1 M CLASS DRILL FOR ACQUISITION AND TRANSFER OF VOLATILE RICH SAMPLES ON THE MOON, MARS, AND OCEAN WORLDS. K. Zacny[1], G. Paulsen[1], [1]Honeybee Robotics, Pasadena, CA, zacny@honeybeerobotics.com,

Introduction: For over a decade, Honeybee Robotics has been developing 1 m class sample acquisition drills for accessing volatile rich planetary regolith on Mars and the Moon. The latest drill system is at TRL6 and ready to be infused into missions requiring acquisition of samples from approx. 20 cm to 2 m depth (the drill is scalable with respect to the depth), on any planetary surfaces (Mars, Moon, Comets, Ocean Worlds)

TRL4 Icebreaker Drill: The technology for 1 m class drill started with the development of the TRL4 Icebreaker drill for the Mars Icebreaker mission (**Figure 1**). The drill has been extensively tested in the Arctic, Antarctica, and Mars chamber as shown in **Figure 2**. The system demonstrated drilling in rocks, ice cemented ground, and ice with low power (100-200 Watt), low Weight on Bit (<100 N) and high penetration rate (1 m/hr). During drilling in Dry Valleys, the bit temperature never exceeded -5 °C (in the ground temperature of -19 °C). These tests have shown that drilling on Mars, in ice cemented ground with limited power, energy and Weight on Bit, and collecting samples in discrete depth intervals is possible within the mass, power, and energy levels of a Phoenix-size lander.

The drill uses a bite sampling approach whereby samples (nominally 10 cc in volume) are captured at the lowest section of the auger. The auger is then pulled out of the hole and sample is transferred to a cup or a funnel. The auger is lowered back into the same hole to drill another 10 cm and capture another ~10 cc sample. This process continues all the way to 100 cm depth. The process can be sped up if needed, i.e. the drill can drill all the way to say 70 cm and capture sample between 60 cm and 70 cm depth. This approach preserves stratigraphy (in bites), allows subsurface to cool, and reduces auger torque and power because sample does not need to be augered to the surface.

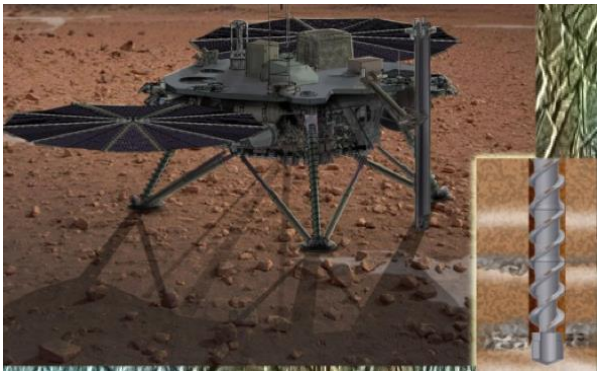


Figure 1. Mars Icebreaker mission concept. [1]

Figure 2. IceBreaker drill in the University Valley, Antarctica. [2, 3]

TRL4/5 LITA Drill: The next generation drill called the LITA drill (Life In The Atacama) achieved TRL 4/5 through significant reduction of mass (the Icebreaker drill weighed 40 kg while the LITA drill weighed 10 kg). The LITA drill has been deployed from a CMU rover in Atacama and in Greenland [4].

The goals of the field campaign were to demonstrate full autonomy the rate end-to-end sample acquisition and delivery from a variety of soils and rocks. During the course of the field deployment 6 holes have been drilled. The autonomy has been successfully demonstrated every time. In all cases, the average drilling power was less than 15 Watts because percussive system did not have to be engaged for most of the time. The Weight on Bit was also low, at 50 N or less. It took approximately 1.5 hours for the end-to-end sample acquisition and delivery.

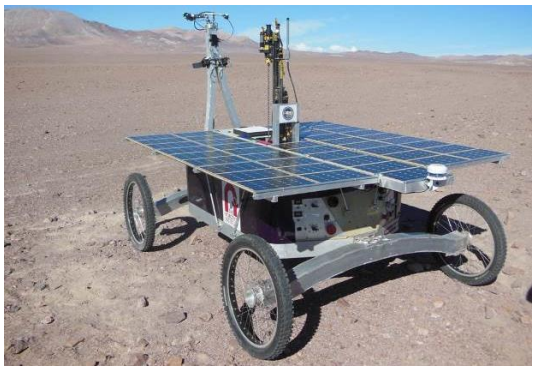


Figure 3. The LITA drill in Atacama deployed off CMU rover. [4]

TRL 5 Resource Prospector Drill: A LITA drill has been modified to reach TRL5 via changes to the drill actuators, lubrication, drill bit designs and so on.

