INTERPRETING REFLECTANCE DIFFERENCES UNDER INDIRECT ILLUMINATION: LUNAR PERMANENTLY SHADOWED REGION ANALOG IMAGES A. C. Martin[1], B. W. Denevi[1], M. S. Robinson[2].
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Introduction: Permanently shadowed regions (PSRs), by nature, never receive direct illumination, but do receive secondary illumination from crater walls and nearby massifs allowing sufficient reflected lighting within PSRs [1] for imaging by the Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Cameras (NACs) [2]. The LROC observations of these permanently shadowed regions show albedo differences on slopes and surrounding fresh impact craters, but none that have been linked to PSR boundaries or the presence of volatiles. This negative detection of volatiles by LROC conflicts with other instrument datasets (LOLA, LAMP, M^3), which suggest the presence of surface ice or frost, and an increased upper regolith porosity relative to non-PSRs [3–5].

LROC has imaged equatorial craters under direct and indirect illumination conditions, providing an improved basis for LROC PSR observations, as well as images that will be acquired by the ShadowCam instrument onboard the Korean Pathfinder Lunar Orbiter spacecraft [6]. In this work, we focus on analyzing PSR analogs to compare albedo differences and surface properties in LROC images and other data sets to permanently shadowed regions.

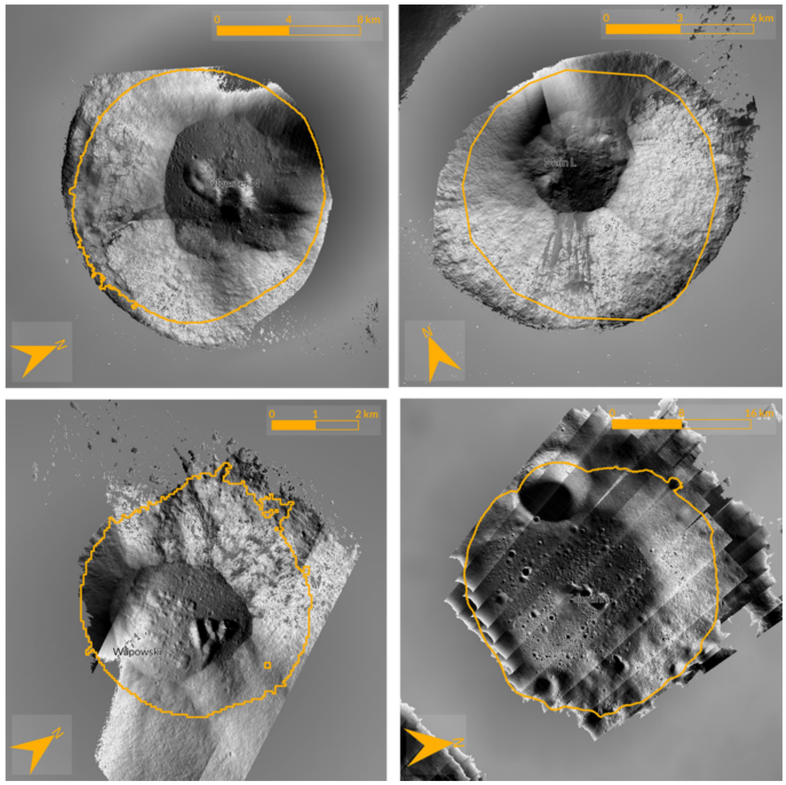

Figure 1. Images from the LROC PSR atlas of PSRs within four craters. (Left to right, top to bottom) Two north pole craters, Sylvester N and Main L, and two south pole craters, Wapowski and Faustini.

PSR Analog Images: Permanently shadowed regions occur at both lunar polar regions in areas of low topography that do not receive direct illumination [7]. The amount of indirect illumination that they receive varies greatly depending on slopes and distance to reflected light sources.

LROC has now collected a series of images of equatorial crater interiors with the low sun on the horizon to get PSR-like illumination conditions for areas that have been imaged under direct illumination at other times. This is achieved by acquiring images when the crater is near the terminator, and shadows stretch across the majority of the crater interior. As when imaging PSRs, a longer exposure time is required to achieve an acceptable signal-to-noise ratio. Because LROC is a linescan imager, the long exposure times result in pixels that cover a substantially larger along-track than cross-track distance (20 m to 40 m along-track vs. 1 m to 4 cross-track).

The images are processed using USGS Integrated Software for Imagers and Spectrometers (ISIS3) [8] where they are resampled to 10 meters per pixel, registered to a control network, and map projected using a NAC digital terrain map (DTM) or an LROC global DTM (GLD100). These “PSR analog images” (indirect illumination) are then compared to images acquired under more typical (direct) illumination conditions (e.g., Fig. 2).

The three equatorial craters chosen for this initial study are Giordano Bruno (35.9°, 102.8°, 23km), Lalande A (-6.6°, 350.1°, 12km), and Gardner (17.7°, 33.8°, 17km). These three craters have distinct albedo variations within their interiors, as viewed under direct illumination, and thus provide useful examples for how albedo variations are manifest under PSR analog illumination conditions.

