PERMANENTLY SHADOWED LUNAR NORTH POLE CRATERS: GEOLOGY AND IMPLICATIONS FOR VOLATILES. J. B. Plescia[1,2], [1]Department of Geology, University of Maryland, College Park, MD, [2]Applied Physics Laboratory, Johns Hopkins University, Laurel, MD.

Introduction: Craters at the poles are of interest as many represent an unusual environment - perpetual darkness and low temperature. This environment has been suggested to act as a cold trap that can sequester volatiles of value to understanding solar system history and for use as exploration resources. Several sources [1-5] have argued that the enhanced presence of H in the polar region is possibly in the form of water ice localized within the permanently shadowed craters.

Spudis et al. [2] and Thomson et al. [6] have shown that some permanently shadowed (PS) craters in the north and south polar regions exhibit radar anomalies (defined as having high circular polarization ratios (CPR) within the crater and nominal CPR beyond the rim) indicative of the presence of water ice within the crater interior. The anomaly is suggested to be the result of the presence of water ice.

About 125 PS craters (or those with large fractions of shadowed interior) identified in the LROC catalog [7] were examined. The objective is to understand the interior morphology, the source of the anomalous CPR, how the interiors evolve over time and the implications for those sites to store volatiles. Long exposure LROC images [8], LOLA [9, 10] and Mini RF data [11] were used in the analysis.

Morphology: The interior morphology of PS craters exhibit no significant differences from other similar size lunar craters. Walls are typically smooth and lack significant number of exposed blocks or bedrock, and there are few superposed impact craters. Mass wasting on the slopes is observed in some craters. Floors are typically smooth to hummocky and have more superposed impact craters. For craters <20 km diameter, depth / diameter ratio is 0.16 ± 0.04 and average wall slopes are $25.5° \pm 4.1°$. Such values are not unusual with respect to non-polar craters.

Figure 1 illustrates a comparison of the for two craters, Rozhdestvenskiy N and Main L.

Rozhdestvenskiy N (8.7 km diameter, 84.0°N, 203.7°E) was identified as an anomalous crater [2] characterized by high CPR in the crater and nominal CPR outside; the CPR was interpreted to indicate the presence of ice. In comparison, Main L (14.3 km, 81.7°N, 22.3°E) exhibits high CPR both in the crater and beyond the rim and was interpreted as indicative of the abundant of blocks associated with fresh craters.

Rozhdestvenskiy N has a depth of 1.7 km and interior wall slope of ~ 28.6°. At radar wavelengths, the walls exhibit streaking with both high and low CPR. Streaks are typically observed on the wall opposite the radar illumination. In radar, the floor appears smooth and has a relatively low CPR. LROC shows a hummocky crater wall and a smooth floor. A subtle downslope texture is present and may be the cause of the radar streaking. Boulders (m-scale) are absent on the wall and floor. Interior LOLA reflectance is ~ 4% higher than the surrounding region.

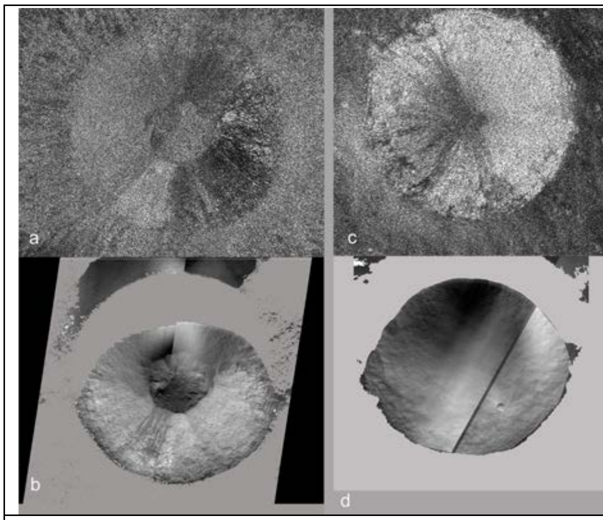

Figure 1. Left: Main . Right: Rozhdestvenskiy N. (a, c) Mini RF CPR, (b, d) LROC NAC.

