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Reconciling LCROSS and Orbital Neutron Water Abundance Estimates in Cabeus Crater

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The Lunar Prospector Neutron Spectrometer (LPNS) first revealed Cabeus crater (84.9°S, 35.5°W) as having the highest inferred hydrogen on the Moon. Because of the broad LPNS footprint (~40 km FWHM), the apparent peak water-equivalent hydrogen (WEH) concentration is only ~0.25 wt%, but could be much higher in smaller areas than the spectrometer footprint. Earlier image reconstruction work suggested that areas within permanent shadow have abundances ~1 wt% WEH. However, the LCROSS impact yielded total water estimates, ice plus vapor, of between 3 and 10 wt%. The large disagreement between LCROSS and apparent orbital values imply that either the ice is buried, by perhaps as much as 50 to 100 cm; or the ice distribution within Cabeus is spatially inhomogeneous, or both.

Modeling reveals that the areal extent of a "shallow permafrost zone" is far greater than the area of permanent shadow (Paige et al., Science, 2010). Ice can be virtually stable for billions of years within a few tens of centimeters of the surface in these areas. However, the LCROSS impact took place in an area of permanent shadow. If stably-trapped volatiles can be found in locales that receive occasional, oblique sunlight, landed missions may target these sites and eventual resource exploitation may be done more easily. Are orbital neutron data consistent with areally-extensive, volatile-rich cold traps?

Orbital epithermal neutron data over the northern half of Cabeus (near the LCROSS impact site) are consistent with 0.2 wt% WEH or less in the "permafrost zone" near the crater. On the other hand, pixon reconstructions that confine the hydrogen enhancements to permanent shadow result in higher abundance estimates – around 1 wt% if homogeneously mixed. But if the PSR abundance is increased to 10 wt%, consistent with the sum of all H-bearing compounds seen by LCROSS, a much larger-than-observed reduction in neutron count rate would be seen from orbit. It is likely that volatiles are inhomogeneously distributed, due to both impact processes and emplacement history. Two possibilities may bring consistency to the orbital and LCROSS measurements.

Inhomogeneous lateral distribution: Consider the extreme case of a bimodal distribution within the crater – dry and wet. In this case the epithermal leakage flux seen from orbit is a mixture of two different values, weighted according to fractional areas. Two possible outcomes, depending on whether the inferred leakage flux for the PSR or "permafrost" areas are considered. In the first case, ~40% of the PSR may be "wet", the remainder dry (and LCROSS was slightly lucky). 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 quite lucky).

Inhomogeneous depth distribution: The leakage flux of thermal and epithermal neutrons depends on depth of burial of an icy layer beneath dry ferroan anorthosite soil (FAn). For the Cabeus PSR, the pixon reconstruction values for the epithermal flux allows a range of abundance and burial depth, while that of the thermal+epi detector constrains this range. (Uncertainties in iron abundance in the FAn can have significant impact on thermal neutron leakage flux estimates.)

Between 20% and 40% of the Cabeus floor may be "wet", or alternatively a 5-10 wt% "wet" 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.