Epithermal Neutrons, Illumination, Spatial Scale and Topography: An Correlative Analysis of Factors Influencing the Detection of Slope Hydration using LRO's Lunar Exploration Neutron Detector.

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Introduction: In this research we correlate the Moon's south polar epithermal neutron flux, topography and a visible illumination model to illustrate evidence that there is a widespread hydration of polward-facing (PF) slopes that is occurring at a continuum of spatial scales. By limiting our analysis to large PF slopes we show that there is a broad decrease in the lunar epithermal neutron flux derived over the large PF slopes relative to the average lunar induced epithermal flux derived over all PF slope conditions. The additional ~1% decrease in epithermal neutron flux over large PF slopes raises the EF vs PF rate contrast to ~2% near the south pole. Results also indicate that an identical scale-dependent comparison of epithermal rates derived over equator-facing (EF) slopes do not contrast, inferring that hydrogen concentrations on those slopes are in equilibrium with local levels. Fully registered south polar maps derived from the Lunar Reconnaissance Orbiter's Lunar Exploration Neutron Detector (LEND) as well as topography and an illumination model derived from the Lunar Observing Laser Altimeter (LOLA) are correlated to characterize slope conditions [1-3]. Regolith temperature does not appear to be an influence in the slope epithermal rates. Lunar Prospector Neutron Spectrometer (LPNS) and LEND's Sensor for Epithermal Neutrons (SETN) corroborate these results but to a lesser extent [4].

Background: Strong evidence for hydrogen concentrations at the lunar poles has been observed by both LPNS, and more recently LEND as indicated by a broad ~4% suppression in the epithermal neutron flux. For decades the prevailing hypothesis had been that cryogenic conditions in permanently shadowed regions were necessary for near surface concentrations of hydrogen [5]. LPNS and LEND results show the suppression of epithermal neutron flux begins near ±70° latitude. Yet only ~1% of this latitude band lies in permanent shadow. Also, evidence from LEND's Collimated Sensor for Epithermal Neutrons, (CSETN) indicate that only a few of the permanently shadowed regions (PSR)'s contain significantly enhanced concentrations of hydrogen [6]. So, what explains the polar epithermal flux suppression?

A possible explanation lies in evidence derived from near infra-red observations. Results from Chandraayan-1's Moon Mineralogy Mapper M^3, suggested enhanced concentrations of hydrogen are diurnally associated with the darkened slopes of mid-latitude craters [7]. Deep Impact suggested a global scale production process where solar wind interactions with regolith oxygen-bearing minerals yield hydroxyl and water [8]. Further, recent re-analysis of M^3 data suggest surface hydrogen concentrations begin near ±40° latitude and increase to ~1000's of ppm hydrogen diurnally present at latitudes above ±60° [9].

Our hypothesis unifies the epithermal and infrared results by suggesting that the broad polar-suppression of epithermal neutrons is primarily due to the localized trapping of hydrogen on PF slopes where locally minimum temperatures and illumination conditions may provide trapping conditions in a continuum of spatial scales perhaps down to a meter. Also, that the necessary PF trapping conditions for hydrogen increase towards the poles.

If our hydrogen trapping hypothesis is correct, then considerations derived from convolution theory provide two predictions regarding the detection of hydrogen in slope conditions. **H1**) The suppression of epithermal count rates should increase in large PF slope conditions as compared to all slope conditions. In these locations hydrogen concentrations are expected to be maximized. Plus, the large slopes subtend a greater fraction of the CSETN field-of-view than small slopes. **H2**) EF slopes are postulated to be anhydrous. If so, there should be no epithermal rate contrast due to those slopes spatial scale.

Methods: To study slopes as a function of spatial scale we decompose the LOLA topography as a function of slope aspect to isolate PF and EF slopes. Fully registered epithermal neutron count rates derived over PF and EF slopes are averaged by convolving a 10° latitude-band analysis window from west to east longitudes between -45° to -90° latitude, using 0.5° latitude steps. At each center position of the window the average epithermal count rates are calculated for PF and EF pixels. A parallel analysis of a LOLA visible illumination model [10] is included to quantify the contrasting average illumination conditions on

PF and EF slopes. Average visible illumination is also used as a proxy for slope temperatures.

Large scale slopes are classified and segmented from the topography as a function of their local variation in slope aspect and its first derivative properties of slopes in craters. PF and EF pixels are aggregated by a region growing process. Small scale slopes whose pixel aggregate areas fall below 15-km^2 area are eliminated, thus isolating large scale slopes.

Results: *Figures-1a,b* illustrate corresponding visible illumination and epithermal neutron % rates derived over LOLA topography as a function of slope aspect and latitude. (*Fig-1a: left*) Baseline visible illumination results illustrate the lower levels of average illumination modeled for PF slopes (*light blue*) relative to equivalent illumination rates modeled for EF slopes (*green*) vs. latitude. Rates derived for large scale slope conditions show the average illumination goes up by 0 to 3% for EF conditions (*red*) and down 2 to 7% for PF (*dark blue*) conditions. Relative rates derived for large scale slopes suggest the isolation of spatially larger and deeper features.

