DRILLING AND AUTOMATION FOR MARS EXPLORATION – 3RD FIELD TEST ON DEVON ISLAND.

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Introduction: The third Drilling Automation for Mars Exploration (DAME) Field test took place inside the Haughton Crater on Devon Island in the Canadian High Arctic between July 18th and 29th. This season's objective was to demonstrate autonomous drilling capabilities while drilling with a peak power of less than 150 Watts. The formation at the drilling location could be described as broken and ground up impact breccia (mainly carbonate) with various fractions of ice ranging from 11 wt% to 100 wt% (i.e. pure ice lenses). The final depth reached was 3.19 m, which is the Devon Island record. Figure 1 shows the depth drilled during consecutive days. The ice was encountered at the depth of approximalet 50 cm as shown in Figure 2.

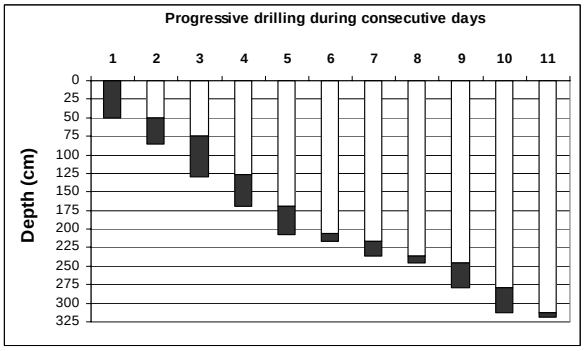

Figure 1. Drilling depth reached during consecutive days. The final depth was 3.19 m, which is new Devon Island record.

Figure 2. The first core retrieved from a depth of around 45-50cm confirmed the boundary of permafrost layer.

The DAME Drill Setup: The DAME drill, shown in Figure 3, was designed and built by Honeybee Robotics [1, 2]. Since this drill had to endure three trips to Devon Island as well as multiple trips across the United States, all including setup and teardown, it was designed in its simplest state. That is, it only actuates the basic two axes required for automated drilling, the auger and Z or vertical axis. Automated drill string addition and removal and automated core capture and retrieval were not included with this model. For this field test, three different drill bits were used. Two bits were full-faced drill bits with Tungsten Carbide cutting teeth and the third was a 5.08 cm (2 inch) coring bit with tungsten carbide cutting teeth.

Figure 3. DAME Drill during 2006 field test on Devon Island, Nunavut Canada.

Drilling automation and fault recovery is the main function of the DAME drill. For this reason, Honeybee included seven sensors in its design. A load cell was used to measure the drilling down force or Weight On Bit (WOB); two optical encoders were used to track and control the position and velocity of the Z axis and the auger; a torque sensor was built into the lead drill string to measure the torque directly at the bit (cutting torque); a thermistor was also built into the lead drill string to measure the bit temperature; and two current sensors were used to measure the current draw from the auger and Z axis motors.

Researchers at Georgia tech also used two different laser vibrometers sensors to measure the vibrations in

the drill string. Each vibrometer measured a different frequency range.

Stratigraphy to the Depth of 3.2 m: From chips (or cuttings) recovered off of the auger flutes and from cores retrieved at known depths, a detailed stratigraphy of the subsurface was reconstructed and is shown in Figure 4. The stratigraphy data was very useful when drilling telemetry such as WOB, power, temperature, rate of penetration (ROP), and torque were analyzed. It is important to note that the actual formation types could only be correctly inferred from cores. Cuttings did provide some information but the interpretation may have been misleading. For example, if the drill penetrated relatively dry permafrost followed by an ice layer, cuttings would have a consistency of a mud. A good example illustrating such a possibility is shown in Figure 4 in a picture marked "161-174 cm". Another plausible interpretation for the origin of mud would also be fully or partially saturated permafrost.

