Title

An automated, low mass, low power drill for acquiring subsurface samples of ground ice for astrobiology studies on Earth and on Mars

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Abstract

As a project that is part of NASA's Astrobiology Technology & Instrument Development Program (ASTID), we are developing a low mass (~20kg) drill that will be operated without drilling fluids and at very low power levels (~60 watts electrical) to access and retrieve samples from permafrost regions of Earth and Mars. The drill, designed and built as a joint effort by NASA Johnson Space Center and Baker-Hughes Incorporated, takes the form of a down-hole unit attached to a cable so that it can, in principle, be scaled readily to reach significant depths.

A parallel laboratory effort is being carried out at UC Berkeley to characterize the physics of dry drilling under martian conditions of pressure, temperature and atmospheric composition. Data from the UCB and JSC laboratory experiments as well as BHI drilling lab tests are being used as input to a drill simulation program which is being planned to provide autonomous control of the drill.

The first Arctic field test of the unit is planned for May 2004. A field expedition to Eureka on Ellesmere Island in Spring 2003 provided an introduction for several team members to the practical aspects of drilling under Arctic conditions. The field effort was organized by Wayne Pollard of McGill University and Christopher McKay of NASA ARC. A conventional science drill provided by New Zealand colleagues was used to recover ground ice cores for analysis of their microbial content and also to develop techniques using tracers to track the depth of penetration of contamination from the core surface into the interior of the samples.

Introduction

NASA's Mars Exploration Payload Assessment Group (MEPAG) has identified the science goals, objectives, investigations and priorities for future Mars exploration in a document (JPL Publication 01-7) that (among other matters) addresses the importance of gaining access to the subsurface. Such access is identified as a priority in determining: 1) "if life exists today", 2) "the nature and inventory of organic carbon in representative soils and ices of the martian crust", 3) "the present state, distribution and cycling of water", 4) "the large scale vertical structure and chemical and mineralogical composition of the crust and its regional variations", and 5) "the distribution of accessible water in soils, regolith, and martian groundwater systems".

The development of the technology that would permit autonomous drilling to gain access to core samples has already begun with several groups in the US funded at modest levels to demonstrate the technology to a technology readiness level (TRL) of six within the next few years (TRL6 = system/subsystem model or prototype demonstrated/validated in a relevant environment). Groups in Canada and Europe are also forging ahead. In the case of drills that eventually must operate on Mars, more than one terrestrial environment may be considered 'relevant'. For the drill being developed by a team at NASA Johnson, Baker-Hughes Incorporated, University of California, Berkeley and NASA Ames the chosen relevant environment is that of the Canadian High Arctic where permafrost conditions are clearly as close as we can get to the anticipated thermal conditions of the martian regolith. The Arctic situation was also chosen because the source of funding for the project is NASA's Astrobiology Technology and Instrument Development program (ASTID; Principal Investigator: Geoffrey Briggs) where a relationship to terrestrial astrobiology research is a desideratum.

The Mars/Arctic Deep Drill

A drill bound for Mars as part of a robotic mission will bear only a passing resemblance to drills used on Earth for geoscience drilling. The mass that will be available will be measured in tens of kilograms and this will preclude the use of drilling fluids for removing cuttings and for cooling the bit. There will also be severe limits on the use of conventional casing. Power may be less of an issue if newly available nuclear power sources can be used; however, bit temperature considerations (sample alteration and bit wear) will likely prevent more than a few tens of watts of electrical power to be used. So, we can anticipate that robotic drilling on Mars will be a slow process and that removal of the cuttings also will be tedious.

Figure 1: Schematic of Initial Bottom Hole Assembly (BHA) (courtesy: Brian Derkowski)

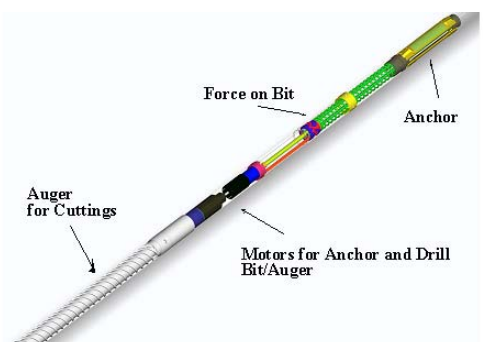
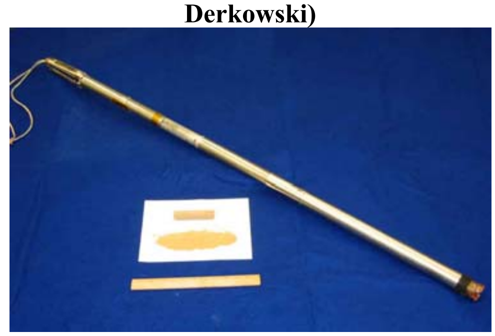


Figure 2: NASA / Baker Hughes Mk 1 Drill with Core and Cuttings (courtesy: Brian Derkowski)



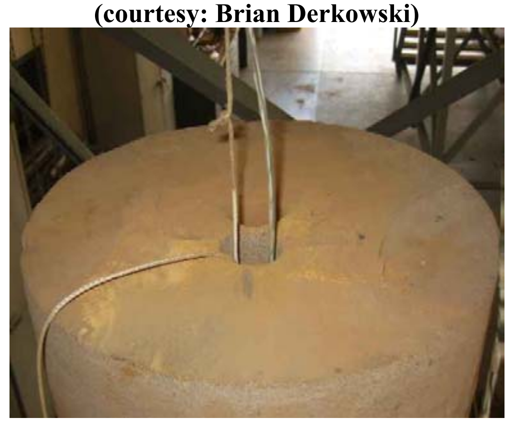
Automation of the drill will be mandatory given 1) the light time delay in communications between Mars and Earth and 2) the need for rapid reaction in the event of off-nominal events (e.g., the lock-up of a drill bit in penetrating an ice lens if the bit is allowed to get warm enough to melt the ice). Drilling on Earth typically involves the close monitoring of progress by the operator who may have only moments to act to avoid losing equipment down the hole. On Mars subsurface conditions are poorly understood and drilling under martian conditions of temperature, pressure and atmospheric composition introduces additional uncertainties. Clearly the automation of a Mars drill will be a challenge.

