CONSTRAINING THE AGE OF VAUGHAN CRATER USING LROC BOULDER DISTRIBUTIONS AND DIVINER ROCK ABUNDANCE. R. N. Watkins[1], K. Mistick[1,2], B. L. Jolliff[2], and R. R. Ghent[1,3], [1]Planetary Science Institute, 1700 E. Fort Lowell, Suite 106, Tucson, AZ 85719, rclegg-watkins@psi.edu, [2]Washington University in St. Louis, St. Louis, MO 63130, [3]Department of Earth Sciences, University of Toronto, 22 Russell Street, Toronto, Ontario M5S 3B1, Canada

Introduction: Ages for impact craters on the Moon are typically established using a combination of relative dating methods (e.g., superposition) and radiometric age determination from returned lunar samples. Here, we use boulder-size frequency distributions and knowledge of rock abundance around young impact craters to constrain the age of Vaughan crater in northern South Pole-Aitken Basin (41.41° S, 171.85° W; Fig. 1). Recently named after Dorothy Vaughan [1], this 3 km diameter crater is in an area for which Lunar Prospector gamma-ray spectrometer data provide a good match to the composition of lunar meteorite Dhofar 961 [2].

Because of the gradual degradation of exposed boulders, boulder population densities decrease as craters age [3], with boulder populations reaching background levels in about 1 billion years [4]. Previous studies of boulder degradation rates have found that, for craters < 1 km in diameter, few boulders remain at craters older than a few hundred Ma [5]. Therefore, the presence of boulders around a crater is a good indicator that the crater is young. Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) images [6] provide high-resolution image data for measuring boulders around lunar impact craters. We compare NAC-derived boulder distributions from six craters of known ages [7] with the boulder distribution at Vaughan crater, along with thermophysically-derived rock abundance, to constrain its age.

Methods: We use Crater Helper Tools in ArcMap to identify and determine the size of boulders, and the haversine formula to compute distance from the rim of Vaughan. Using NAC images with 0.5-1.0 m/pixel resolutions, the smallest boulders that we identify with confidence are ~1-2 m.

We use cumulative boulder-size frequency distributions (BSFDs) as our tool for comparing boulder distributions across craters. BSFDs display the number of boulders at each recorded size surrounding the crater of interest, and inform how the frequency of ejected boulders varies as a function of distance from the crater rim (in units of crater radii). Boulder distributions around six craters (< 1 km in diameter) with known ages (2-200 Ma) were analyzed by [7], and we use these for comparison with Vaughan.

Diviner Rock Abundance: In addition to NAC counts, we use Diviner rock abundance (DRA) to quantify the rockiness of Vaughan's ejecta. DRA measures the areal density of boulders covering the surface using thermal data from LRO's Diviner Radiometer [3]. Following the methods of [4], we take the 95th percentile

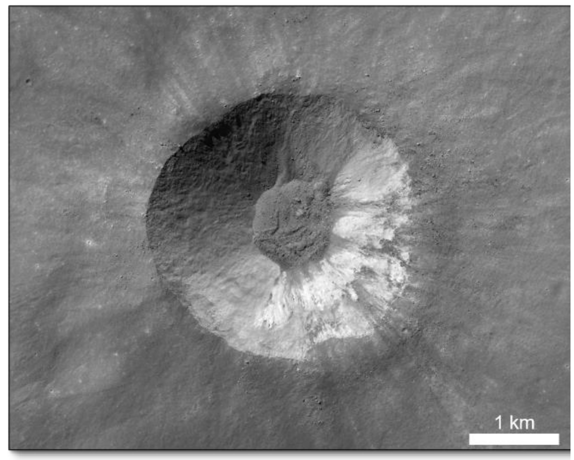

Figure 1: Vaughan crater (41.41° S, 171.85° W) on the lunar farside.

rock abundance value (RA_{95}) of the ejecta within one crater radius and plot histograms showing the distribution of DRA values.

Results: For Vaughan, our count site is defined by a western slice with an area totaling 62.3 km^2 (Fig. 2); we assume this area to be representative of the boulder field surrounding Vaughan. The abundance of boulders decreases with increasing distance from the crater rim; we count boulders out to ~13 crater radii. When fit with a power-law function, the BSFD for Vaughan gives a relatively shallow slope and reveals that Vaughan has a high cumulative frequency of boulders relative to other young craters (Fig. 3).

The RA_{95} value from the rim of Vaughan to 1 crater radius is 0.072, interpreted as 0.72% of the surface covered in boulders. RA_{95} values for background regolith and for the ejecta blanket were plotted using histograms and are shown in Fig. 3.

Discussion: The BSFD plot for Vaughan is slightly shallower than what we find with the count sites from [7], but it matches well with results demonstrated in previous studies [5;8-9]. This shallowness may be attributable to Vaughan's slightly larger size compared with the other sites, which should result in the excavation of more large fragments than for a smaller crater, given ~equal regolith thickness. The shallower slope may also be a result of impact conditions (e.g. velocity); smaller impact velocities may allow a crater to retain larger boulders, owing to less fragmentation during impact [10]. The presence of large boulders decreases as craters age [11], so the higher cumulative frequency of larger boulders at Vaughan is further evidence that this crater is very young. North and South Ray craters are young relative to the estimated time required to break down boulders [5]; therefore they still retain many of their boulders. Vaughan's BSFD placement near these two young craters is an additional indication of its young age.

