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Geologic Evidence for an Impact Ejecta Origin of Tycho's Antipode Terrain

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Abstract

A region roughly antipode to the lunar crater Tycho exhibits anomalous melt geomorphologies and rock abundance characteristics. Although previous LROC and LRO Diviner observations cautiously link its origin to the Tycho impact and ballistic models demonstrate that antipodal ejecta focusing is possible, uncertainties remain regarding the plausibility of this formation mechanism. A multi-dataset analysis of the geomorphologies and terrain distributions located within Tycho's antipode region implicates the Tycho impact in the formation of this unusual deposit.

1. Introduction

Terrains with compositional or physical anomalies antipode to sizeable craters have been contentiously hypothesized to form by the convergence of seismic waves or airborne ejecta from the crater-forming impact [1-4]. The formation mechanisms should leave unique geomorphologic and spatial signatures [1], which may be detectable with remote sensing.

In this contribution, we analyze one such irregular region located on the lunar farside antipode to Tycho crater. The deposit exhibits smooth, formerly molten morphologies [5] and high rock abundances like those typically detected at Copernican-aged impacts [6]. The distribution of rock abundance within the region suggests that the material converged from a distal location [6] and crater counting places melts concurrent with the Tycho impact [7]. Global ballistic ejecta models demonstrate that material leaving Tycho could reach the antipode within hours leading to the emplacement of semi-viscid lava bombs [3] or particulate "rain" that becomes molten by frictional heating upon reimpact [8].

2. Methods and Datasets

Four distinct morphologies have been identified at Tycho's antipode: ponds, veneer, rock fences and rubble [5,8]. We use LRO NAC images to evaluate and map each of these morphologies on an individual basis. ArcGIS and Global Mapper software is then used to integrate NAC image analyses with Diviner Rock Abundance [6] and H-parameter maps [9], the WAC global color dataset, and SELENE DEMs. By employing a multi-scale and -dataset approach, we can preserve important morphological details while investigating regional scale relationships of the features to one another, and to underlying topography.

3. Results

3.1 Morphologic Analysis

Careful inspection of LROC NAC images reveals several new details regarding the four morphologies of the Tycho antipode region. The smooth pond morphology is seen to extend further toward the west than previously thought [5] in an elongate tail (Fig. 1), which is not unlike deposit geometry predicted from ballistic modeling [1,8]. Comparing pond and enclosing drainage area diameters shows that small craters fill more so than large ones, suggesting a regionally uniform emplacement consistent with the ballistic particulate "rain" hypothesis. We find no morphological evidence of meter-scale or larger molten ejecta blobs striking the surface [3].

At convex slopes in thick veneer flows where rock fences tend to form, we observe instances of detached boulders lying above smooth veneer or ponds. The superposition of these features indicates the occurrence of post-emplacement modification. The "weird terrain" on Mercury has been proposed to have formed as a result of the convergence of seismic waves from its antipodal crater [2]; although our tumbling boulders could be an outcome of shaking, we do not think this is the case here, as seismic waves should arrive more quickly than melt ponds could cool. A size-frequency distribution of boulders gives a mean diameter (~ 6m) that suggests veneer deposits may be thicker than previously reported [5].

We also noted several instances of “pond breakouts,” locations where depressions spill out into an adjacent depression. The fronts of breakouts frequently exhibit morphology akin to ropy pahoehoe lava flows on Earth [10]. To achieve viscosities of terrestrial pahoehoe, lunar highlands anorthosites would require temperatures over 1500 K [11]. Using a reasonable pahoehoe viscosity as a baseline, the known flow distance and slope from the SELENE dataset, and a minimum flow thickness of 1 m, we calculate that material must accumulate rapidly (on the scale of hours) for the ejecta “rain” scenario to be plausible.

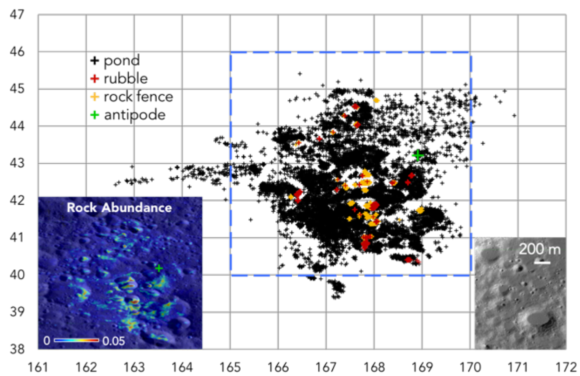

Figure 1: Distribution of morphological features at Tycho’s antipode. Ponds (right inset) are the most common feature in the region. Rock abundance map (left inset) of the dashed blue box is ~100 km wide.

3.2 Integrated Dataset Analysis

Results from the GIS portion of our study show that Tycho’s antipode terrain is apparent not only in high-resolution NAC images, but also at the regional scale in rock abundance, H-parameter, and WAC global color datasets. LRO Diviner rock abundance [6] and H-parameter [9] maps demonstrate the westward pointing chevron geometry of the deposit, consistent with our pond map and ballistic antipode ejecta models [1,8]. Several tails emanate outward from the main concentration of the deposit, bearing azimuths that mirror rays originating from Tycho. As in a previous study [6] we note the absence of high rock abundances on the S to SE-facing slopes of craters, which conveniently mirrors the shadow zone of Tycho’s rays. Such shadow zones are thought to be a product of low angle (oblique) impacts, which in turn produce low angle (<45º) ejecta [12]. Low angle ejecta is required to form much of the high rock abundance signature found Tycho’s antipode [6]. Finally, we find that the WAC color anomaly, which displays UV properties characteristic of glass and shocked plagioclase [13], covers a more diffuse area of Tycho’s antipode than other datasets.

4. Summary and Conclusions

The Tycho antipode region exhibits terrains with unique geomorphologic and physical characteristics, which are apparent in multiple datasets. Detailed examination of the local and regional geology demonstrates that a ballistically emplaced antipode ejecta model consistent with particulate “rain” is plausible for the formation of the deposit. The recognition of these unique set of features as being linked with antipodal impacts will aid in future analysis of planetary surface and impact processes.

References

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