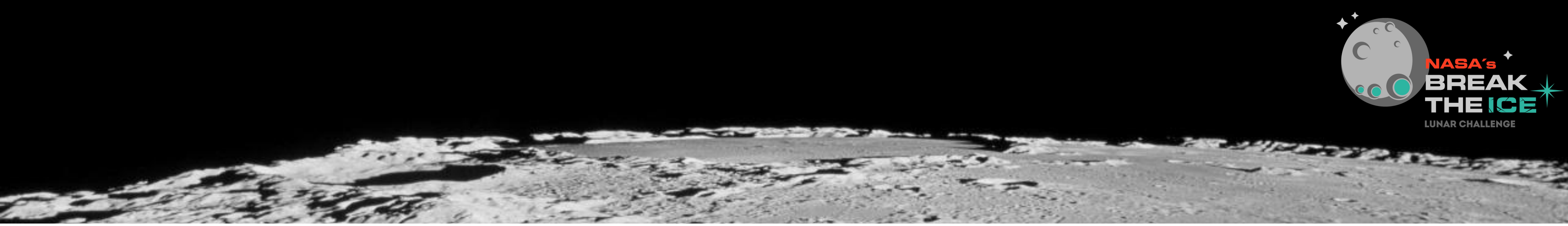


NASA's BREAK THE ICE LUNAR CHALLENGE

Lunar Icy Regolith and Controlled Low Strength Materials

Webinar and Q&A

August 25th 1 – 2 pm (Central)

Agenda

- Welcome, Introductions & Housekeeping
- Background on Lunar Ice
- Simulating What We Don’t Know
- CLSM What It is and How Do I Get Some
- Q&A

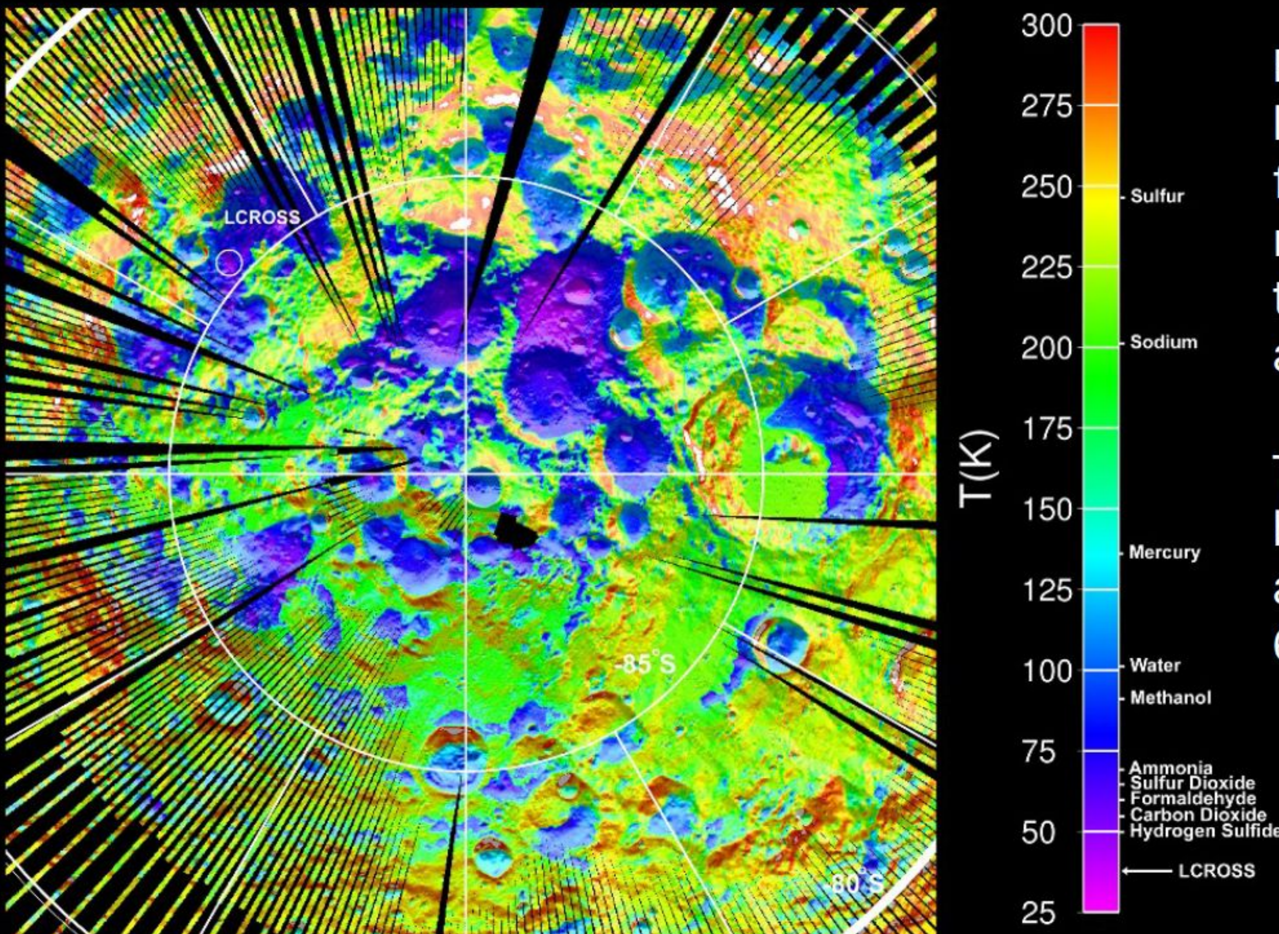
BREAK THE ICE LUNAR CHALLENGE: THE GEOLOGY OF LUNAR ICE

