Icebreaker-3 Mars-Analog Sample Acquisition Tests

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Abstract: Looking for organics, biomarkers and signs of past or extant life on Mars will require sample acquisition there below the desiccated and irradiated surface. A decade of evolutionary development of integrated automated drilling and sample handling at analog sites and in test chambers has made it possible to go deeper through hard rocks and ice layers on Mars. The latest Icebreaker-3 drill has been tested with a Phoenix mockup and at the Haughton Crater Mars-analog site in the Arctic (with sample transfer arm) and in a Mars chamber, with successful sample acquisition under automated control.

Introduction: 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. In 2013 the Icebreaker-2/LITA drill, designed for use at the Atacama Desert Chilean Mars-analog site, was tested at the Haughton Crater Mars-analog site [1]. Unlike previous tested prototypes since 2004, the 10kg/1m depth LITA did not demonstrate a capability of penetrating hard rock or ice-consolidated material. Earlier Mars-drill prototypes could penetrate these materials, but are too massive to fly on a Phoenix-sized payload [2] (Table 1)

Unlike terrestrial drills, Mars 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 drill automation is required. [3]

Icebreaker-3 Approach: While the earlier LITA drill worked well in the Atacama desert [4] and in lab tests, it did not perform satisfactorily in Haughton Crater's impact-breccia permafrost [1]. A stiffer drillstring material was needed to improve rotary-percussive operation in when there was significant torsional drag on the drillstring. Post-test analysis of the LITA drill performance issues in ice-cemented ground and ice lenses indicated that a stiffer shaft design with more drill-head rotary power (applied torques) would be needed to break those layers and overcome parasitic auger drag on the sides of the drill string. The ability to reverse-rotate would be also needed in order to extricate the drill by backing out when sensors indicate that a jam or sticking is imminent. And a temperature sensor in the drill bit would be very useful to monitor when the frictional heating of cuttings is approaching the triple point (and hence sample alteration, and Phoenix-like clumping of materials). Figure 1 shows the design changes.

The resulting Icebreaker-3 drill, completed in June 2014, added back 2 kg mass (to 12 kg) compared to LITA, but was still 3-5x less massive than earlier prototypes. Power consumption is comparable to LITA (typically 30-40 W, 200W max during 5-10 min drilling sequences). It was tested at the Haughton Crater analog site in the Canadian Arctic, as have a series of drill prototypes (shown in Table 1).

Study Objectives: Objectives for the Icebreaker-3 (IB-3) drill tests in 2014 were: (a) to confirm nominal operations and the efficacy of the design changes under lab conditions, (b) test drilling operations and behavior under the same permafrost conditions at Haughton Crater that hampered the LITA drill, and confirm satisfactory performance there with the IB-3, (c) confirm the interoperability of the IB-3 with a sample transfer robotic arm (into instrument inlets [5]), and (d) test the IB-3 in a Mars chamber to confirm performance and to study the grain size of the icy cuttings produced (see [6] for that description and results).

Objectives for the Haughton Crater tests in 2014 were to test the IB-3 drill in frozen impact breccia; to surpass the maximum single-hole depth drilled by the earlier LITA Mars-prototype drill design (92 cm); to demonstrate the expected fault modes of this drill, for use in developing failure detection and automated control software; and to compare the reliability, required energy and the downward forces needed to make headway, compared with other drill designs (Table 1). For initial lab testing of IB-3 prior to Arctic deployment in June 2014, a Phoenix deck mockup platform at Honeybee Robotics 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(a) shows IB-3 deployed over the deck alongside integrated sample transfer arm. The Haughton Crater deployment is shown in Fig. 2(b).

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 2014 at Drill Hill was observed to be at 51cm depth.

Results: The IB-3 drill was tested at the Haughton Crater site in August 2014. IB-3 drilled >5m, in six boreholes, and with sufficient power (torque) and shaft stiffness to break and penetrate hard rock or ice-consolidated material (a typical "bite" shown in Figure 3). IB-3 drilled >2m in ice or ice-consolidated material (compared to 30cm by the LITA drill in 2013). Unlike prior prototypes (Table 1) IB-3 drilled rapidly and experienced almost no fault conditions. Prior melt-refreeze and binding faults seen often with LITA were not experienced by IB-3. A corkscrewing fault recovery upon drill retraction is shown in Figure 4.

Interoperability testing at Honeybee in June 2014 demonstrated that the IB-3's sample (cuttings) was handed-off from the drill to a sample transfer arm and thence to instrument inlets ("dirt-to-data" from [5]).

