IMPLICATIONS FOR THE DISTRIBUTION OF WATER ICE AND OTHER VOLATILES FROM LCROSS AND LUNAR ORBITAL DATA.

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Introduction: The LCROSS impact occurred within Cabeus crater (84.9°S, 35.5°W), where the Lunar Prospector Neutron Spectrometer (LPNS) mapped the highest inferred hydrogen abundance on the Moon [1]. Image reconstruction work [2,3] suggests an abundance of ~1 wt% WEH, if confined to the area of permanent shadow. However, the LCROSS impact yielded total water estimates, ice plus vapor, of between 3 and 10 wt% [4]. LRO/Diviner data/modeling reveal that shallow subsurface temperatures ≤100K prevail over extensive areas outside strict permanent shadow [5]. Ice-bearing regolith could conceivably exist within a few tens of centimeters of the surface in such permafrost regions. If placed in the relatively limited Cabeus permanently shadow region (PSR), a uniform regolith mixture of 5 wt% water-equivalent hydrogen (WEH) based on LCROSS would create measurably lower epithermal neutron count rates than are actually seen in orbital data; 17.9±0.08 ct/s instead of the 18.20±0.08 ct/s. If such an ice mixture is present in the areally more extensive permafrost region, the disagreement with orbital data is even greater.

It is likely that volatiles are inhomogeneously distributed, due to both impact processes and emplacement history. Here we examine two possibilities that may bring consistency to the orbital and LCROSS measurements.

Inhomogeneous lateral distribution: Consider the extreme case of a bimodal distribution within the crater – patches of relatively dry and relatively icy regolith. Such a model may seem overly simplistic, were it not for the case that LCROSS impacted a doubly-shadowed region with the Cabeus PSR [6]. The evolution of cold-trapped volatiles may be controlled in part by such double-shadowing. In this case the epithermal leakage flux seen from orbit is a mixture of two different values, weighted according to fractional areas. One possibility is that ~40% of the PSR area may be "icy", the remainder dry (implanted solar wind levels of <0.1 wt% WEH). However, if the whole area of permafrost is considered, then as little as 20% of the area will be as "wet" as the LCROSS results (and LCROSS was lucky).

Inhomogeneous depth distribution: For inhomogeneous mixtures, the leakage flux of thermal and epithermal neutrons depends on both depth of burial of an icy layer and its ice abundance. For a given regolith composition, the combination of epithermal and thermal leakage fluxes imply a burial depth and ice abundance. Therefore, for the Cabeus PSR, the pixon reconstruction values for the epithermal flux defines a range of burial depths and ice abundances. The ambiguity is resolved by a reconstruction of the thermal+epithermal flux. There can be significant uncertainties, however, due mainly to variations in iron abundance in the anorthositic regolith. Even small variations in FeO (2 – 6 wt%) can have a significant impact on thermal neutron leakage flux. We use the Lunar Prospector Gamma Ray Spectrometer results for FeO to gauge the thermal neutron dependence on soil composition. With this effect removed, it is possible to estimate both the burial depth of an icy layer and its WEH abundance. The two measurements require one additional assumption: the upper layer is dry and has a prescribed WEH abundance comparable to returned lunar samples. Nevertheless, plausible thermal neutron values in the PSR, while uncertain, include the LCROSS abundances under 50-100 cm of dry soil.

Conclusion: The discrepancy between LCROSS water-equivalent hydrogen abundances of between 5 and 10 wt%, and the inferred orbital homogeneous abundances of 0.2 to 1 wt% can be resolved. It is physically realistic to expect that lateral and/or depth variations in volatile abundances occur, and a reasonable range of these values leads to agreement. Between 20% and 40% of the Cabeus floor may be "icy", or alternatively a 5-10 wt% "icy" layer exists between 50 and 100 cm beneath a layer of dry regolith within the PSR. But volatile abundances of 5 wt% or more, distributed uniformly and homogeneously throughout the Cabeus PSR do not agree with orbital measurements.

References: [1] Feldman, W. C. et al. (2001) *J.Geophys.Res., 106,* 23,231. [2] Eke, V. et al., (2009), *Icarus 200,* p 12. [3] Teodoro, L., et al., (2010), *Geophys. Res. Lett., 37,* L12. 201. [4] Colaprete, A et al. (2010) *Science*, *330*, 463-468. [5] Paige, D. A. et al. (2010) *Science, 330*, 479-482. [6] Colaprete, A., et al. (2011), *this conference.*