DISCOVERY OF LAYERED EJECTA CRATERS ON CHARON, AND IMPLICATIONS FOR FORMATION.

S.J. Robbins[*,1], K. Runyon[2], K.N. Singer[1], V.J. Bray[3], P. Schenk[4], O.L. White[5], W.B. McKinnon[6], J.M. Moore[5], R.P. Binzel[7], M.W. Buie[1], B.J. Buratti[8], A.F. Cheng[2], W.M. Grundy[9], I.R. Linscott[10], H.J. Reitsema[11], M.R. Showalter[12], J.R. Spencer[1], G.L. Tyler[10], H.A. Weaver[2], L.A. Young[1], C.B. Olkin[1], K. Ennico[5], S.A. Stern[1], the *New Horizons* GGI Theme Team, *New Horizons* Pluto Encounter Team, *New Horizons* LORRI Instrument Team, and *New Horizons* MVIC Instrument Team. [1]Southwest Research Institute, 1050 Walnut Street, Suite 300, Boulder, CO 80302. [2]The Johns Hopkins University, Baltimore, MD. [3]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ. [4]Lunar and Planetary Institute, Houston, TX. [5]NASA Ames Research Center, Moffett Field, CA 84043. [6]Washington University in St. Louis, St. Louis, MO. [7]Massachusetts Institute of Technology, Cambridge, MA. [8]NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA. [9]Lowell Observatory, Flagstaff, AZ. [10]Stanford University, Stanford, CA. [11]Ball Aerospace [retired], Boulder, CO. [12]Sagan Center at the SETI Institute. [*]stuart@boulder.swri.edu

Introduction: NASA's *New Horizons* revealed diverse landscapes on both Pluto and Charon during its July 2015 flyby, and we have been investigating the craters upon them. Crater ejecta on Charon consists of two primary morphologies: Classic ballistic ejecta and rays (lunar-like); and cohesive single or multiple layers of ejecta ("LE") (Fig. **1**) first discovered on Mars [1]. While the latter type comprises ~⅓ of Martian ejecta [2], it is significantly less common on other bodies. Recent work has suggested LE on Mercury [*e.g.*, 3], but they could be landslides. Earth craters might display LE, but because of short geologic resurfacing timescales, it is difficult to state this conclusively [4]. Some LE craters have been observed on Jupiter's moons Ganymede and Europa [5]. At least one has been observed on Saturn's moon Dione, a putative one on Tethys, but none are seen on Enceladus. Herein, we overview characteristics of Charonian LE in context of Martian work and implications for formation.

Geographic and Size Distribution: Figure **2** shows a map of Charon with locations of identified LE (possible and certain) and approximate detection-limited regions based on solar incidence, emission angle, and pixel scale: While LE are almost exclusively found on the informally named Vulcan Planum ("VP") (32 of the 34 LE), it is unclear whether this is due to detection ability or exclusive provenance.

The size-frequency distribution of Charonian LE matches the background population of both the overall body and Vulcan Planum ("VP") for craters $D \gtrsim 15$ km. Of ≈70 $D \geq 15$ km craters in VP, LE are ≈45% the total. The diameter range for LE-bearing craters is 8.5–66 km; smaller LE ($D<15$ km) are not nearly as numerous as the larger ones relative to the the background crater population, and this is *not* due to detection limitations.

Morphology: Using a combination of nomenclature from [6] and [7], all Charonian LE are SLE, displaying a single cohesive layer of ejecta, except for one. There is a second which might be DLE or even MLE (double or multiple (3+)), but these additional layers are either unrelated montes or have been too eroded for a clear genetic link to the crater (Fig. **1**A); there are additional facies within the otherwise SLE, as well. Using 1 or 2 layers around this crater gives DLEs the range 3–6% of the total LE population. For comparison on Mars, using [2], the $D \geq 15$ km population shows 36% SLE, 34% DLE, and 28% MLE (and LE are 12% of the total $D \geq 15$ km crater population).

