Hard rock water jet mining, a novel method to extract water from poly-hydrated sulphates on Mars. P.J. van Susante[1], J. Allen, T. Eisele, E. Medici, and . K. Zacny[2], [1]Michigan Technological University, Dept. of Mechanical Engineering – Engineering Mechanics, 1400 Townsend Drive, Houghton, MI 49931, pjvansus@mtu.edu, [2]Honeybee Robotics, 398 West Washington Blvd, Suite 200, Pasadena, CA 91103, KAZacny@honeybeerobotics.com.

Introduction: Several potential water sources have been identified on Mars below 50 degree latitude including buried glacial ice and hydrated minerals such as smectite clays and gypsum [1]. Of the minerals, gypsum has been identified as the most efficient source of water due to the low water release temperature at 150 ºC and the high water content; 20% water by mass. This paper will give an update on the project progress of the Early Stage Innovation grant with the objective to demonstrate an innovative process for extraction of water from hard extraterrestrial soils and gypsum in particular. The process involves 'dissaggregating' material using a water jet to form a slurry, and pumping the slurry to a processing system for separation and water extraction. An artist's impression can be seen in Figure 1.

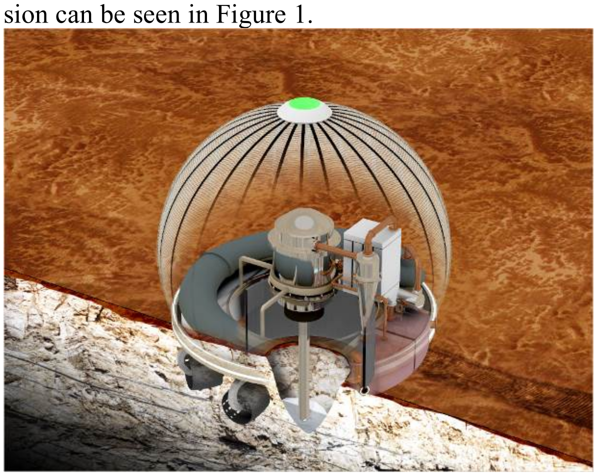

Figure 1: Artist impression of the gypsum water jet mining method (Credit: JetPortal/MTU/Honeybee Robotics.)

This innovative process eliminates the hardest problem in mining: comminution, which involves heavy equipment, significant energies, forces, and tooling impractical for sustained extraterrestrial ISRU. The process combines the steps of excavation and extraction within a simple, self-contained system of minimal mechanical complexity; resulting in a durable system with low mass and low energy requirements. The process takes advantage of mineralogy with benign processing temperatures that are generally less than 200 ºC and it is adaptable to a wide range of geomechanical properties, deposit sources and contaminants. This paper reports on the experimental studies of water-gypsum disaggregation, slurry transportation, water-particle separation and sealing. This promising approach could potentially be used for other hydrated minerals and even ice-cemented soils in other locations such as the Moon.

Production Requirements: To produce enough rocket fuel and oxidizer on Mars to refuel the empty tanks of a Mars Ascent Vehicle (MAV) it is estimated that 16 metric tons of water needs to be produced in 480 martian days (sols) [3] which translates to an average of 1.8 kg/hr of water. Given that gypsum has 20% of water by mass bound in the mineral of which 75% releases around 150 ºC and the remaining 25% at 210 ºC, this means that for a pure gypsum deposit at a density of 2.3 g/cc a volume of a 15.8 cm side cube or a 17.5 cm side cube to be excavated per hour. Figure 2 shows an estimate of the scale of the amount of gypsum to excavate.