It has subsequently been deployed from a Resource Prospector rover at NASA JSC (Figure 4) and has undergone thermal vacuum tests at NASA GRC [6]. During these vacuum tests, the drill captured volatile rich samples (NU-LHT-3M with 5wt% water) at -100 °C and deposited them into cups. The drill has also successfully withstood vibration tests (Figure 5).

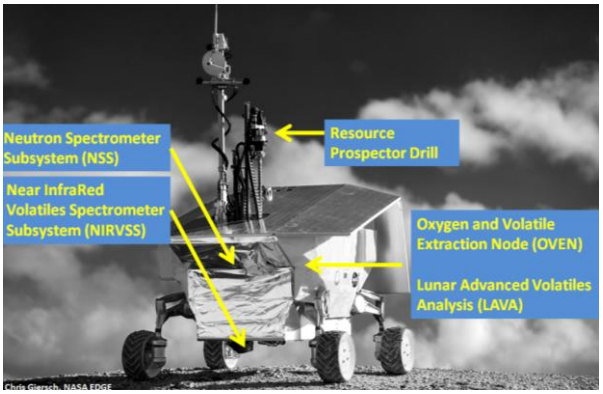


Figure 4. The Resource Prospector (RP) rover with Honeybee 1 m class drill. [5]

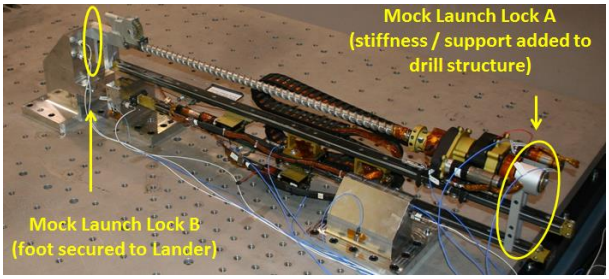
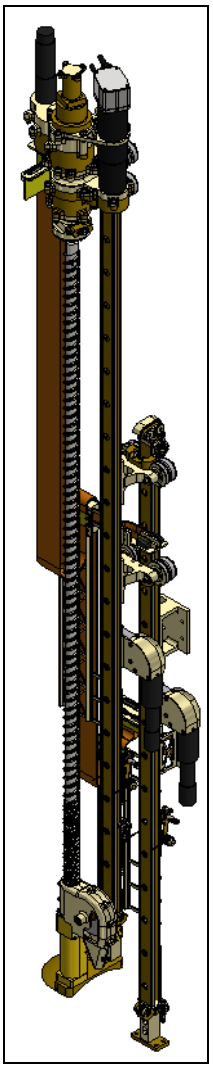


Figure 5. LITA drill setup for Vibration Tests at NASA KSC. [7]

TRL6 Resource Prospector drill: The latest 1 m class drill is being fabricated and will be available in October 2016. The drill has four actuators - two to drive rotary-percussive drill head and two to lower the deployment stage and the auger into the ground. The total rated power is approx. 500 Watt. The drill weighs approx. 15 kg. we plan to fabricate three such drills. First copy will be delivered to NASA KSC for testing for the Resource Prospector mission, second copy will be delivered to NASA Ames for integration with the K-Rex2 rover and deployment in the Atacama and the third copy will remain at Honeybee Robotics for further testing. All three drills in the course of their life will undergo further field deployment (Arctic, Atacama), chamber tests (Mars chamber at Honeybee Robotics and Lunar chamber at NASA Glenn Research Center). The drills will be deployed on two rovers (NASA JSC and NASA Ames). They will also undergo vibration tests at a subsystem level and as part of the entire system (while mounted on the rover). Finally, the drill will undergo thermal vacuum tests.



Parameter	Value
Bit Diam. (mm)	25.4
Auger Max (RPM)	120
Auger Torque Cont. (Nm)	14.9
Auger Max Cont. Power Out (W)	187
Percuss Energy (JPB)	4.0
Percuss Rate Max (BPM)	1160
Drill Stroke (mm)	~1186
Drill Depth (mm)	~1000
Deployment Stroke (mm)	~800
Z Stage Force Cont. (N)	~508
Total Mass (kg)	~15

Figure 6. TRL6 - 1 m drill.

References: [1] McKay et al., (2013), The Icebreaker Life Mission to Mars: A search for biomolecular evidence for life, Astrob. [2] Zacny, et al., (2013), Reaching 1 m Deep on Mars: The Icebreaker Drill, Astrob. [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] Cabrol et al., (2015) Life in the Atacama: Science and Technology Pathways to the Robotic Search for Life on Mars, LPSC. [5] Andrews et al., (2014), Resource Prospecting Mission, AIAA Space. [6] Kleinhenz et al., (2015), Impact of Drilling Operations on Lunar Volatiles Capture: Thermal Vac Tests, AIAA SciTech.

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