Kevin M. Cannon

cannon@mines.edu

@kmcannon

NASA's BREAK THE ICE LUNAR CHALLENGE



Broad regions at both lunar poles are shadowed from direct sunlight and reach cold enough temperatures to trap ice and other volatiles.

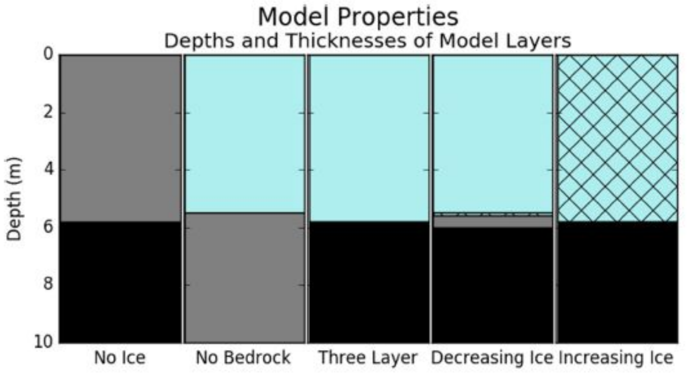
This was predicted dating back to the 50s (Urey) and first published in the 60s (Watson et al.)

Image credit: NASA

First "direct" detection: LCROSS experiment in 2009

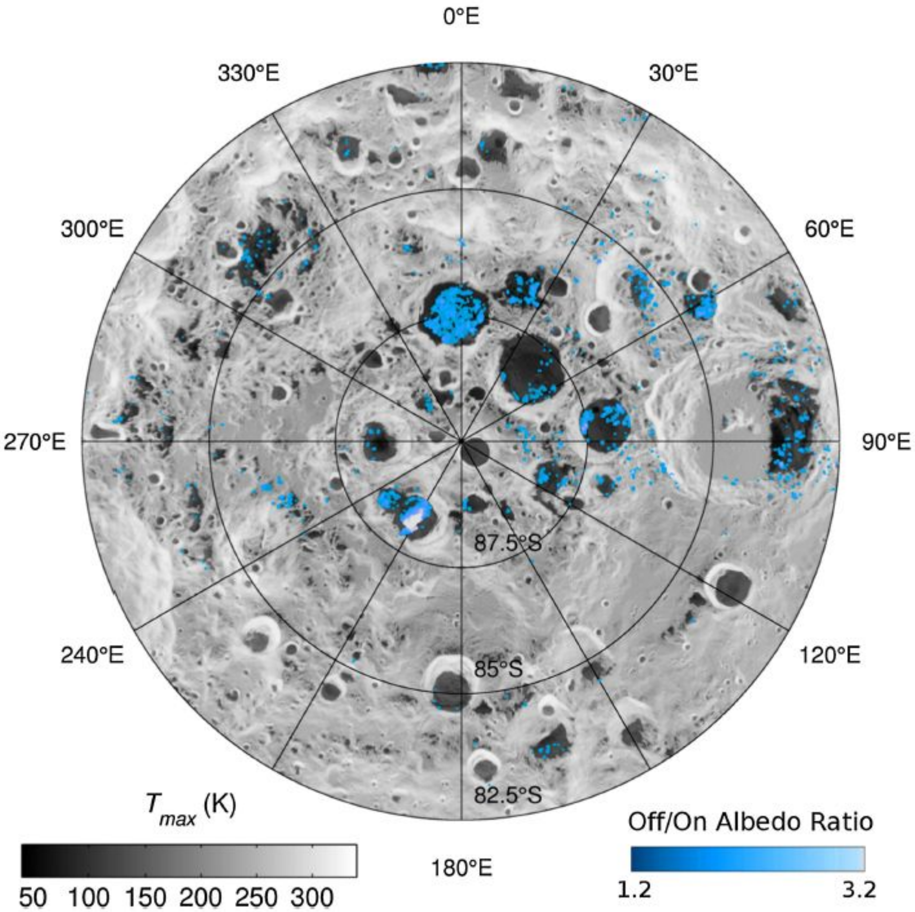
Image credit: NASA

Compound	% Relative to H2O(g)*
H_2O	100.00%
H_2S	16.75%
NH_3	6.03%
SO_2	3.19%
C_2H_4	3.12%
CO_2	2.17%
CH_3OH	1.55%
CH_4	0.65%
OH	0.03%

