Hard Rock Water Jet Mining, a Novel Method to Extract Water from Poly-Hydrated Sulphates on Mars

Picture Credit: MTU/Honeybee Robotics/Jetportal SFC

6/13/2018 SRR/PTMSS

Jeff Allen (PI), **Paul van Susante (Co-PI)**, Ezequiel Medici, Timothy Eisele, Kris Zacny (HBR), Julie Kleinhenz (NASA GRC)
+ many students

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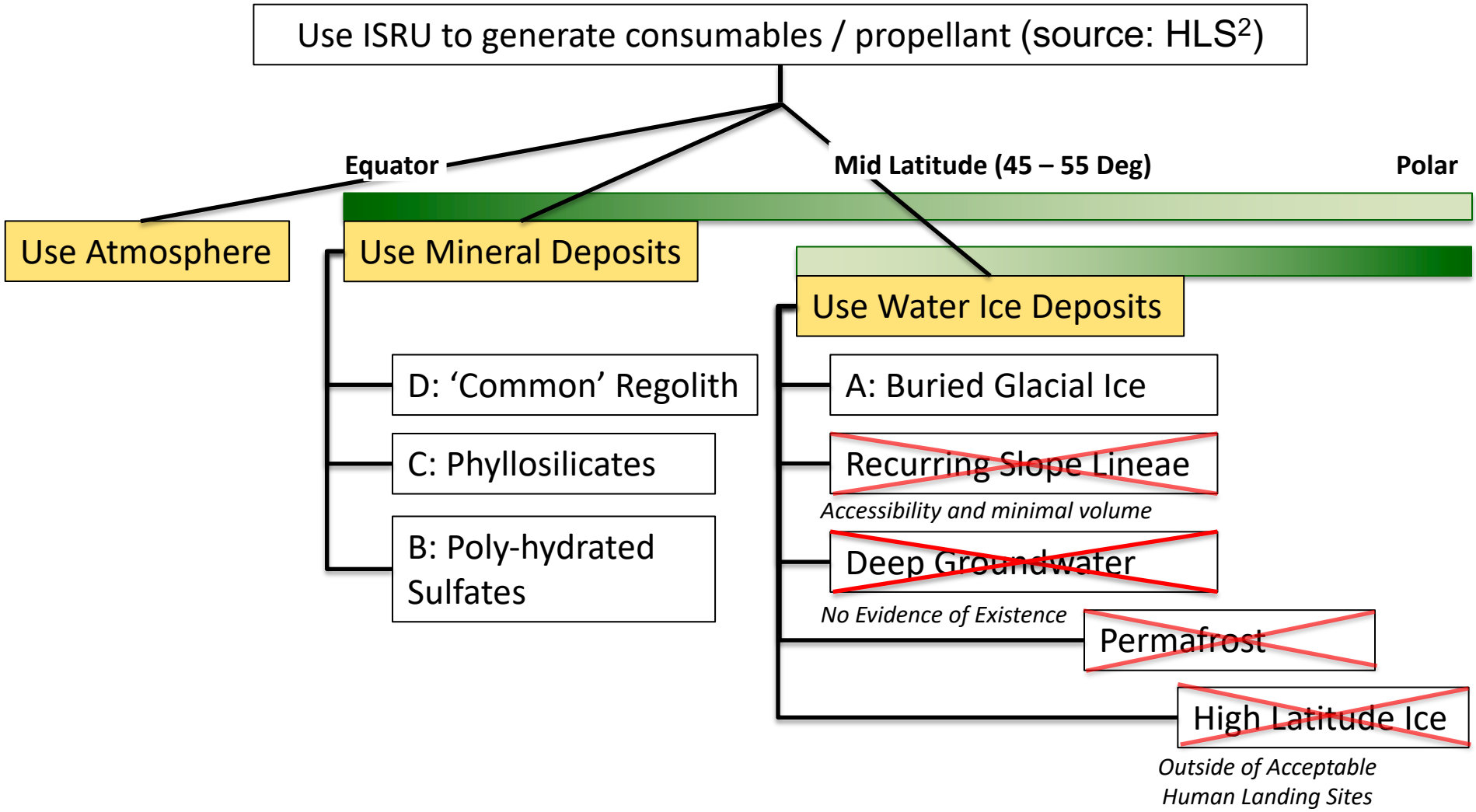
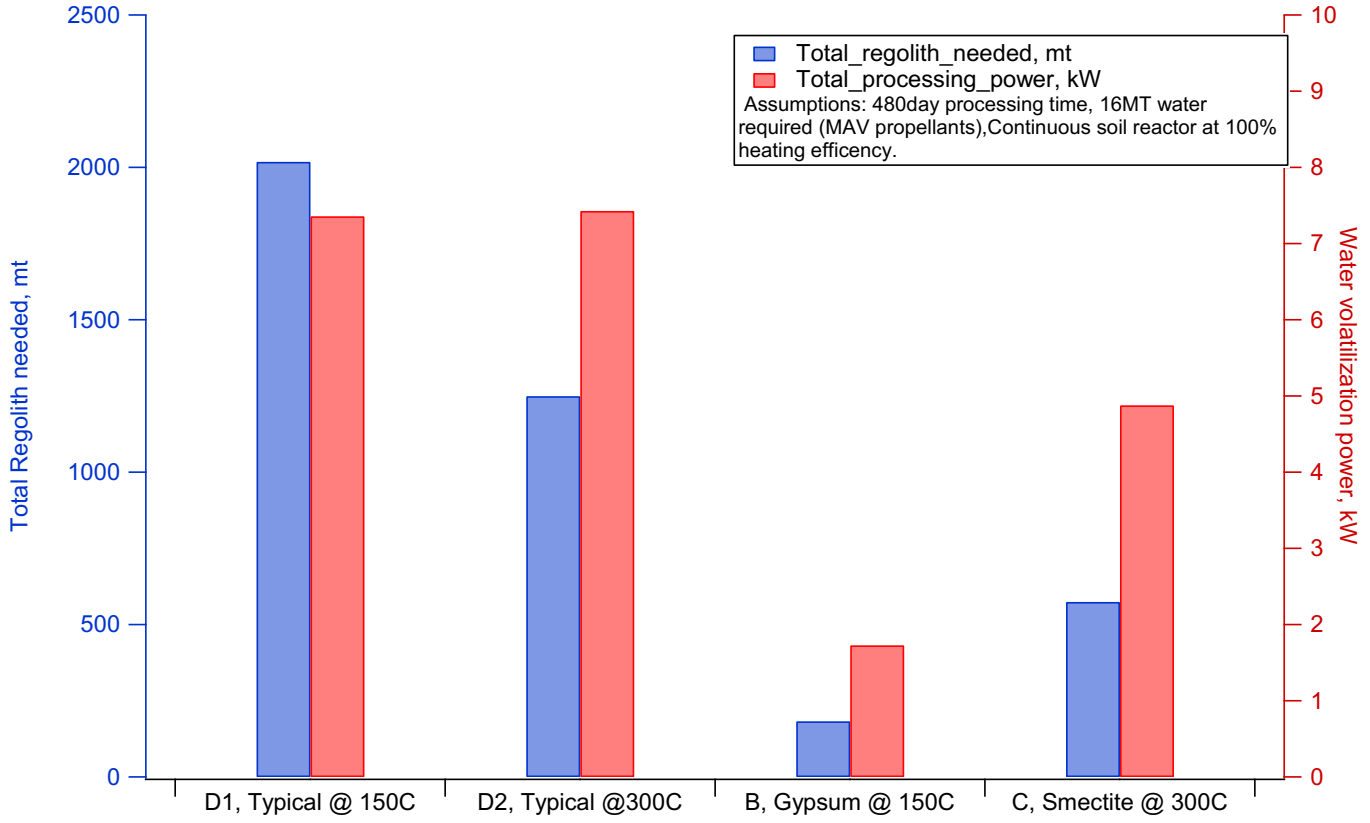
ESI17 Award: 80NSSC18K0252

