CONSTRAINTS ON LUNAR HYDROGEN MOBILITY PROVIDED BY HIGH SPATIAL RESOLUTION STUDIES OF EPITHERMAL NEUTRON EMISSION. W. V. Boynton[1], G. F. Droege[1], K. Harshman[1], M. A. Schaffner[1], I. G. Mitrofanov[2], T. P. McClanahan[3], and the LEND team. [1]The University of Arizona, Tucson, AZ USA, wboynton@lpl.arizona.edu, [2]Institute for Space Research, 117997 Moscow, Russia, [3]NASA Goddard Space Flight Center, Greenbelt, MD USA

Introduction: The Clementine mission suggested that deposits of water ice might exist in the permanently shadowed regions (PSRs) near the lunar south pole [1]. Subsequent data of the Lunar Prospector Neutron Spectrometer (LPNS) showed suppression of epithermal neutrons at both poles above 70° latitude, which were interpreted to indicate enhancement of hydrogen, predominantly within PSR areas [2]. More recently the Lunar Exploration Neutron Detector (LEND) onboard the NASA Lunar Reconnaissance Orbiter (LRO) showed, when viewed with its high spatial resolution, that the regions of neutron suppression were not closely related to the PSRs [3]. Two of the PSRs, those associated with the Cabeus and Shoemaker craters, showed significant suppression of neutrons, but others did not. In this work we shall focus not on the neutron suppressed regions (NSRs), rather we are concerned with the hydrogen content of the region between the NSRs.

Methods: A map of the epithermal neutron counting rate was made by binning the LEND counts from the four collimated epithermal neutron detectors using HEALPix [4] bins of 1.7 km. The maps are smoothed by a Gaussian filter. Uncertainty maps based on counting statistics were made and smoothed by the same filter.

We first made a plot of epithermal neutron count rate as a function of latitude in one-degree latitude bands between -82° and -90° (similar to those shown in figure 1). A general decrease in count rate (increase in H content) is observed toward the poles. This increase in H content is the subject of this study, but in order to determine the count rate of only the regions outside the NSRs, we had to eliminate the effect of the NSRs on the count-rate plot. A preliminary difference map was made by subtracting the initial latitude-dependent count rates from the smoothed map. The resultant maps are similar to that shown in figure 2, and from these we determined all HEALPix bins that had values lower than -0.05 cps. With these HealPix bins removed, we generated a second-iteration plot of count rate vs. latitude and a second-iteration difference map. A third iteration showed no significant change, and these data were then used to generate the final count-rate vs. latitude plots shown in figure 1.

Discussion: It can be seen that the count rates decrease linearly and nearly identically at both poles. The decrease in epithermal-neutron flux is due to an increase in the H content of the regolith. This distribution of H is very different from the much higher H content of the strong flux depressions seen in the NSRs (Figure 2). The cause of the high H content in the NSRs is not well understood, but this work will discuss what the regular increase in H with latitude (figure 1) can tell us about H mobility on the lunar surface.

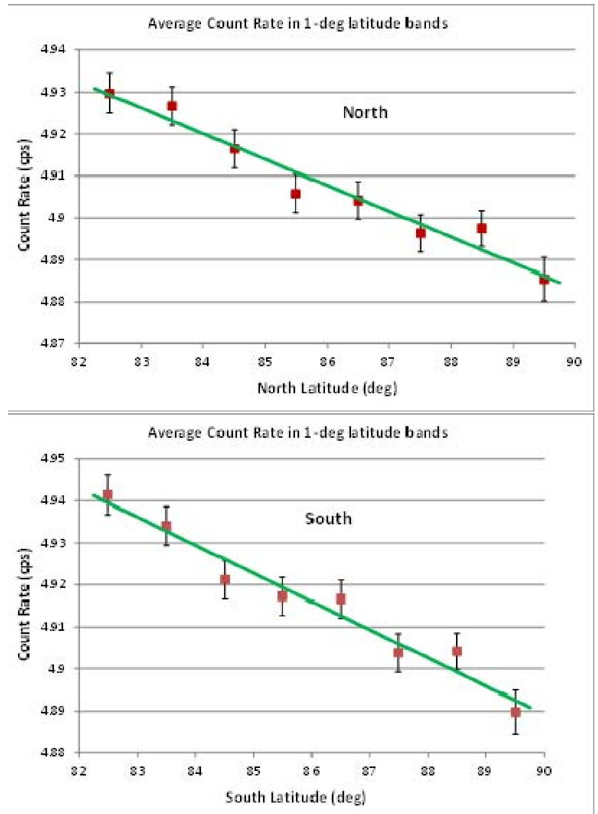

Figure 1. Latitude averages of the epithermal neutron count rate show a linear decrease at both poles that is nearly identical. The decrease in count rate is due to an increase in H content with latitude. The effect of the NSRs has been removed in these data, so the increase in H is entirely due to the region between the NSRs.

There are two obvious sources of hydrogen found on the moon: H_2O from impacts of volatile-rich comets or meteorites and hydrogen from the sun associated with the solar wind or solar particle events (SPEs). By a large margin, the solar wind accounts for the bulk of the lunar H [5]. To first order the solar wind H is deposited along the line of sight to the Sun. Clearly the increase in H we see near the poles cannot be a result of direct deposition since the polar regions receive less solar wind than lower latitudes in proportion to the cosine of latitude. In addition, any H delivered by impacts is expected to be nearly isotropic, so impacts themselves cannot account for the high polar H content.