Conclusions: The very lightweight, low-power, low weight-on-bit, Icebreaker-3 drill with its design improvements was capable of penetrating hard rock and ice-consolidated material in lab, chamber and field tests. The stiffer drillstring, stronger motors and reverse rotation capability improved drilling operations notably over prior designs and with sample transfer interoperability demonstrates a technology readiness level suitable for consideration as a flight sample acquisition instrument.

References: [1] Glass, B., et al, (2014) *LPSC XLV.* [2] Glass, B. et al, (2014) *J. Field Robotics.* [3] Glass, B. et al. (2008) *Astrobiology*. [4] Zacny, K., et al, (2013) *LPSC XLIV.* [5] Dave, A., et al, (2013) *Astrobiology.* [6] Bergman, D. et al, (2015) *LPSC XLVI.*

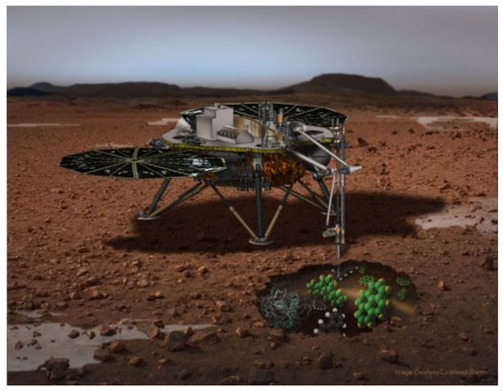
Aerial view from 10,000 feet of the Haughton Crater impact structure, showing grey fallback breccia deposits and eroded crater landforms and gullies analogous to Mars terrain. Drill Hill is on the left edge of the breccia as shown.

Location of Haughton Crater field tests, in Nunavut, Canada [NGS]

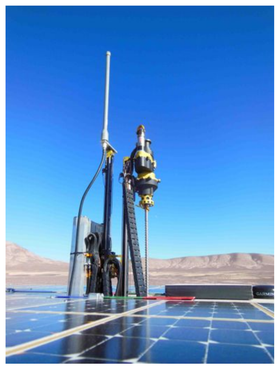
Arctic field test camp location at Drill Hill in Haughton Crater. Note the frost polygons in the grey impact breccia.

Table 1. Mars-prototype drill tests at Haughton Crater.

Drill	Program	Type	Depth Max	Deployed Mass (kg)	Haughton Crater Field Tests
DAME	MIDP, MTP	Rotary	7m	55	2004-6, 2008
CRUX	HEOMD and ASTID	Rotary-Percussive	4m	43	2009, 2010
Icebreaker (IceBite)	ASTID and ASTEP	Rotary-Percussive	3m	32	2011, 2012
LITA/Icebreaker-2	ASTEP	Rotary-Percussive	2m	10	2013
Icebreaker-3	ASTEP and MMAMA	Rotary-Percussive	2m	12	2014

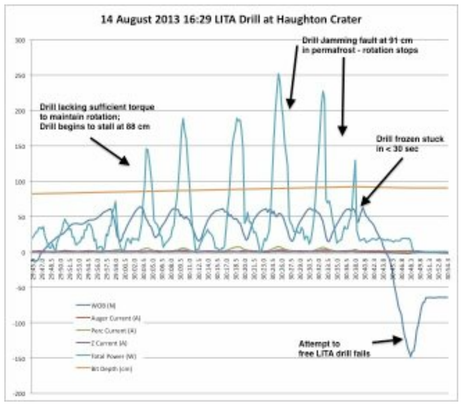


Icebreaker drill and life-detection science payload, proposed for a 2020-21 Discovery mission on a InSight-based platform [LMA].



Life In The Atacama (LITA) drill, mounted on the CMU Zoe rover deck in Chile in 2012. [HBR] [4]

In 2013 Haughton Crater tests, the LITA sampling auger end-flutes were susceptible to fouling and became stuck. [1]



In 2013 prior tests, LITA drill could not maintain headway beyond 19 cm of permafrost, became jammed and then frozen stuck at 91 cm depth.

