RAPID ABRASION OF WATER ICE SEDIMENT DURING SIMULATED FLUVIAL TRANSPORT IN THE TITAN TUMBLER. A. D. Maue[1], P. R. Matulka[2], J. S. Levy[3], D. M. Burr[1], E. Nathan[4], [1]Northern Arizona University (NAU Box 6010, Flagstaff, AZ 86011-6010; maue@nau.edu), [2]Washington University in St. Louis (St. Louis, MO), [3]Colgate University (Hamilton, NY), [4]Brown University (Providence, RI).

Introduction: The frigid rivers of Saturn's largest moon, Titan, are likely capable of transporting alluvial sediment [1], but the abrasion processes common in terrestrial rivers require more exploration for Titan-like compositions and conditions. Rounded sediment at the Huygens landing site [2] and the inferred abundance of spheroidal cobbles in Titan's radar-bright fluvial features [3] are evidence of rounding of sediment in fluvial transport. Although chemical weathering could also induce rounding, currently low temperature gradients across Titan are not conducive for dissolution/sublimation at present [4], at least for the H_2O-rich and fluvially dissected regions of interest in the present study (e.g., Xanadu). We experimentally constrain endmember abrasion rates for icy sediment at Titan temperatures under various initial conditions.

Methods: The Titan Tumbler is a liquid-N_2-cooled roller mill designed to approximate the mechanical weathering experienced by clasts rolling and colliding in fluvial transport (see [5,6,7]).

Tumbler design. The current iteration of the tumbler utilizes a 15-cm-diameter polyvinyl chloride (PVC) barrel. Initial runs were cooled to 190 K with solid CO_2, whereas most data were collected with the lower ~1/3 of the rotating barrel submerged in liquid nitrogen (LN_2) for cooling to Titan-like temperatures of ~100 K. A drive chain spins the barrel with the motor elevated away from the LN_2 bath. The rotation speed was set such that clasts of a few centimeters are transported similar to bedload, by predominately rolling rather than sliding or cascading.

Experimental procedure. Water-ice clasts are produced from deionized and degassed H_2O in a 253 K freezer. Clasts are then cooled to ~77 K in LN_2 and placed in the LN_2-cooled barrel. During the experiment, a thermocouple on the barrel axis monitors temperature.

The tumbler operates within a 253 K walk-in freezer so that H_2O sediment can be periodically removed from the barrel and measured under consistently frozen conditions. Grains are sieved, weighed, and imaged before being returned to the tumbler (except for those with diameter <1 mm, theorized to be carried away by suspension under Titan conditions [8]). These measurements allow observation of mass-loss, grain size distributions, and roundness, calculated (after [9]) as $4\pi A/P^2$. For most runs, the sampling intervals are initially every 15 minutes (~300 m), sometimes extending to 1 hour as comminution slows. Reported tumbling distances are maximum estimates based on barrel rotation rate and circumference assuming no sliding (e.g., [10]).

Influence of various parameters: We vary our experimental procedure in a few different ways to assess the controls on ice clast evolution (**Fig. 1**).

Temperature. Experiments show higher mass-loss and rounding rates at 190 K than at 100 K. At lower temperatures, ice has increased tensile strength [11]. However, in our coldest experiments we observed increased clast splitting to produce more pebbles, which we infer to also cause delayed rounding. Initial warmer runs at 253 K in an small prototype tumbler produced significantly lower mass-loss and rounding rates than our improved, cooler experiments.

Clast size. Rates of mass-loss increase with initial clast size whereas rounding rates have significant variability. For comparison, terrestrial tumbler studies indicate mass-loss rates correlated with grain size if well-sorted and inversely correlated if poorly sorted [12].

Clast shape. Runs with six equant clasts produce repeatable trends but results change for different initial shapes—though these experiments also varied in number of clasts. Randomly angular clasts show significant spread in mass-loss rates and slightly lower initial roundnesses compared to equant clasts. However, both shapes round rapidly toward circularity indices of ~0.9, among the highest roundnesses we measure for the Huygens landing site cobbles.

Ice composition. Given the evidence for some water-rich locations on Titan [13,14,15] we consider pure H_2O as an endmember composition, but run experiments for both "igneous" ice based on inferred cryovolcanism [14] and for "sedimentary" ice based on the potential for icy sedimentation [16]. We consider H_2O clasts frozen overnight in a freezer from a liquid as analogous to Titan's igneous ice. To produce ice clasts analogous to terrestrial sandstones, we grind and sieve ice to specific sand sizes, then cement these sieved grains by saturation with chilled liquid H_2O and freezing.

No difference in mass-loss rate due to ice type was detected and likewise the spread in roundness values shows no clear distinction. Interestingly, the grain size distribution of abraded fines was the same under either condition, i.e., no more sand is produced from the ice sandstone compare to igneous ice. This result is supported by microscope images indicating breakage planes that are indiscriminate of clast versus matrix.

