THE ICEBREAKER DRILL SYSTEM: SAMPLE ACQUISITION AND DELIVERY FOR THE LUNAR RESOURCE PROSPECTING MISSION. K. Zacny[1], G. Paulsen[1], P. Chu[1], B. Mellerowicz[1], B. Yaggi[1] J. Kleinhenz[2], Jim Smith[3], [1]Honeybee Robotics, Pasadena, CA, zacny@honeybeerobotics.com, [2]NASA Glenn Research Center, Cleveland, OH 44135, julie.e.kleinhenz@nasa.gov, [3]NASA Kennedy Space Center, Florida, 32899, james.t.smith@nasa.gov

Introduction: The goal of the Lunar Resource Prospecting Mission (RPM) concept is to capture and identify volatiles species within the top one meter of the lunar regolith layer [1]. The RPM rover consists of five elements: 1. The Neutron Spectrometer Subsystem (NSS) which will localize elevated hydrogen concentration and in turn select optimum drilling location. 2. The Drill Subsystem which will capture samples from up to one meter depth and deliver these to the the Oxygen and Volatile Extraction Node (OVEN). 3. The Near InfraRed Volatiles Spectrometer Subsystem (NIRVSS) which will characterize hydrocarbons, mineralogical context for the site, and the nature of water ice. It will be placed in such a way as to enable characterization of fresh cuttings as they are being augered by the drill and in turn it will help in determining at what point in the drilling process to stop and deliver samples to the Oxygen and Volatile Extraction Node (OVEN) subsystem. 4. The OVEN will heat up and in turn evolve the volatiles in the sample delivered by the drill. Volatiles will be transfer to the Lunar Advanced Volatiles Analysis (LAVA) subsystem. 5. LAVA is a GC/MS and will quantify and characterize volatile species. The OVEN has a secondary goal to demonstrate hydrogen reduction process, while LAVA will perform Water Droplet Demonstration (WDD).

This abstract focuses on the Drill Subsystem.

The Drill: The RPM drill is based on the Mars Icebreaker drill developed for capturing samples of ice and ice cemented ground on Mars [2]. The drill weighs approximately 10 kg and is rated at ~300 Watt. It is a rotary-percussive, fully autonomous drill system designed to capture powdered rocks and regolith samples for analysis. The drill consists of following subsystems: 1. Rotary-Percussive Drill Head, 2. Sampling Auger, 3. Brushing station, 4. Z-stage, 5. Deployment stage.

The drill head has been designed with rotation and percussion decoupled. This allows the use of more energy intensive percussive system only when required (e.g., to penetrate harder formations). Both rotary and percussive motors are approximately 150 Watt each.

To reduce sample handling complexity, the drill auger was designed to capture cuttings and soils as opposed to cores. High sampling efficiencies are possible through a dual design of the auger (**Figure 1**). The lower section of the auger has deep and low pitch flutes. This geometry creates natural cavities ideal for retaining granular materials (cuttings and soil). The upper section of the auger has been designed to efficiently move the cuttings out of the hole.

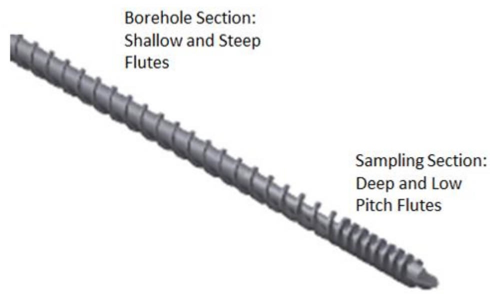

Figure 1. Dual stage auger.

The drill uses a “bite” sampling approach where samples are captured in ~10 cm intervals as shown in **Figure 2** [3, 4]. After drilling 10 cm, the auger with the sample is pulled out of the hole, and the sample is brushed off into one-cc cups by a passive brush within the Brushing station. An advantage of the “bite” sampling approach is that stratigraphy is preserved because a sample comes from a known depth.

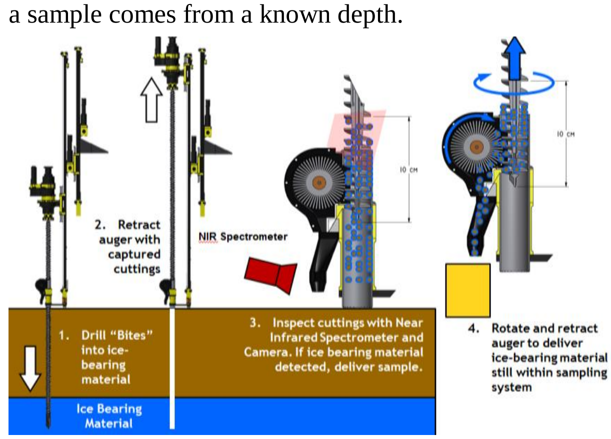

Figure 2. Implementation of the Icebreaker drill system for the RPM mission.

The Deployment stage lowers and preloads the drill system on the ground. The Z-stage, on the other hand, is used to advance the auger to a one meter depth. Both stages are pulley-based to reduce system weight and vibration to the rover and improve dust tolerance.

