.1- and 6418.4-keV for Ti).

The sum of the GRS accepted gamma ray spectra acquired at high altitude over a 5° square is shown in Fig. 1 along with fitted spectral components from O, Fe, and Ti as well as an empirically-derived background function. The magnitude of the components were determined using linear least squares. The spectral features for elemental components include the full-energy peak and the single-escape peak broadened by the resolution of the spectrometer. The continuum associated with scattering in the lunar surface was not included in the elemental response. Prior to fitting the spectrum, an exponential background was subtracted from the data. The parameters for the exponential were determined by fitting the continuum region above the highest energy iron peak.

Relationship between count rate and abundance: In order to calculate the elemental spectral components used in the least squares fit, the relationship between the full-energy (uncollided) count rate in the spectrometer and the production rate of gamma rays in the surface must be known. Monte Carlo calculations were carried out to determine the response of the GRS to parallel beams of gamma rays as a function of incident direction and energy. The calculations were benchmarked against measurements of radioactive standards prior to flight. The parallel beam response functions give the relationship between measured count rates and gamma ray flux, which can be used to determine absolute elemental abundance.

If the depth profile of gamma ray production in the lunar surface is known, then the absolute full energy interaction rate can be calculated. The full energy interaction rate is given by

$$C = RG(\lambda, E) \quad (1)$$

where R is the total number of gamma rays produced per unit surface area per unit time, G is the effective cross sectional area of the detector, λ is the latitude of the spacecraft, and E is the energy of the gamma rays. R is obtained by integrating the volumetric production rate of gamma rays over depth. The function G accounts for attenuation of the gamma rays by lunar materials, the orientation and altitude of the spacecraft relative to the surface, and the depth profile of gamma ray production in the lunar surface. We have found that G does not depend on the composition or density of lunar materials; however, because the depth profiles are different, G differs significantly for gamma rays produced by inelastic and capture reactions. At high-altitude (100 km) over the equator, G=0.047 cm^2 for the Fe 7631 keV capture gamma ray. In contrast, G=0.188 cm^2 for the O 6130 keV gamma ray produced by inelastic scattering.

The production rate of gamma rays per unit area in the lunar surface is given by $R=ayMP$, where a is the abundance of the element (atoms/atom), y is the number of gamma rays produced per reaction, M is the number of reactions that occur per neutron normalized to the elemental abundance (reactions/neutron)/(atoms/atom), and P is the production rate of neutrons by cosmic rays (n/cm^2/s). The parameter M was computed by Monte Carlo for prominent capture and inelastic scattering reactions for a wide range of lunar compositions. M varies negligibly with composition for inelastic scattering reactions. However, for capture reactions, M varies significantly with composition. Based on Monte Carlo simulations, we find that M varies linearly with the ratio of thermal to epithermal counts measured by the HeSn and HeCd detectors. Maps of the thermal and epithermal counts measured by LP [2] were used to determine maps of M for Fe and Ti capture gamma rays.

Iron and Titanium Maps: Maps of relative iron and titanium abundances were determined by fitting the elemental spectral components to high-altitude data binned on 5° squares (Fig 2). Eq. 1 was used to determine the relative variation of peak areas with latitude and energy. Corrections for the variation of capture gamma ray production described in the previous section were included in the analysis. Note that these are the first maps constructed using analytical estimates of the variation of count rate with latitude. No latitude variation is evident in the resulting maps.

Our iron values are strongly correlated with iron derived from band analysis of the gamma ray data carried out by *Lawrence et al.* [3]. Ti values are moderately correlated with CSR-determined TiO_2 [4]. There is some evidence for feed-through of iron to the determined abundance of TiO_2 using the present method. We suspect that this is caused by our neglecting the continuum contributed by Fe gamma rays (primarily in the lunar surface) to the region in the spectrum containing Ti gamma rays. A systematic study of the lunar surface continuum is underway and results will be incorporated into future estimates of Ti.

References: [1] Reedy R. C. (1978) *LPS IX*, 2961-2984; [3] Feldman et al. (2000) JGR, 105, #E8, 20347 – 20363; [3] Lawrence et al. (2001) *32nd LPSC*, Abstract #1830; [3] Lucey et al. (2000) *JGR*, 105, #E8, 20297 – 20305;.

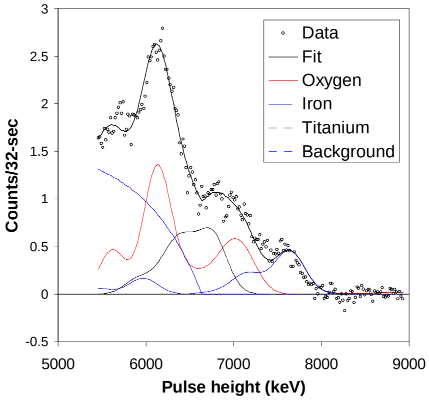

Fig. 1: GRS pulse height spectrum showing data and fitted components.

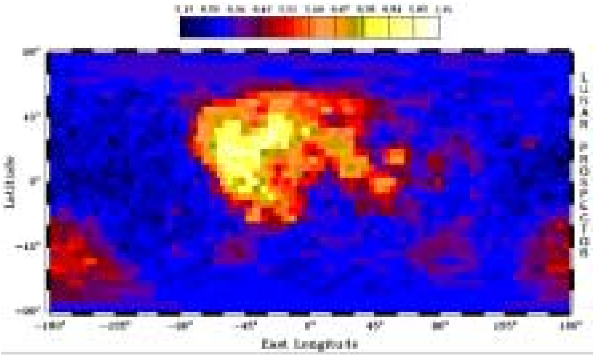

Fig. 2: Map of relative iron abundances.

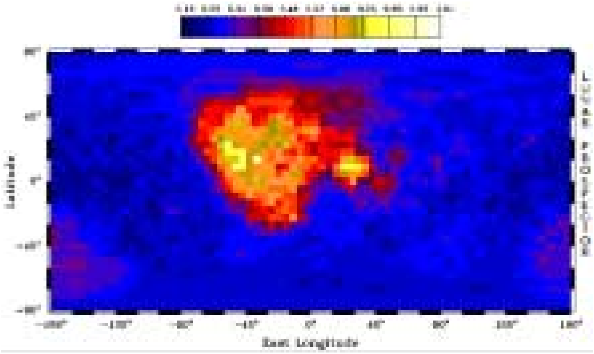

Fig. 3: Map of relative titanium abundances.

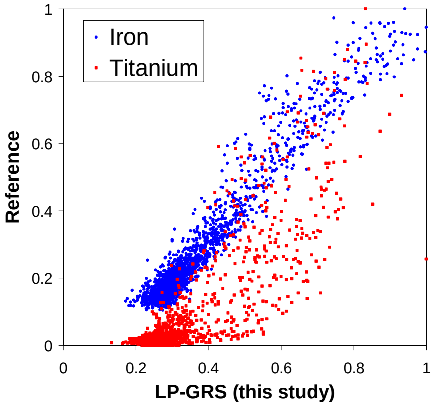

Fig. 4: Correlation between relative abundances for iron and titanium determined in this study with CSR (TiO_2) and low-altitude LP-GRS.