PLANETARY DEEP DRILLING FOR MARS, EUROPA, AND ENCELADUS. G. Paulsen[1], M. Shara[2], K. Zacny[1], B. Mellerowicz[1], J. Spring[1], A. Ridilla[1], R. Sharpe[3], J. Bowsher[3], N. Hoisington[3], J. Abrashkin[4], [1]Honeybee Robotics, 398 W Washington Blvd., Suite 200, Pasadena, CA 91103, zacny@honeybeerobotics.com, [2]American Museum of Natural History, New York City, NY, 10001, mshara@amnh.org, [3]United States Gypsum Company, Plaster City, CA, RSharpe@usg.com.

Introduction: Arguably the most important goal of planetary exploration is to determine if life exists, or ever existed, on another world. To understand the evolution of planetary bodies and to find definitive signs of present or past life, we need to go deep into planets or the Moon's subsurface. On Mars, Europa, and Enceladus, planetary objects with a high potential for life, one needs to penetrate deep below the surface that has been affected by damaging cosmic and solar radiation.

Conventional drill systems deployed in the oil and gas industries screw drill pipes together to form a long drill string. To get deeper, more drill pipes are added. This is a very robust approach and solves many problems related to deep drilling. These drills require high power drives, weigh a lot, and occupy significant space. These are not major issues on Earth; however, they are show-stoppers in extra-planetary settings.

The energy limitation also drives the drilling approach. Since locations of interest to Astrobiology may be covered with water-ice, an obvious way to drill is to melt through ice. Melting, however, is an extremely inefficient process. Melt probes require kW-levels of power to keep penetrating and preventing the probe from freezing in a hole [1]. Much heat is lost into surrounding ice, making the approach even less efficient. Another major drawback to this approach is that there are no power systems currently available that would provide multiple kW of electrical energy. Fission reactors for space exploration have been developed in the past, but their power outputs were less than 1 kW. The most recent study suggests that developing and space-qualifying fission based power system that would enable melting probes to operate, for example, would take over ten years and billions of dollars [2]. Clearly, the melt probe technology is not something that can be flown in the next 10-20 years. For nearer term missions, an electro-mechanical drilling approach, used every day in Antarctica and Greenland, is the only methodology likely to succeed.

Deep Drill: To solve the mass and volume problem while enabling deep penetration, it was decided to use a wireline drilling approach (Figure 1). In a wireline approach, a drill is suspended on an umbilical that provides power and data to the surface. This is the reverse of the paradigm usually used on Earth. Typical terrestrial drills are large and the drill bit is small. In a wireline approach, a drilling bit is bigger in diameter than a drill itself behind it. This is a critical requirement for this drilling approach since the drill bit needs to create space for the drill to fit into. The drill itself is a slim tube with all actuators, sensors, controllers, and instruments packaged tightly inside it.

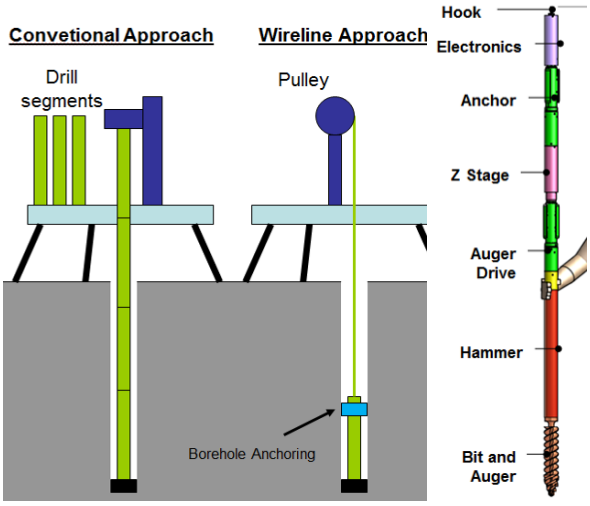

Figure 1. Left: Conventional drill string vs. wireline drilling approach. Typical components of the wireline drill.

