TESTING OF LUNAR PERMANENTLY SHADOWED REGIONS FOR WATER ICE.

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Introduction: More than 40 years ago, it was suggested that some areas near the Lunar poles are sufficiently cold to trap and preserve for a very long time (~Gy) hydrogen bearing volatiles, either produced at the Moon via solar wind interactions or brought to the Moon as water ice by comets and meteoroids [1,2]. The results of observations made by radar onboard the Clementine spacecraft and by neutron (LPNS) and gamma-ray (LPGRS) spectrometers onboard the Lunar Prospector mission have been interpreted as an enhancement of hydrogen abundance in permanently shadowed regions (PSRs) [3,4]. Unfortunately, the spatial resolution of the LPNS was much broader than the size of PSRs [5] requiring model dependent data deconvolution of smaller surface features and the inference that hydrogen may concentrate at the bottom of permanently shadow craters.

In the presented analysis we are use Lunar Exploration Neutron Detector (LEND) data to look at distribution of neutron flux at Moon poles with much better spatial resolution then was achieved at previous space missions. LEND is a collimated neutron spectrometer onboard the NASA Lunar Reconnaissance Orbiter (LRO) spacecraft. The LEND instrument is capable to distinguish footprint with radius ~5 km [6-7]. It is comparable with large PSRs and provides unique possibility to test hypothesis if all major PSRs are reservoirs of Hydrogen or even water ice.

Data Analysis: In our analysis we are using the collimated LEND data gathered during the primary part of the LRO mapping phase (see maps on Figures 1 and 2). Using these data we accomplishing statistical comparison between distribution of neutron flux outside and inside PSRs. This analysis includes:

1) Individual approach to test properties of particular PSRs with well visible effect of neutron suppression.

2) Collective estimation approach to test all known PSRs with area greater than 3 km^2 (and sampled by three groups by PSR area) in order to estimate significance of average local variations of neutron flux inside and outside PSR area.

Discussion: Both analyses of individual PSRs and studies of groups of PSRs have shown that these spots of extreme cold at lunar poles are not associated with a strong effect of epithermal neutron flux suppression [8]. To estimate the local effect of suppression of PSRs, we have compared the count rates to the sunlit vicinity around them. We found only three large PSRs, Shoemaker and Cabeus in the south and Rozhdestvensky U in the north, which manifest significant neutron suppression, from -5.5% to -14.9%. All other PSRs have much smaller suppression, no more than few percentages, if any. Some PSRs even display excess of neutron emission in respect to sunlit vicinity around them.

Testing PSRs collectively, we have not found any average suppression. Only the group of large PSRs, area >200 km^2, show a marginal effect of small average suppression of about 2%, with moderate statistical confidence. LEND will collect more data and provide better counting statistics for PSR, but even now the data is enough for definite conclusion that PSRs at both poles are not reservoirs of large deposits of water ice, which would be seen as holes in the emission map of lunar neutrons. The major effect of extended suppression of neutrons at lunar poles is associated with the sunlit surface, and one has to test the local neutron suppression regions (NSRs) outside the permanent darkness of PSRs.

On the other hand, the exceptional cases of PSRs in Shoemaker, Cabeus and Rozhdestvensky U craters show that large enhancement of hydrogen exists in some particular PSRs. Comparison of neutron data, surface altimetry and surface temperature shows very good agreement between the shadow in Shoemaker and emission of epithermal neutrons (see Figure 3). The presence of water ice has also been experimentally proven for regolith in Cabeus (5.6 ± 2.9 %) by direct measurements of plume from LCROSS impact [9].

This shows that physical processes for trapping of volatiles is not so simple, as previously thought, with trapping of water molecules from the exosphere in cold spots of PSRs. One must study more complex physical models, where all PSRs are not the principal depository of lunar water and where should be some physical difference between PSRs, which make some more favorable for additional content of water in comparison with regolith at sunlit surface around them.

References: [1] Watson K. et al. (1961) *JGR*, 66, 3033-3045. [2] Arnold J. R. et al. (1979) *JGR*, 84, 5659-5668. [3] Feldman W. C. et al. (2001) *JGR*, 106, 23231-23252. [4] Lawrence D. J. et al. (2006) *JGR*, 111, E08001, 19PP. [5] Maurice S. et al. (2004) *JGR*, 109, E07S04, 40 PP. [6] Mitrofanov I. G. et al. (2008) *Astrobiol*., 8, 793. [7] Mitrofanov I. G. et al. (2010) *Space Sci. Rev.*, 150, 183. [8] Mitrofanov I. G. et al. (2010) *Science*, 330, 483. [9] Colaprete A. et al. (2010) *Science*, 330, 463.

