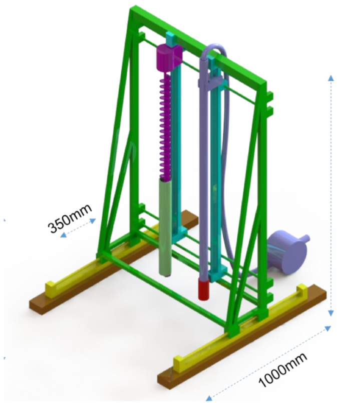

HYDRATION III

High-**Y**ield **D**ihydrogen monoxide **R**etrieval **A**nd **T**errain **I**dentification **O**n **N**ew worlds

Space Resources Roundtable, 8 June 2022

George Lordos, Prakash Manandhar, Roland de Filippi, Eric Bui, Palak Patel, Tao Sevigny, Sophie Yang, Marcellin Féasson, Paula do Vale Pereira, Dr. Olivier de Weck and Dr Jeffrey A. Hoffman.

Massachusetts Institute of Technology

Funding sponsor: National Institute of Aerospace, on behalf of NASA

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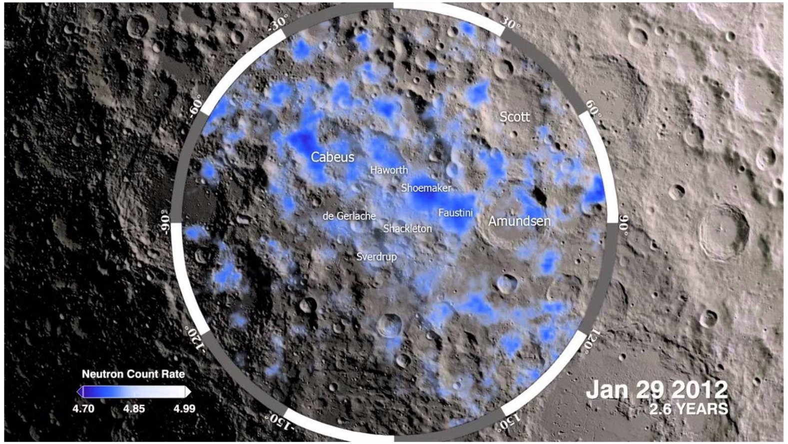
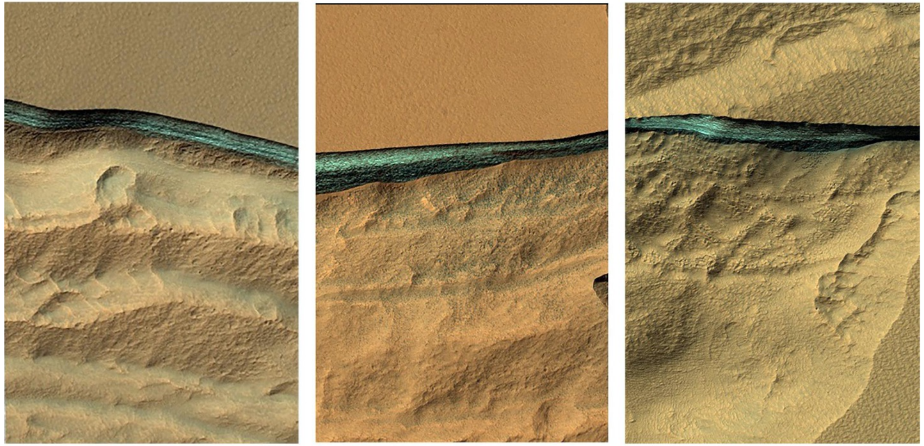
Motivation: NASA's Moon to Mars Ice and Prospecting Challenge, 2016 – 2021

- Competitive technology development by student teams to demonstrate digital core prospecting capability for the Moon and water extraction on Mars