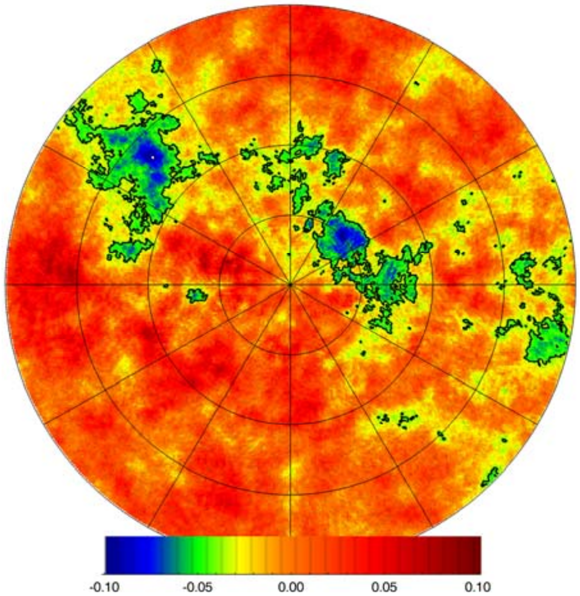

Figure 2. Epithermal-neutron count rate differences near the South Pole from 82° S latitude. The count rate differences are relative to the linear fit in figure 1. The contours are drawn at -0.04 cps. All values less than -0.04 cps are significant at the 3σ level or greater.

The H implanted by the solar wind, as well as H_2O deposited from impact sources, can be mobilized by a variety of processes, but all them that rely on external sources, e.g. solar wind sputtering, solar photons, or impacts, are either isotropic or have at most a cosine dependence on latitude [5]. Figure 3 shows the background-adjusted count rate as a function of latitude, and it can be seen that the decrease in count rate at the poles is much steeper than that expected based on cosine dependent processes. The background of counts in the LEND collimated sensors come from a variety of sources and is approximately 3.3 cps [5].

Because the solar-wind deposited H in the grains is saturated, we consider the H in the lunar regolith to be determined by differences between the rates of steady-state gain and loss mechanisms. As shown above, cosine dependent mechanisms cannot by themselves account for the steep decrease in count rate observed in the polar regions. The rate of loss of species due to diffusion of implanted H out of the grains or thermal vaporization, however, are expected to show a very strong dependence on temperature. We suggest the decrease in epithermal-neutron count rate (and in-

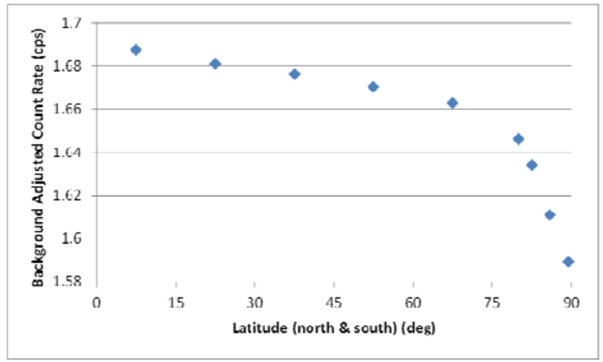

Figure 3. The background adjusted epithermal count rates show a very steep decrease toward the poles. The change in count rate is too steep to be accounted for by a cosine-dependent mechanism.

crease in H content) is due to much slower vaporization of H in the polar regions.

Before we try to semi-quantitatively model the migration of H, we must first convert the count-rate data into concentrations of H (in all species). To do this we first calculate an epithermal-neutron suppression value. The suppression is defined as the ratio of the background-adjusted count rate in an area of interest to that of a reference flux expected for an area containing no H.

Following a procedure like that used by [3], we take an area between 150° and 220° E. longitude and -30° and +60° N. latitude for which we find an average background-adjusted count rate of 1.6938 ± 0.0012 cps. We then take the average H content in Apollo 16 soils of 45 ppm from [6] as our best estimate of the H content in this area. Using Figure S-1 in the supplementary on-line material of [3], we calculate a reference count rate of 1.79 cps.

Based on the above model-dependent assumptions and the data in Figure 3, we calculate a H content of 120 ppm at 82° latitude and 200 ppm at 89° latitude. The bulk of the excess H above the 45 ppm assumed for that typical of lower latitudes must reside on the surface of the grains since it is difficult for an H_2O molecule on a ballistic trajectory to be imbedded into a grain. The implications of this conclusion will be discussed.

References: [1] P. D. Spudis *et al.*, *Solar Syst. Res.* 32, 17 (1998). [2] W. C. Feldman *et al.*, *Science* 281, 1496 (1998). [3] I.G. Mitrofanov, *et al. Science*, 330, 483–486 (2010). [4] Hierarchical Equal Area isoLatitude Pixelization, http://healpix.jpl.nasa.gov. [5] Boynton *et al.*, *JGR*, (under revision, 2012). [6] Bustin *et al.*, *Proc. Lunar Sci. Conf.* (1984)