To drill deeper, the drill first sets a set of anchors. These anchors push against the borehole wall and lock the drill from rotation or moving up or down. In low gravity environment, this is an extremely important consideration since now, the drill Weight on Bit (i.e. the force needed to be applied on the drill bit) is no longer limited by the weight of a rover or a lander. Once the anchors are set, the drill's internal Z-screw advances forward and pushes on the drill bit. A set of motors spin and hammer the drill bit at the same time. This inch-worming action could be repeated several times until the target depth is reached.

After reaching the target depth, the drill with its valuable sample is pulled back to the surface by the umbilical wound on a drum. The sample is transferred to onboard instruments for analysis, while the drill is lowered back into the hole and the entire process is repeated. To drill deeper, a longer umbilical is needed. Hence the majority of the system mass sits within the drill itself and the downstream support equipment (umbilical drum, science instruments, and so on).

This approach has some drawbacks. The major one is that it demands a stable borehole. If the borehole is unstable, it will collapse and trap the drill in the hole.

There are various methods of addressing this such as expandable casing that would require the use of a bi-center bit to deal with smaller diameter hole above the drill bit, or a system that could drill itself out. None of these are trivial solutions though. That's why this approach is best suited in ice, which coincidently is also the primary target for near-future Astrobiology missions.

Ice on Mars, Europa, and Enceladus is very cold, while the gravity in all cases is low. Both of these aspects create an extremely stable borehole that would remain open for years. On Earth, borehole closure is a real issue because of relatively warm ice and high gravity; as such holes in Antarctica are filled with ethylene glycol solutions or other low freezing point mixtures.

Deep Drill: In the past two years, we designed and fabricated Planetary Deep Drill (PDD) for penetrating 100s of meters to kilometers into Mars' ice caps and Europa's ice sheets. This prototype drill weighs approximately 40 kg and is 4.5 m long. All mechanisms and electronic drivers have been integrated inside it. The drill also has a microscope with 0.5 micro per pixel resolution.

The PDD has undergone extensive testing in the Plaster City Gypsum quarry [4] owned and operated by the US Gypsum Company (Figure 2).

Figure 2. Drill testing at the US Gypsum quarry.

Initially one hole was drilled to a 10.5 m depth. At that depth, wet silty-clay was encountered which reduced daily penetration rates from 1.5-2 m per day to 0.5 m per day. The decision was therefore made to move the drill from site 1 and establish site 2. Within a week the drill again reached 10 m depth. Drilling continued to 13.5 m depth, which is 3x the drill's length of 4.5 m.

Drilling telemetry has been extremely useful in predicting formation density. Drilling at lower power in a range of 50 Watts and penetration rates as fast as 2 cm/min indicated the rock is porous and in turn cuttings volume would be low. When the drilling energy increased to 250 Watts, and penetration rates dropped to 0.5 cm/min, this indicated the rock is very dense.

The microscopic imager worked extremely well with four LEDs (white light and UV light) as shown in Figure 3. Focusing has been relatively easy as well. Downhole sensors and imagers are extremely valuable for providing initial data on subsurface conditions.

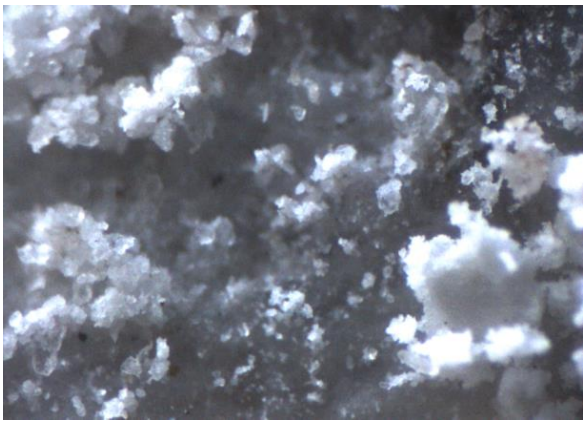

Figure3. Downhole microscopic imagers captured images of the borehole wall in white and UV light.

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