MAXIMUM SECONDARY CRATER SIZES AND MAXIMUM EJECTA FRAGMENTS AT ESCAPE VELOCITY: ANALYSIS FROM SIX SECONDARY CRATER FIELDS ON THE MOON. K. N. Singer¹, W. B. McKinnon², and B. L. Jolliff². ¹Southwest Research Institute, 1050 Walnut St. Suite 300, Boulder, CO 80302, USA (ksinger@boulder.swri.edu), ²Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University in St. Louis, Missouri 63130, USA.

Introduction: We mapped secondary craters around primary craters ranging in size from ~0.83–660 km in diameter using Lunar Reconnaissance Orbiter Camera (LROC) Narrow and Wide Angle Camera images. The analysis includes secondary craters from Orientale, Copernicus, Kepler, and three smaller unnamed craters 3.0, 2.2, and 0.83 km in diameter. Extensive additional details about every aspect of this project can be found in Singer et al., 2020 [1].

Secondary Craters: Identification of secondary craters was based on expected secondary crater morphologies (e.g., v-shaped ejecta, clusters or chains, and elongation in the direction radial to the primary, similarity in degradation state across the secondary field) and secondaries were assigned a confidence level (as to whether they were likely a secondary crater) based on the number of expected morphologies they displayed (Fig. 1). Only the most confident features were utilized in this work, as there is no way to capture all secondary craters within a given secondary field. Maximum secondary crater size-range relationships are characterized [1].

Ejecta Fragments: The secondary crater ranges from the primary crater yield the fragment ejection velocities. The secondary crater sizes are used to estimate the size of the ejecta fragments that formed them through scaling laws [e.g., 2]. A variety of different possible parameter sets are explored in [1] and we provide an example for the Copernicus crater in Fig 2.

Quantile Regression Upper Envelopes: We fit a power law to the upper envelope of the data for both (i) the secondary craters as a function of range/distance from the primary, and (ii) the ejecta fragment size-velocity distributions (Fig. 2). We use quantile regression [3] to achieve a representation of the maximum secondary crater sizes for a given distance from their primary crater and the maximum ejecta fragment sizes for a given ejection velocity.

Additionally, we found a trend for the power law parameters (just described) as a function of primary crater size. This allows us to define maximum secondary crater size as a function of both the primary crater size and its distance from the primary. Thus, the maximum secondary crater size can be found at any distance from most primary craters on the Moon (Fig. 3). Currently we recommend relatively large uncertainties on this master function of ±50%. As described in [1] there is natural variation even among primary crater sizes of the same diameter, and we are working to characterize that better with in-progress efforts mapping more secondary crater fields.

Figure 1. Example secondary crater mapping around a 2.2-km-diameter crater in the proximal ejecta of Orientale.
Figure 2. Example scaling to ejecta fragment sizes for secondary craters around the 93-km-diameter Copernicus crater [1, 2]. These different parameter sets show the range of possible scalings under different assumptions of material parameters and impact angles. Upper envelopes of the data are fit to a power law function with quantile regression (QR) [3].

Conclusions: 1. We developed an empirical estimate for the maximum secondary crater size at a given distance from a given size primary crater on the Moon and estimate ejecta fragment sizes and velocities.

2. We find a steep scale-dependent trend in ejecta fragment size-velocity distributions. Maximum ejecta fragment sizes fall off more steeply with increasing ejection velocity for larger primary impacts. This trend may be important for future fragmentation models.

3. Using our ejecta fragment size-velocity distributions, we can extrapolate to the escape velocity of the Moon. Maximum fragment sizes ejected at escape velocity for the Moon could be as large as \(~1\) km for the larger lunar impacts, but more typically would be tens or a few meters for mid-sized and smaller impact. The fragments do not necessarily remain intact throughout their flight, but this represent the equivalent diameter of the originally ejected mass.

4. These results have been compared to those for icy satellites [1, 4] and previous lunar studies [e.g., 5].

Figure 3. Master function of secondary crater sizes per size of primary crater and distance from that primary. Black dots show how the same size secondary crater (1-km-diameter) could be ejected from a smaller primary closer to the secondary, or a larger primary farther from the secondary.

Future Work: Additional secondary fields are being mapped on both the Moon and Mercury to further explore these trends and examine the role of gravity.

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