PATCHY SECONDARY ILLUMINATION AT THE SHACKLETON CRATER FLOOR PERMANENTLY SHADOWED REGION P. Mahanti[1], M.S.Robinson[1], R.V. Wagner[1], E.J. Speyerer[1], J.-P.Williams[2], ShadowCam Team[1] [1]School of Earth and Space Exploration, Arizona State University, Tempe, Arizona; [2]Dept. Earth, Planetary, and Space Sciences, University of California, Los Angeles (pmahanti@asu.edu)

Introduction: The lunar south pole is located on the rim of Shackleton crater (diameter (D) = 21 km), a well-preserved ancient (3.6Gy [1]) simple crater. Due to low obliquity of the Moon and its depth (4000 m), the floor and most of the walls of Shackleton crater are in permanent shadow resulting in temperatures constantly below 120K (summer high) and reaching as low as 40K (winter low) where volatile molecules deposited from various sources (e.g. exogenic and endogenic) can remain cold trapped over geologic time. [2, 3]. The cold trap nature of Shackleton crater and the apparent high reflectance of the floor and walls make it a prime target for volatile exploration. While average temperatures below 90K are conducive for volatile retention, albedo signatures obtained at Shackleton PSR (wall and floor) are not conclusive for exposed ice but may exist as mixture with soil [4]. An alternate hypothesis for the bright walls is ongoing down-slope creep resulting in exposure of fresh crustal materials [5]. The floor consists masses of hummocky deposits interpreted as material slumped from the walls – a morphology seen in other lunar craters of similar size and age (e.g. Hipparchus G, D = 15 km, Imbrian age; 5.03° S, 7.40° E.).

Topographic characterization of the Shackleton floor was obtained from Lunar Reconnaissance Orbiter Lunar Orbiter Laser Altimeter [6]. The largest floor mound (south) exhibits ∼200m of relief and is hypothesized to be a combined result of ejecta fallback and wall slumping [6]. North of this large mound is a more spread-out deposit of shorter relief (∼100m). Compared to the depth of Shackleton, the relief of floor features is small, yet, we find that local topographic features exert strong influence on received secondary radiance. In this abstract, we discuss the possible variation in floor temperatures, and thus cold trap behavior, based on the dynamic secondary illumination of the crater interior.

Methods: Inside PSRs, secondary illumination received from scattered light reflected from nearby topographic facets controls the temperature and lighting conditions for imaging over time. The dynamic secondary lighting can be modeled simply based on the sub-solar point and topography [7]. The secondary illumination is computed only for the topographic facets within the PSR boundary based on the calculations of viewfactors that represent the path between the primary illuminated facets (areas outside the PSR) and the facets inside the PSR. For simplicity, We assumed a Lambertian photometric function and uniform albedo for the simulations. Further details of the simulation and examples of usage

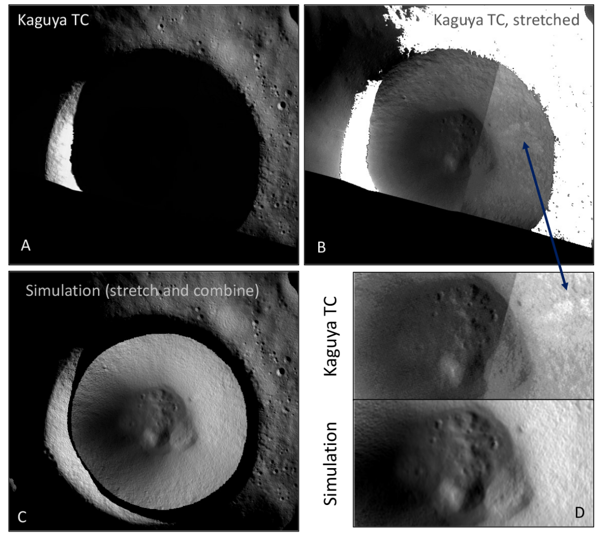

Figure 1: Comparison of Kaguya TC image (DTMTCO_03_00504S894E0575PS) and simulated image at same subsolar point (Lon=58.769, Lat=-1.514): A-Primary illumination with no stretch, B- Stretched image showing inside the PSR, C-Simulated primary and secondary illumination superposed, D-Secondary illumination at compared at crater floor

can be found in our earlier work [8, 9, 10]. In this work, we visually compare the simulated image generated at the same subsolar point in time to the calibrated and map-projected Kaguya Terrain Camera image (Fig.1); the simulated image shows the geology at the floor, inside the PSR. Second - floor secondary illumination statistics were computed from a stack of simulations for Shackleton PSR were obtained for the full range of primary illumination conditions. Primary illuminations were computed for subsolar points uniformly sampling (0.1° increments) the subsolar latitude range (-1.5° to +1.5°) and longitude range (0° to 360°). The stacks are then converted to images representing the maximum secondary illumination (Fig.2A and 2C) within the PSR and average primary illumination (Fig.2B). From the simulation, we found that secondary illumination was not always significant within the PSR (at the spatial pixel scale at which the simulation was done). We identified the presence/ absence of secondary illumination to assign a percentage value of time when secondary illumination was present for each pixel (Fig.2D).

