ROUNDING AND COMMINUTION RATES OF ICE CLASTS USING THE TITAN TUMBLER: FLUCTUATING ROUNDNESS AND STEPPED MASS LOSS. P. R. Matulka[1], J. S. Levy[1], D. M. Burr[2], and A. D. Maue[2]. [1]Colgate University (Hamilton, NY 13346; pmatulka@colgate.edu, jlevy@colgate.edu), [2]University of Tennessee – Knoxville (Knoxville, TN 37996).

Introduction: Titan, the largest moon of Saturn, shows evidence of fluvial features [e.g., 1-3]. Reflectance spectra from the surface of Titan reveal that it is composed largely of water ice as well as organic compounds such as tholins [1]. Some radar-bright sediment transport features that drain Xanadu have been inferred based on radar reflectance to host rounded pebbles and cobbles [4] similar to sediment imaged by the Huygens lander (Fig. 1) [1]. An improved understanding of the relationship between rounding and comminution of ice sediments is necessary to interpret the distribution and size of clasts on the surface of Titan from radar images and to determine which geological processes could cause this rounding.

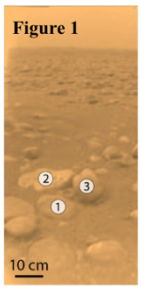

Figure 1 This south-facing view of Titan's surface from the Huygens lander shows several rounded stones (e.g. 1, 2, 3).

One possibility is that the rounded clasts formed during transport from clast-clast and clast-bed collisions causing rounding and comminution [5]. Dunes composed of finer grains have been observed on Titan with compositions of organic compounds or water ice coated in organics [6]. Fine grains have also been identified beneath the Huygens lander [7, 8]. Fine grains produced from ice tumbling could be a source for fine grain dunes.

The purpose of our study is to understand the effects of ice sediment transport on the surface of Titan by simulating clast rounding due to rolling as occurs during bed-load transport at cryogenic temperatures. We aim to address the relationship between rounding and comminution in ice clasts over distance tumbled. The lack of a liquid to cushion the impacts between ice clasts means that the rates we observe will be upper limits on those possible on the surface of Titan.

Methods: Ice cubes, cooled at -20 °C and tempered in a container partially submerged in liquid nitrogen (LN2), were placed in the barrel of the Titan Tumbler – a roller-mill. This barrel was partially submerged in LN2 so that its internal barrel temperature could be held at ~105 K. The temperature was monitored with a thermocouple inserted through a hole in the lid to the barrel. The roll rate was tuned to ensure that the ice cubes rolled (tumbled) rather than slumped or cascaded. At 15 minute intervals, the barrel was removed from the tumbler. The total mass of the ice cubes was measured and pictures were taken of them from three orthogonal sides. The ice cubes were then reloaded into the barrel and tumbling continued with interruptions every 15 minutes to measure the mass and photograph.

Results: The size and shape of the ice clasts during a tumble (run) is depicted in Fig. 2. Mass and roundness (using the methods in [9]) were plotted as a function of time, demarcated in 15 minute time steps (Fig. 3 and 4,