Another common morphologic characteristic is the edge of the ejecta and whether it terminates in a pancake-like flow front or a topographic high referred to as a "rampart." Our classification has 61% pancake and 39% rampart, compared with 54% and 46% on Mars, respectively, reasonably similar (though this is for $D \geq 3$ km on Mars and the balance shifts to more rampart on Mars for larger diameter cut-offs). Note that these are based on pixel-scale shading differences on Charon and are preliminary, so percentages may change. DLER are also observed on Ganymede [5].

Morphometry: A classic measurement is the sinuosity of the ejecta perimeter, Γ, defined as the perimeter divided by the circumference of a circle with the same area. Of the 16 ejecta blankets that could be measured all around their perimeter, only 2 (12%) were defined as sinuous ($\Gamma \geq 1.5$). In [2] for Mars, 649 SLE craters are $D \geq 15$ km, and 329 had Γ directly measured: 84.8% were $\Gamma \geq 1.5$, almost the opposite for Mars relative to Charon, and this was *not* an artifact of vertex spacing along the perimeter [2,8]. We found no geographic trends for Γ, and there was a very weak relationship between Γ and D that can be attributed to the fractal nature of measuring perimeters [8].

We also measured ejecta runout distance (radius of a circle with the equivalent area of the crater's ejecta, measured from the crater rim). We found no trend with crater diameter, but there was a small geographic trend for larger runout in the eastern portion of VP; this is the only area of VP that does not have a topographic "moat" as it transitions to the rugged terrain to the north and east.

Charon's imaging campaign was in part designed to produce images suitable for stereophotogrammetry to model topography, but the vertical accuracy for Charon is ~100–200 m at best [9] which is not accurate enough for measuring these ejecta. Instead, solutions for spacecraft timing, trajectory, and camera pointing, and instrument calibration changes are just now (July-August, 2016) becoming accurate enough to use photoclinometry to estimate finer-scale topography. We will be using this in addition to shadow lengths to analyze these ejecta blankets and may be able to present preliminary results at the August 2016 meeting.

Pluto: No convincing LE-bearing craters were observed on Pluto. While only ≈80% of the surface was imaged, and ≈46% at favorable pixel scales for their detection, it is *possible* they are present on other terrains on such a geologically diverse world, but we consider this an unlikely explanation. It is more probable that: (1) They do *not* form on Pluto due to differences in the upper crust between the two bodies; (2) the lack of smooth topography on Pluto's older terrains impedes ejecta flow, preventing LE from forming; or (3) they *do* form on Pluto but geologic processes are so rapid that they were removed. Whichever is the case, it is difficult to use Pluto as a constraint because of problems associated with proving a negative.

Discussion: Since LE-bearing craters were first observed on Mars, two dominant hypotheses have emerged for their formation: Aeolian [*e.g.*, 10] or volatile fluidization [*e.g.*, 11]. While there is technically not yet a consensus for which model is more likely to be correct (and it is possible that each is required to explain the different LE morphologies), many outside the Mars impact crater community assume by default that the fluidization explanation is more likely. Definite LE existence on Europa, Ganymede, and Dione (airless bodies) prohibit an atmosphere from being required for those types' formation.

Similarly, the existence of LE on Charon further constrains their formation and requires that all of the morphologic and morphometric properties we observe from Charonian LE be producible without an aeolian component. Differences between Charon's LE population and Mars' are still being investigated, but differences could be due to formation and/or properties of the bodies, such as surface gravity and target strength.

