LUNAR EJECTA MODEL OF CRISIUM BASIN-FORMING IMPACT: ANALYZING EJECTA DISTRIBUTION AND PROVENANCE.

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Introduction: We utilize the latest hydrocode modeling methods to analyze the formation and geology of the Crisium basin region. Crisium and Fecunditatis play an important role in our understanding of the lunar surface due to the Luna mission returning with samples from this important region. By modeling the Crisium and Fecunditatis impact events, we hope to better understand the effects of these events on the lunar crust and mantle. The latest impact modeling studies showed it is possible to model the ejecta blankets distribution and provenance to explore the subsurface of lunar basins such as Crisium [1].

Methods: We simulate the impact crater and ejecta formation with the iSALE-2D and 3D shock physics code [2,3,4,5], which is an extension of the SALE hydrocode [6,7]. Previous studies validated the iSALE code against comparable hydrocodes, cratering observations, and laboratory experiments [8]. We vary the impactor speed (12-20 km/s), diameter (10-100 km), and angle (in the 3D model; 15-90 degrees) to match the Crisium basin crater and ejecta blankets. The impact modeling employs the latest model parameters for lunar cratering in order to match the Crisium basin formation [1,9,10]. First a simple vertical model is used to match the basin size, then the impact angle and velocity is adjusted within the iSALE-3D code to provide a thorough suite of impact parameters and results.

Simulation Space: Our model Moon consists of a flat half-space dunite target surface with a surface gravity of 1.62 m/s^2. For our model, dunite serves as a proxy for the Moon's bulk mantle composition [11] and the spherical impactor. The equation of state for dunite is well defined within the iSALE ANEOS library. We vary impact angle between 45° and 90°.

Ejecta tracking: We place Lagrangian tracers in the center of each cell of the simulation space, which track the motion of a parcel of material through the Eulerian mesh. The tracers act as proxies for the ejected mass. We track the tracer trajectories and determine the locations where they ballistically emplace on the lunar surface relative to the current location of the crater. As an example of this technique, Figure 1 shows the final locations of ejected materials relative to the crater center at (0, 0) for a 10 km diameter impactor striking the lunar surface at 15 km/s with a 45 degrees oblique angle. Each simulation uses 20 cells per projectile radius to maintain accuracy while retaining reasonable computational speeds [1,8,10]. The iSALE-3D simulations

take between 7 and 21 days with parallel computing. Future simulations will use smaller cell sizes to improve accuracy while requiring longer computation times.
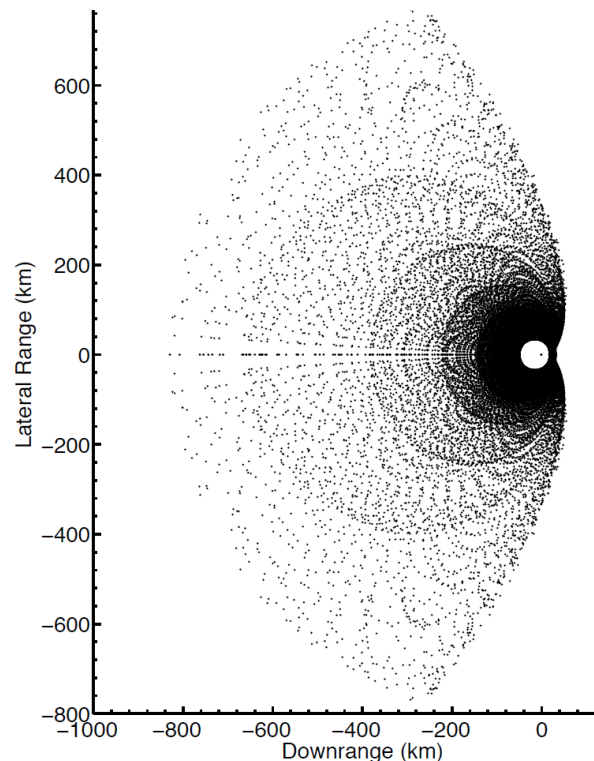

Figure 1. Here we show the emplacement of material ejected during the cratering process of a 10 km diameter impactor (15 km/s, 45°). Each dot represents a tracer that follows the ejected path of parcels of lunar material. Both the initial (pre-impact) and final (post-ejection) locations of each parcel is known. From this data, we infer where the material underlying the regolith originates with respect to neighboring crater ejecta blankets (Melosh et al., 2017).