ISRU Resource Trade Tree



Abbud-Madrid, A., D.W. Beaty, D. Boucher, B. Bussey, R. Davis, L. Gertsch, L.E. Hays, J. Kleinhenz, M.A. Meyer, M. Moats, R.P. Mueller, A. Paz, N. Suzuki, P. van Susante, C. Whetsel, E.A. Zbinden, 2016, Report of the Mars Water In-Situ Resource Utilization (ISRU) Planning (M-WIP) Study; 90 p, posted April, 2016 at http://mepag.nasa.gov/reports/Mars_Water_ISRU_Study.pptx

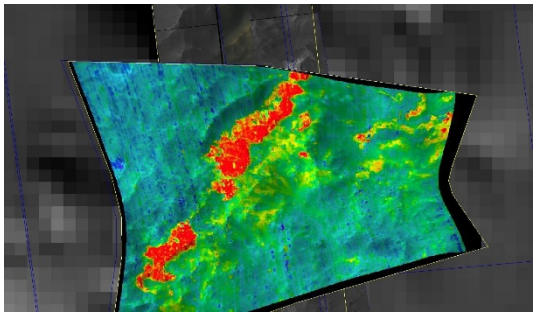
Key Characteristics by Feedstock

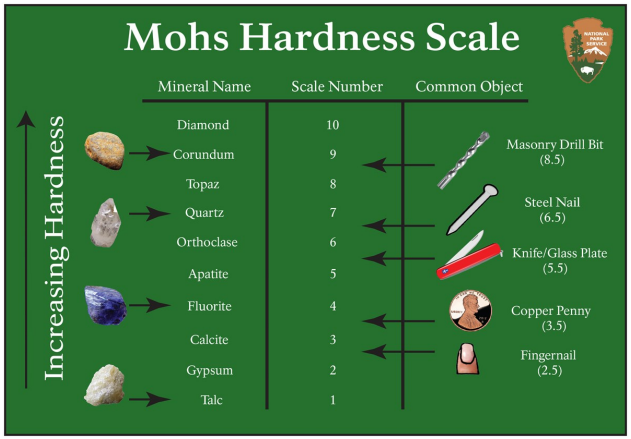


- Gypsum deposits would have the lowest mass AND power requirements of the granular deposits. Ice mining power not established due to less experience and available data.
- Typical martian regolith processed at low temperatures doesn't result in lower power (due to production rates) AND requires more mass -> NO ADVANTAGE

Gypsum ($CaSO_4 \cdot 2H_2O$) is promising

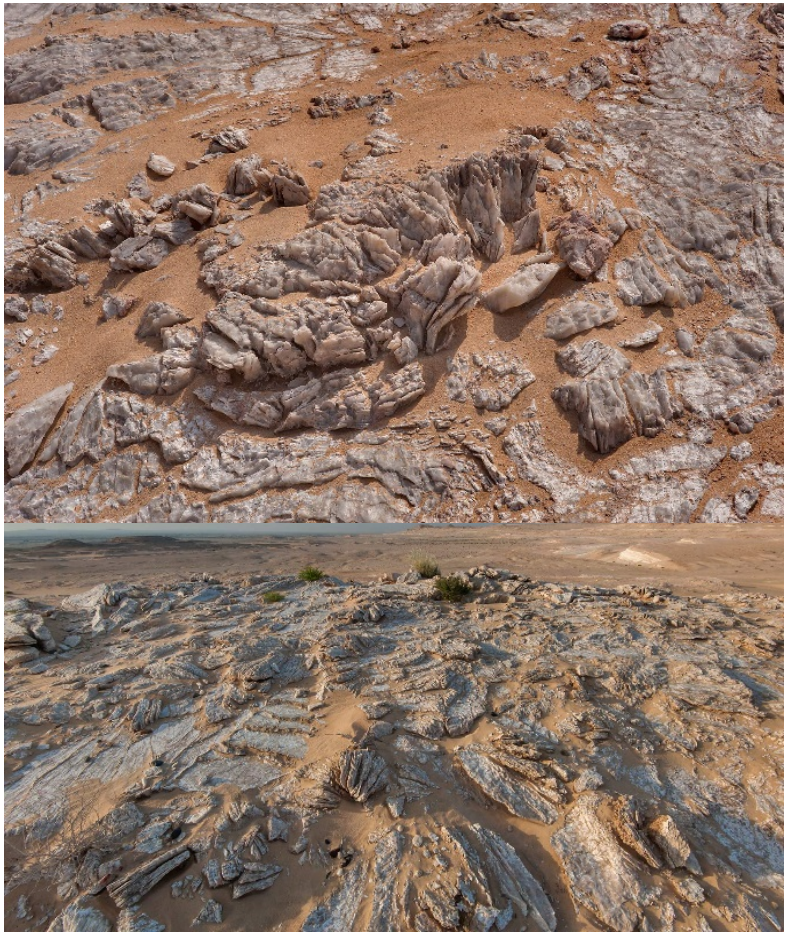
- Exists on Mars in all hydration forms (Gypsum, Basanite, Anhydrite)
  - Gypsum ($CaSO_4.2H_2O$)
  - Alpha and beta hemihydrate ($CaSO_4.0.5H_2O$)
  - Anhydrite ($CaSO_4$)
- Exists in many places
  - Noctis Labyrinthus, Melas Chasma, Columbus Crater, Gale Crater, Mars poles etc.
- Promising source of water
  - 20.9% water by mass
  - Water bound in crystal, disassociates around 150 °C
  - Soft (Moh's Hardness of 2, 3-60MPa)