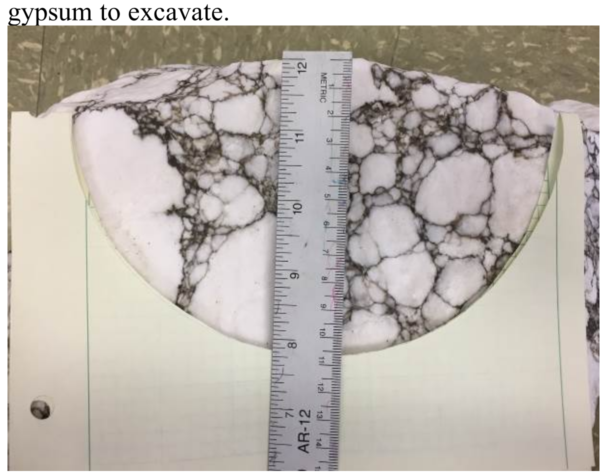

Figure 2: Approximate scale of required gypsum production volume per hour

Earth Gypsum Mining Process: On Earth, many millions of tons of gypsum are mined every year, mostly for the construction industry to manufacture drywall. The process on Earth excavates gypsum using either traditional blasting or the ever more popular surface miner. After excavating the gypsum rock, it needs to be crushed to smaller than 100 micron particles due to flash calcining (heating until 75% of water is released and alpha-hemihydrate is formed) and this plaster is then reconstituted by adding water to the particles along with other additives in between two outer paper layers to form drywall. Gypsum is further used in agriculture to control moisture content, as a retarder in cement and even as an inert filler for pills and molding material for dentistry models. Instead of wasting the removed water it would be collected and stored and the resulting plaster or anhydrite (with zero percent water) will be discarded. Plaster, or hemihydrite, which is the partially dehydrated form of gypsum can be reconstituted to rock in the form of drywall or other applications if so desired. Figure 3 shows a rock, extracted water and some plaster.

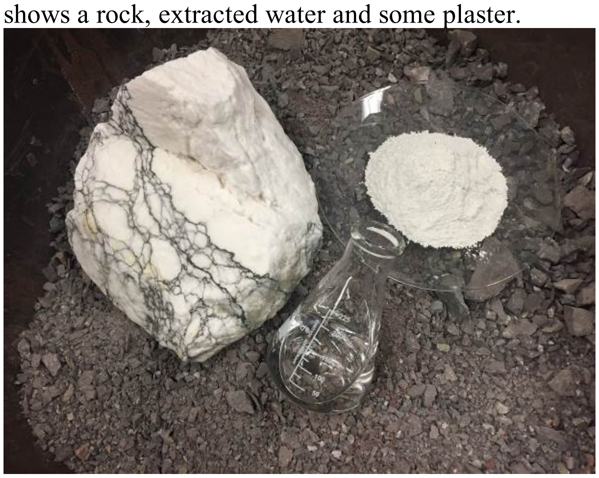

Figure 3: Natural gypsum rock from the US Gypsum quarry in Alabaster, MI, water and plaster powder.

Preliminary test results: Preliminary testing has shown that with a regular commercial, 2700 psi, 1.7 GPM, pressure washer, gypsum rock from a quarry in Alabaster, MI, can be disaggregated into particles at rates varying from 1.2 to 10 g/s depending on the spray width of the nozzle (zero, 15 and 25 degrees). The particle size as measured by a sieve test reveals the largest size fraction for all three nozzle types consists of particle sizes between 100 and 250 microns but the more concentrated the spray, the more large chunks were released and less very fine (<100 micron) were created. This indicates that the concentrated zero degree spray at 2700 psi is too powerful to create a nice uniform particle size. This is indicated in figure 4 by the low cumulative percentage of smaller than the 2000 micron (2 mm) cutoff. The missing percentage was the amount of particles (rock chunks) great than 2 mm. Using a commercially available hydrocyclone those particles can be separated from the water stream at 98% efficiency after one pass and then heated to release their crystalline bound water at >150 °C.

Ongoing Work: Research, modeling and experimentation is continuing as part of a NASA Early Stage Innovation Grant to Michigan Technological University that started in January 2018 and will run until January 2021. Other components that will be researched and prototyped are the enclosure seal, the pump and pressure systems, slurry transportation and particle separation and heating as well as water extraction component leading to a full TRL-4 system design that will be partially tested by Honeybee Robotics. A variation of this technology could be used for extracting icy regolith or other hydrated minerals. Gypsum was chosen due to its low processing temperature and thus wider material availability, relative ease of sealing and virtually no by-products that complicate processing. The process is not very sensitive to contamination in the rock composition.

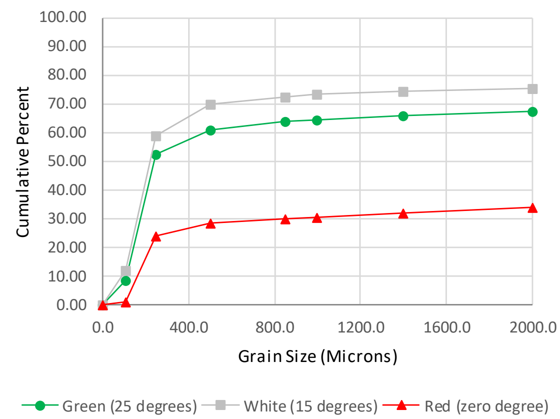

Figure 4: Sieve test particle size resulting from tests with 2700 psi waterjet using three different nozzles indicating that the zero degree nozzle fractures the rock too easily in too large chunks.

References:

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[3] Kleinhenz, J.E. and Paz, A. (2017) “An ISRU Propellant Production System to Fully Fuel a Mars

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