**ATYPICAL SMALL CRATER MORPHOLOGY IN THE SHACKLETON PSR: INDICATIVE OF SUBSURFACE VOLATILE DESTABILIZATION?** H. A. Danque[1] and K. M. Cannon[1], [1]Colorado School of Mines, Golden CO, USA. (hdanque@mines.edu).

**Introduction:** The Shackleton Permanently Shadowed Region (PSR), is within a crater near the lunar south pole with temperature conditions that can cold trap volatiles such as water ice for billions of years. Shackleton crater offers unique insights due to its early PSR formation and characteristic debris aprons [1–3]. We analyzed a two m/pixel resolution image mosaic [4] from the ShadowCam instrument on the KPLO spacecraft and found small craters (30-100 m in diameter) with unusual crater floor morphologies. We suggest that impact-induced destabilization of subsurface volatiles may have disturbed the crater floor material. The described features are at the Shackleton crater floor transition from a steeply sloped crater wall to the older hummocky crater floor terrain.

**Methods:** We observe the morphology of the small craters on the Shackleton crater floor in ShadowCam imagery (Figs. 1-3). We also calculate the current thermal environment of the Shackleton crater, assuming it is in a steady state equilibrium. We use our previous work's thermal model methods and values for the regolith and mega-regolith [5]. We calculate a subsurface sublimation rate from the saturation vapor pressure and the maximum sublimation rate in a vacuum [6, 7]. An effective subsurface sublimation rate *J(z)* assumes that diffusion is within the Knudsen regime, where diffusion is controlled by collision with the pore walls instead of with other molecules.

$$J(z) = \frac{\mu\delta E(z)}{2z} \quad (1)$$

Where *J(z)* has units of kg $m^{-2}$ $s^{-1}$, $z$ is the depth below the surface in meters, E(z) is from Eqn. 3 by predicting a temperature at the depth $z$, and the particle diameter $\delta$ is chosen at 100 µm here. This equation was used in prior work in the upper few meters of regolith with a mean grain diameter of 75 µm [6, 7].

**Results:** Analysis of ShadowCam imagery on the Shackleton crater floor has identified seven craters with distinctive morphologies (Fig. 1). Two of the seven are found near the Shackleton crater floor-to-wall transition and near the associated debris apron. Both craters have DIVINER summer max temperatures of ~95 K and mean temperatures of ~60 K.

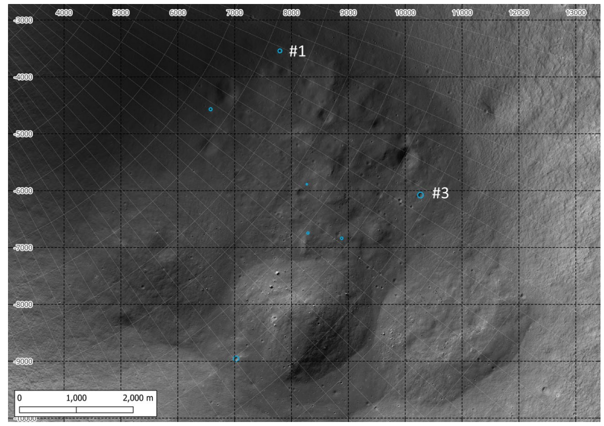


**Fig. 1.** The location of the seven small craters with unusual morphologies (blue circles). Two of these craters, labeled #1 and #3, are near the Shackleton crater wall-to-floor transition and are shown in detail.

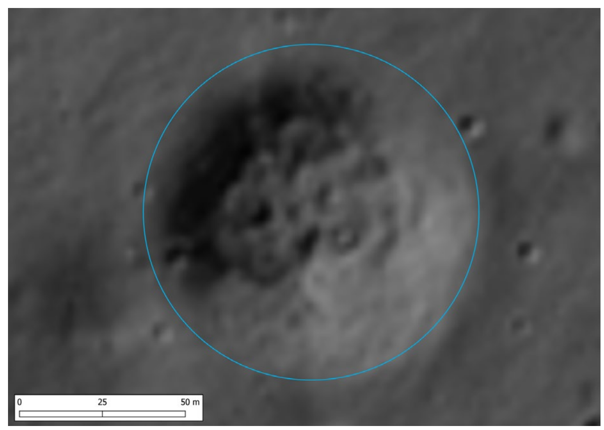


**Fig. 2.** The small crater #3 shows an unusual floor morphology with apparent overlapping ring shapes.

Crater #3 is 98 m in diameter. It has overlapping raised rings apparent in the crater floor regolith (Fig. 2). The individual elevated rings have 10-12 m diameters around pits 4-5 m in diameter. Crater #1 is about 65 m in diameter and exhibits a pronounced moat-ring structure, 30 m and 20 m in diameter, respectively, with a central pit that is about 10 m in diameter (Fig. 3). The diameters of these craters suggest the crater-forming impacts penetrated tens of meters into the subsurface.