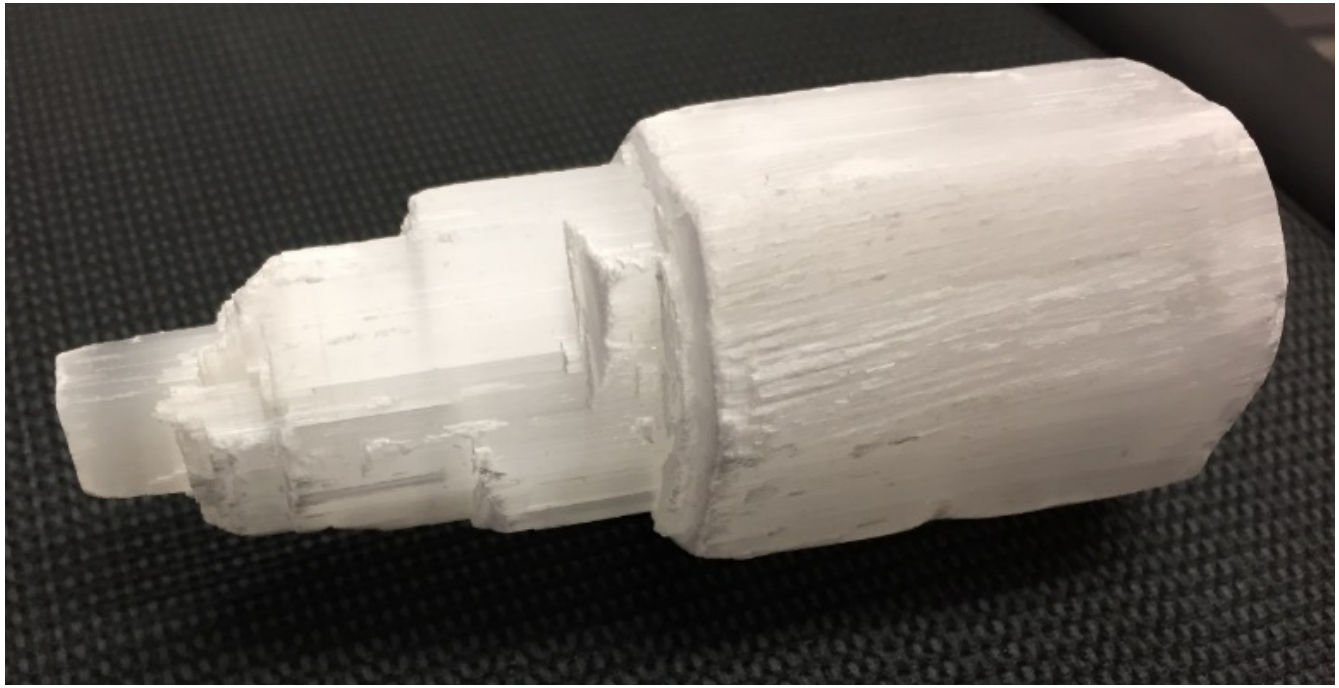


Surface occurences of gypsum

(on Earth)



- Selenite tower gypsum crystal
- 4-5 inch tall



- Desert rose gypsum crystal
- 2 inch diameter

Other occurrences of gypsum

National geographic picture of Cave of Crystals in the Naica Mine in Mexico.

Gypsum curtains and stalagtites in Lechuguilla cave in New Mexico as part of the Carlsbad Caverns National Park

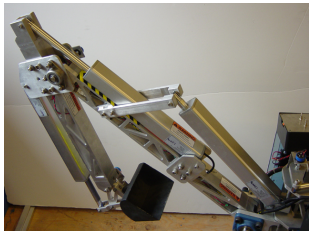
White Sands, NM (gypsum sand dunes)

- Gypsum dunes exist in the Martian Polar areas

Typical Excavation Methods

- Granular vs. Hard rock (ice cemented)



- Has to be already granular

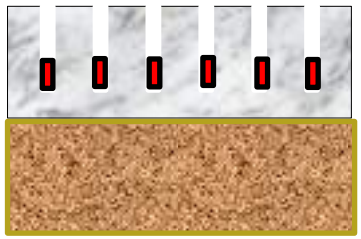
- Large reaction forces
- Wear / maintenance
- Operation for long periods
- Needs crushing/milling



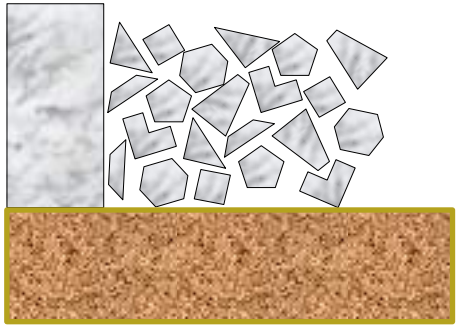

Classic Gypsum Mining Process (Earth)