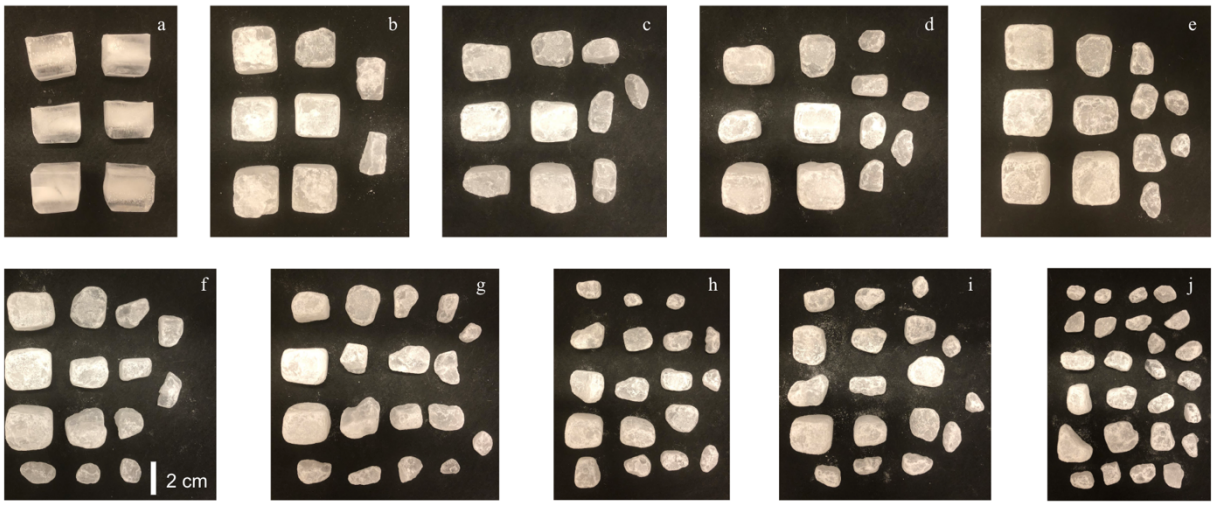

Figure 2 The images above are photos taken at time steps of 15 min throughout a tumble on November 09, 2018. The roundness of the ice clasts varies as time progresses (alphabetically from Figure 2.a-j). The clasts become rounder over time unless they break, which creates pieces of debris with low roundness caused by sharp corners and uneven axes that eventually round out, too. The number of clasts increases while the size of each decreases.

respectively). The roundness was also plotted as a function of mass (Fig. 5).

Discussion: Ice clast mass decreases over time whereas roundness generally increases over time. Earlier experiments at 253 K and 195 K showed a single exponential decay in mass with distance [e.g., 10], but our results show stepped mass changes and decays, with each subsequent step generally smaller than the previous one. Likewise, the roundness did not asymptotically approach 1. Rather, the roundness values increased to between 0.8 and 0.95, and remained there with some fluctuations over time.

After only an hour, the grains achieved a fairly consistent roundness value above 0.8. This result suggests that the roundness of ice clasts at cryogenic temperatures may be largely set early in transport and that clasts at the end of riverbeds at least 1 km long (corresponding to an hour of tumbling at a rate of 30 cm/s) would likely have a roundness value of ≥0.8. These data also suggest that comminution of clasts at low temperatures occurs not just by mineral grain detachment but also by fracture [10]. This is a possible explanation for the fluctuating roundness values (Fig. 4); when a clast fractures, the debris is less round. The changing mass loss rates suggest that fractured debris production might change, resulting in non-monotonic changes in roundness and clast size with distance traveled downstream.

References: [1] Tomasko, M. et al. (2005) *Nature*, 438, 765-778. [2] Perron, J. et al. (2006) *JGR*, 111, E11. [3] Burr et al. (2013) *GSAB*, 125, 299-321. [4] Le Gall, A. et al. (2010) *Icarus*, 207, 948-958. [5] Lewin, J. and P. Brewer (2002) *ESPL*, 27, 145-164. [6] Barnes, J. et al. (2008) *Icarus*, 195, 400-414. [7] Fulchignoni, M. et al. (2005) *Nature*, 438, 785-791. [8] Zarnecki, J. et al. (2005) *Nature*, 438, 792-795. [9] Manga, M. et al. (2011) *Bull. Volc.*, 73, 321-333. [10] Levy, J. et al. (2017) *48th LPSC, Abstr. #1105.*

