DRILLING INTO TITAN CRYOGENIC MATERIALS : WATER-AMMONIA ICE AND PARAFFIN WAX

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Introduction: The determination of Titan's surface composition was recognized as a likely pressing post-Cassini scientific priority at that world, even in the late 1990s [1], and remains a central objective in Ocean Worlds exploration [2]. Of particular astrobiological interest [3,4] is material where Titan's abundant photochemical organics (nitriles, PAHS and other hydrocarbons) have interacted with liquid water, in impact melt sheets or cryovolcanic flows. In such environments, laboratory experiments have shown that important biology-relevant compounds such as amino acids and pyrimidines can be generated, and will be preserved once these environments freeze. To assess the extent of this prebiotic chemistry, it will be necessary to ingest Titan surface material into sensitive chemical instrumentation, requiring sample acquisition and transfer. While Titan also has sediments (notably in sand dunes and streambeds) sampling of bulk solid targets will require a drill or similar system to generate cuttings which can be ingested using a pneumatic sample transfer system [5]. Supported by the NASA COLDTECH program, we have begun testing drill operations (figure 1) into candidate Titan materials at Titan temperatures to verify that suitable cuttings are generated.

Target Materials: As for other outer planet satellites, the dominant crustal material on Titan is expected to be water ice, which behaves mechanically at 94K like rocks on Earth. For cryolava flows, the expected material would be the water-ammonia peritectic (lowest-melting-temperature mixture), which melts at 176K and has a composition of ~30% NH_3. This water-ammonia ice has thermal and mechanical properties which differ from pure water ice [6]. A wide range of organic materials are present on Titan, and indeed appear to dominate the observable surface. Although these likely are in complex refractory mixtures ("tholins"), Titan's methane hydrological cycle may form evaporite deposits (analogous to salt or gypsum deposits on Earth) of simple compounds (e.g. paraffins such as butane [7]). For these initial tests, a paraffin wax that is solid at room temperature (Sigma-Aldrich, melting temperature 58-62^{o}C per ASTM D87) was used for convenience, and to permit comparison with room temperature tests of the same material.

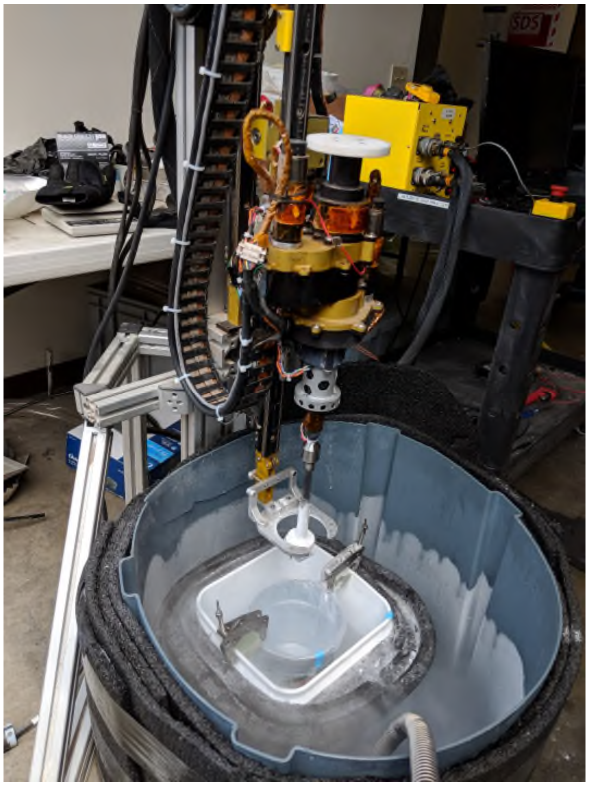

Figure 1: Test set-up at Honeybee's Pasadena facility. A rotary-percussive drill (black/gold) drives a custom bit (white, surrounded by a stabilization foot) into a ~2l sample container which is maintained below 100K by a liquid nitrogen bath. Outside this is a basin (blue) which retains a cold dry nitrogen atmosphere above the sample, preventing atmospheric moisture from freezing onto the sample or drill bit.

Test and Results: Water and ammonia solution were frozen to make their respective ices ; for the organic target, paraffin wax blocks were melted and then frozen to form a monolithic sample. Once samples were cooled by liquid nitrogen at 77 K, the Honeybee LITA (Life In The Atacama) rotary-percussive drill [8] was used with a dedicated bit (figure 2) advanced at 2 mm/s or less with a total (auger plus percussion) power of 50-60 W. The bit is conical to ensure it can always be withdrawn safely.

The first result is simply that of drill success : in all three materials tested, the drill generated cuttings and no seizing occurred. The specific energy for both water ice and water-ammonia ice was the same (~0.005 Whr/cc), while the paraffin wax had a value about 2x higher.

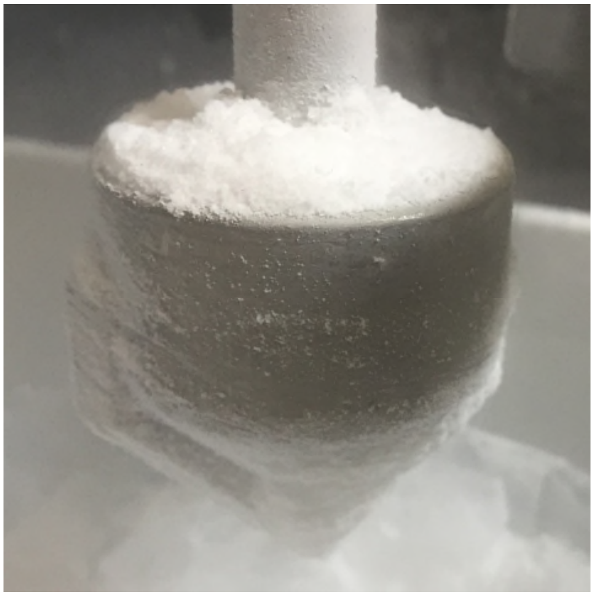

Figure 2: Close-up of the DRACO bit (DRill for the Acquisition of Complex Organics), 46mm in diameter, after drilling into frozen 30% ammonia solution (~ammonia dihydrate) ice at sub-100K temperatures. Satisfactory fine cuttings are generated.

Cuttings: Careful measures were taken to prevent condensation of moisture onto the sample cuttings, which were evaluated by an chilled inclined teflon plane to estimate friction coefficient and were visually inspected to assess particle size and shape. The materials tested generated more or less equant particles (i.e. no long 'swarf'). The water ice target generated fine powder, while the ammonia-water seemed to have a wider particle size range, with a number of larger chunks and aggregate particles, but many fine particles were also present. The paraffin wax (figure 3) interestingly had a prominent modal size fraction of 2-3 mm, the reason for which is not yet understood (it may be intrinsic to the material/temperature combination, or to the drill geometry, or both). Some fine particles were also present, however.

The water ice and water-ammonia cuttings had similar slip angles ; a steeper angle was required for the paraffin wax cuttings to slide, suggesting a higher cohesion/adhesion.

Figure 3: Close-up of the rotary-percussive cuttings from paraffin wax drilled at near 77K. Interestingly, a distinct 2-3mm particle size fraction dominates, although some finer particles exist

Conclusions: We have demonstrated that a rotary-percussive drill yields cuttings of Titan materials at Titan temperatures. The cuttings including fine material that can be ingested pneumatically. Further experiments are underway to evaluate different drill procedures (e.g. rotary-only) and different materials and temperatures.

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