The drill system that we are developing has a number of innovations. The drill's down hole unit (DHU) is attached to a wire-line (cable) so that the depth to which it can, in principal, penetrate is not constrained by the mass and complexity of a drill string of individually joined rods. Further, the wire-line allows high rate date to be returned from the down hole unit, easing the challenge of automation. The DHU anchors itself to the sides of the hole being drilled and weight on bit (WOB) is provided by a spring that is compressed by a motor in the unit.

The coring bit (we are presently using a custom-made but generally conventional diamond bit) comminutes only the minimum amount of material needed to capture a core of diameter about 2 cm. The cuttings are carried upward by an auger and deposited in a 'basket' sitting on top of the core receptacle. When sufficient core has been captured it is snapped off and the entire unit is winched to the surface where the cuttings are disposed of and the core extracted. Drilling rates in sandstone of about 8 to 15 cm per hour have been demonstrated in the laboratory while expending 60 watts of electrical power (~20 watts mechanical). Drilling in the laboratory rig is limited to about 2 meters.

Figure 3: 2.2 m Sandstone Demonstration (courtesy: Brian Derkowski)

Figure 4: Top of borehole with umbilicals trailing down to fully submerged drill. (courtesy: Brian Derkowski)



Field Test Plans for MADD

A first field test of a second generation prototype is planned for April 2004 on Ellesmere Island at one or more sites that were identified this Spring.

Since drilling in the Arctic was outside the experience of the JSC-BHI and UCB team members, an opportunity was taken in the spring of this year (14 – 28 May) for the team to carry out field work on Ellesmere Island at Eureka (a site that had been previously investigated by team members Wayne Pollard and Christopher McKay). The team used a (relatively) small portable drilling rig provided by Webster Drilling and Exploration Ltd of New Zealand that had been previously used for field work in Antarctica. Samples of ground ice (estimated age 10,000 years) were recovered from depths of up to 20 meters during which time the team logged drill performance data and recorded the numerous practical problems that can arise when drilling in permafrost terrain. In addition the team carried out experiments using fluorescent tracer beads of appropriate size (representative of bacteria) to understand contamination issues that 1) will be faced on Mars and 2) are not fully quantified for terrestrial research. McGill University team associates have sectioned the ice cores and measured the depth of penetration of the beads to determine how much of the outer core must be discarded to avoid contamination issues in the analysis of recovered microbes.

The Eureka field effort, led by Co-Is Christopher McKay and Wayne Pollard was successful in all respects and provides us with confidence in our planning for the first field experiments of the Mars/Arctic Deep Drill.

Figure 5: Observing Commercial Drilling Team at Eureka, Ellesmere Island (courtesy: Brian Derkowski)

Automation

Encouraging progress has been made in understanding the automation problem through the combined efforts of the UC Berkeley and NASA Ames team members (note: funding to develop an autonomous control system is being sought outside of the ASTID program). A highly detailed drilling simulation program written by Co-I George Cooper has all the functionality needed to provide the diagnostic element of software for Mars drill automation. This program (*Payzone*) is in the process of being modified to include performance data that are being collected in the JSC-BHI laboratory and in a special laboratory set-up at UCB where Co-I Kris Zacny is carrying out experiments in a CO_2 environment at martian temperatures and pressure. The team has identified the sensors (e.g., motor currents, rpm, rate of penetration, temperatures, etc.) that will be required to allow the state of a Mars drill to be closely and continuously monitored. (The laboratory data also provide essential information about the heating of the cores.)

The execution software will require a 'Contingent Executive (CX)' module and a 'Feedback Control' module. The former will be based on CX software that was tested in *Marsokhod* and *K9* rover field tests in the last several years. The feedback system is being developed in the laboratory using *Labview* software to control and monitor the equipment.

Terrestrial experience suggests that a fully autonomous scientific drilling system must be able to deal with a diversity of situations that challenge even the best operators. So the task is a major one. One advantage that we will have is the very slow rate at which the drill will penetrate and the expectation that our drill will be fully instrumented with sensors whereas the performance monitoring of a a typical geoscience drill relies mainly on the senses of the operator.

Laboratory Research

The team members at UC Berkeley, where an experimental test system has been constructed over a six month period and where an electron microscope is available, have already provided insights that would be hard to achieve without the ability to simulate martian conditions. Thus we are accumulating a body of data about the effect of pressure on casing temperature and on torque, bit and rock temperatures, auger performance and bit wear.

Summary

The NASA-BHI-UCB collaboration in the development of a drill capable of robotic operation on Mars has made good progress over the last year; we are encouraged regarding the feasibility of adding a new (vertical) dimension to the scientific exploration of Mars.

Acknowledgement

Through Dr. Wayne Pollard the Eureka Field work had the support, on a cost-recovery basis, of the Polar Continental Shelf Project (a Canadian Government Agency that is part of the Natural Resources Agency).