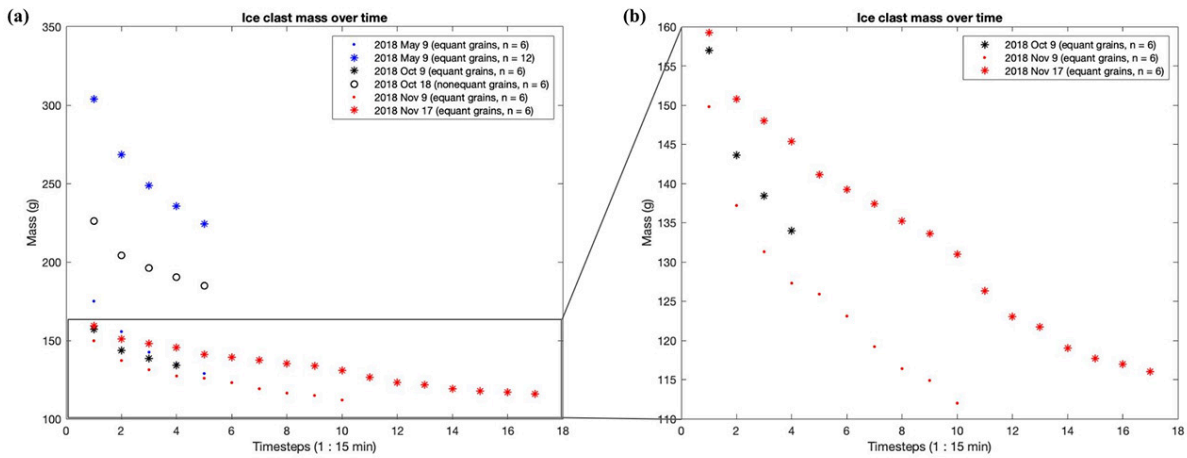

Figure 3 The total mass of the ice clasts decreased at varying rates over time. The masses shown are median values from runs conducted in the spring and fall of 2018. **(a)** Larger initial masses experienced larger initial decreases in mass, as seen in the runs on May 9 and October 18. However, the amount of mass lost towards the end of each run continually decreased. **(b)** To understand the end behavior of mass loss, runs conducted on November 9 and 17 were continued for longer to quantify how the mass lost changed over time. These runs indicate that mass loss decreases in a stepped manner over time.

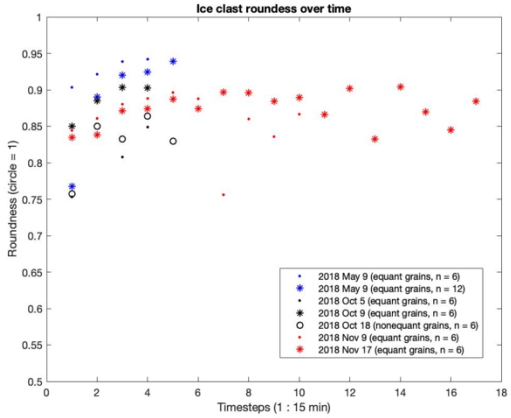

Figure 4 The roundnesses shown here are the median values of the runs conducted in the spring and fall of 2018. The roundness of the generally ice clasts increased for the first hour. The values levelled off toward a consistent roundness about which they fluctuated.

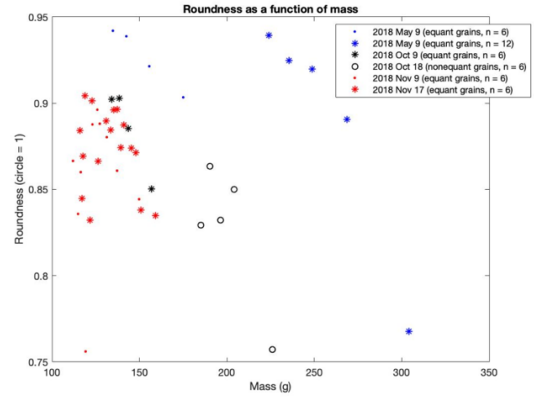

Figure 5 Plotting the roundnesses of the ice clasts as a function of their total masses suggests that roundness generally increases as mass decreases.