Main L has a depth of 2.9 km and wall slopes of ~ 33°. In radar, the interior and exterior exhibit high CPR. Crater walls appear streaked, with high and low CPR. Radial streaking is also observed on the ejecta. LROC shows the walls have landslides of relatively dark, fine (with respect to image scale) material extending downslope and onto the floor. The wall is hummocky and there are areas of ponded landslide materials. The crater floor is complex with a melt pool and hummocky material. Hummocks have a lobate appearance and may reflect the base of mass wasting events. Boulders are common below the rim and on the floor, but are absent from the wall. Interior LOLA reflectance is >20% greater than the background.

Crater counts were made for the walls, floors and exterior adjacent to the rim. As is typical, walls have significantly fewer craters than the floor or the exterior. The paucity of wall craters is the result of downslope movement that erases them. While crater counts for ejecta may provide an indication of the absolute age, counts for walls and floor represent an equilibrium between crater formation and erasure.

Similar findings occur for the other craters studied: high interior CPR, radar streaked walls, hummocky walls with localized mass wasting, few craters on the walls, few boulders, floors that can be smooth to complex and hummocky, crater wall slopes of ~ 25°, and a LOLA bright interior.

Implications: The objectives here are to understand the geology of PS craters and whether it differs from craters periodically illuminated, the cause of anomalous CPR, and geologic evolution as it relates to the CPR and presence of volatiles.

The low crater frequency on the walls is indicative of continued mass movement. Mass wasting results in an erosion and retreat of the crater walls, in turn exposing fresh material and an accumulation of material on the floor. Constraining the rate of crater wall erosion / retreat is difficult.

However, one approach is to use the size-frequency distribution of craters on the ejecta. Given that the same crater distribution must have formed on the wall (although they are no longer present) as on the ejecta, sufficient material must have been removed from the wall to erase the craters. Assuming a depth/diameter ratio for small craters, the amount of material required to erode the largest expected crater can be estimated. Combined with an absolute model age derived from ejecta counts, a gross estimate of the retreat rate can be had. This method suggests an average retreat rate of 1 μm/year or 1 m/10 Ma. This rate is significantly greater than the average regolith overturn (e.g., 5 cm in 10 Ma at Shorty Crater). Such a rapid rate has implication for the origin of the CPR and the potential to hold volatiles.

If the anomalous CPR is the result of rocks at radar scale or bedrock at shallow (m-scale) depth, it provides insight into highlands megaregolith. If bedrock were present in the highlands, it should be exposed on the crater walls as bedrock would be more resistant to erosion than impact debris (as seen in the mare); it is not. If the CPR is due to rocks, then the megaregolith must have a high frequency of rocks distributed throughout, such that rocks are continuously exposed and the anomalous radar signature persists. It may be that the CPR signatures are rather the result of the geometry of the data acquisition [13]. If this is the case, it resolves the issue of continuously exposing bedrock or rocks.

If the anomalous CPR is the result of water ice (in toto or in part) then there are implications for the nature of the volatiles. Orbital neutron data have been interpreted to indicate that H is sequestered in areas of PS [14-16]. If ice is the cause of the anomalous CPR, one implication is that the highlands megaregolith is infused with ice to depths of multiple km such that ice-rich material is continuously exposed at the crater wall as the wall retreats. Alternatively, ice could migrate through the megaregolith at a rate such that it is continuously replenished as the wall retreats.

The low temperature of PS crater (<<100K) [17] precludes high diffusion rates of H into the regolith [18]. The low turnover rate precludes physical mixing at a rate to overcome wall retreat. Craters having diameters of a few 10s of km, have small floor areas and those areas are continuously buried by material from the crater wall. Thus, the crater floor is unlikely to be the total reservoir for the proposed volatiles.

Conclusions: Permanently shadowed craters at the lunar north pole exhibit morphometry and morphology similar to craters elsewhere on the Moon whose interiors are periodically illuminated. Permanently shadowed craters exhibit interior walls that have low crater frequency, relatively high reflectance and mass wasting indicating continuous crater wall retreat. The retreat rate is estimated to be of the order 1 m / Ma.

With respect to volatiles in the shallow subsurface, a rapid retreat implies that volatiles must be implanted at a rate commensurate with wall retreat or that the highlands megaregolith is infused with volatiles to depths of several km. With respect to anomalous CPR, either rocks and bedrock are scattered through the megaregolith to be continually exposed or the anomaly is due to the geometry of observation.

Regardless, the data present a conundrum that has not been resolved.

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