THE TITAN TUMBLER: LABORATORY SIMULATION OF ICY SEDIMENT COMMINUTION AND ROUNDING PROCESSES.

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Introduction. Sediment rounding and comminution, two fundamental consequences of fluvial transport, provide basic information about the duration and intensity of liquid/sediment interactions [1]. As clasts of bed load material are transported in flowing liquid, they become smaller and less angular as a function of distance traveled, time in transport, and the energetic regime of transport. On Titan, rounded pebble- to cobble-sized clasts are both observed [2] and inferred to be present in alluvial/fluvial deposits [3]. However, the lack of a systematic study that relates fining and rounding rates of icy particles to transport distance limits our ability to infer the source region(s) for, and in-transport modification of, these particles. The composition of these alluvial/fluvial pebbles and cobbles is likely water ice with a hydrocarbon coating [2]. In more arid regions, aeolian dunes composed of fine sand (clasts hundreds of microns in diameter) are also present [4-5]. The dunes exhibit an organic spectral signature, consistent with either organic grains or an organic coating over water ice grains [6]. On Earth, alluvial/fluvial sediments often source aeolian sands and vice versa, and on Titan both the icy alluvial/fluvial pebbles and the aeolian sands are concentrated at low latitudes [7]. However, on Titan the connection between the coarse liquid-lain sediments and the finer wind-deposited sediments is not known.

As a first step towards understanding sedimentary ice processes on Titan, we experimentally explore the high-energy endmember process of ice clast rounding and comminution in a cryogenically-chilled roller mill. By examining ice erosional behavior in the absence of cushioning liquids or enhanced fluid viscosity from fine-grained debris entrainment, we will be able to 1) place an upper limit on the rates of ice particle rounding under Titan-like temperatures and 2) evaluate the grain size distribution resulting from the most forcible ice-ice and ice-bed collisions. We expect that all subsequent experiments and simulations will be capped by this maximum rounding rate, providing a key benchmark for framing future studies that explore a more complex parameter space.

Our guiding hypotheses are that the rounding rate and comminution rate, as well as the resulting grain size distribution (GSD) of eroded ice fragments, are controlled by the energy of clast-clast or clast-bed collisions, rather than by the initial grain-size distribution of ice crystals in the ice cobble. Put simply, we hypothesize that faster rolling speeds will break down cobbles faster, round them faster, and produce finer-grained erosion products than slower rolling speeds. In principle, then, we predict that Titan channel systems with large discharges should produce finer-grained sediments than smaller channel systems. Given the complex connections between ice fracture strength, ice temperature, and ice crystal grain size [reviewed in 3], we further hypothesize that rounding rate and eroded sediment GSD are invariant over a range of initial ice crystal sizes and that fractures resulting from clast rolling and clast impacts govern the rounding rate and resulting GSD of clastic ice particles.

Methodology. *Determining Ice Rounding and Comminution Rates.* We use a cooled clast tumbling system – dubbed 'The Titan Tumbler" (Fig. 1, next pg) – to measure the rate of change of ice particle mass, rounding, and sphericity as a function of ice crystal grain size, ice clast size, rolling rate, and distance rolled. The tumbler consists of three ~1L volume PET plastic tumbling barrels mounted on a steel drive shaft inside an insulating vessel. The barrels sit in a liquid nitrogen bath. An external, variable-speed motor drives the rotation of the barrels through a transmission rod that enters the insulated chamber via a pass-through. The pass-through also allows the liquid nitrogen bath to vent safely into the cold room in which the apparatus is stored. Ice clasts are grown in cubic, insulated molds using a modified CRREL-method for generating uniform, polycrystalline ice [8], in which deionized water (18 MΩ) is degassed and frozen under unidirectional cooling. Initial ice crystal grain size can be adjusted to bracket the fine-sand grain size most relevant to Titan sand (100-300 µm) by sieved crystal seeding.