Neutron spectrometry by Lunar Reconnaissance Orbiter indicates hydrogen, supporting indications of water vapour in the impact plume of LCROSS upper stage at Cabeus Crater, Lunar South Pole Region, 2009
Image credit: NASA



Evidence of subsurface ice on Mars covered by a shallow layer of regolith, seen from the orbiting HiRISE camera
Image credit: NASA / JPL / University of Arizona, Dundas et al (2018)

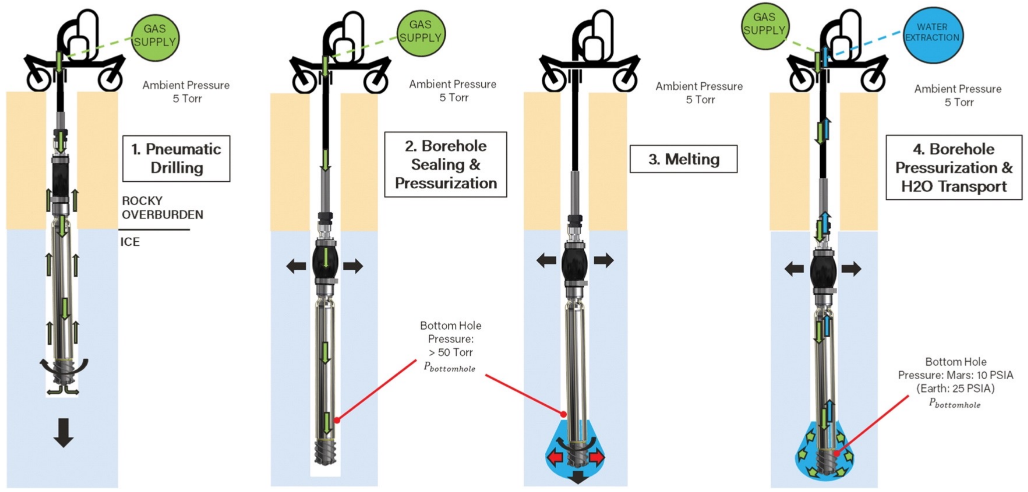
Current State of Art for Extracting Water from ice sheets: Rodwell, used in Antarctica

Source: http://glacier.lbl.gov/gtp/SouthPole/rod_well.html

<u>Rodwell concept</u>

- Heat recovery from diesel generator exhaust
- Use hot water spray to make initial hole
- Pump in hot water, it melts more water
- Pump out some cold water, while maintaining a self-deepening well

Current State of Art for Extracting Water from ice on Mars: Honeybee's RedWater system