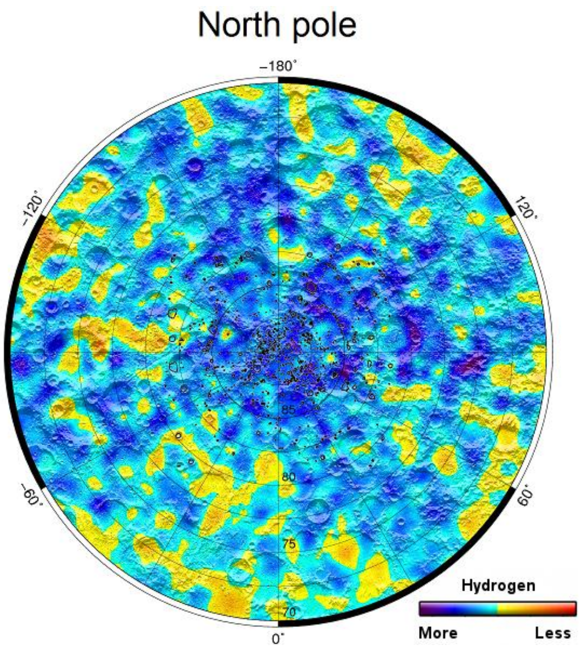

Figure 1. LEND map of epithermal neutrons at the North lunar pole. Black spots and contours on the map represent the boundaries of PSRs according to LOLA data.

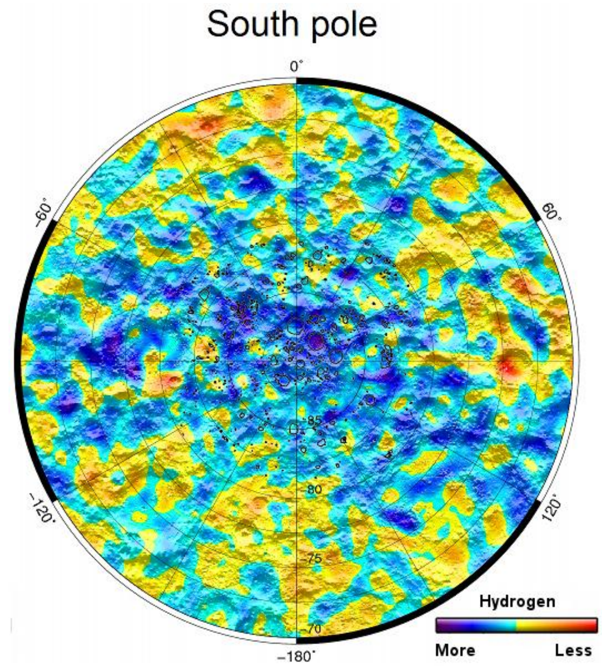

Figure 2. LEND map of epithermal neutrons at the North lunar pole. Black spots and contours on the map represent the boundaries of PSRs according to LOLA data.

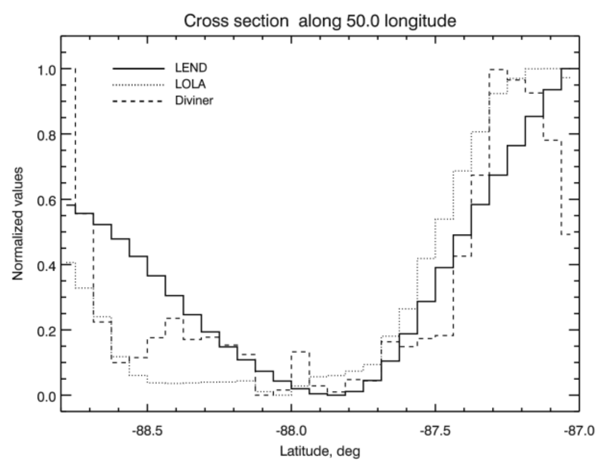

Figure 3. Longitudinal cross section of Shoemaker crater according the LEND (solid line), LOLA (dotted line) and Diviner (dashed line) data. Good correlation of minimum values in all three datasets is visible. Maximum hydrogen concentration in this crater is well correlated with crater typography and with minimum of observed average temperature of regolith.