The tumbling experiments reported here will measure the rates of change of particle mass, rounding, and sphericity for cubic (3 cm) ice particles with three distinct grain size distributions, under three transport regimes: onset of rolling, rapid rolling, and cascading. Sediment rounding and comminution are measured as a function of transport. In the cold room, ice cubes at each of the three ice crystal grain sizes are weighed, and then placed on a dark background and photographed in their a-b (long-intermediate) and a-c (long-short) axis geometries so that initial mass, roundness, and sphericity values can be determined. Changes to mass, sphericity, and roundness of the clast population are measured through time. The minimum experimental transport distance is the shortest likely distance for the clasts at the Huygens landing site, which is the distance from the nearby networks: ~2-2.5 km. The maximum distance is be ~100 km, which approximates the longest channel networks previously mapped [9].

At each 500 m rolling increment, the mill barrels are emptied into nested sieves after the cobble/pebble-sized clasts have been removed for photographic documentation. Fine particles are sieved into three classes, <100 μm, 100-300 μm, and >300 μm, via dry sieving, or using a small amount of liquid nitrogen as a particle-carrying fluid. Grain size separates are weighed to determine the grain size distribution resulting from bed load rolling over each distance increment.

Pilot Results. Three-cm cubic clasts of polycrystalline ice were loaded into an 11 cm diameter roller mill chilled to 195 K (dry ice cooling). The clasts were rolled at 30 cm/s, an intermediate shear velocity for Titan bed load [10], for 63 hours to produce a 70 km rolling distance, s, which is a length typical of highland channels on Titan [6]. As expected, the angular ice clasts became rounded, and retained their high degree of sphericity (Fig. 2).

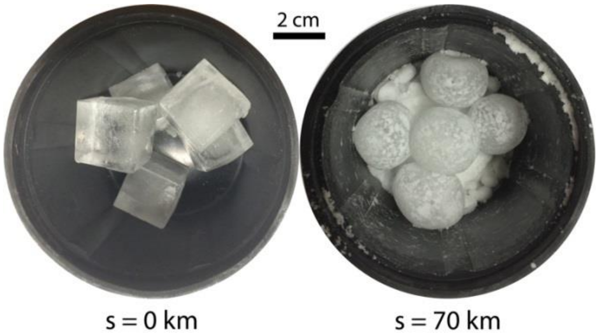

Fig. 2. Example of comminution and rounding of ice clasts as a product of rolling over 70 km of effective transport distance (s). View is down into the mill barrel with clasts and fines at the bottom (i.e., 90˚ off the rotation orientation).

The grain size distribution at the end of the experiment (Fig. 3) shows that, of the initial ~160 g of water ice introduced into the roller mill as cubic clasts, 75% remained in the pebble size fraction (>2 mm), while nearly all of the remaining 25% of the mass had been reduced in size to silt (<63 μm). Less than 1 g of ice that had been removed from the cubes during the rounding and comminution process was sand-sized (63 μm – 2 mm). Sand is the size range of dune-forming material on Titan (100-300 μm). Thus, the lack of sand produced in our preliminary experiments raises a fundamental geological question for Titan—are the sedimentary products of the fluvial system on Titan a source for fine-grained, aeolian-transported sediments, or do the experimental grain size results indicate that additional processes such as cementation by organics or aggregate formation [11-12] act on fluvial sedimentary products before they enter the aeolian system? Continued experimentation will address this question.

Fig. 3: Grain size distribution data (by mass) for sedimentary products resulting from rolling of ice clasts.

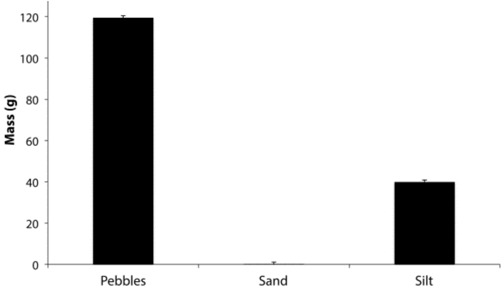

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Fig. 1: Schematic illustration of the Titan Tumbler experimental chamber as seen from the side.