From Mars to the Moon: The Icebreaker was designed for the Mars Icebreaker mission to capture ice and ice cemented ground at the Northern Polar Regions of Mars [2]. The difference between the Mars mission and the lunar mission are as follow: Mars mission requires adherence to the Planetary Protection protocols while the lunar mission does not – this makes Lunar drill less expensive. Mars regolith contains perchlorate, which depresses freezing point. Since atmospheric pressure on Mars is high enough to support liquid water, the presence of perchlorates in icy-soils presents additional sampling complexity related to stickiness of soil. Drill cuttings might stick, clump up, and refreeze – this problem is less likely on the Moon. Large distance (and in turn communication delay) between the Earth and Mars requires full autonomy, while drill on the Moon, could be teleoperated or include supervised autonomy. The Moon, on the other hand, has large thermal swings from 40K – 400K which presents design challenges. In addition, in hard vacuum, ice sublimation is extremely fast at temperatures above >106 K. Hence the drill needs to be extremely efficient to reduced sample heating, the sample delivery system needs to be fast and preferably in a shadow to keep cold at all times.

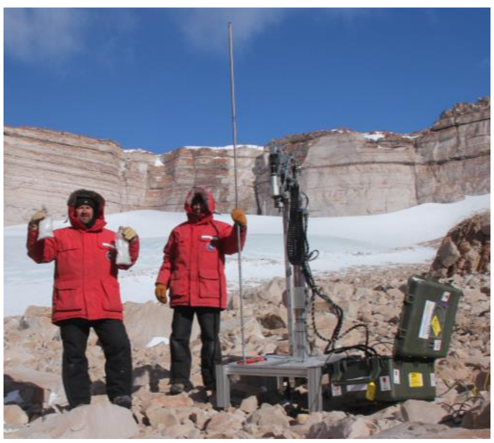

Figure 3. The Icebreaker1 tests in Antarctica [3, 4].

Figure 4. The IceBreaker2 (called LITA) was tested in Atacama on CMU Zoe rover [5].

Drill Testing: The 1st generation Icebreaker drill has been tested in a Mars vacuum chamber as well as in Antarctica and the Arctic (**Figure 3**). It demonstrated drilling at 1-1-100-100 level (1 meter in 1 hour with 100 Watt and 100 N Weight on Bit) in ice, ice cemented ground, soil, and rocks. The 2nd generation Icebreaker drill has been deployed on a Carnegie Mellon University rover, called Zoe, and tested in Atacama in 2012 – see **Figure 4** [5]. The tests demonstrated fully autonomous sample acquisition and delivery to a 20 cup carousel – in a similar manner as on the RPM rover. The 3rd generation Icebreaker drill has been redesigned to allow testing in NASA GRC's vacuum chamber, VF13, at 10^{-5} torr and approximately 200 K [6]. These tests contacted in frozen bed of NU-LHT-3M lunar regolith simulant with 5 wt% water, demonstrated suitability of the auger sampling approach for the RPM mission. During the tests, samples lost average 30% water during drilling and transfer operation. The percentage of water loss correlates well with ambient temperature (lower temperature → lower loss). Volatiles loss matches sublimation rates at the same temperature.

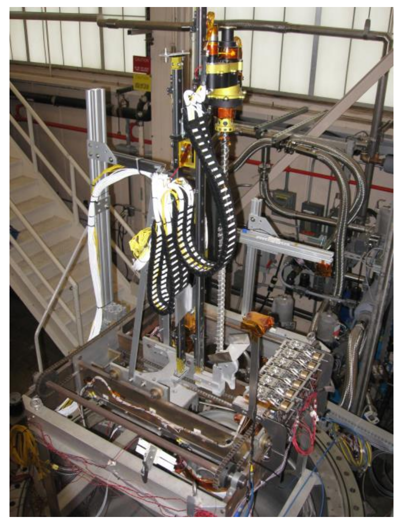

Figure 5. The Icebreaker3 drill system was successfully tested at NASA GRC vacuum chamber, VF13, at 10^{-5} torr and 200 K. [6].

Currently the drill is being modified for integration with the NASA JSC RPM rover prototype and field testing in the summer of 2015.

References: [1] Andrews et al., (2014), Resource Prospecting Mission, AIAA Space. [2] McKay et al., (2013) The Icebreaker Life mission to Mars: a search for biomolecular evidence for life. Astrobiology 13. [3] Paulsen et al., (2011), Testing of a 1 meter Mars IceBreaker Drill in a 3.5 meter Vacuum Chamber and in an Antarctic Mars Analog Site, AIAA Space. [4] Zacny, et al., (2013), Reaching 1 m Deep on Mars: The Icebreaker Drill, Astrobiology. [5] http://www.youtube.com/watch?v=QE7aYUnAA9o; [6] Kleinhenz et al., (2015), Impact of Drilling Operations on Lunar Volatiles Capture: Thermal Vacuum Tests, AIAA SciTech.

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