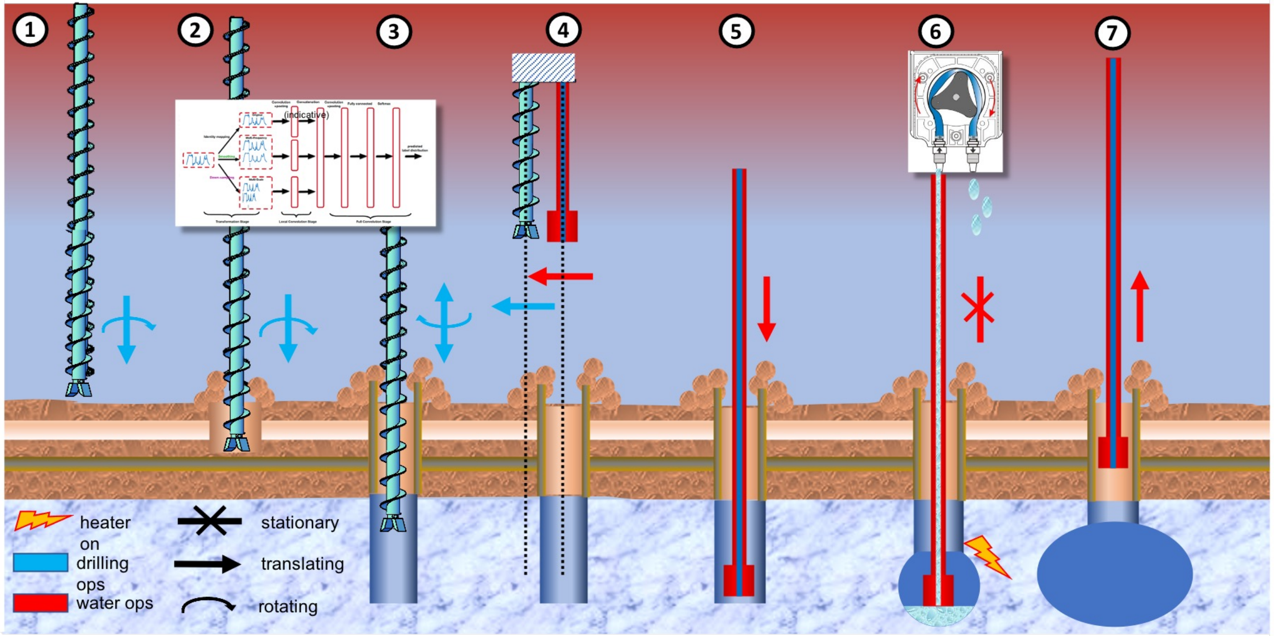


RedWater concept

- Use proven coiled tubing and pneumatic drilling for initial borehole
- Seal borehole with packer and pressurize to 50 torr
- Uses proven Rodwell approach and borehole pressurization to lift water to surface

Mellerowicz B, Zacny K, Palmowski J et al., 2022. RedWater: Water Mining System for Mars, New Space 2022 10:2, 16-186