Natural state

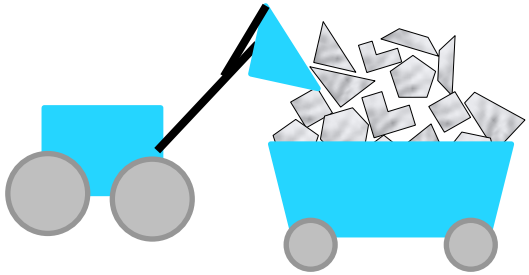
Drill blast holes



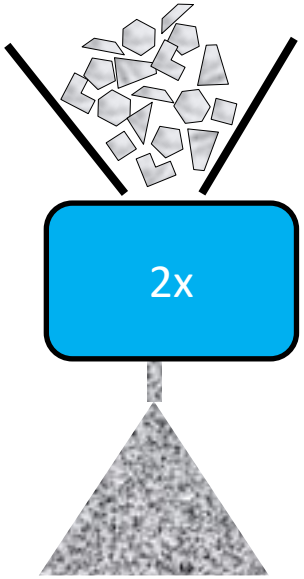
Load explosives



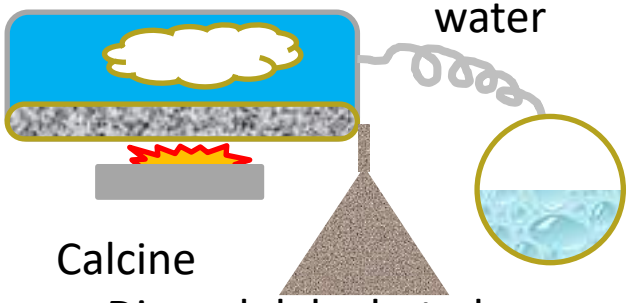
Blast



Load & Transport

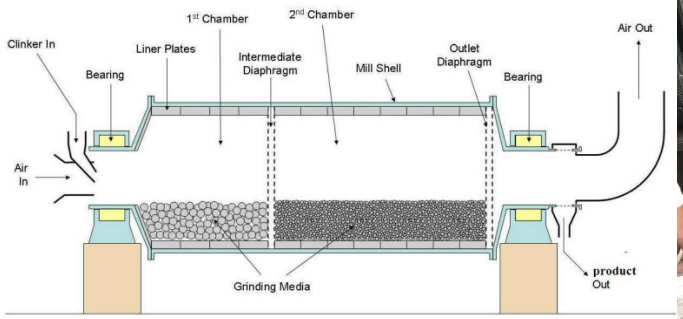


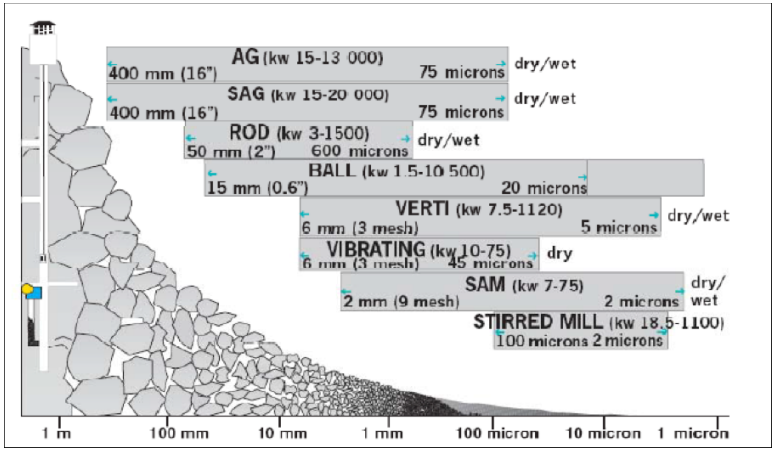
Crush / Mill rocks

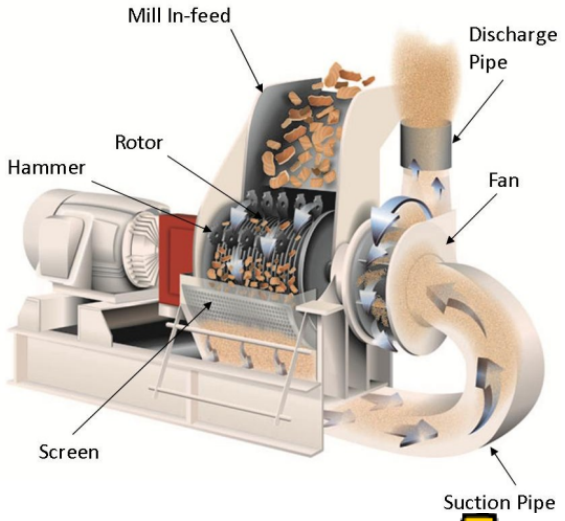


Award: 80NSSC18K0252

Size Reduction on Earth

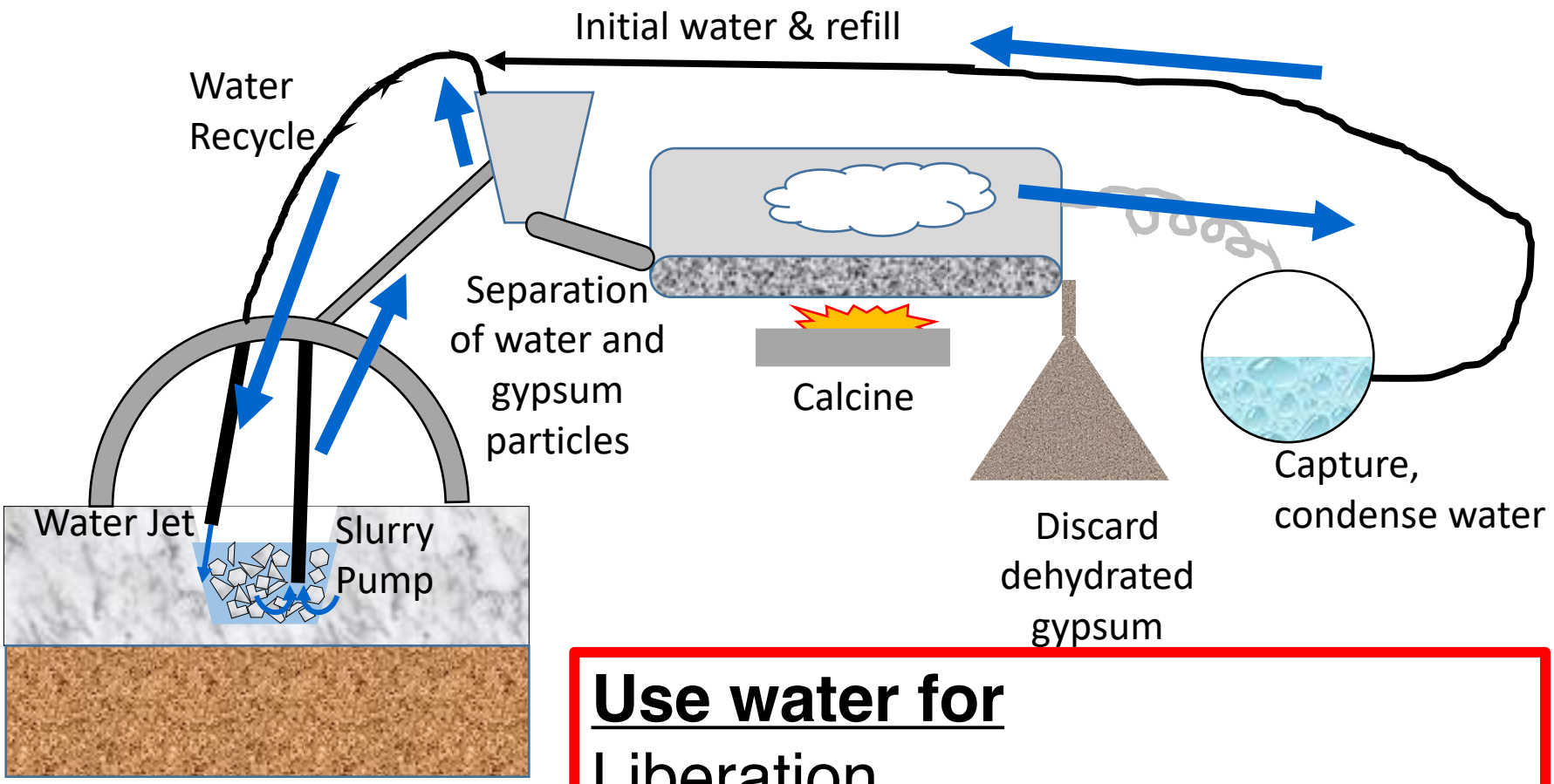






- For drywall production needed
  - Particles <100 micron before Calcination

Alternate Excavation & Calcination Process



Use water for

Liberation,
Comminution
Transportation
Separation

To extract MORE water

Advantages

No mechanical excavation and comminution = no wear

Early Stage Innovation Project

- Started Jan 15, 2018
- 3 years
- Understanding
  - Gypsum (contamination)
  - Sealing / Enclosure
  - Excavation
  - Particle sizes generated
  - Slurry Pumping
  - Particle separation
  - Water extraction
  - Thermal & Fluid flows

Gypsum

- Deposit Mechanism
  - Sabkha (tidal flats)
  - Deep basin
- Porosity/permeability
- Thermal properties
- Mechanical properties
- Variability

