**THE AVERAGE WATER CONCENTRATION WITHIN CABEUS CRATER: INFERENCES FROM LRO/DIVINER, LCROSS AND LUNAR PROSPECTOR.** R. C. Elphic[1], L. F. A. Teodoro[2], V. R. Eke[3], David A Paige[4], Matthew A Siegler[4], A. Colaprete[1], [1]Planetary Systems Branch, NASA Ames Research Center, Moffett Field, CA, USA. [2]BAER Institute, NASA Ames Research Center, Moffett Field, CA, USA, [3]Institute for Computational Cosmology, Physics Department, Durham University, Durham, UK, [4]Earth and Space Sciences, UCLA, Los Angeles, CA, USA.

**Introduction:** 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 broad LPNS footprint (~40 km FWHM), apparent peak water-equivalent hydrogen concentration is only ~0.25 wt%, but could be much higher in smaller areas [1]. Earlier image reconstruction work [2,3] suggested that areas within permanent shadow the abundance ~1 wt% WEH. 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]. Relaxing the permanent shadow constraint results in abundances in Cabeus, near the LCROSS impact site in permanent shadow, need be no larger than 0.25 wt% to explain neutron data. Such large values imply that either the ice is buried, by perhaps as much as 50 to 100 cm; and/or the ice distribution within Cabeus is spatially inhomogeneous. Here we explore plausible ranges of abundance and burial permitted by the data.

**LRO/Diviner Polar Temperatures:** Diviner data and modeling reveal that shallow subsurface temperatures ≤110K prevail over extensive areas outside strict permanent shadow. Figure 1 shows depth, in meters, to the isotherm corresponding to a loss rate of 1 $kg/m^2/Ga$ of water ice [5]. The areal extent of this "shallow permafrost zone" is far greater than the area of permanent shadow. Shackleton is at lower right, Cabeus is center upper left. White denotes ice stability within 1 cm of surface, which generally corresponds closely to areas of permanent shadow. Beige denotes ice stability depths >1 m.

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. So is it possible to reconcile the relative high LCROSS abundances with areally-extensive, volatile-rich cold traps?

**Orbital Neutron Measurements:** Figure 2 shows smoothed LP epithermal neutron count rates mapped on a section of the lunar south polar region. The low in count rate over the northern half of Cabeus corresponds with the LCROSS impact site and is consistent with 0.2 wt% WEH or less in the "permafrost zone" near the crater. On the other hand, pixon reconstructions that confine the WEH 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 <u>all</u> H-bearing compounds seen by LCROSS, a much larger-than-observed reduction in neutron count rate results. A predicted minimum count rate is 17.9 cnts/s, much lower than neutron observations permit.

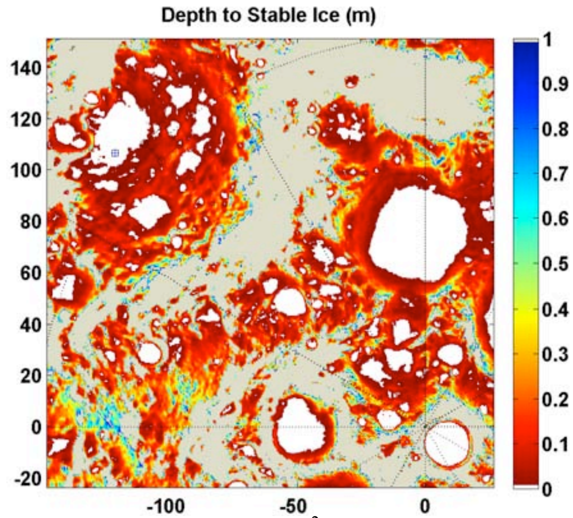


Fig. 1. Depth to the 1 $kg/m^2$ per billion year ice loss isotherm, from [5]. White denotes stability within 1 cm of the surface, beige denotes stability at depths greater than 1 meter. The crater Cabeus occupies the upper left corner, Shackleton the lower right. Polar stereographic coordinates, units are km.