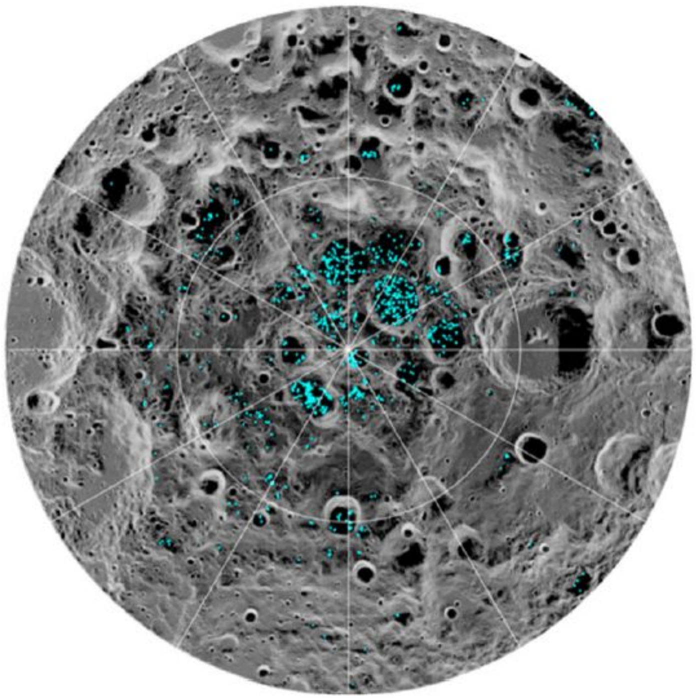


From Luchsinger et al. 2021

Other detections from