Icebreaker-3 Drill Testing – 2014 Results

- **Icebreaker-3 drill with its design improvements was capable of penetrating hard rock and icy material in lab, chamber and field tests. IB-3 drilled >5m, in six boreholes.**
- **IB-3 drilled >2m in ice or ice-consolidated material (compared to 30cm by the LITA drill in 2013).**
- **Very lightweight (12 kg), low-power (30-40W), low weight-on-bit (40-80N), few faults detected (compared to LITA).**
- **With sample transfer interoperability, demonstrates a technology readiness level suitable for consideration as a flight sample acquisition instrument.**

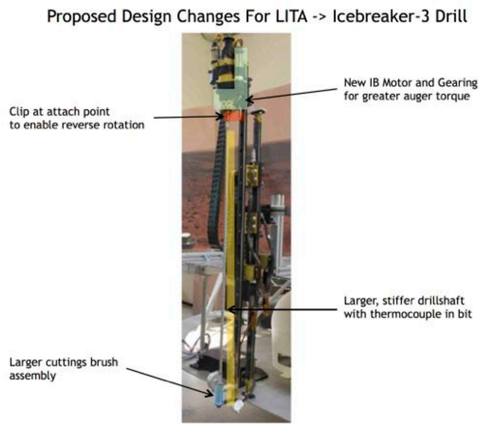


Fig. 1. Changes to the LITA drill design, addressing the 2013 results – new "Icebreaker-3" configuration as a Mars-prototype for sample acquisition.

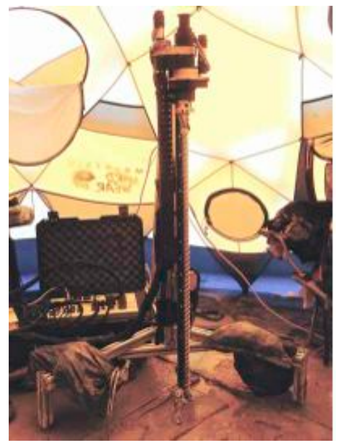


Fig. 2(b). In August 2014, the revised-design IB-3 drill was tested at the Haughton Crater Mars-analog site.

Fig. 2(a). IB-3 tested June 2014 with sample transfer arm on InSight deck mockup; drilled sample transferred to Wet Chemistry Lab mockup inlet.

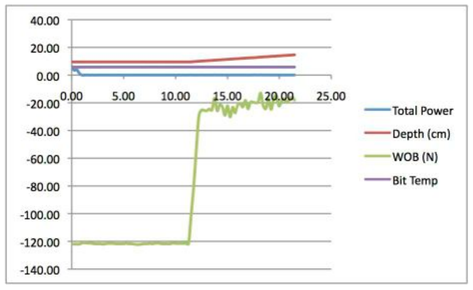
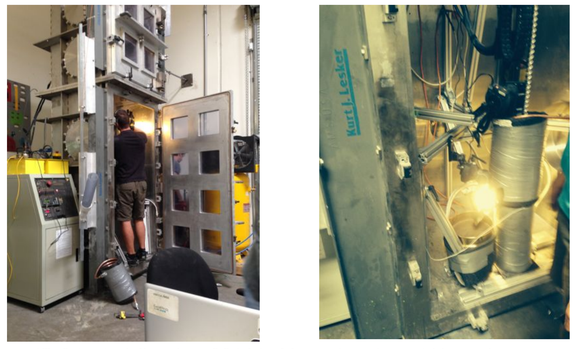


Fig. 4. Corkscrewing fault recovery on 2 August 2014 at Haughton Crater by Icebreaker-3 drill.



IB-3 tested October 2014 in Mars chamber at Honeybee Robotics, to study sample particle sizes produced by drilling (see results in Bergman et al [6]).

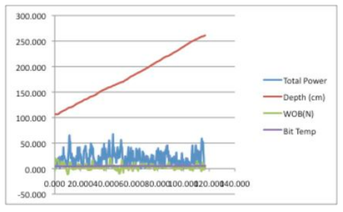
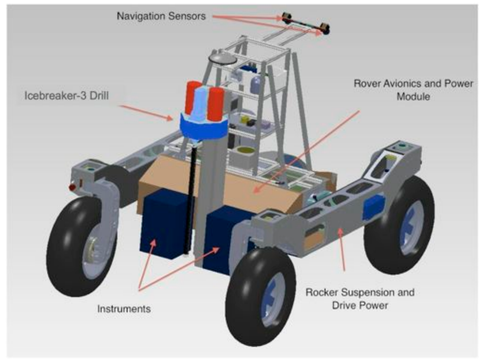


Fig. 3. Nominal 15 cm (150mm) drilling "bite" by IB-3 during Haughton Crater tests.



IB-3 drill will return to the Atacama, on a NASA Ames K-REX rover, as part of new ARADS PSTAR project.