Scratching At the Surface: Determining Regolith Compositions and Provenance At Probable Artemis Landing Sites Using Ejecta Modeling. J. D. Kendall[1,2] (jordan.d.kendall@gmail.com), N. E. Petro[1]. [1]NASA Goddard Space Flight Center, Greenbelt, MD 20771. [2]University of Maryland Baltimore County, Baltimore, MD 21250.

Introduction: The Artemis and CLPS missions represent a profound opportunity for planetary science and our understanding of the Moon and our solar system. As such, the selection of a landing site that will satisfy a wide range of scientific objectives is preferable. The use of remote sensing plays a vital role in understanding what awaits the Artemis astronauts upon the surface. However, the use of impact modeling to determine the sequence of ejecta layering around and within the potential landing sites provides another data point for understanding and confirming these remote sensing results. In conjunction, advanced modeling of the history of a surface along with rmeote sensing (e.g., M3 mineralogy mapping) may provide the best chance at predicting which sites will provide the best samples of South Pole-Aitken (SPA) basin impact melt, Shackleton impact melt, and other scientifically useful samples.

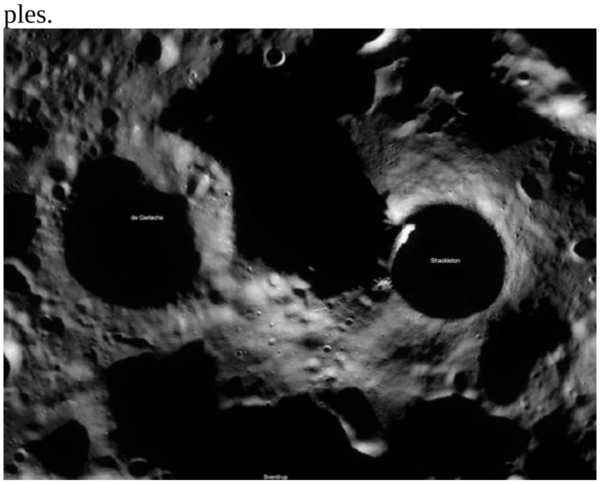

Figure 1: Lunar Reconnaissance Orbiter Camera's (LROC) Wide-angle Camera (WAC) image of the Shackleton (21 km diameter) and de Gerlache (32 km diameter) craters near the lunar South Pole. Shoemaker crater lies out of frame along the upper right of the image. Any landing sites near such craters will have ben blanketed by ejecta from nearby craters.

Here, we describe part of a comprehensive method utilizing impact modeling (iSALE-2D and iSALE-3D) to reconstruct the cratering and ejecta of a landing zone to supplement remote sensing data and possibly in-situ samples. In the case of the South Pole landing regions, we consider the formation of de Gerlache and Shackleton crater. We start by modeling Shackleton crater in 2D and 3D to determine the likely ejecta blanket layering and provenance of material around the crater rim, as well as the location of any impact melt.

The location of Shackleton and de Gerlache (Fig. 1) relative to the Shoemaker crater and SPA basin suggest that excavated and ejected material from SPA underly the surface of the South Pole. Understanding how these craters blanket and transport impact melt of the later formed craters will help elucidate the thermal history and provenance of the regolith found at Artemis landing sites. We utilize previous simulations of the SPA basin-forming impact to determine the layering and provenance of material underneath the South Pole region [1]. From there, we use the SPA output as the initial state of the surface upon which craters such as Shackleton and de Gerlach impact into and transport material.

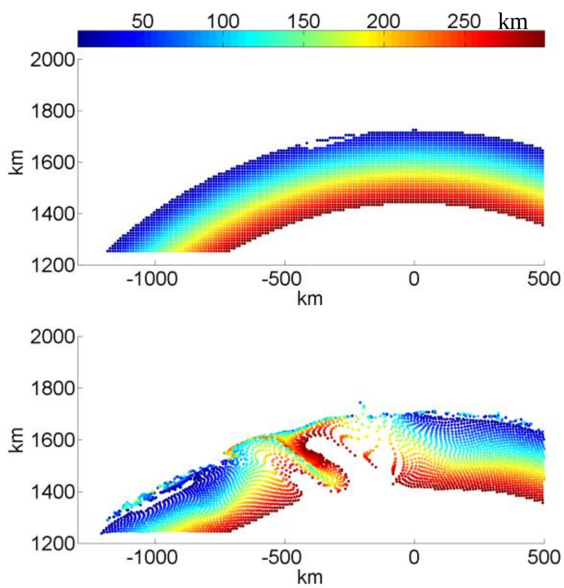

Figure 2: Cross-section along the direction of impact showing tracer provenance depth (colormap in km) of the SPA basin forming impact in iSALE-3D. The South Pole is around 0 km on the x-axis. Here the nominal impact scenario of a 45° impact was used [1], and we show the before and after basin formation. The cross-section gives an estimation of how the region near the South Pole (right side of bottom image) would form layers of crust and mantle material excavated atop the initial crust.