Observations: Diffuse illumination (light from many directions) within PSRs makes interpretation of reflectance variations and photometric normalization

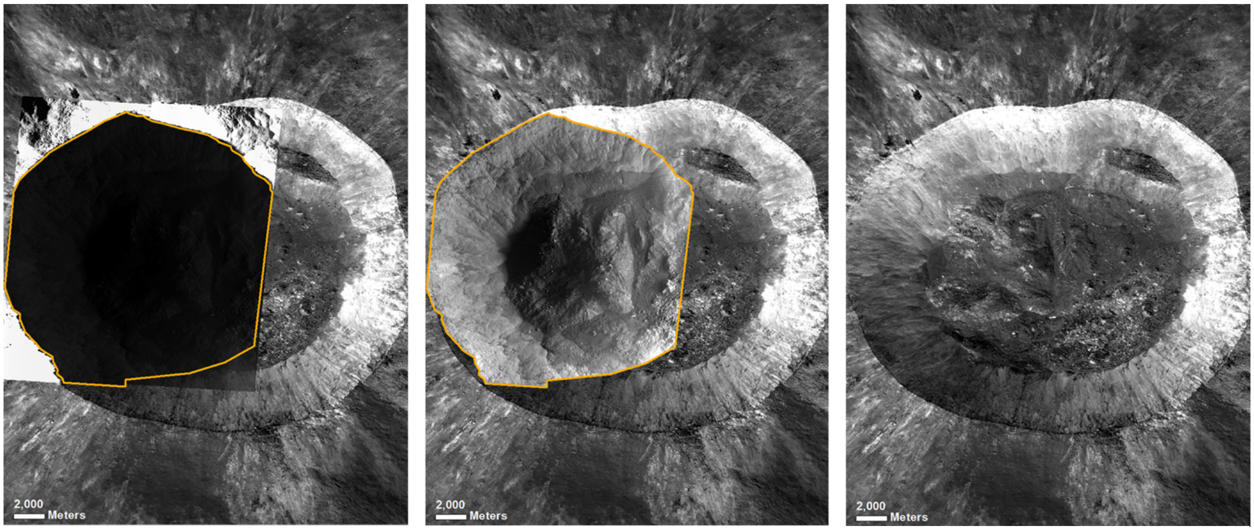

Figure 2. Giordano Bruno crater (35.9°, 102.8°). Three LROC images showing the alignment of a NAC controlled mosaic and a PSR analog mosaic. Left: Unstretched PSR analog (80° incidence) overlaid onto the NAC controlled mosaic. Middle: PSR analog image stretched to highlight the shadowed region and overlaid onto the NAC controlled mosaic. Right: NAC controlled mosaic acquired under direct illumination (39° incidence).

challenging. In *Figure 1*, there are four PSRs that are similar in features, size, and exposure times (~0.011806 seconds) to the PSR analog observations [9, 10]. Note the low-reflectance streaks on their walls. These streaks appear dark in the PSR observations, but this may be due to the indirect illumination. High-albedo streaks observed on the walls of equatorial craters under direct illumination can show strong variations under indirect illumination (*Figure 2*). For example, high albedo streaks can remain high in reflectance, show little to no contrast, or even display a reversal in contrast in indirect illumination. This variability is likely caused by differences in surface textures, rather than composition or maturity. Initial observations suggest that surface textural differences such as roughness and particle size, have a significant effect on reflectance when illumination is indirect, and must be considered in addition to inherent albedo differences.

Continuing Work: The comparison of features under indirect and direct illumination will aid in the interpretation of reflectance in PSRs and the search for reflectance differences that could be related to the presence of volatiles, such as seen in other datasets.

Illumination Model: Modeling of the indirect illumination will further support our interpretations of PSR analog images. In order to calculate reflectance, the incoming illumination at each point within the scene must be known, something that is nontrivial when illumination is indirect. To calculate the illumination conditions at each pixel within a PSR analog image, we will use the simulated temporal illumination method of Thompson et al. [11], which requires a digital terrain model (DTM) and sub-solar points. This method results in a calculation of the fraction of incident light at each pixel that will be cast to the pixel of interest under assumed constant albedo and phase function. When multiplied by the primary illumination conditions, it provides illumination impinging upon the pixel of interest in the shadowed region [11].

Once the model illumination results for Giordano Bruno, Lalande A and Gardner are complete, we will use these to understand how roughness, albedo, and other surface properties influence observations.

Conclusion: Understanding how albedo differences observed under typical illumination conditions are manifest under PSR-like lighting conditions will aid in the interpretation and understanding of images of PSRs. With a more in-depth study on lighting conditions and surface properties, and other data sets, we can reconcile LROC observations of reflectance in PSRs with those from M^3, LOLA, and LAMP.

References: [1] Speyerer et al., 2013, *Icarus*, 222, 122-136. [2] Robinson et al., 2010, Space Science Review, 150, 81-124. [3] Qiao et al., 2019, *Earth and Space Science*, 6, 467-488. [4] Hayne et al., 2015, *Icarus*, 255, 58-69. [5] Li et al., 2018, *Proceedings of the National Academy of Sciences*, 115 (36), 8097-8912 [6] Robinson, M. S., 2018, *LPV*, Abstract #5028. [7] Spudis et al, 1996, *Ice on the Bone Dry Moon, Planetary Science Research Discoveries*. [8] Becker et. al., 2013, LPS 44, abs. 2829. [9] Lunar Reconnaissance Orbiter Camera PSR Atlas, https://www.lroc.asu.edu/psr. [10] Cisneros et al., 2017, *LPSC*, Abstract #2469. [11] Thompson et al., 2018, *Informatics and Data Analytics*, Abstract #6037.