Results and Discussion: Primary illumination and nearby topography dictate the nature of secondary illumination within PSRs and for Shackleton crater this is marked by the asymmetric nature of the primary illumination, when integrated over time. The west walls

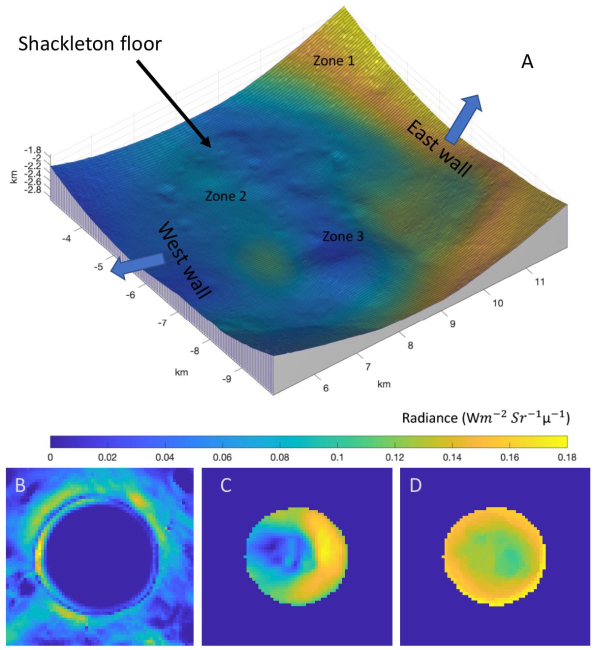

Figure 2: Shackleton floor showing patchy secondary illumination segregated into 3 zones (A) by dividing the radiance range. Average primary illumination statistics (B) shows a persistent sliver at the top of the west wall. Secondary illumination radiance values are higher towards the east wall (C). Over all primary illumination conditions simulated, the crater floor 'sees' secondary illumination for lesser percentage of time (D)

receive more insolation resulting in asymmetric secondary illumination with the east side of the PSR having higher values of secondary illumination and the floor and northwest side of the PSR having lower values. The regional tilt around Shackleton crater, is the cause of the primary illumination asymmetry. This effect also manifests in the percent time when secondary illumination is received – the eastern PSR boundaries have secondary illumination for longer times (80%). The availability of secondary illumination decreases towards the center and north-west to about 60% at regions on the crater floor.

The secondary illumination at the crater floor is patchy and moderated by the topography. The maximum secondary illumination on the floor (aggregated over the range of subsolar points) can be segregated into 3 zones (Figure 2). Zone 1 has the highest secondary illumination and is close to 270° longitude wall. Zone 2 covers the generally flat central floor and exhibits intermediate values, while Zone 3 straddles the largest hummock and has the lowest secondary illumination. Radiative interaction from the west wall and the top of the mounds (and eastwards) is reduced due to the undulating nature of the topography (leading to small view factor magnitudes). We hypothesize that the patchy nature of the secondary illumination indicates a patchy (50 m scale) temperature distribution and hence spatially irregular concentrations of volatiles.

The secondary illumination modeling results also demonstrate that even during optimal imaging conditions (South pole summer, low beta) there will be large differences in radiance values with the PSR. Thus, highest SNR within the crater will require merging of observations (e.g. by ShadowCam [11]) taken across a broad range of sub-solar positions.

The crater floor has been in permanent shadow (having the potential to collect volatiles) for at least the last 2 billion years [1]. If the deposits were formed during crater formation (e.g. by ejecta fallback) then they would not have affected the thermal conditions but if the deposits were formed well after the crater formation (e.g. in the last 1 Ga, due to later slumping) then they could have affected the temperature distributions thereafter. This effect is in addition to material property changes at the floor due to the deposits.

Conclusion: Pre-existing topography causes asymmetric primary illumination of Shackleton walls and leads to an asymmetric secondary illumination. When aggregated over time the thermal variation and hence the distribution of volatiles is affected by this asymmetry. Statistically aggregated over time, the brightest zones of secondary illumination are on east walls close to floor, and the darkest zones are on the west walls, close to floor. Floor secondary illumination is patchy due to deposits with small relief leading to spatially non-uniform temperature zones and volatile distributions. . Formation of hummocky deposits (if formed well after crater formation) could have affected the initial thermal equilibrium and initial spatial concentration of volatiles at equilibrium. Future lunar mission that will investigate PSRs can shed further light on the patchy secondary illumination at Shackleton crater and spatially non-uniform cold traps temperatures at the Shackleton floor.

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