RedWater: Approach for Mining Water from Mars' Ice Deposits Buried 10s of meters Deep. K. Zacny[1], Z. Mank[1], M. Buchbinder[1], D. Sabahi[1], M. Hecht[2], N. E. Putzig[3], P. van Susante[4], [1]Honeybee Robotics (zacny@honeybeerobotics.com), [2]Haystack Observatory, Massachusetts Institute of Technology, [3]Planetary Science Institute, [4]Michigan Technological University.

Introduction: In the past decade orbital measurements revealed that a third of the Martian surface contains shallow ground ice. MRO's SHARAD sounder has revealed the presence of ice-rich materials in several non-polar terrains, including debris-covered glaciers and ground ices extending down to latitudes of 37° [1]. These deposits are up to several 100 m thick and many appear to consist of nearly pure water ice. The ability of the radar to resolve shallow layering is limited to ~20 m .Thus, to reach ice and extract water, a system would need to penetrate through at most 20 m of regolith. The discoveries of nearly pure ice deposits in mid latitudes on Mars enable implementing two proven terrestrial technologies: Coiled Tubing (CT) for drilling and Rodriquez Well (RodWell) for water extraction.

CT rigs use a continuous length of tubing (metal or composite) that is flexible enough to be wound on a reel and rigid enough to withstand drilling forces and torques. The tube is pushed downhole using so-called injectors (for example, a set of actuated rollers that pinch the tube and advance it downward). The end of the tube has a Bottom Hole Assembly (BHA) – a motor and a drill bit for drilling into the subsurface. To remove drill cuttings, compressed air (or other drilling fluid) is pumped down the tube. A hole is drilled by advancing coiled tubing deeper into the subsurface while blowing cuttings out of the way. A commercial CT rig, such as RoXplorer, weighs 15 tons and drills to 500 m at 1 m/min in hard rock.

RodWell is a technology where a hole is drilled in ice, which is melted and pumped to the surface. It has been developed and tested in Antarctica in the 1960s and used at the South Pole station since 2002 [2].

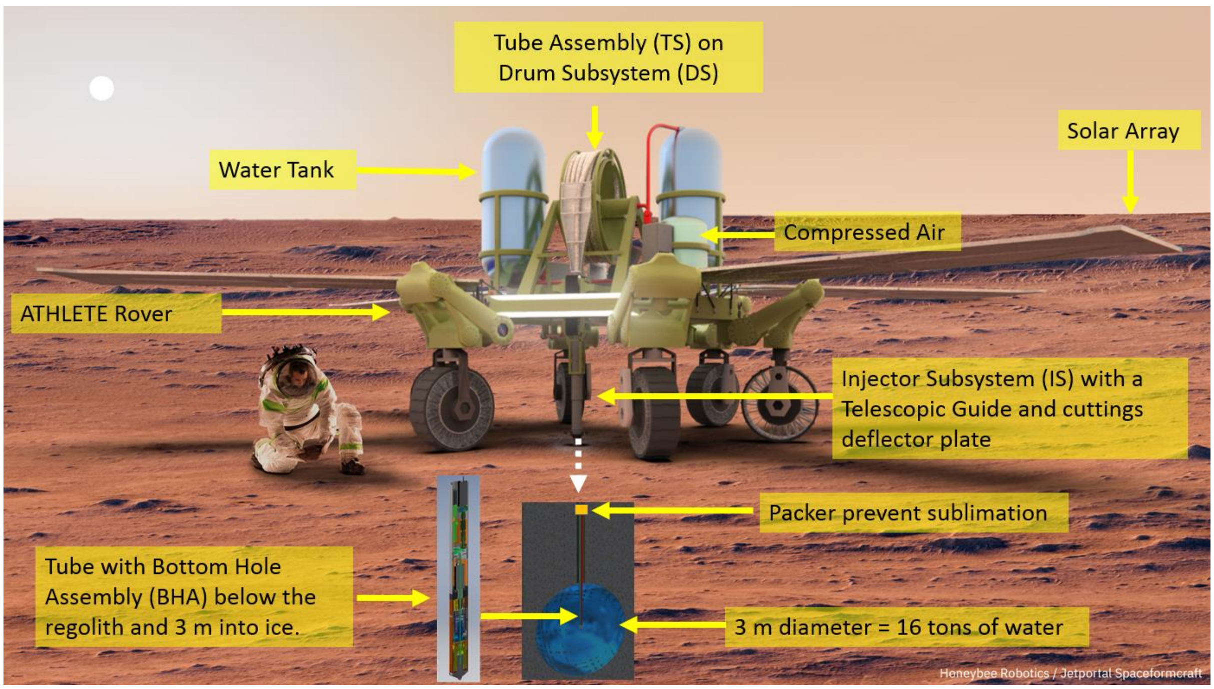

Figure 1. RedWater with all the subsystems.

