ANALYZING EJECTA THICKNESS AND MIXING IN THE CRISIUM AND NECTARIS LUNAR BASINS.
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Introduction: The Moon preserves ancient crustal features that have been eroded on other planetary bodies; its surface can therefore be compared to the ancient surfaces of other planets [1]. Much of the current knowledge of lunar surface features is based on Apollo and Luna samples, which have been used to study the composition and history of the regions where they were collected [2]. However, new orbital data and models require additional samples from proposed missions to resolve uncertainties and enhance our understanding of the features of the lunar crust.

The Crisium and Nectaris basins, which represent important events on the lunar nearside, have been proposed as landing sites for future *in situ* or sample return missions. The formation of Nectaris is a key time horizon that marks a major transition in the lunar geologic timescale. Determining Nectaris' history will therefore indicate the age of an active era of basin formation. Crisium is a young, well-preserved basin that may have excavated lower crustal material. Since Crisium and Nectaris are near each other, their melt and crustal material would have mixed through the deposition of ejecta during basin formation, potentially allowing for the selection of a single landing site that contains material from both basins.

In order to identify a landing site within Crisium or Nectaris, it is necessary to determine the composition of ejecta at the surface of the two basins. This will allow for the selection of a landing site with impact melt material from both Crisium and Nectaris, and minimal contamination from other basins. Here we present a model of the thickness and depth of ejecta mixing into Crisium and Nectaris from a comprehensive list of lunar basins.

Methodology:

Modeling Ejecta Thickness and Mixing. We combined a GRAIL basin database [3] with studies of the stratigraphy of major basins [4, 5] to identify basins younger than Crisium and Nectaris that deposited ejecta in these regions. We used Python scripts to map each property in question every 0.1° x 0.1° of latitude and longitude across Crisium and Nectaris.

We calculated the mixing ratio (μ, the ratio of local to foreign material) for each of the younger basins depositing ejecta into Crisium and Nectaris. The mixing ratio is defined as $\mu = 0.0183r^{0.87}$ [6], where r is the distance from the center of a basin to Crisium or Nectaris in kilometers. This equation likely overestimates the amount of mixing that occurs [7], so we reduced the mixing ratio by a factor of 2.5 to create a more realistic estimate.

Multiple models have been used to estimate the thickness of ejecta at a given distance from a crater. Here, we utilized the Housen et al. and Fassett et al. equations [8, 9]. The Housen model estimates ejecta thickness as $t = 0.0078R(d/R)^{-2.61}$ where d is the distance from the basin to Crisium or Nectaris in meters, and R is the radius of the basin's transient crater in meters. The Fassett model estimates ejecta thickness as $t = 0.0062R(d/R)^{-2.8}$. We applied a correction to the models to account for the curvature of the Moon [10].

The depth of mixing of ejecta into the lunar crust is the product of the mixing ratio and thickness of ejecta ($DoM = \mu * t$) [10]. We determined the mixing ratio, Housen and Fassett ejecta thicknesses, and depth of mixing of ejecta from each Nectarian and Imbrian-age basin landing in Crisium and Nectaris.

Cumulative Ejecta Thickness and Depth of Mixing. After mapping ejecta for each basin, we synthesized the data in a series of cumulative maps. We estimated the cumulative ejecta thickness and maximum depth of mixing across 0.1° x 0.1° grids within Crisium and Nectaris, similar to a previous analysis that studied ejecta on a global scale [11]. We also created charts of the percentage of the total ejecta thickness that was derived from each basin (Figs. 1 and 2).

Using existing geologic maps of the region, we identified areas that may expose *in situ* impact melt, which could be used to determine the age of Crisium and Nectaris. For these areas, we utilized the sequence of basin formation and depth-of-mixing values to estimate the percentage of the surface composition derived from each basin. We searched for regions that had significant surface material from both Crisium and Nectaris, and comparatively little material from other basins [12].