remote sensing

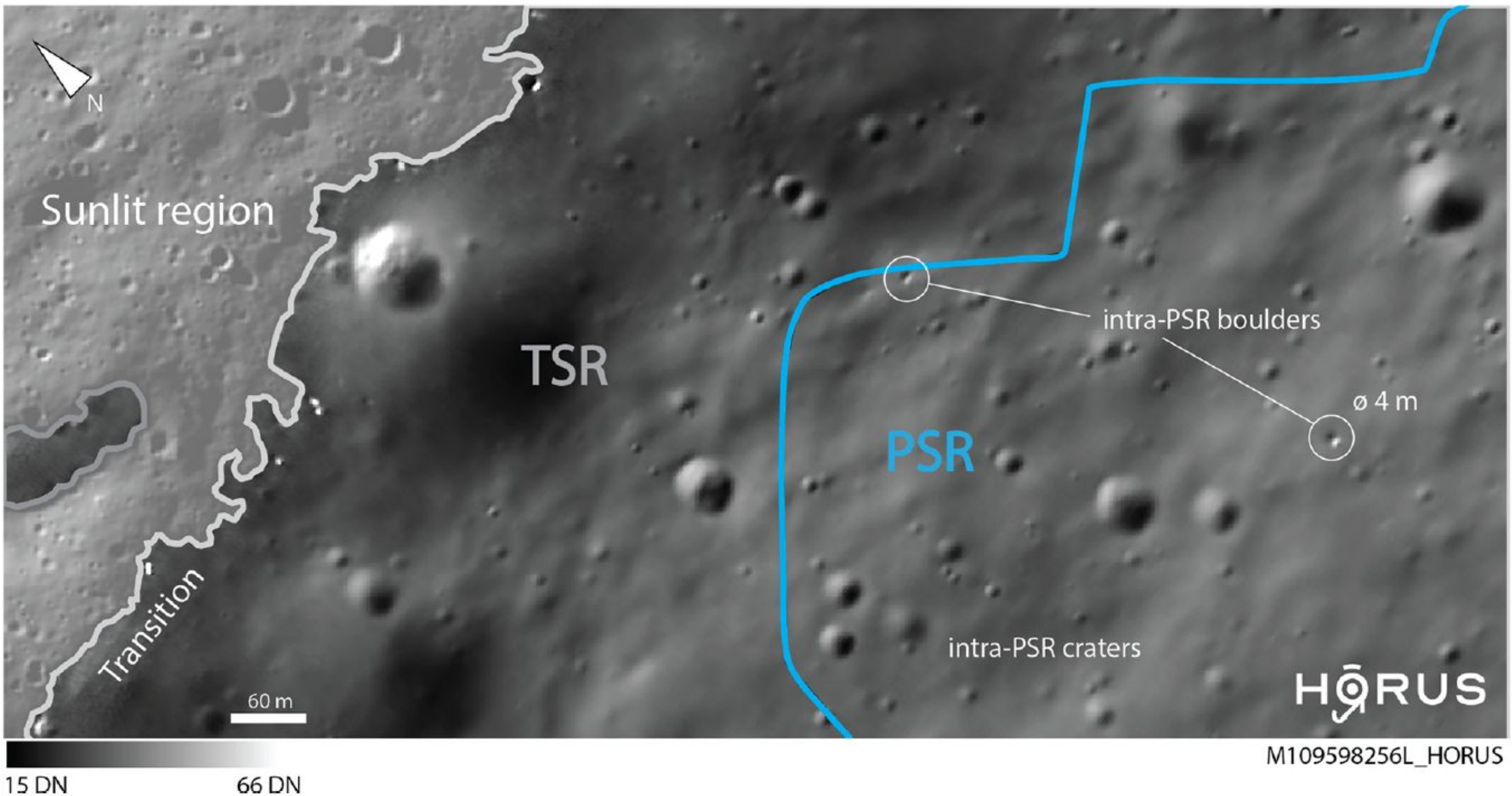


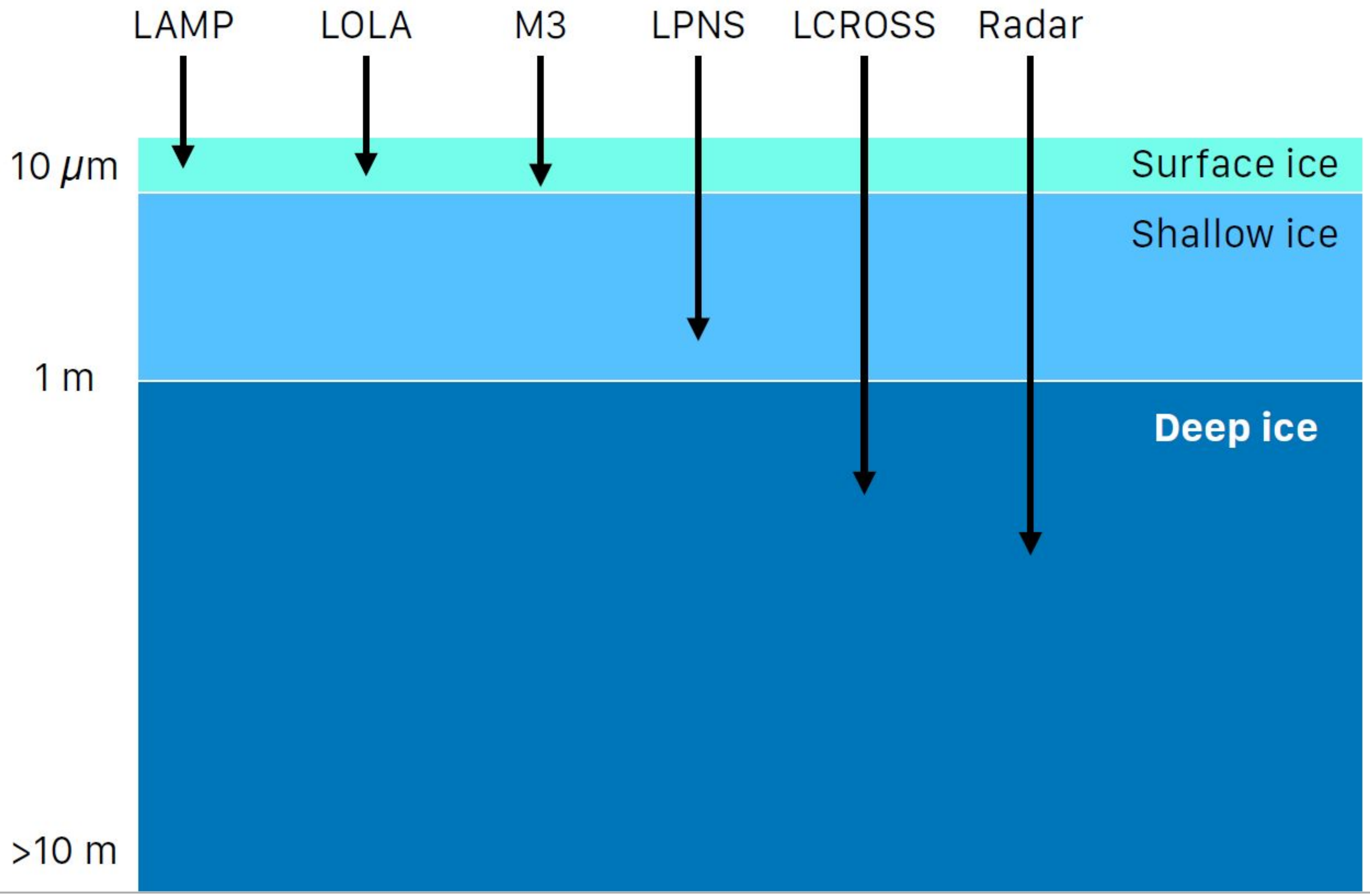
