Geophysical Research Abstracts, Vol. 7, 05719, 2005
SRef-ID: 1607-7962/gra/EGU05-A-05719

Can models of permanent shadow constrain the location and abundance of lunar polar water?

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Introduction: Reservoirs of volatiles cold-trapped in permanent shadow at the lunar poles are scientifically valuable and a potential *in situ* resource for exploration. While Clementine radio science data was interpreted in favor of the presence of lunar polar ice [1], this has been disputed [2]. Nevertheless, it is clear that there are polar enhancements of hydrogen, and it has been argued that these are in the form of shallow buried ice [3,4,5]. Radar results have not shown the expected return due to large bodies of ice, however [6]. This does not preclude the existence of interstitial ice. We have previously reported on efforts to use models of permanent shadow to help constrain Lunar Prospector neutron spectrometer (LPNS) water-equivalent hydrogen abundances [7]. Here we report on further work in which we find that the LPNS data are consistent with small regions of $>$ 10 wt% WEH.

Lunar Prospector NS Measurements: Reductions in epithermal neutron count rates measured by the LPNS over the lunar poles indicate the presence of hydrogen in or near regions of permanent shadow [3,4,5]. Implanted hydrogen contributed by solar wind and hot magnetospheric particles is also likely. The maximum inferred water abundances based on LPNS measurements and estimates of areas of permanent shadow is about 1.5 $\pm$ 0.8 %. The actual abundance on/under the surface, however, depends on the areal distribution of the permanently shadowed regions, including the very numerous small craters near the poles. Based on conservative estimates of only a few hundred square kilometers of permanent shade, the water abundance upper limit of 10% was found [5]. Increases in shadowed areas lead to decreases in cold-trapped water abundance at any one location.

Polar Shadow Modeling: Clementine imagery and radar observations now leave little doubt that sizeable areas of the Moon's poles are permanently shadowed. Recent analysis of simple craters less than 20 km in diameter yields estimates of approximately 7500 and 6500 km^2 in permanent shadow for the north and south poles, respectively [8]. Here we combine the analysis of smaller craters with permanent shade, the north pole radar map, and illumination derived from Clementine imagery to construct two possible shadow models, one with a conservative shadow area totaling 5020 km^2, and a more liberal shadow model with 26,100 km^2. For our purposes, these shadowed areas will be allowed to have more than 5 wt% H_2O under a thin layer of desiccated regolith. Areas not in permanent shadow will be considered sunlit (at least part of the time), and will only be allowed to have no more than 330 ppm hydrogen.

Data Deconvolution and Modeling: The LPNS footprint for epithermal neutrons has a FWHM of $\sim$40 km from 30-km altitude. We attempt to deconvolve the mapped epithermal fluxes in order to improve the spatial resolution of the inferred WEH. We initially sum the $\sim$6 months of low-altitude (30 km) LPNS data in small spatial bins (5 km). These data have been normalized to cosmic ray and orbital altitude variations [9]. We then smooth the raw, summed count rates with a gaussian filter of approximately 75-km FWHM. Finally we deconvolve the smoothed map using an iterative technique: $I_{k+1} = I_k + r\,(O - p \otimes I_k)$, where I_{k+1} is the current estimate of the restored image, I_k is the previous estimate, r is a relaxation function, O is the original smoothed image, p is the total effective point spread function (equivalent to the Gaussian smoothed NS response function), and $\otimes$ denotes a convolution operation. The relaxation function r serves to constrain restored image estimates to physically reasonable values, for example non-negative values. This function can restrict different values depending upon whether a pixel is in permanent shade or sunlight.

Discussion: Enhanced abundances of WEH are found in some notable north polar locations: (1) the southern ramparts (but not inner wall) of Rozhdestvensky crater; (2) a small part of the southern wall of Hermite crater; (3) part of the western wall and floor of Peary crater; (4) part of the southern wall of Lovelace crater. WEH exceeds 1 wt% in numerous smaller unnamed craters and locations on the poleward-facing slopes of outer crater ramparts.

We are currently working on a similar map for enhanced WEH at the Moon's south pole. In this case, developing a good shadow model is more difficult owing to winter lighting conditions during the Clementine mission. However, radar-derived DEMs will help.

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