HYDRATION I, II and III concepts: first designed 2018, demo at MMIP in Sept 2021



CONOPS

(1) Positioning

(2) Overburden drilling

(3) Casing borehole with drilling mud

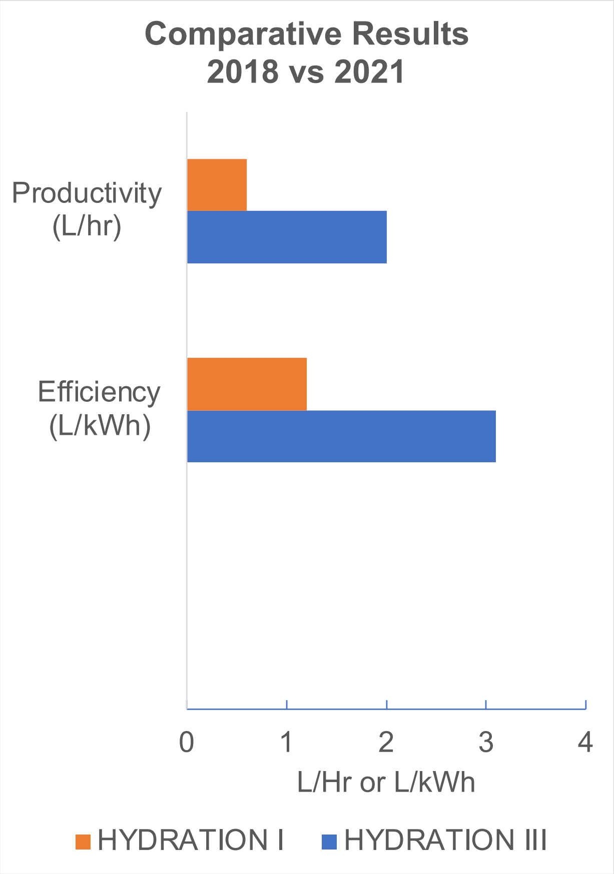
(4) Translating

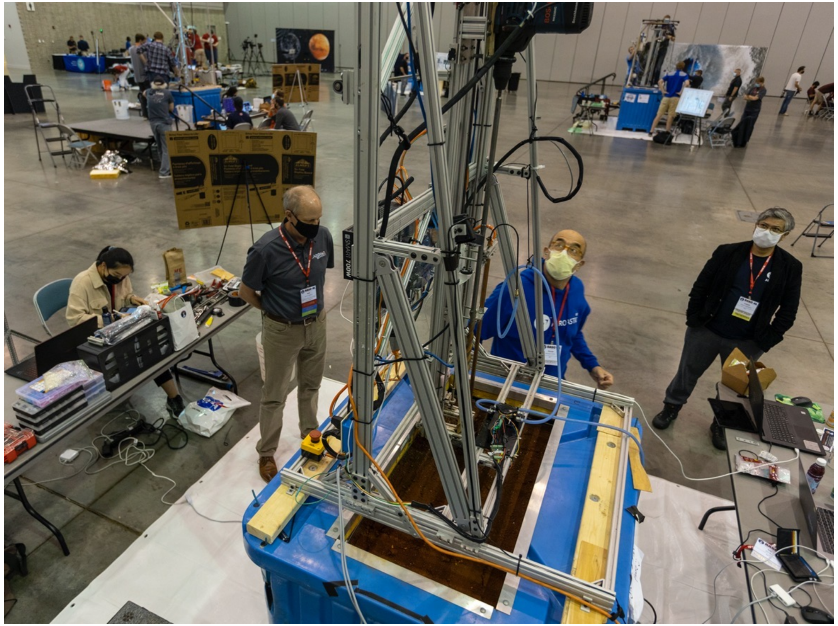
(5) Lowering heater & water inlet

(6) Ice melting & water pumping

(7) Remove heater

HYDRATION III Results, September 2021





HYDRATION III produced 24.3 L of water in 12 hours, all by remote control, vs. 5.5L in 9 hours of hands-on operations for HYDRATION I.

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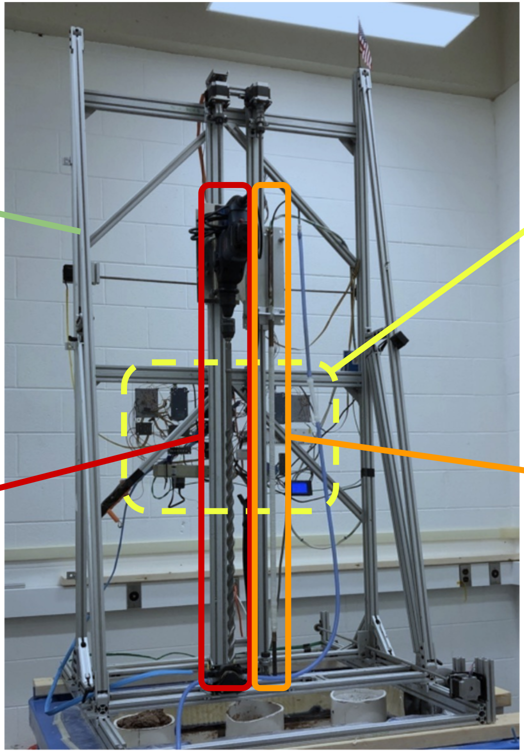
HYDRATION III system and subsystems

Supporting Structure

Supporting Electronics



Drilling Assembly:

- 8A Rotary Hammer Drill
- 1” x 42” carbide drill bit
- Lead screw + motor
- Sensors: torque on lead screw, weight on bit, drilling current, vibration

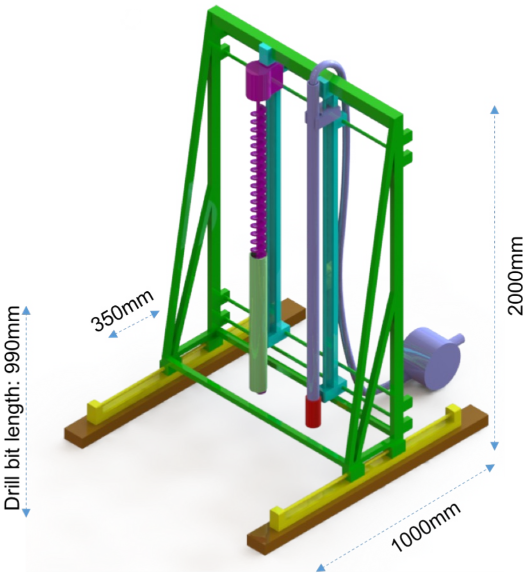
Water Collection Assembly:

- 700W Cartridge heater
- Bronze downhole filter
- Tubing + peristaltic pump
- Lead screw + motor
- Sensors: weight on heater

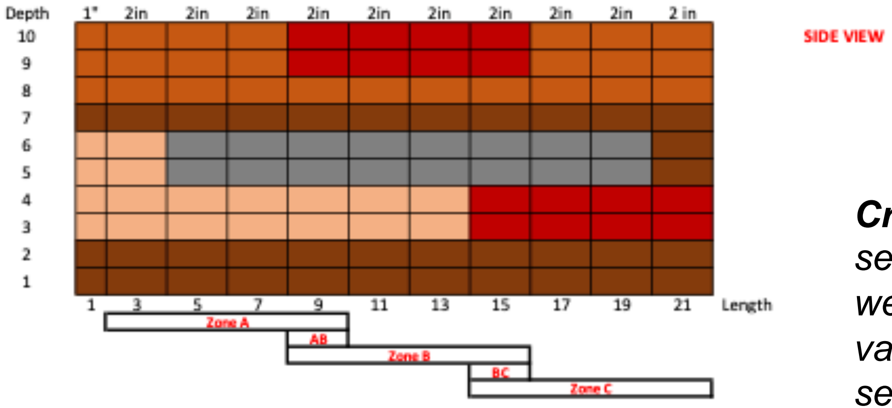
Contact: marsice2020@mit.edu

HYDRATION III design and specifications

Overall Mass	**58.3 kg**	**Maximum drilling speed and typical drilling current**	900RPM (5A)
Overall Volume and dimensions	$1.9m^3$ **(1m x 1m x 1.9m)**	**Z1 Servo Peak and Cont. (RMS) Torque @75VDC**	5.8 N-m (peak) 1.2 N-m (cont)
Drill bit	1” x 42” carbide-tipped pyramid point concrete bit	**On-board computer**	2x RaspBerry Pi 4
WOB / Drill force	**<150N**	**Communications interface**	Wireless, via WiFi and long distance LTE
Rated load @ 115VAC	9A	**Software**	**Our own client/server using PyQT and ClearPath C++ libraries**
Maximum vertical speed at cont. torque	**$0.053\ m\ s^{-1}$** (1600 RPM on Z1)	**Maximum Heater Power**	700W



Testbed design: test as you fly, fly as you test



Clay1	pure clay
Clay2	clay with 20% sand and 5% pebbles
Clay3	clay with 20% sand
Stone	size is 12" x 8" x 2"
Concrete	size is 16" x 16" x 2" (actually 48mm) or 16" x 8" x 2"

Cross-section of test overburden layers. *By selecting a different Y coordinate in zones A, B or C, we can drill through various vertical profiles of varying difficulty, producing different labeled data sets with which to train our neural net.*