Whereas lithological composition is important in abrasion on Earth [12], differences between the types of ice tested here may have less effect. Abrasion of clasts that include the variety of non-ice compositions present on Titan remain to be tested in cryogenic conditions.

Liquid presence. The presence or absence of LN_2 in the barrel enabled comparisons between "wet" and "dry" runs—with and without the cushioning liquid. Comparing the results from relatively dry runs to those of runs with more LN_2 in the barrel suggests no effect on mass-loss but possible differences in the rounding rate. In contrast, terrestrial tumbling experiments have found increased abrasion rates with the presence of liquid water, though this finding may be due to chemical effects [10]. Alternatively, fines in the barrel could buffer impacts when coating clasts during dry runs.

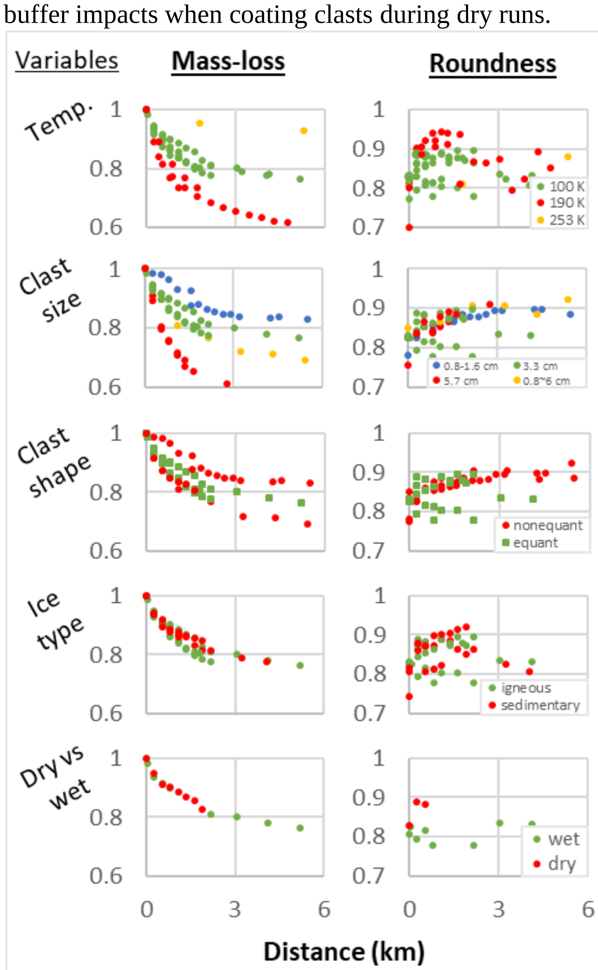

Figure 1. Mass-loss plotted as normalized mass (left) and roundness plotted as circularity index (right) over transport distance for various parameters.

Comparison to terrestrial sediment: We examine our results compared to those from abrasion of clasts in terrestrial rivers and in other tumbler experiments (**Fig. 2**). We compare the evolution of roundness over the normalized mass, where mass-loss is an exponential decay function of distance travelled [11,12]. For Titan-like ice, this evolution is similar to that of relatively weak non-crystalline rocks on Earth, perhaps rounding faster than limestone but similar to pumice and volcaniclastics relative to their normalized mass [6,17]. Note that igneous volcanic rocks (e.g., basalt) typically have an order of magnitude lower abrasion rates than limestone for the same transport conditions [9,17].

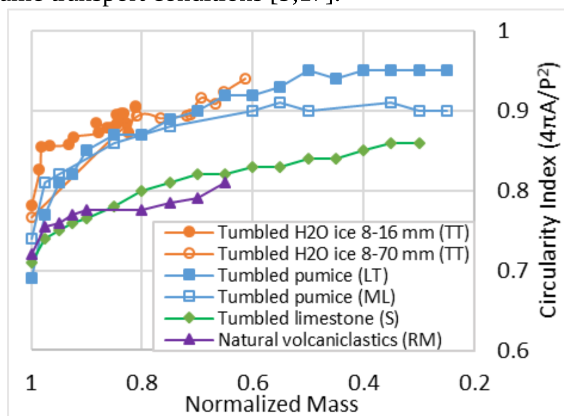

Figure 2. Rounding over mass for two runs with different initial clasts sizes (orange) compared to various terrestrial compositions at similar size ranges (where LT is from Lake Taupo, New Zealand [6], ML is from Medicine Lake, California [6], S is from Sóskút, Turkey [17], and RM is measured in Rio Mameyes, Puerto Rico [17]).

Conclusions: Water-ice clasts transported in Titan's rivers may break down rapidly compared to many terrestrial compositions under similar transport conditions. Although temperature, clast size, and shape are important for setting the experiment, Titan-relevant parameters of ice type and liquid presence show little/no effect. Improved environmental control and liquid containment would enable tighter constraints and better characterization of fines. Furthermore, inclusion of various amounts of organics and pre-experimental stressing of the ice clasts would also add realism to these experimental simulations of Titan processes.

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