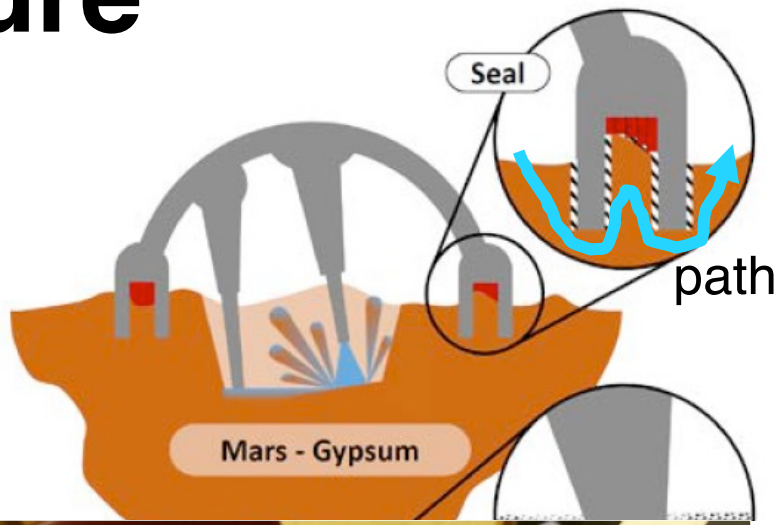


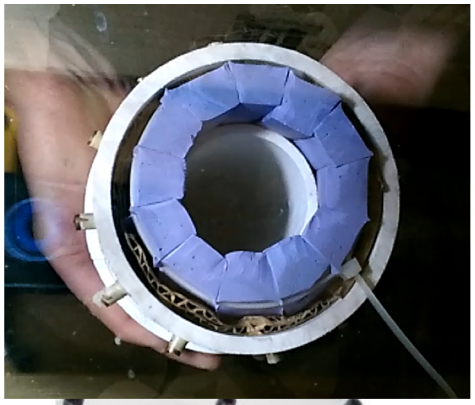


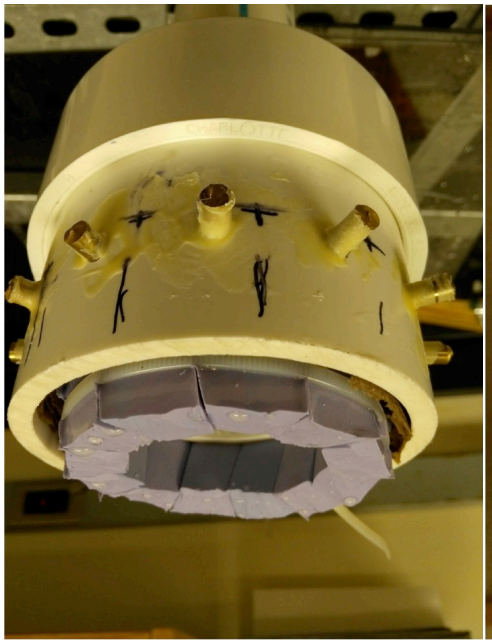


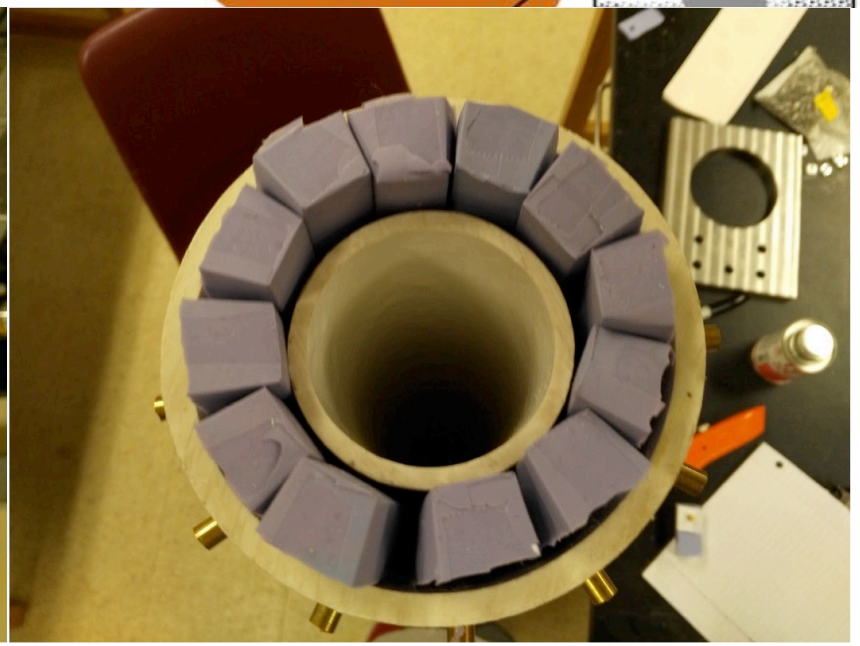
Sealing / Enclosure

- Exploring options
  - Double ring of ‘saw edge’
  - Silicone fingers in between









Excavation

- 20 minute yield varied from a few oz. to 11 lbs (@ 2200 psi and 15 deg nozzle)



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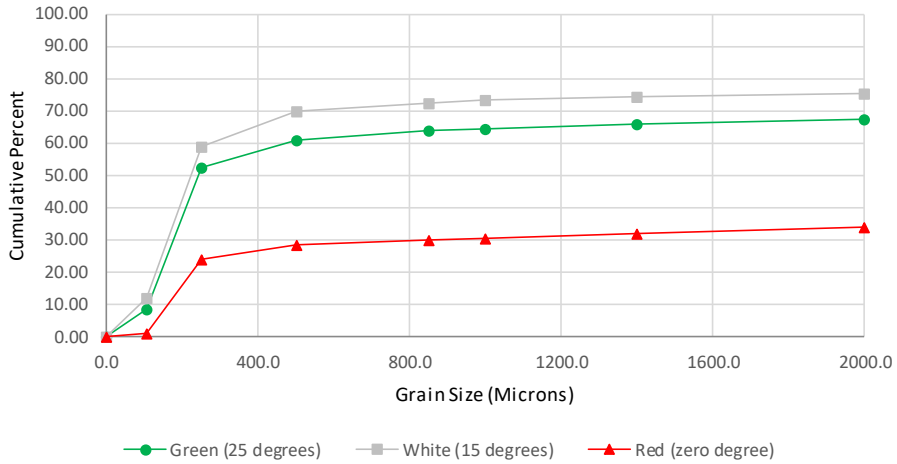
Particle Sizes Generated

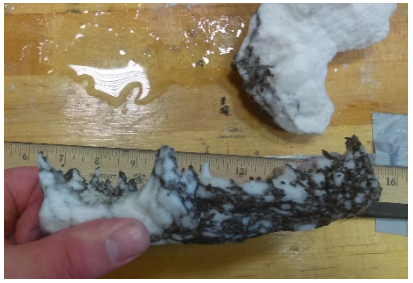
- Effect of spray intensity
- 2700 psi
- 1.7 GPM
- Zero degree vs 15 degree