Results: The Housen and Fassett ejecta thickness models yielded similar overall trends, although the actual values in the Housen model were larger than those of the Fassett model. Only results derived from the Fassett model are presented, since it was developed using data from the large Orientale Basin and is thus more applicable to the large basins studied here.

Ejecta in Crisium Basin. The model described here predicts that much of the ejecta in the Crisium basin is derived from the Serenitatis impact, due to its size and proximity to Crisium (Fig. 1). However, Serenitatis' age relative to Crisium is unknown, and if it is older, its ejecta would not affect Crisium. If results from Serenitatis are excluded, Imbrium contributes the most ejecta to Crisium (unsurprising since Imbrium ejecta dominate much of the lunar nearside).

Crisium is a young basin, and as such, very few basins' ejecta contaminate its surface. As Crisium is younger than Nectaris and its ejecta composition is not well characterized, it is not an ideal landing site to obtain material from both Crisium and Nectaris at once. However, there may be locations within Nectaris that contain Crisium ejecta.

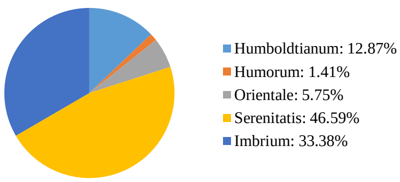

Figure 1: Percent thicknesses of ejecta in the regolith in the northeast region of Crisium using the Fassett model. Only basins that contributed >0.50 m of ejecta are included.

Ejecta in Nectaris Basin. The results from the Nectaris basin show a wider spread in ejecta thickness estimates than the Crisium results. Since it is older than Crisium, the contributions of 41 basins were considered when determining its cumulative ejecta thickness. Of these 41 basins, only the Crisium, Imbrium, and Serenitatis basins contributed a significant amount of material to the surface of Nectaris (Table 1).

Most of the areas mapped did not provide the opportunity to collect material from both Crisium and Nectaris, but the East Nectaris area, located at -11.8° N, 41.5° E, seemed to be a possible landing site that would contain material from both basins. This area is believed to have exposed impact melt from Nectaris, which is critical in determining its age. Crisium material makes up about 41% of the total ejecta thickness in this region, so Imbrium ejecta do not dominate this area (Fig. 2). About 60% of the material at the surface is derived from either Crisium or Nectaris (Table 1), which makes it possible to sample rock from both basins at once in this location.

Table 1: Percent composition of rock at the surface of East Nectaris. Only basins that make up more than 10% of the surface composition are included.

Basin	Percent Composition at Surface
Nectaris	35.96
Crisium	24.39
Imbrium	14.73
Serenitatis	11.98
Orientale	10.41

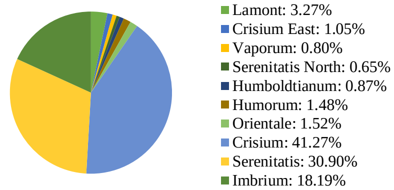

Figure 2: Percent thicknesses of ejecta in the regolith in East Nectaris using the Fassett model. Only basins that contributed >0.50 m of ejecta are included.

Future Steps. Upon further analysis, the data from this study may be able to identify more possible landing sites with optimal ejecta compositions. If a site is selected using other criteria, it should be studied using the methods in this paper to ensure that it has the desired surface ejecta composition.

The limitations of this study were derived from the assumptions made in developing the model. We assumed a 90° angle of impact and symmetrical ejecta deposition around each basin, which may not be realistic in some cases. Also, the ages of some basins with prominent ejecta deposits (such as Serenitatis) were not known. To rectify these issues, the model should be altered to simulate more realistic impact and ejecta conditions, and the stratigraphy of lunar nearside basins should be studied in greater depth.

This study represented the first use of an ejecta thickness model to study the Crisium and Nectaris regions with a comprehensive list of basins identified by GRAIL. Modeling the origin of the surface material in lunar basins may help identify a future landing site and explain the history of some features observed in remote sensing data. In the future, the Moon's record of ancient geologic processes such as ejecta deposition will allow the evolution of the early Solar System to be studied in greater detail.

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