LITA DRILL TESTS AT HAUGHTON CRATER. B. Glass[1], A. Wang[2], S. Huffman[1], K. Zacny[2], P. Lee[1]. [1]NASA Ames Research Center, Moffett Field, CA 94305, USA, Email: brian.glass@nasa.gov, [2]Honeybee Robotics, Pasadena, CA, 91103, USA.

Abstract: Exploring and interrogating the shallow subsurface of Mars from the surface will require some form of excavation and penetration, with drilling being the most mature approach. The latest LITA drill, designed for use at the Atacama Desert Chilean analog site, was recently tested at the same Arctic site (Haughton Crater) as have a series of past NASA drill prototypes since 2004. Unlike previous tested prototypes, the smaller LITA did not demonstrate a capability of penetrating hard rock or ice-consolidated material at the Drill Hill test site.

Introduction: For sample return and in situ Mars surface missions, delving past the near-surface ice layers on Mars in search of organics and possibly signs of past/extant life will require lightweight, low-mass planetary drilling and sample handling. Unlike terrestrial drills, these exploration drills must work dry (without drilling muds or lubricants), blind (no prior local or regional seismic or other surveys), and light (very low downward force or weight on bit, and perhaps 100W available from solar power). Given the lightspeed transmission delays to Mars, an exploratory planetary drill cannot be controlled directly from Earth. Drills that penetrate deeper than a few cm are likely to get stuck if operated open-loop (the MSL drill only goes 5cm, and the MER RATs 5mm by comparison), so some form of local drill control is required. In the relatively near-term (prior to 2030), human crews cannot be presumed to be available for surface instrument teleoperation in the vicinity of Mars. Therefore highly automated drill and sample-transfer operations will be required, to explore the shallow Martian subsurface with the ability to safe the robotic drilling system and recover and continue on from the most probable fault conditions. [1]

Planetary Sampling Drill Concepts: Several past NASA-sponsored development efforts have attempted to test different aspects of automated drilling. The Mars Analog Rio Tinto Experiment (MARTE) went to a biological analog site with a local anaerobic ecosystem, to test life-detection instruments fed by a multi-string drill with automated string changeout, sample core extraction, handling and curation. It demonstrated fully automated topside operations, but all drilling was human-supervised in the field [2]. The Drilling Automation for Mars Exploration (DAME) project conversely went to an Arctic impact crater site (Haughton Crater) to develop and test fully automated drilling, including fault detection, recovery and resumption of drilling, without human intervention [3]. Put together, MARTE and DAME demonstrated end-to-end the automation necessary for a drilling mission beyond the Moon, with conventional rotary-drag drills.

However, given the presence of likely basaltic rocks and ice on Mars, rotary-percussive drills make more efficient headway and are faster than rotary-drag designs. The Construction and Resource Utilization Explorer (CRUX) drill and Icebreaker drills were rotary-percussive prototype drill designs that were tested with hands-off fully-automated controls, also at the Haughton Crater analog site and in Mars chamber tests, in 2009-12 [4]. The most recent generation of Mars-prototype robotic drills is the Life In The Atacama (LITA) rotary-percussive drill (Figure 1) [5]. LITA has been deployed in 2012-13 in Chile to break through salt crusts and into modestly consolidated soils to depths of 0.5-1m, from a mobile platform. It was designed to be a smaller and lighter cousin of the Icebreaker drill (9kg vs 32 kg) while retaining the latter's sampling auger flutes (rather than coring).

Figure 1. Life In The Atacama (LITA) 9kg drill during August 2013 testing at Drill Hill in Haughton Crater.

Capabilities: LITA, like Icebreaker, operates under 100W power and at low downward forces (<100N). It was tested in Chile (manual control) in

May 2012, then at Haughton Crater in August 2013. It is considered to be at TRL 5.

Study Objectives: Objectives for the Haughton Crater tests in 2013 were to test the LITA drill in frozen impact breccia; to equal the maximum single-hole depth drilled by the earlier Icebreaker Mars-prototype drill design (2.1m); to demonstrate the expected fault modes of this drill, for use in developing failure detection and automated control software; and to compare the reliability, the required energy and the downward forces needed to make headway, compared with other drill designs tested in the past at the same site.