Results: Assuming the parcels of ejecta emplace upon the lunar surface, we calculate the layering or stratification of the ejecta blanket. This approach gives an estimate of the ratio between the upper crust, lower crust, and possible upper mantle material emplaced beneath the subsurface of the ejected blanket [1]. For the parameter space tested in 2D and 3D, we find the ejecta to be dominated by upper crustal material while

containing a ~1/3 ratio of lower crustal material that overlays the upper crust material within the ejecta blanket (Fig. 1 and 2). Further exploration of the parameter space is required to precisely match the diameter and ellipticity of the Crisium basin before precise results can be found. Since the provenance depths and subsequent ejecta blanket thicknesses and distributions are strong functions of the initial impact parameters, such as impact angle [1], further exploration of the parameter space will yield more insights into the surface before and after the Crisium basin formation.
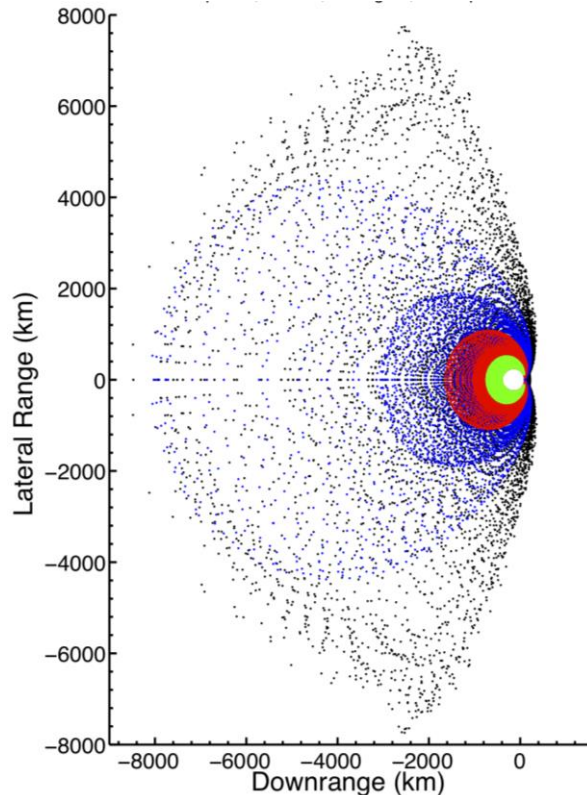

Figure 2: For a 100 km diameter impactor striking at 45° and 15 km/s, we show the ejecta distribution as colored by the initial depth of each parcel of material. The ejecta originates at depths of $0 < D < 10$ km (black), $10 < D < 20$ km (blue), $20 < D < 30$ km (red), and $30 < D < 40$ km (green).

Conclusion: The latest improvements in hydrocode modeling gives an opportunity to study the ejecta of basin scale impacts such as the Crisium basin [1]. As such, here we outline the first steps in a progressive plan to model the formation of Crisium and improve our understanding of the basin's ejecta and surrounding area. So far, we have been able to determine estimates of the ejecta distribution, provenance, and layering. Currently ongoing simulations will further improve these models and return an estimate of the material that underlies the surface of the Crisium region. Subsequent impact gardening occurs after the impact event and will

result in this material being exchanged throughout the region. Thus it is likely that sample return missions, both from the past such as the Luna missions, and future missions may hold answers to what lie beneath the lunar surface.

References:
[1] Melosh et al., *Geology*, 2017. [2] Wünnemann et al., 2006. [3] Collins 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 et al., 1997 [8] Pierazzo et al., 2008. [9] Ivanov et al., 2010. [10] Collins, 2014. [11] Pierazzo et al., 1997.