CHARACTERISTICS OF THE MOON'S YOUNG CRATER POPULATION: CAUGHT BETWEEN A ROCK AND A RAYED PLACE.
R. R. Ghent[1], E. S. Costello[2,3], and A. H. Parker[4], [1]Planetary Science Institute, Tucson, AZ, USA (rghent@psi.edu), [2]Hawaii Institute of Geophysics and Planetology, [3]Dept. of Geology and Geophysics, University of Hawaii, Honolulu, HI, USA, ecostello@higp.hawaii.edu, [4]SETI Institute, Mountain View, CA, USA, aparker@seti.org.

Introduction: The population of young lunar craters provides important insights into current physical processes affecting the lunar surface, and their consequences for the evolution of the Moon-Earth system. During the most recent epochs of lunar history, these processes have been dominated by impacts of extra-lunar debris ranging in size from micrometeorites to large bolides, and by solar wind-related processes. Together, these have acted to shape the large-scale lunar surface environment, and to age surface materials in characteristic ways and at characteristic rates, leading to observable properties that provide information about their nature and evolution. In addition, the young crater population reflects the present-day impact flux, and variations in the statistical properties of that population relative to that of older craters can reveal time-dependent changes in the impact flux, and in the characteristics of the impacting population. For these reasons, reliable means of identifying young craters, and determining their relative and absolute ages, represent valuable tools in the quest to understand important aspects of the evolution of the Earth-Moon system.

The most common criterion for identifying young craters has historically been the presence of rays in UVVIS reflectance data, optical maturity data, and radar observations [*e.g.*, 1-4], and the properties of individual rayed craters, and indeed, of individual rays, have been well-studied [*e.g.*, 5-7]. Thermophysical properties of crater ejecta—specifically, the presence of large warm rocks in nighttime thermal IR observations—have also been proposed to signal crater youth [8], and the resulting population of rocky craters over 10 km in diameter has been used to support the idea of an increase in lunar impact rate in the Phanerozoic [9], previously suggested by other workers [*e.g.*, 10].

Here, we present a new database of both rayed and rocky lunar craters with diameter ≥ 5 km between 70º N and 70º S, document the properties of the resulting population, and address some key implications for ray production and destruction.

Method: We identified rayed and rocky craters with diameters 5-130 km everywhere on the Moon between 70ºS and 70ºN latitude, using the UVVIS reflectance and thermophysical data listed in Table 1 (rays) and the Lunar Reconnaissance Orbiter (LRO) Diviner thermal radiometer derived rock abundance dataset (rocks). For the latter, we confirmed the presence of large rocks clearly associated with the ejecta of each crater using LRO camera (LROC) Narrow-Angle Camera (NAC) images. We recorded center latitude, center longitude, diameter, and host terrain (mare vs. highlands) for all craters; for rocky craters, we also computed summary statistics of the Diviner rock abundance for a one-crater-radius annulus outside the crater rim.

Table 1: Datasets used to identify rayed craters (https://pds-geosciences.wustl.edu)

Feature type	Datasets
Albedo rays	LROC WAC Global Morphology Mosaic, WAC Hapke 7-band mosaic, WAC empirical 7-band mosaic, and WAC empirical 643 nm mosaic
	Kaguya Multiband Imager 750 nm Global Reflectance Mosaic
	Clementine 750 nm global reflectance mosaic
Maturity rays	Kaguya Lunar Multiband Imager Derived Optical Maturity 50N50S
	Clementine Derived Optical Maturity
Thermophysical rays	LRO Diviner H parameter map

In this work, we analyze the size distribution, spatial distribution, and size-frequency distribution for each sub-population. We also create a forward model of candidate relationships between rays, rocks, and crater age using a likelihood-free Bayesian inference framework to test these models against the observations listed below. Here, we present a few of the most intriguing characteristics of the rayed and rocky crater populations.

Selected results: Our catalog contains: 543 unique craters with either rocks or rays; 389 rayed craters, of which 211 have rays but no rocks; and 332 rocky craters, of which 154 have rocks but no rays. We take the population of craters with albedo rays as the "super set" of rayed craters. Of these, 80% occupy the highlands, and 20% lie in the maria. Maturity rays are present for 80% of the craters with albedo rays, with 83% and 17% lying in the highlands and maria, respectively. Thermophysical rays in the form of elevated H parameter values are present for 48% of the albedo-rayed craters with highlands / maria fractions of 85% and 15%, respectively. For comparison, there are 76,401 total craters with diameter ≥ 5 km in this region identified by Robbins (2019) [11].

