Introduction: The Artemis and CLPS missions to the lunar surface represent a profound opportunity for 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 necessary. The use and interpretation of remote sensing data plays a vital role in understanding what awaits future missions to the surface. However, the application of impact modeling to determine the local stratigraphy of ejecta layering around and within the potential landing sites provides another data point for interpreting remote sensing results. Advanced modeling of the history of a surface along with remote sensing (e.g., mineralogy mapping) may provide the best chance at predicting which sites may provide samples of South Pole-Aitken (SPA) basin impact melt, Shackleton impact melt, and other scientifically useful samples [1,2,3].

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 been blanketed by ejecta from nearby craters.

Our recent studies show SPA melt is redeposited along the entire circumference of the basin rim, even in the case of oblique impact [1,2]. Additionally, it was shown [3] that the large craters near the south pole (i.e., Shackleton crater) are likely to deposit their own impact melt along their crater walls and rim. Since these craters excavate material sourced from SPA event [1,2], this suggests collecting samples of material melted by the SPA event as well as material mixed with mantle and lower crust material at potential landing sites to the south pole or regions near the proximal ejecta blanket of the SPA basin. The likelihood is higher near craters that have subsequently re-excavated and deposited the deep-seated material onto the surface, where it will be available for sampling.

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 craters. 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 distribution 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 [1,2]. From there, we use the SPA output as the initial state of the surface upon which craters such as Shackleton and de Gerlache impact into and transport material.

Methods: We used the iSALE-3D shock physics code [4–7], which is an extension of the SALE hydrocode [8,9], to model craters near the south pole. The iSALE codebase has been validated against comparable hydrocodes, laboratory experiments, and cratering observations [10]. 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 shape of the Shackleton and de Gerlache craters. The impact modeling employs the latest model parameters for lunar cratering [1,11,12]. 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.

We approximate the Moon using a flat half-space with a surface gravity of 1.62 m/s². Dunite is a proxy for the Moon’s bulk mantle composition and the impactor [1,13], and is well-defined within the iSALE ANEOS library, while gabbroic anorthosite is a reasonable estimate for the crust [3].
which later craters excavate, improving upon recent 2D simulations of Shackleton crater [1,3]. The model results may suggest that in addition to collecting SPA impact melt, melts from nearby post-SPA craters is possible.

This method has applications not only at the South Pole but also at other sites on the Moon (i.e. Apollo 17 collected core samples near a set of craters and avalanche deposits). Additionally, these results combined with remote sensing results from LRO and M3 may help us understand the regolith composition found at any potential landing site area chosen for robotic or human missions.

**Results:** To determine the transportation history of material 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 [1,10,12]. The iSALE-3D simulations take between 2 and 21 days with parallel computing.

**Conclusions:** Here, we present a method for combining successive modeling efforts to better understand the cratering record of the south pole region. We begin by using the output from our 3D models of the South Pole-Aitken basin-forming impact that incorporate the curvature of the Moon to form an initial surface by

![Image](image_url)

**Figure 2:** Cross-section along the direction of impact showing tracer provenance depth (colormap in km) of the SPA impact in iSALE-3D. The South Pole is at 0 km on the x-axis. Here the 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.

**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 originate relative to nearby ejecta blankets.

**Acknowledgments:** We give special thanks to the developers of iSALE: Kai Wünnemann, Tom Davison, Gareth Collins, Dirk Elbeshausen, and Boris Ivanov.

**References:**
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