(*Fig-1b: right*) Corresponding baseline epithermal neutron count rates on poleward (*light blue*) and EF (*green*) slopes as a function of latitude. **H1**) Results show the relatively decreased rates on PF slopes between -50° W and -60° E that are consistent with expected illumination trends. At the pole the rate difference is ~1% of the lunar induced epithermal count rate. In large scale slope conditions the suppression of epithermal neutron rates on PF slopes (*dark blue*) is enhanced by an additional ~1%, yielding a ~2% contrast at the poles. The contrast decreases towards mid-latitudes. Importantly, the rates derived from large-scale EF conditions (*red*) are equivalent to the rate of the baseline measurements (*green*). This result is consistent with **H2**) Non-contrasting epithermal rates derived over EF slopes suggest anhydrous conditions that are in equilibrium with local near surface hydration conditions.

Conclusions: Our results indicate that there is a widespread hydration of PF slopes occurring in a continuum of spatial-scales, possibly down to the level of a meter-scale in latitudes >±60°. Evidence for the hydrogen concentration bias towards PF conditions is that epithermal neutron rates from PF slopes are scale dependent and EF slopes are not. This result importantly suggests EF slopes are hydrated to local equilibrium levels.

If slope temperature was the sole contributor to the observed epithermal-rate contrasts we should expect: 1) In EF conditions epithermal rates should go up with the observed illumination rates, they don't. 2) Temperature should provide a uniform contribution to the rate contrasts as slope scale distributions are assumed similar in low to high latitudes. Instead the rate contrasts are maximized at the poles and diminish towards mid-latitudes.

References: [1] Vondrak et al. (2010) *Sp. Sci. Rev., 150(7-22)* [2] Mitrofanov et al.(2010) *Sp. Sci. Rev., 150(183-207)* [3] Smith et al.(2010) *Sp. Sci. Rev., 150(1-4)* [4] Feldman et al. (1998) *Science*, 281(5382) [5] Arnold (1979) *JGR 84-B10* [6] Sanin et al., (2012) JGR-Planets 117-E12 [7] Pieters et al., (2009) *Science*, (23) 568-572 [8] Sunshine et al., (2009) *Science* (326) 595 [10] Li et al. *Proc. of the 44th Lun. and Plan. Sci. Conf.* #1337

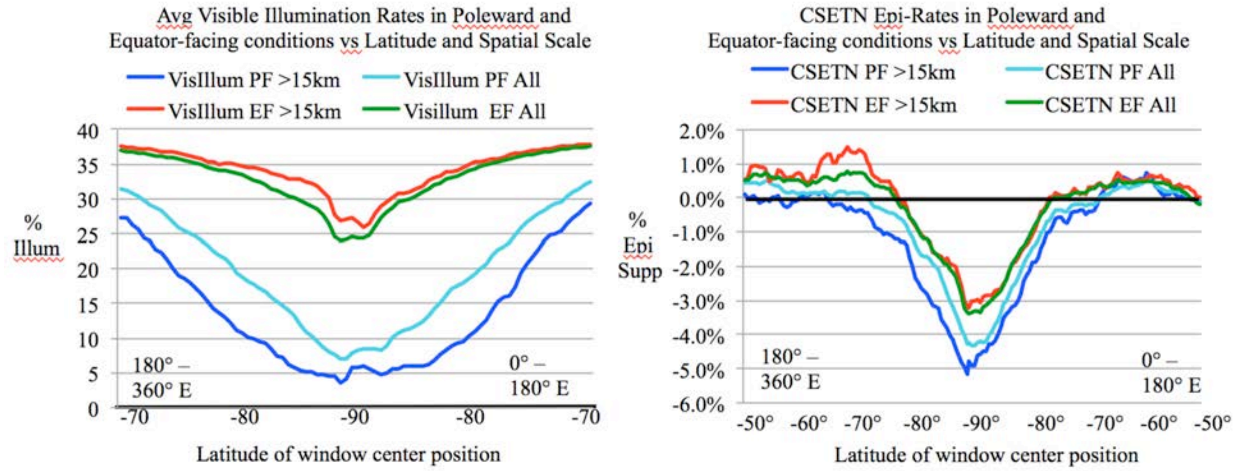

Figure 1: (*left*) Plots of Visible Illumination rates on poleward and EF conditions vs latitude and slope spatial scale. By limiting the slope analysis to slopes of larger spatial scale (>15km) compared to the baseline rates (All) illumination rates increase (*red*) in equator-facing conditions and decrease (*dark blue*) for poleward-facng conditions. (*right*) Plots of corresponding epithermal rates vs latitude and slope spatial scale. The suppression of epithermal rates is enhanced by ~2% of the lunar induced epithermal rate at the pole for large-scale slopes in PF conditions as compared to the baseline evaluation for both EF scale conditions. In EF conditions the rates for both large and All cases are equivalent suggesting hydration on EF slopes is in equilibrium with local surroundings.