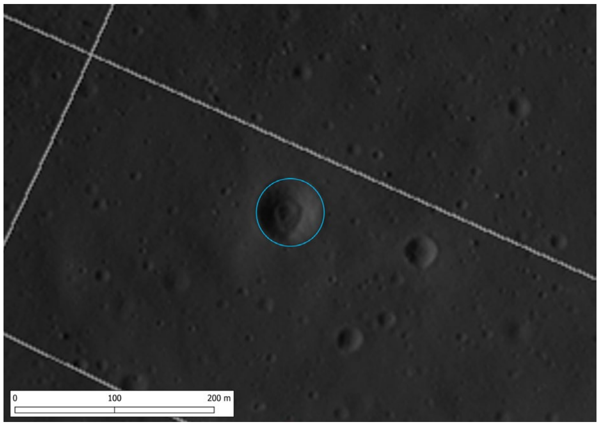


**Fig. 3.** Small crater #1 shows an unusual floor morphology with an apparent central pit with an elevated moat and ring.

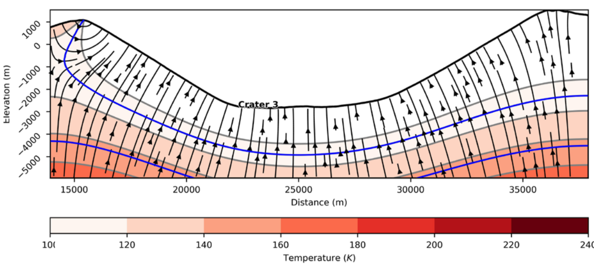


**Fig. 4.** The thermal model results show that the current volatile stability zone is thick.

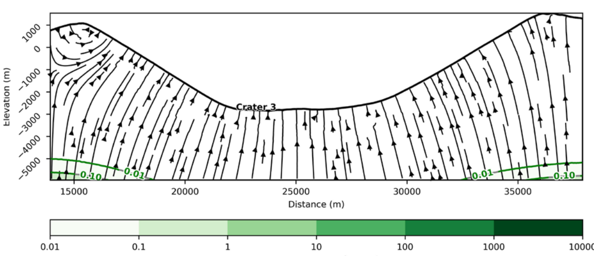


**Fig. 5.** A depth-dependent sublimation potential across the Shackleton PSR bisecting Crater #3.

If volatiles were embedded within the regolith before an impact, the energy imparted by the impact possesses sufficient magnitude to perturb the distribution of volatiles within a volatile-regolith mixture both during and subsequent to the impact event [8, 9]. This perturbation manifests in a hemispherical volume expanding outward from the impact site, where the temperature decreases as a function of distance from the source. The rate of thermal diffusion governs the temperature gradients within this affected volume.

The results of a steady-state 2D planar thermal model over Shackleton Crater are shown in Fig 4. It indicates volatiles buried in the regolith would be stable to well below the depth likely to be disturbed by impacts of 30-100 m diameter craters. The temperature plots are converted to sublimation rates by Eqn. 1. A scenario with a polar heat flow value of 6 $mWm^{-2}$ [10] and a mean of 62 K upper boundary condition near Crater #3 shows a low sublimation potential (Fig. 5).

**Discussion:** We consider several causes for these crater floor morphologies. Notably, the patterns on the small crater floors are inconsistent with imaging artifacts or multipath lighting, given the typical appearance of nearby craters (Fig. 3). The density of circular features in crater #3 and the distinct pit near the center of crater #1 with a raised ring-moat surrounding it reduce the probability that subsequent impacts and sidewall collapse were the cause. Some of the remaining possibilities are subsurface ice or volatile vaporization. There are central pit craters cited in the literature, but they have relatively small central pits relative to the crater floor diameter. By contrast, we observe small craters with disproportionately large central pits, where much of the crater floor is modified.

We hypothesize that the release of volatiles after the impact is influenced by several processes, including thermal dispersion, overburden removal, and radial fracturing from the impact. These mechanisms collectively facilitate the directional migration of gases from released volatiles, converging towards the crater's floor, which may modify the morphology of the regolith fill. These factors may form gas escape features analogous to Earth's seabed pockmarks.

**Conclusion:** The Shackleton PSR floor contains small craters that exhibit atypical floor morphologies that may indicate volatile release following some small impacts. This observation enriches our knowledge of the Moon's geology in areas that may host volatiles and suggests a patchy subsurface volatile distribution within PSRs. Furthermore, thermal models indicate the potential for higher volatile concentration near the crater wall transition of large PSRs and some potential for local remobilization. Further in-situ research is vital for understanding these processes and assessing the prospects for extracting lunar volatiles.

**References:** [1] Schorghofer, N., and Rufu, R., (2023), p. 1806. [2] Mitusov, A. V., Stark, A., Khrisanov, V. R., and Oberst, J., (2023), PSS, 238, p. 105795. [3] Zuber, M. T.,et al. (2012), Nature, 486, pp. 378–381. [4] ASU, (2024), [Online]. http://www.shadowcam.asu.edu/images/1357. [Accessed: 12-Mar-2024]. [5] Danque, H. A., and Cannon, K. M., (2024), Icarus, p. 115953. [6] Schorghofer, N., and Taylor, G. J., (2007), JGR: Planets, 112. [7] Siegler, M., et al. (2015), Icarus, 255. [8] Pierazzo, E., Artemieva, N. A., and Ivanov, B. A., (2005), GSA. [9] Barlow, N. G., (2006), Meteoritics & Planetary Science, 41, pp. 1425–1436. [10] Siegler, M., et al., (2022), JGR: Planets.