RedWater: The RedWater system combines the two technologies into one (**Figure 1**, **Figure 2**, **Figure 3**). It uses the CT approach to create a drill hole. Once the hole is made, the coiled tubing is left in the hole and used as conduit for water extraction. The BHA contains a rotary-percussive drill subsystem (similar to the one used in Honeybee Robotics Deep Drill [3]), a downhole pump, and heaters. The tube houses an insulated and heated hose as well as wires for downhole motors and heaters. During drilling, compressed gas is sent downhole through the hose [4, 5, 6]. The gas escapes through the annular space between the tube and borehole wall and removes cuttings that can be collected and analyzed for science. Upon reaching an ice layer, the drill continues for another ~3 m and then stops advancing forward, but the bit continues to spin. Heaters are turned on to melt the surrounding ice. Once ice starts to melt, the peristaltic pump starts pumping a fraction of the melted water up the same hose that was used for the compressed gas, and into a storage tank on the surface via a three-way heated valve, which switches between the gas tank and the water tank. The remaining water passes through a downhole heater and is pumped into the rotating bit for water jetting. This continuous stirring and the injection of hot water speeds up the melting process. After melting a section of ice, the CT is reactivated to drill further into the underlying ice and the melting process continues.

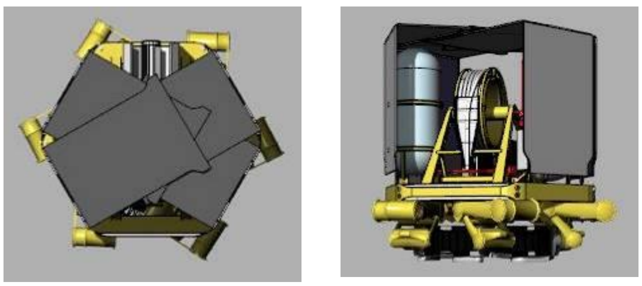

Figure 2. RedWater in Stored Configuration.

Since atmospheric pressures and temperatures in the Martian northern plains extends above water's triple point, liquid water can exist at the surface. However, it is unstable and will boil off very quickly. For this reason, it is desirable to seal off the hole. This can be achieved via active means (e.g., a packer can expand in the hole and seal off the annular space between the tube and the borehole) or passive means (e.g., water vapor would re-condense on the cold borehole wall and seal it; this in fact has been observed). In the latter case, the tube would have to be heated to free itself up before continuing further down, when needed.

Our pneumatic excavation tests at 7 torr showed penetration rates of 1 m/min in regolith. The mass ratio of gas used to material removed out of the hole was 1:500. Assuming a 5 cm diameter hole (current baseline for RedWater), the required mass of gas to achieve 20 m depth would be 10 kg. Most of the sources of compressed gas are at high Technology Readiness Level (TRL). Gas can be brought from the Earth (Mars 2020 mission brings a tank of compressed N_2 to blow dust off rocks), Helium pressurant can be used from landed systems, rocket fuel can be burned and turned into gas, and ISRU gasses (H_2, O_2) could also be used. Finally, a compressor could compress Martian air. For example, MOXI on Mars 2020 has a compressor that would take 100 hours to compress 10 kg of CO2 from 7 torr to 760 torr.

Meeting NASA ISRU Goals: To extract 16 tons of water needed to produce 30 metric tons of oxygen and methane for ascent propulsion for Mars human surface missions [7], a pool of approximately 3.1 m in diameter has to be created, which is feasible. The process of water extraction would take several weeks. Our thermal models using MathCad show that require heat for melting is ~1.5 kW and for keeping the water hose warm along the 25 m length is ~1 kW. These power levels are within the limits of the ISRU power system envisaged for human missions [8].

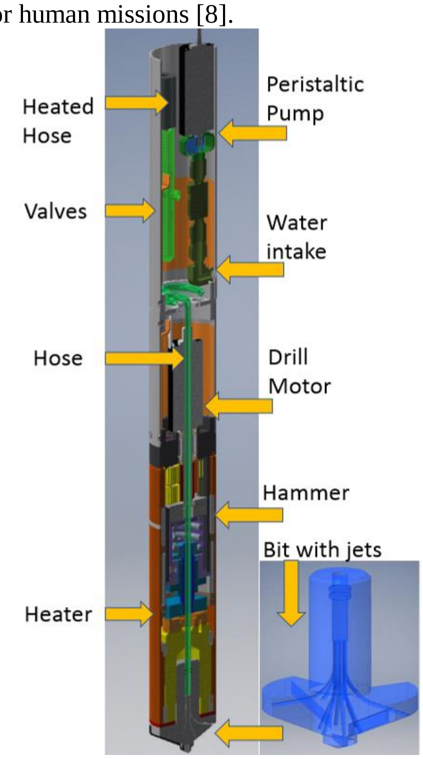

Figure 3. Bottom Hole Assembly.

References: [1] Putzig et al., this conference (2018), [2] Haehnel and Knuth, Potable Water Supply Feasibility Study for Summit Station, Greenland, CRREL TR-11-4, [3] Zacny et al. (2016), Development of a Planetary Deep Drill, ASCE Earth and Space, [4] Zacny et al., (2010), Investigating the Efficiency of Pneumatic Transfer of JSC-1a Lunar Regolith Simulant in Vacuum and Lunar Gravity During Parabolic Flights. AIAA Space, [5] Zacny et al. (2008), Pneumatic Excavator and Regolith Transport System for Lunar ISRU and Construction, [6] Nagihara et al., (2016), Options for Heat Flow Probe Deployment on Robotic Lunar Missions, LPSC, [7] Kleinhenz and Paz (2017), An ISRU Propellant Production System to Fully Fuel a Mars Ascent Vehicle, AIAA SciTech; [8] NextSTEP-2 Appendix D In-Situ Resource Utilization (ISRU) Technology