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.

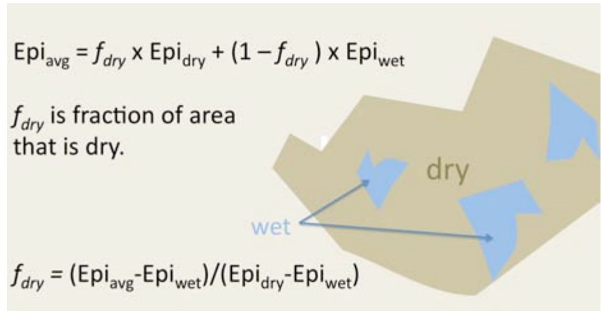
**Inhomogeneous lateral distribution:** Consider the extreme case of a bimodal distribution within the crater – dry and wet. In this case the epithermal leakage flux seen from orbit is a mixture of two different values, weighted according to areal fractional areas. Figure 3 illustrates this and shows 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 lucky, but not too 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 lucky).

**Inhomogeneous depth distribution:** Figure 4 shows how the leakage flux of thermal and epithermal neutrons depends on depth of burial of an icy layer beneath dry FAn. Here are plotted the LPNS HeSn (thermal+epithermal) vs. HeCd (epithermal only) fluxes as would be observed by LP at 30 km altitude. The top layer is assumed to have 50 ppm solar wind H; red lines are contours of constant WEH wt%, blue lines contours of constant burial depth, in cm assuming 1.8 g/cm$^3$.

For the Cabeus PSR, the pixon reconstruction values for the epithermal flux defines the vertical orange arrow, while that of the thermal+epi detector defines the orange horizontal arrow. Estimated error bars are shown in green, due mainly to uncertainties in iron abundance in the FAn. Even small variations in FeO (2 – 6 wt%) can have significant impact on thermal neutron leakage flux.

**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 1.1 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 "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 does 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.




| Inferred Avg Epi Count Rate (WEH) | Dry Component Count Rate (WEH) | Wet Component Count Rate (WEH) | Fractiona Dry (wet) |
|---|---|---|---|
| 13.4 ct/s (1 wt%) | 19.5 ct/s (0.06 wt%) | 4.2 ct/s (10 wt%) | 60% (40% |
| 16.5 ct/s (0.4 wt%) | 19.5 ct/s (0.06 wt%) | 4.2 ct/s (10 wt%) | 80% (20% |

Fig. 3. Concept of bimodal lateral inhomogeneous volatile distributions. One fraction of the crater floor is dry, $f_{dry}$, the other wet (1 - $f_{dry}$). The orbital neutron data then mix the two epithermal leakage fluxes together proportionally. The table is described in the text.

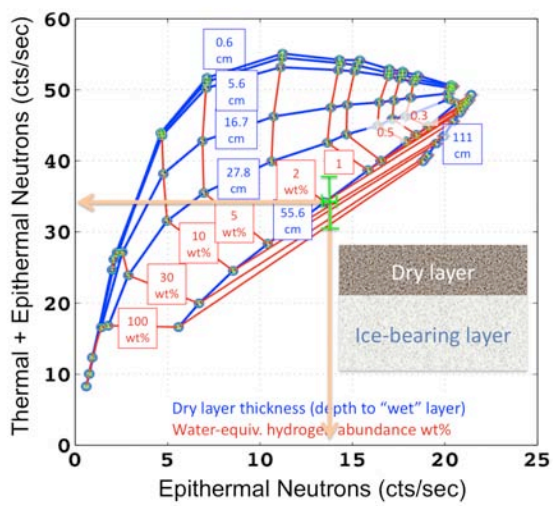



Fig. 4. LPNS HeSn (thermal+epithermal) count rate versus HeCd (epithermal only) count rate. The leakage fluxes vary as a function of burial depth (blue isocontours) and lower-layer ice abundance (red isocontours). Top layer is considered dry.