As was done with the Icebreaker drill tests in 2012 [4], a Phoenix-sixed platform was set up adjacent to the drill with a sample transfer arm and a mockup SOLID instrument with an inlet target for automated delivery of sample.

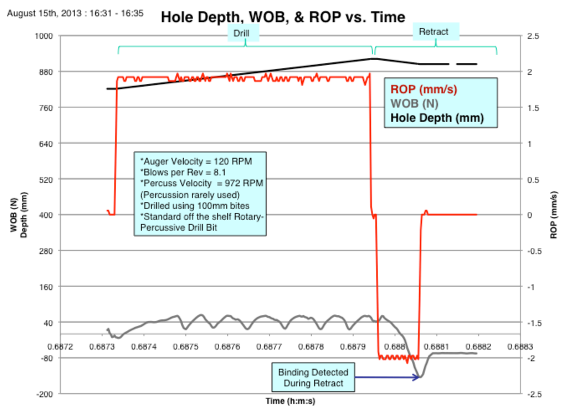

Fig. 2. The LITA drill was not able to penetrate into the fallback breccia permafrost and became stuck at 90cm depth (18cm into permafrost).

Field Test Site: The Haughton Crater planetary-analog drilling site is a high-fidelity analog for Mars landing sites with subsurface ice (as at the Martian higher latitudes) and the broken, depth-graded textures similar to impact regolith. The active-layer boundary in 2013 at Drill Hill was observed to be at 72cm depth. The Haughton-Mars Project operates a research station in the Canadian Arctic adjacent to Haughton Crater, on Devon Island, Nunavut at 75.2N, 89.7W. The Haughton Crater Research Station (HCRS) base provides seasonal logistical support for up to 40 researchers and staff working in or around the 22-km wide Haughton Crater impact site during summer months.

Results: The LITA drill was tested at the Haughton crater site in August 2013. LITA drilled >3m, in four holes, but LITA lacked sufficient power (torque) and shaft stiffness to break and penetrate hard rock or ice-consolidated material. Once past the dry active layer, the drill could not apply enough torque to avoid binding/freezing once in permafrost. At LITA's deepest penetration (90cm), the drill string became stuck (Figure 2), and the drill string itself failed, with metal sheared through at the string attachment point. Subsequent boreholes were constrained to penetrate no more than 10cm into ice-consolidated soils, hence with most drilling done in the relatively drier unfrozen active layer. Despite this operating restriction, five (of six) primary drill hardware faults were encountered naturally in the course of drilling.

The LITA drill strings were modified from an existing commercial drillstring (unlike those of the larger drills tested in previous years at Haughton, which were designed for those drills specifically). The greater string-length-to-cross-sectional-area aspect ratio, and greater flex of the LITA strings, may have caused applied torques to elastically wind the string rather than transmit energy efficiently to the bit. Observed torsional shear loading, which caused 20-25 binding faults, are probably due to partial melt-refreeze on the augers' sampling-end flutes, as shown in Figure 3.

Fig. 3. LITA sampling auger end-flutes were susceptible to fouling and refreezing given a microcrystalline matrix of ice particles and cuttings.

Conclusions: The very lightweight, low-power, low weight-on-bit, thin-shafted LITA drill was not capable of penetrating hard rock or ice-consolidated material at the Drill Hill test site – unlike earlier results with larger and more-massive drills tested there. Rather than use a LITA-like design for an Icebreaker-like mission (1-2m depth into icy layers), LITA would be better used as a prototype for sampling in relatively unconsolidated, dry material to 0.5 m depth (like asteroid anchoring, Atacama salt crusts, or as a shallow 20-30cm rover-mounted drill). A stiffer drillstring material would be likely to improve rotary-percussive operation in when there is significant torsional drag on the drillstring.

References: [1] Glass, B. et al. (2006) *LPSC XXXVII*, Abstract 2300. [2] Stoker, C. et al. (2008) *Astrobiology*. [3] Glass, B. et al, (2008) *Astrobiology*. [4] Glass, B., et al, (2013) *LPSC XLIV*. [5] Zacny, K., et al, (2013) *LPSC XLIV*.