Methods: We used the iSALE-3D shock physics code [2,3,4,5], which is an extension of the SALE hydrocode [6,7], to model craters near the South Pole. The iSALE codebase has been validated against comparable hydrocodes, laboratory experiments, and cratering observations [8]. We vary the impactor speed (12-17 km/s), diameter (1-5 km), and angle (in the 3D model; 30-90 degrees) to match the Shackleton and de Gerlache craters. The impact modeling employs the latest model parameters for lunar cratering [1,9,10]. First, we match the crater size using a simple vertical model. Then, we vary the impact velocity and angle to provide a test of impact parameters and results.

We approximate the Moon using a flat half-space dunite target surface with a surface gravity of 1.62 m/s^2. Dunite is a proxy for the Moon's bulk mantle composition and the impactor [1,11], is well-defined within the iSALE ANEOS library.

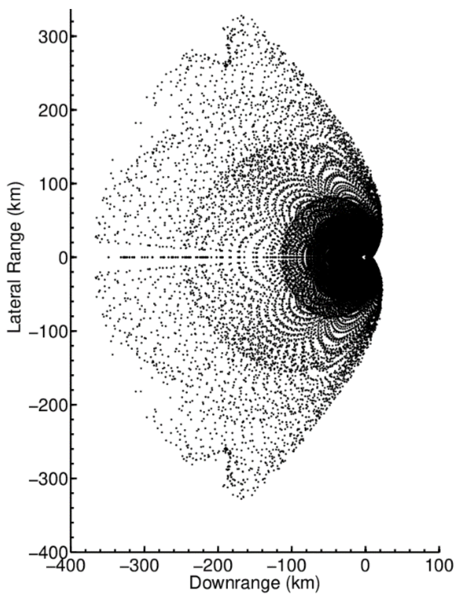

Figure 3: An example impact simulation of a likely ejecta distribution for Shackleton class crater. A 1 km diameter impactor strikes at 15 km/s and 45°. Each point represents a tracer that follows the ejected path of lunar material. The positional data is known for both before and after the impact, allowing the accounting of the ejecta's provenance and thermal state. This data allows an inference of where the material underlying the regolith originates relatively to nearby crater ejecta blankets.

Results: To determine the transportation history of material initially ejected by the South Pole-Aitken basin, we use the data from SPA basin-forming impacts [1], as shown in Figure 2, to determine the initial surface layers for the vertical impacts of Shackleton crater.

We place discrete Lagrangian tracers in each cell and track the motion of each volume of material through the simulation space. We follow the tracer trajectories and determine the locations where they emplace on the lunar surface relative to the current position of the crater. As an example of this technique, Figure 3 shows the final locations of ejected materials relative to the crater center for a 1 km diameter impactor striking the lunar surface at 45° and 15 km/s. We maintain accuracy while retaining reasonable computational speeds by using 20 cells per projectile radius resolutions [1,8,10]. The iSALE-3D simulations take between 2 and 21 days with parallel computing. Higher accuracy and detailed simulations require longer computation times and parallel computing nodes.

Conclusions: Here, we have outlined a method for combining a series of impact modeling efforts to better understand the cratering record of the South Pole region. We begin by using the output from 3D models of the South Pole-Aitken basin-forming impact and apply the results near the South Pole to follow-up simulations of Shackleton crater.

As this method is improved, we can then use the modeling to better explain the series of cratering events near the South Pole and at other sites on the Moon. For example, Apollo 17 collected core samples near a set of craters and avalanche deposits. Additionally, these modeling results will be combined with remote sensing results from LRO and M3 to understand better the regolith found at any potential landing site area.

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References: [1] Melosh, H. J. et al., Geology, 2017. [2] Wünnemann, K. et al., 2006. [3] Collins, G. et al., 2004. [4] Elbeshausen, D. et al. (2009) Icarus, 204, 716-731. [5] Elbeshausen D. and Wünnemann K. (2011) Proc. 11th Hyper. Imp. Symp. [6] Amsden et al., 1980. [7] Ivanov, B. et al., 1997 [8] Pierazzo, E. et al., 2008. [9] Ivanov, B. et al., 2010. [10] Collins, G., 2014. [11] Pierazzo, E. et al., 1997.