Start: Ice block

+Clay, concrete

+Clay, paving stone

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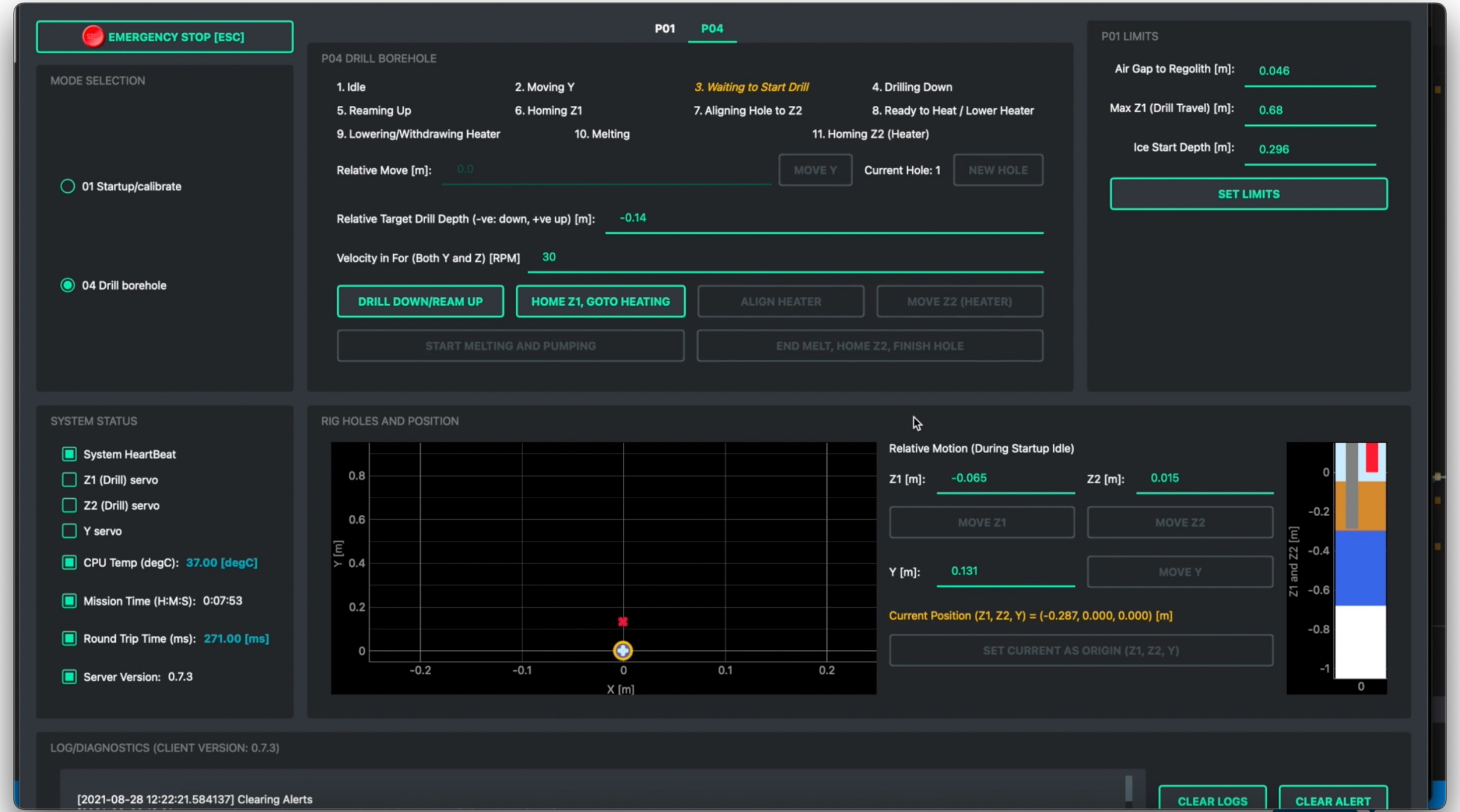
Mission Control user interface



Filtering melted ice requires a unit that is sturdy and a system that is resilient in mud and fine particulate.