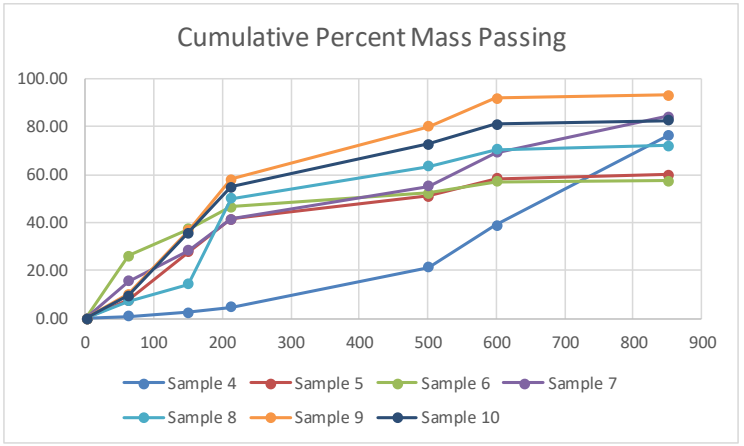


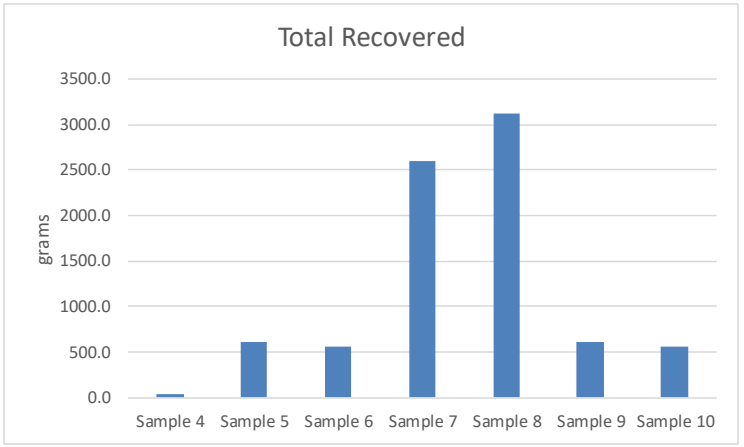
		2700 psi, 1.7 GPM, 30 seconds					
Combined	25 degree		15 degree		zero degree		
	Green (25 degrees)		White (15 degrees)		Red (zero degree)		
Microns	percent of start	retained on sieve (g)	percent of start	retained on sieve (g)	percent of start	retained on sieve (g)	
2000.0	14.24	27.06	16.53	42.98	58.56	511.20	
1400.0	0.76	1.44	0.71	1.84	1.74	15.18	
1000.0	0.61	1.15	0.75	1.94	1.10	9.64	
850.0	0.33	0.62	0.42	1.08	0.52	4.52	
500.0	1.25	2.38	1.96	5.10	1.49	13.04	
250.0	3.58	6.80	7.32	19.04	4.01	35.00	
106.0	19.38	36.82	31.48	81.84	20.29	177.14	
0.0	3.67	6.98	7.95	20.66	0.74	6.46	
		84.84		176.3		772.9	total started
		83.25		174.48		772.18	total recovered
		190.00		260.00		873.00	mass on paper towel
	56.18	106.75	32.89	85.52	11.55	100.82	left on paper towel (small particles)

Particle Sizes Generated





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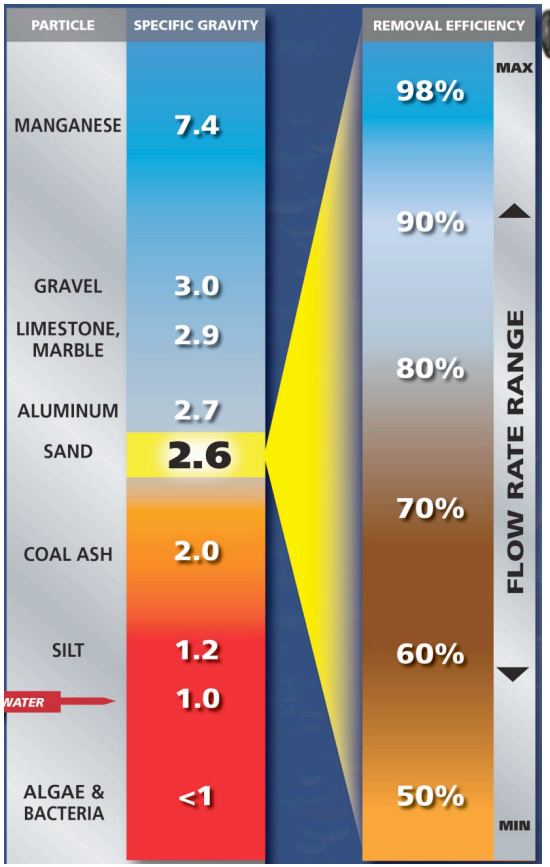
Slurry Pumping

- Currently using Sump pump
- Particles settle quickly
- May require agitation using mixer or waterspray

- Sand particles found their perfect hole to get stuck in
- If using screens → need method to clean

Particle Separation

- 98% solid removal at >40 micron
- 4-10 GPM



Gypsum = 2.3 g/cc

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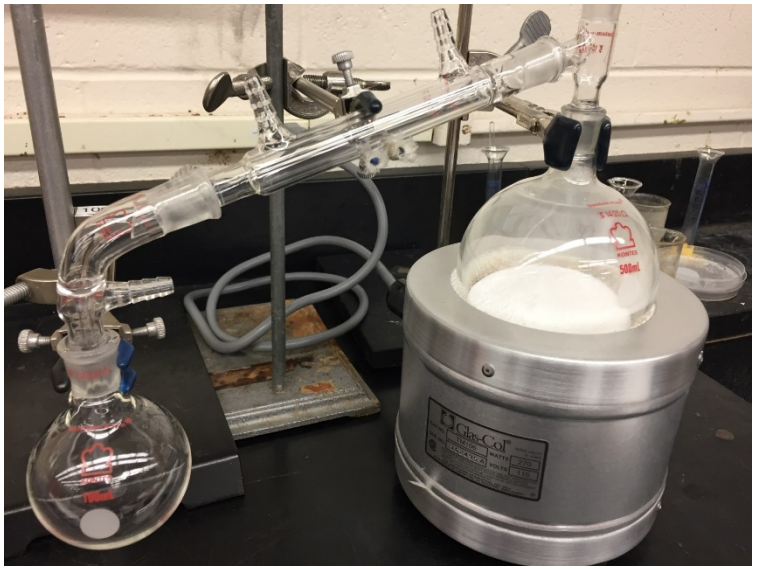
Water Extraction



Product	Process	Options	Temp Start of process	Stages
Alpha Hemihydrate	Fully saturated environment	Steam Autoclave	43-49 C, above 97 C	110-130 C, end at 160 C
Beta hemihydrate	Under-saturated environment	Rotary kiln, kettle, flash calcining	43-49 C	116-121 C 1st boil, 149-166 C Continuous up to 140-154 C Batch up to 150-165 C
Soluble anhydrite	Keep heating either one		177 C 2nd boil	Up to 210 C
Dead burned anhydrite	Keep heating either one		210 C	Up to 540 C

Dry heating issue

110 g gypsum got
16 g water
(22 g max)

