DEPTH DISTRIBUTION OF WATER ICE IN LUNAR PERMANENT SHADOW. D. M. Hurley[1], [1]Johns Hopkins Applied Physics Laboratory, Laurel, MD, USA (dana.hurley@jhuapl.edu).

Introduction: Water ice in lunar Permanently Shadowed Regions (PSRs) has a heterogeneous distribution, both laterally and with depth. The heterogeneity exists on many scales down to the limit of existing spatial resolution. This paper discusses what is known about the depth distribution of water ice on the Moon and about expectations from modeling.

Existing data on depth distribution: Neutron data are sensitive to the presence of volatiles within the top meter of regolith. Data from Lunar Prospector Neutron Spectrometer (LPNS) and Lunar Energetic Neutron Detector (LEND) are consistent with regions of enhanced hydrogen content, presumed to be in the form of water ice, associated with cold traps in PSRs. LPNS data are consistent with 1.5 ± 0.8 wt.% water-equivalent hydrogen distributed within the top 1 m of regolith in the polar regions if it is confined to the area in PSRs [1]. LEND data suggest water abundances of 0.3-0.5 wt.% in the regions with the strongest neutron signature [2].

Analyzing the flux of neutrons in multiple energy ranges provides information about the average depth distribution. Most analyses assume a dry layer of regolith over top of a wet layer of regolith. In these models, the data are consistent with a dry overburden of ~10 cm. One location, Shackleton crater, has fast neutron flux consistent with H on the surface [3]. There is nothing in the neutron data to preclude a change in the ice content, either higher or lower, at depths greater than 1 m.

The abundance of water inferred from the LCROSS impact, 5% [4], was greater than the abundance of the surrounding region, 0.5% inferred from neutrons [2], indicating the impact was into a subregion that was relatively ice-rich. Alternatively, the high abundance of water could have originated at depth below the ~1 m depth probed by neutron spectroscopy. The crater formed by the LCROSS impact is expected to have excavated to a depth of 2-3 m.

Radar data are capable of finding coherent ice blocks down to a meter or more depth. [5] noted anomalous craters that could be due to significant ice content in the ejecta. Bistatic observations from Mini-RF have been interpreted to indicate ice in the subsurface of an illuminated region of Cabeus [6], which would be interesting for potential extraction operations. While there have been interesting results from studies of Mini-RF data, these data have not revealed any “ice skating rink” features in lunar PSRs.

There are multiple data sets that detect the amount of water on the top surface of lunar PSRs. This includes the Lyman Alpha Mapping Project (LAMP) far ultraviolet spectrograph, the Lunar Orbiter Laser Altimeter (LOLA) 1064 nm laser reflectance data, and the Moon Mineralogy Mapper (M3) infrared spectroscopy data. These data show that there is not a strict correlation between data consistent with frost on the surface and data indicating water at depth (e.g., [7]).

Modeling of depth distribution: Models of the depth distribution of water ice in PSRs incorporate known physical processes to attempt to explain the distribution of ice. They incorporate an assumed source of water, which can affect the distribution. Because of impact gardening, there is a general trend with deeper depths being associated with older ages (e.g., [8]). However ,this is not a strict 1-to-1 relationship.

Models of impact gardening produce expectations for the heterogeneity of the depth distribution of water ice as it evolves over time [9]. These models are applicable in the extremely cold regions where thermal diffusion is not efficient. Assuming a coherent initial ice layer, this model predicts heterogeneity on ISRU spatial scales in ~100 Myr times.

Where temperatures > 110 K exist, thermal diffusion is a dominant mechanism for redistributing water with depth. A thermally stable zone may exist at depth even if ice is not stable for long times on the surface. [10] describe the thermal pumping effect, which has the potential to create a layer of ice in the subsurface.

Additional removal processes may be active at the extreme surface, including photolysis by ultraviolet light, impact vaporization by meteoroids, and sputtering by solar wind. For these reasons, it is expected that subsurface access may be either beneficial or required for ISRU of lunar polar water ice deposits.

Conclusions: Because the heterogeneity persists down to the spatial resolution of existing measurements, new measurements with better spatial resolution would improve the understanding of the lateral and depth distribution of volatiles.

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