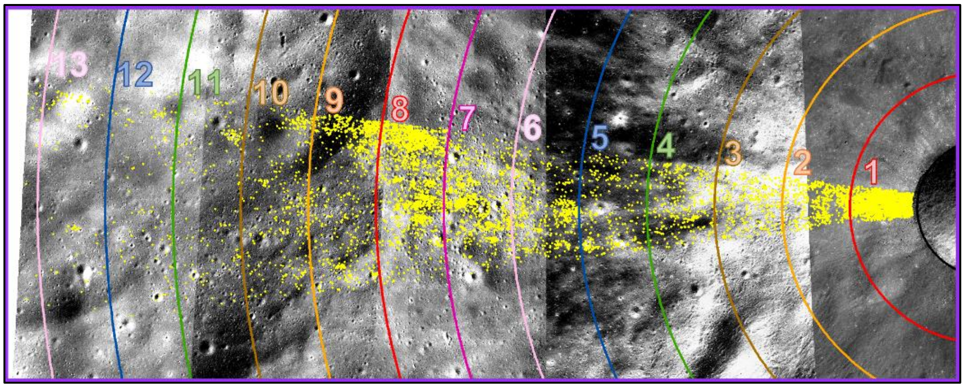

Figure 2: Distribution of boulders (yellow) as a function of distance from the rim of Vaughan, in units of crater radii.

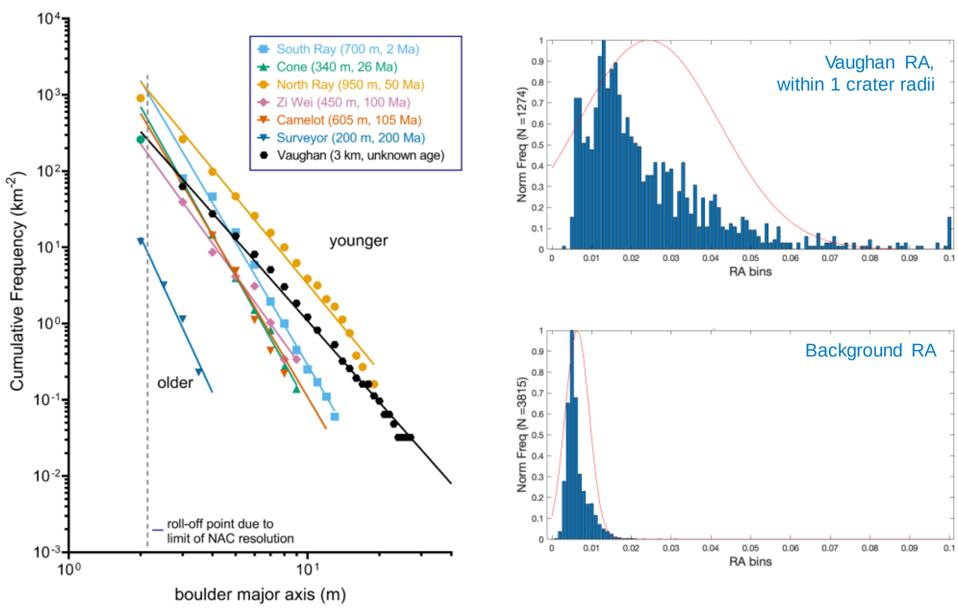

Figure 3: (Left) BSFDs of Vaughan and the six comparative sites (see [7]). BSFDs show that young craters have higher boulder populations; each distribution is fit with a power-law function. (Upper Right) Histogram of RA values for Vaughan, out to 1 crater radius. The RA_{95} value for this region, 0.072, suggests Vaughan is very young. (Upper Left) Histogram of RA values for the background regolith near Vaughan.

The RA_{95} value for Vaughan, 0.072 is quite high compared to the background value, 0.004. Though an exact calibration for small craters has not yet been established, and regolith thickness certainly plays a role for small-crater boulder production, the difference between the RA_{95} value for Vaughan's ejecta and the nearby regolith indicate that Vaughan is indeed young. Based on its place ment within the BSFD comparison plot, we estimate Vaughan's age to be <25 Ma. However, owing to variations in impact energy, terrain type, and regolith thickness, further analyses of boulder distributions around craters of similar size and terrain type to Vaughan are necessary to further constrain its age. By evaluating variations in boulder distributions as a function of crater properties, we will be able to improve upon the method of using boulder distributions as an additional technique for placing approximate ages on lunar craters in the absence of ground-truth age data.

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References:

[1] https://planetarynames.wr.usgs.gov/Feature/15862?__fsk=-1476546764 [2] Jolliff et al., (2008) *LPSC 39*, Abstract #2519. [3] Bandfield et al. (2011) *JGR* 116. [4] Ghent et al. (2014) *Geology*, 42, 1059–1062. [5] Basilevsky et al. (2013) *PSS, 89*, 118–126. [6] Robinson et al. (2010) *Space Sci. Rev.* 150, 81–124. [7] Watkins et al. (2019) *JGR, 124*, 2754–2771. [8] Cintala and McBride (1995) *NASA TM-104804*. [9] Bart and Melosh (2010) *Icarus, 209*, 337–357. [10] Hartmann (1969) *Icarus, 10*, 201–213. [11] Moore (1971) *NASA SP-232*, 26-27.