Pyrex (820 C) softening point

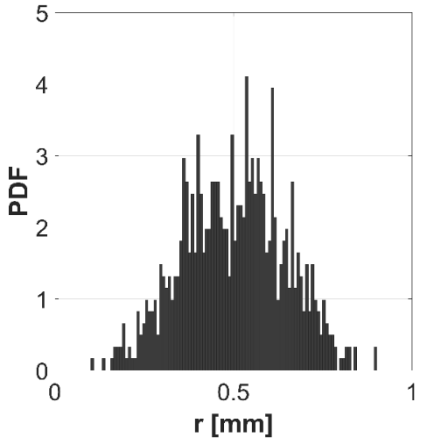
Modeling: Analytical & Pore Network Model

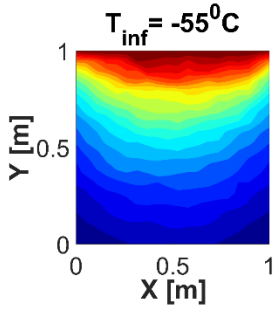
Coarse pores: 400 pores

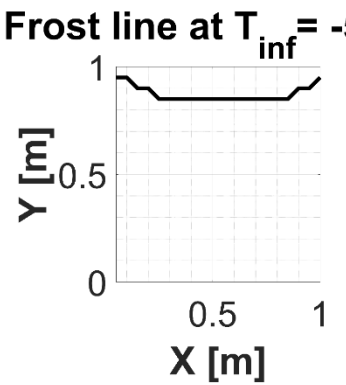
T_0=20 C

P_0=2-3 kPa

T_{inf} = -55 C



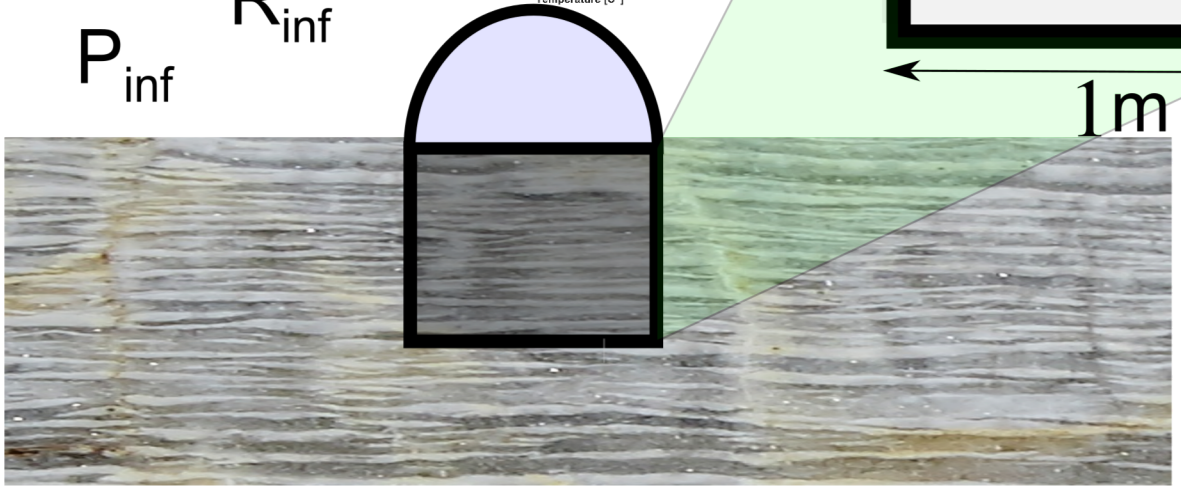




T_{inf}

P_{inf}

R_{inf}



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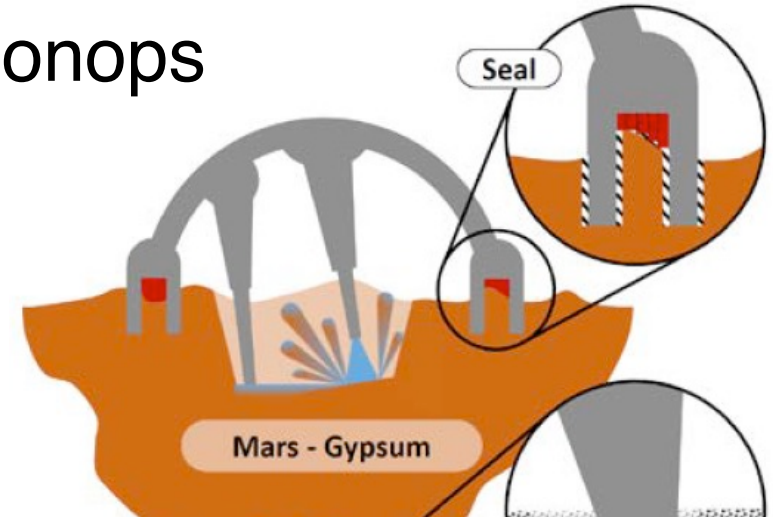
Conclusion

- No show stoppers found
- Large variability of natural rock material
- Component requirement definition ongoing
- Starting system analysis / synthesis
- Mining process for detailed conops



- Future expansion:
  - Combine with gas transport
  - Shopvac / dental setup
  - Works with granular, ice-cemented and hard rock

Available Facilities MTU – Looking for ISRU Partners

- Rock crushing lab — April 2018
- Vacuum chambers
- Chemical Processing Operations lab
- Modeling capabilities (super computer)
- KRC
  - 900 acres test terrain (all year)
  - Cold, ice, snow, winter testing
  - Many different terrains, slopes, surface features
  - Multiple 18-wheeler bays climate controlled (-80C)
  - Mobility, robotics, detection etc.
  - Basalt quarry

Acknowledgements

This work was supported by an Early Stage Innovations grant from NASA's Space Technology Research Grants Program

- Many students:
  - Shahab Bayani Ahanger (Grad Student)
  - Wonyoung Choi (Highschool Student)
  - Michael Foetish (Grad Student)
  - Preston Hogue (Undergrad Student)
  - Udit Sharma (Grad Student)
  - Andrew Watson (Undergrad Student)
  - Mining INnovation Enterprise students (12)