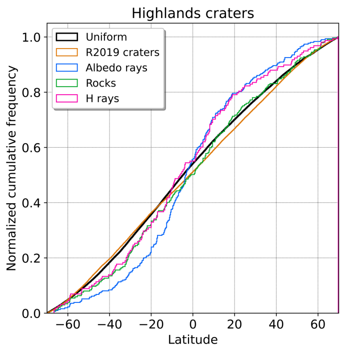

Figure 1: Normalized cumulative histogram showing latitudinal distribution of rayed and rocky craters.

Latitude distribution. Figure 1 shows that the albedo ray distribution is strongly concentrated near the equator (Fig. 1, blue curve: steep slope) relative to the other populations, and relative to both the Robbins craters (orange curve) and a calculated uniform distribution (black curve). Analysis of synthetic populations tuned to match these observations indicates a factor of ~1.5 enhancement in the number of rayed craters at the equator relative to that at ±35º latitude. The rocky crater distribution, however, cannot be distinguished from the uniform distribution.

Longitude distribution. Figure 2 shows the position of rocky, rayed, and Robbins 2019 craters in the highlands relative to the apex of lunar motion (center of the leading hemisphere), in 30º increments plotted every 10º. The dotted black curves are for a calculated population of 10^5 craters uniformly distributed on a sphere, truncated at ±70º latitude. Contrary to previous work (e.g., [4]), we find that neither rayed nor rocky craters show leading / trailing hemisphere asymmetry.

Discussion: The small sample of results shown here illustrates the nature of the constraints provided by our new catalog of young craters. Any attempt to explain the evolution of the lunar surface must be able to reproduce all of the properties of the population in this catalog. We seek to understand the spatial and temporal properties of the rayed and rocky crater populations within the context of a self-consistent model that accounts for both production and destruction of rayed and rocky craters. We have a wealth of data to match, including: a) the relative abundances of rayed and rocky craters; b) the size-frequency distributions of both populations; c) the quantitative rock abundance in the ejecta of rocky craters; d) the spatial distributions of both

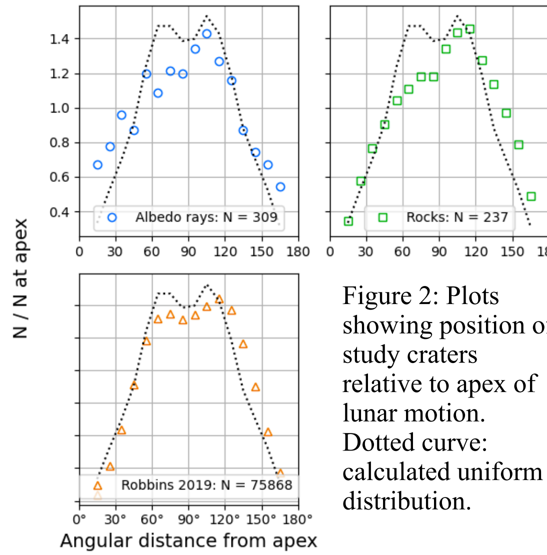

Figure 2: Plots showing position of study craters relative to apex of lunar motion. Dotted curve: calculated uniform distribution.

populations; e) the fraction of each population that overlaps the other; and f) the relative longevities of rays and rocks. Preliminary models suggest that we can approximately match the relative rayed / rock crater abundances as a function of latitude using a uniform model of crater production and relatively simple parametric models of ray and rock aging functions with a smooth and monotonic latitude dependence. Modeled lifetime ratios are latitude-dependent; reasonable preliminary fits correspond to ray longevity at the equator of ~2.4 times the equatorial rock longevity, but this ratio drops rapidly and reaches unity at ±50º latitude. The origin of such a latitude dependence on the aging process remains enigmatic. This latitude dependence does not currently appear to result from sampling biases (e.g., photometric variations), but testing is ongoing. Further ongoing work includes model refinement and progressive inclusion of additional constraints, including compositional data.

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