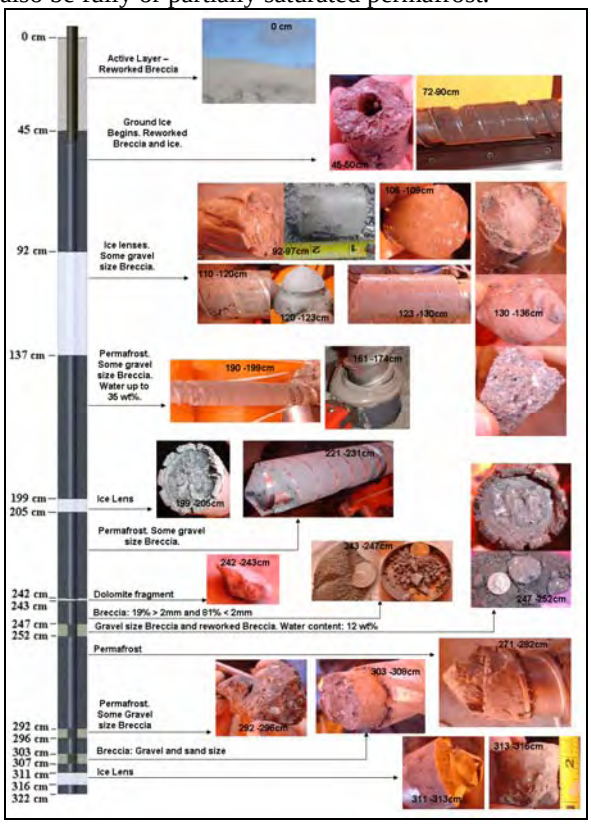

Figure 4: Stratigraphy of "Drill Hill" on Devon Island, Nunavut Canada to a depth of 3.2 meters.

Temperature of the Formation: The depth of the hole and the temperature of the formation at the bottom of the hole were measured each morning before the start of the drilling test. Figure 5 shows the thermal profile of the subsurface and the air temperature as a function of hole depth. The formation temperature decreased with depth, as expected. The lowest temperature (-12.8 ºC) was recorded at a depth of 312 cm (the temperature at the maximum depth of 319 cm was not measured). Note the arrow pointing to the temperature data point at a depth of around 215 cm. This temperature measurement was slightly higher than expected and can be attributed to the fact that the top of the hole (the hole entry) was not sufficiently capped (or insulated) overnight. In all other cases, the top of the hole was covered to prevent warm outside air from entering the hole.

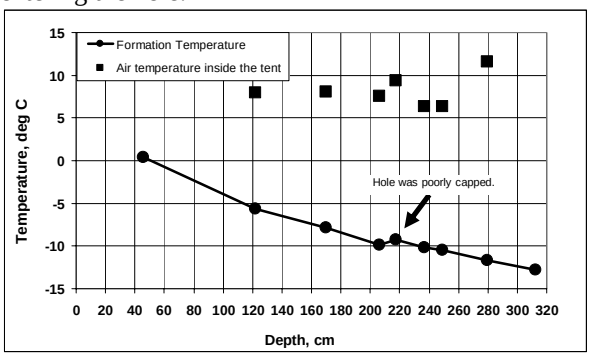

Figure 5. Temperature profile of the permafrost as measured at the bottom of the drilled hole each at the beginning of each field day. Also plotted is the ambient air temperature.

Bit Temperature: During the drilling process, the bit temperature was measured using a thermistor embedded inside the bit body. The data shown in Figure 6 shows the bit temperature vs. bit power for two different depth regions. The temperature of the formation is also indicated on the same graph. The data shows that the temperature in the 161 cm to 166 cm region is a few degrees higher than the temperature in the depth range from 272 cm to 276 cm for the same power values. The explanation for this difference is that the physical temperature of the subsurface is about 5 ºC lower in the 272 cm to 276 cm region and in turn the heat flow out of the bit occurred at a higher rate.

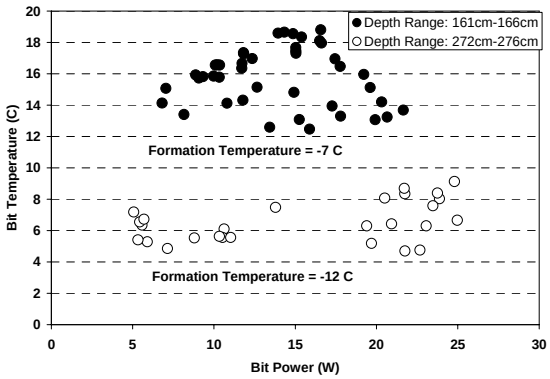

Figure 6. Bit Temperature (ºC) vs. Bit Power (Watts) in the depth ranges of 161 cm to 166 cm and 272 cm to 276 cm.

References: [1] Paulsen G. et al. (2006) AIAA, Abstract #7512. [2] Glass B. et al. (2006) LPSC *XXXVII*, Abstract #2300.