Requirements
- Self-priming pump
- Remove objects larger than 200 microns
- Keep the heaters from being submerged,
- In place cleaning
- Sturdy

Design
- Peristaltic pump can run in both directions
- Open-cell brass construction
- Mounted below heaters
- Back-flush filter to clean
- Steel collection tube

Contact: marsice2020@mit.edu

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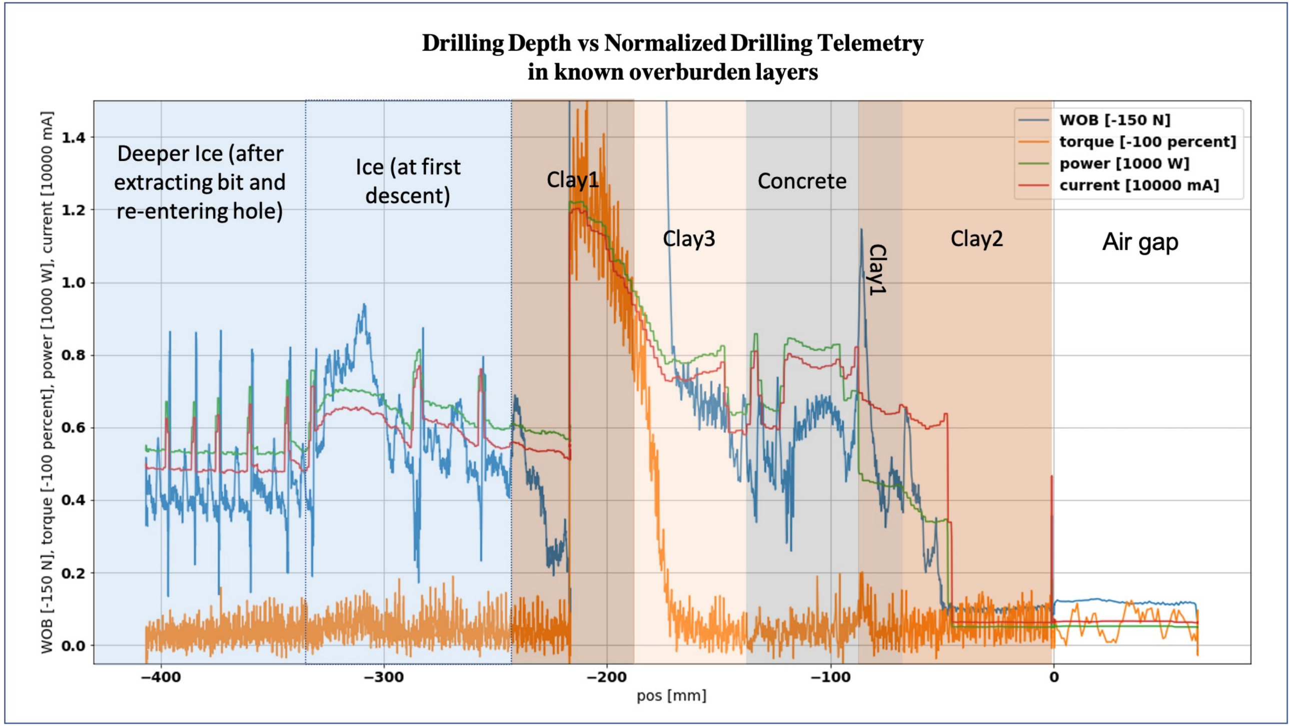
Finding: it may be possible to construct self-casing boreholes using drilling mud.

Contact: marsice2020@mit.edu

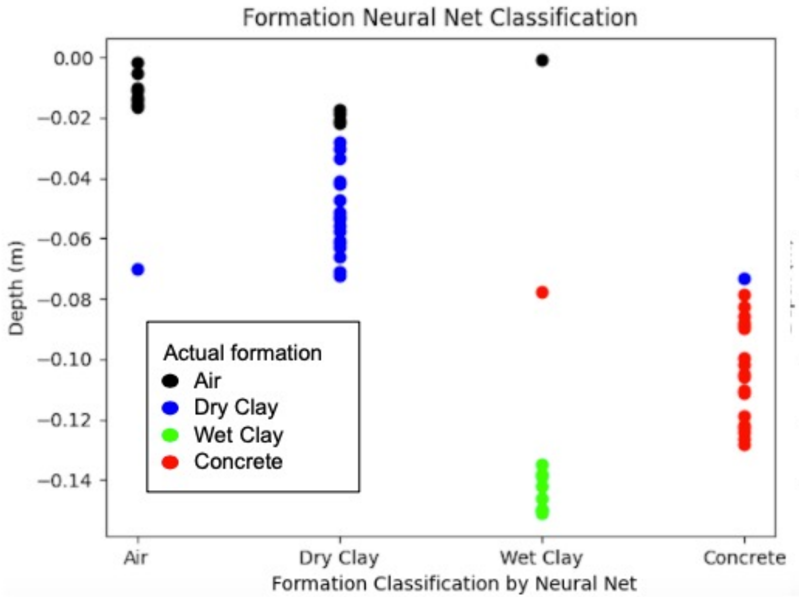
Current/power and weight on bit both correlate with changes in drilling resistance

