REACHING WATER: PLANETARY DEEP DRILLING. B. Glass[1], D. Bergman[1], R. Davis[2], C. Hoftun[3], B. Johansen[3], and P. Lee[1,3] . [1]NASA Ames Research Center, Moffett Field, CA 94305, USA, Email: brian.glass@nasa.gov [2]NASA Headquarters, Washington, DC 20024, USA; [3]Mars Institute, NASA Research Park, Moffett Field, CA 94035, USA.

Abstract: Deep drilling to >km depths is commonly achieved on Earth, but an extreme challenge on other Solar System bodies. Deep planetary subsurface access may be possible with new drilling concepts operated together with an automated coiled-tubing drill. This light weight, energy efficient concept could enable ice wells for liquid water access for future Mars surface stations, enable low-weight asteroidal and lunar drilling, as well as penetration through Europa's icy crust.

Introduction: Existing or proposed planetary exploration drills are shallow (few cm to 2m) mechanical augers, and terrestrial drills used for oil and gas exploration (Figure 1) require drilling lubricants (muds) and megawatts of energy input, so going deeper on other Solar System bodies will require a new approach. Lightspeed communication delays require a fully-automated planetary drilling approach, or else the nearby (surface or on-orbit) presence of astronauts [1]. We propose that an automated coiled-tubing drill, redesigned for low mass and power consumption, can reach depths of hundreds of meters through ice and rock layers, deep enough to reach massive subsurface ice deposits on Mars and well below the irradiated icy surface of ocean worlds. Currently at a TRL of 2, these concepts could be raised to flight-level prototypes within 15 years.

One primary architectural motivation is that hydrogen and oxygen are very expensive to carry to Mars, yet available there from H_2O. Over the past decade, investigators have looked at ways of producing in-situ resources from processing Mars surface soils or atmospheric gases. These have been incremental and evolutional technologies developed over the past decade. But they consume large amounts of energy for the small quantities of water or methane produced, and are complex, multi-stage processes. Evidence is abundant that large amounts of water have existed near Mars' surface in the past [2] and it is expected that large quantities remain in the subsurface cryosphere and possible hydrosphere [3]. A Martian ice well will cost a significant amount of energy to drill, but then could produce substantial, relatively inexpensive supplies of water from the Martian cryosphere for use in further exploration and space-based facilities.

Deeper drilling is also crosscutting, and would enable highly valuable planetary science investigations, such as direct evidence of past or present microbial life (the Mars cryosphere will be a COSPAR Special Region), characterization of the volatile content of the regolith and cryosphere (including organic molecules and ice densities), and measuring the mineralogy and isotopic chemistry as a function of depth to better understand the climate and geologic history of Mars.

Fig. 1. Current DOE 4.75in diam. coiled-tubing manually-controlled drill (capable of 3km depth)

Drilling Approach: An intelligent, automated deep drilling mission on Mars (see Figure 2 for an example combining a coiled tubing drill, with a future commercial space Mars lander) would probably aim at acquiring samples and cores from a depth of one to five hundred meters where, unless a region of near-surface water can be located from orbital sensing, cold temperatures will be consistent with ground ice only. A robotic coiled-tubing deep drill will be limited in mass, probably to less than 1 ton payload and to a power consumption of 10 kWh per sol. Under these circumstances it will be necessary to minimize the energy expended in rock comminution (pulverizing). One possible approach would be to extract segments of continuous core, perhaps at a rate of about 1 meter per day. Mission length on Mars would typically be about 200 sols if the precursor lander was solar powered. With RTG power, the drill penetration rate could increase and the mission duration could be extended. And the technology developed for the first deep (100m-class) drilling robotic precursor mission would be intended to be scaled up to penetrate to kilometer depths, presumably as an element of a later human exploration mission when more robust power systems would be available.

Another way to reduce the time and energy spent grinding rock at the head-end would be to fracture the rock. The NASA-Honeybee Mars rotary-percussive prototype drills, CRUX and the Icebreaker series [4] (Figure 3), use mechanical hammering as well as rotary grinding. Zaptec has developed several electric-percussive (electropulse) drills for ESA [5] that shock the rock face to break it for more-efficient drilling and cuttings removal. The basic principle of electropulse drilling is to charge an electrode in the drill bit which then discharges an electric spark into the rock face. The plasma channel created in the rock then vaporizes microscopic parts of the rock which expand and explodes the rock from inside. Fracturing is assisted by the acoustic pulse from the spark.

Drilling Site: Although deep drilling systems should be developed with built-in robustness against subsurface unknowns, the anticipated performance of the proposed drilling approaches will depend significantly on the selection of optimal drilling sites. Areas on Mars where the cryosphere might be thinner due to higher regional or local geothermal gradients, for instance, might allow significantly easier access to the deeper aqueous hydrosphere. Similarly, regions with more continuous subsurface ground ice might be significently more amenable to drilling than rock glaciers which, on Earth at least, often present mechanically challenging surface barriers to subsurface access and sampling.

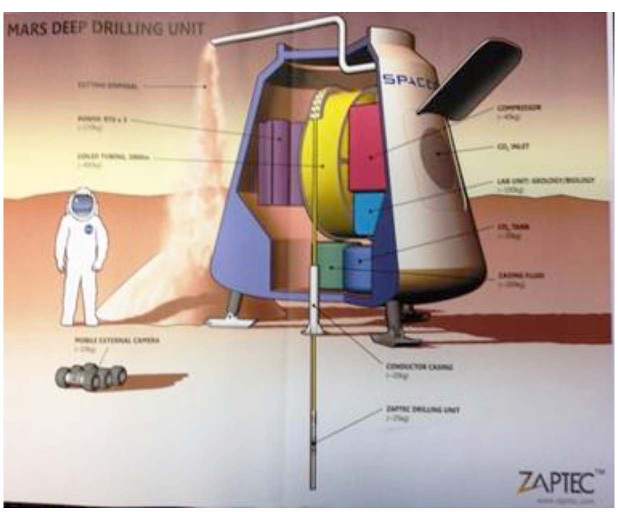

Fig. 2. A 100-200m-capable deep drill concept deployed from a 1-ton-payload Red Dragon or equivalent. (From [5]) *(Human figure for scale)*

Potential Impact: Access to the Martian hydrosphere and cryosphere would greatly reduce the cost and increase the habitability of the future human exploration presence on Mars. Deeper drilling would answer otherwise-unaddressable Mars science questions. And the technologies developed would also enable deep drilling on other Solar System bodies. Electropulse drilling would be particularly helpful for contact drilling into asteroids and other small bodies, due to its very low downward force needs (and hence low/no anchoring).

References: [1] Blacic et al, (2000) *AIAA Space 2000,* AIAA-2000-5301. [2] Heldmann, J. et al, (2005) *JGR*, 110, E5. [3] Clifford, S and T. Parker, (2001) *Icarus,* 154(40). [4] Glass, B., et al, (2016) *LPSC XLVII.* [5] Johansen, B. et al. (2014) *LPSC XLV.*

Fig. 3. NASA/Honeybee Icebreaker-3 drill tested with Spanish SOLID instrument (black case) and sample transfer arm at Rio Tinto in July 2015.