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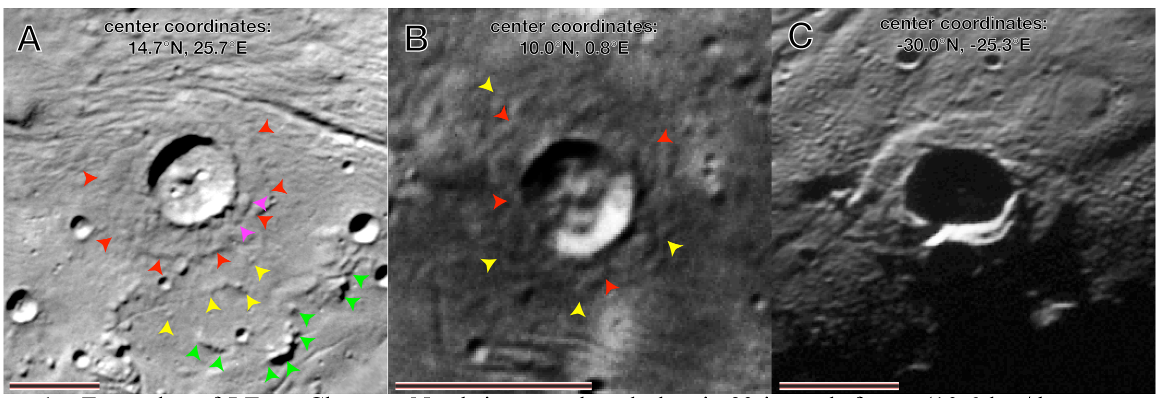

Figure 1: Examples of LE on Charon. North is up and scale bar is 3° in each frame (10.6 km/deg at equator). (A) "Spock" crater with SLE (red), more facies upon the SLE (pink), and possible additional layers (yellow/green). (B) Unnamed DLE with inner and outer ejecta marked. (C) Unnamed SLE near the terminator during flyby.

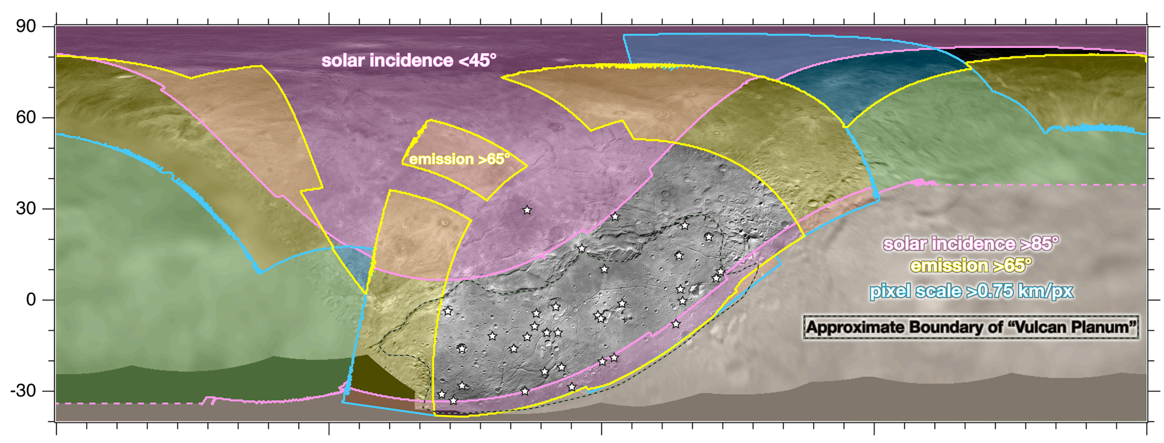

Figure 2: Charon basemap. Magenta contours at 45° and 85° bracket area of favorable illumination for topographically identifiable ejecta blankets, cyan bounds ≤0.75 km/px, and yellow at 65° are emission angle (angle between the spacecraft and the surface). The intersection of these three regions is unshaded. The unshaded area indicates where we should reasonably be able to identify any LE craters with diameters $D \gtrsim 5$ km. The black/green dashed outline is the approximate boundary of Vulcan Planum (southern margin based on terminator of high-resolution imagery). LE craters are indicated by a white star, and this does not differentiate between possible versus certain LE.