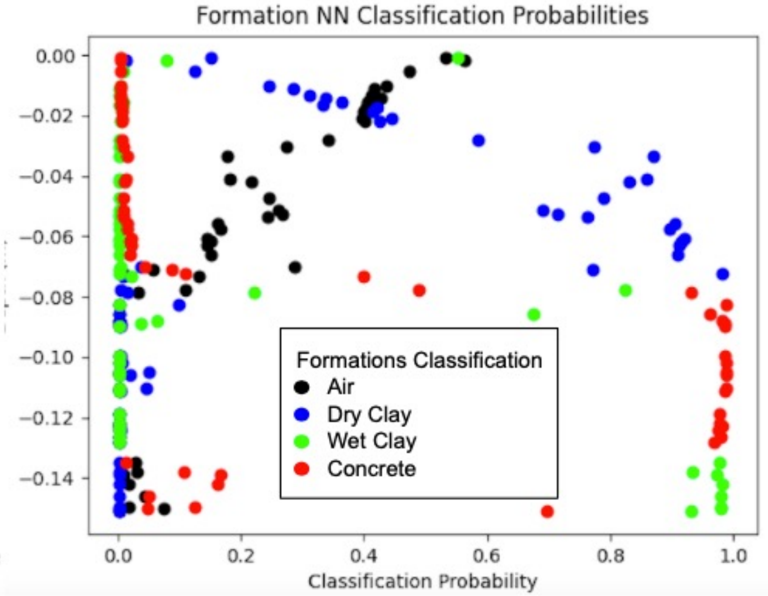


Lessons learned during hardware-rich design development cycle, 2019 - 2021

Change	Rationale	Benefits of change	Costs of change	Costs mitigated by
Removed drill tachometer	Redundant, not essential for main functions	Reduced mass, coding load & complexity	None apparent	
Removed pump flow meter	Not necessary for competition	Reduced mass, coding load & complexity	Impacts true remote operability	Overhead video provides indication of water flow
Removed X-axis motor, bearings and lead screw	Not necessary on Moon, Mars nor at the competition	Reduced mass (-2.1kg), eliminated vibrations during drilling	Will have to drill in a straight line at competition (one line per day)	Can still slide the base over by hand and lock it to a new position
Replaced Z1 servo with a more powerful model	More margin to help pull the drill bit out of tough situations	60% more torque, reduced risk of stalling, tolerance to unexpected friction in system	More mass (+0.6kg), no longer identical with others so no spare if it fails	Since it's still a NEMA23 mount, if it fails we can replace with our smaller spare
Shortened the structural frame by 22cm	Needed to cut mass to pay for higher mass of servos and new e-panel	Reduced system mass (-1.4kg); contributed to reducing vibrations	Drilling (Z1) and water assembly (Z2) stacks hang below zero level of system, closer to top of overburden	If Z1, Z2 are too close to overburden, we can mount them higher up
Simplified Mission Control software	Best use of limited software dev resources	Essential features for competition have been more thoroughly tested	Some of the initially planned features will not be available	Workarounds exist for the unavailable features

Work in progress: neural net classifier to detect formations. More drilling data is needed.





Thank you!

Questions?

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