From Hayne et al. 2015

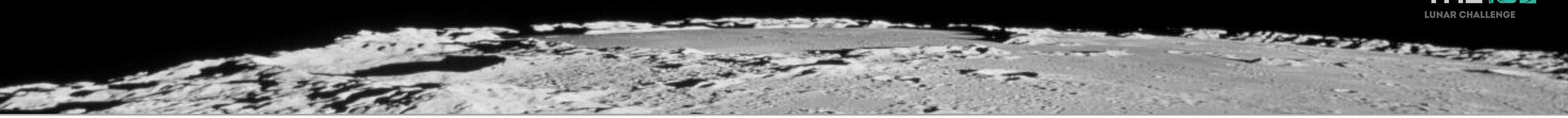


From Li et al. 2018

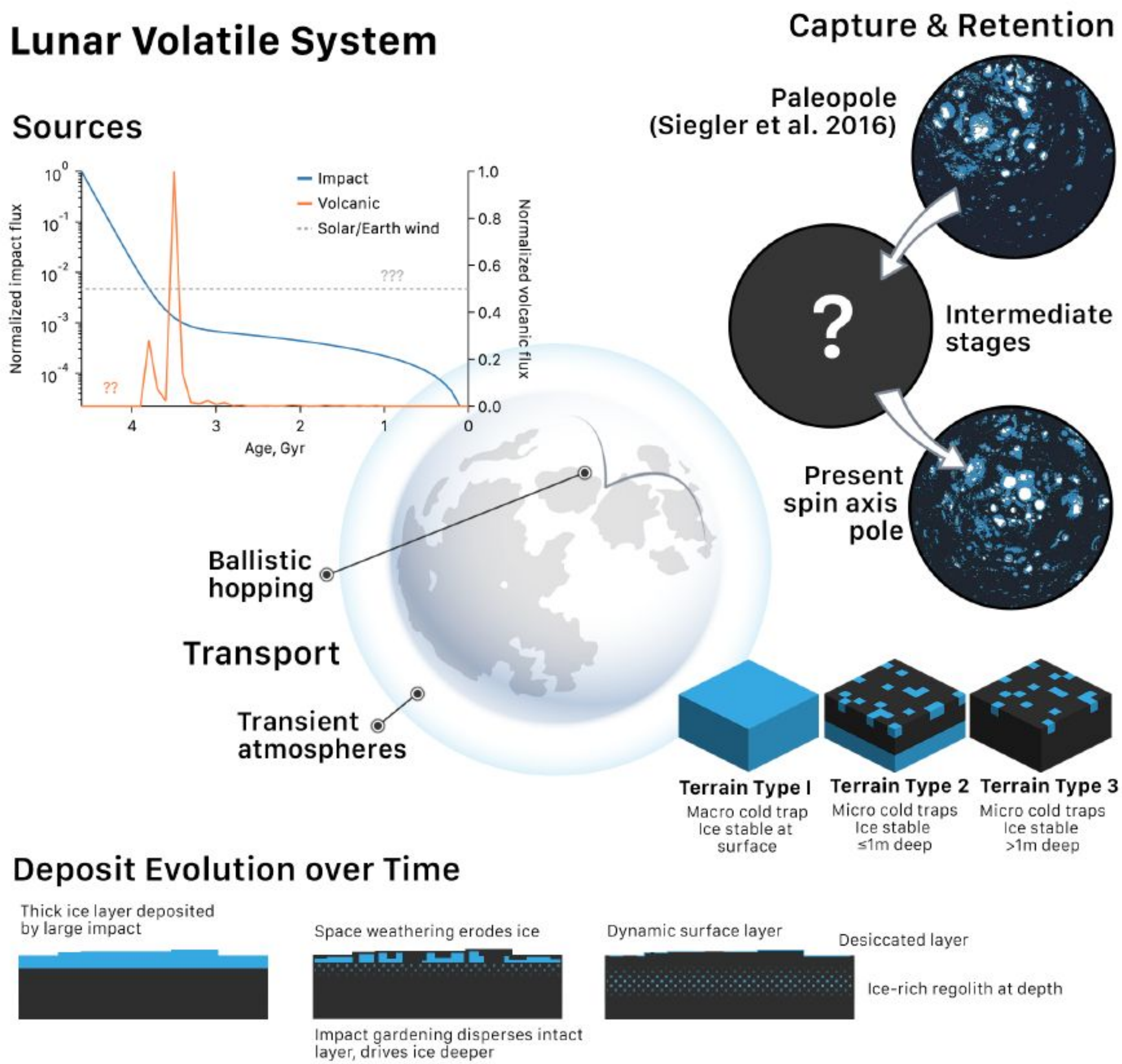
HORUS HYPER-EFFECTIVE NOISE REMOVAL UNET SOFTWARE

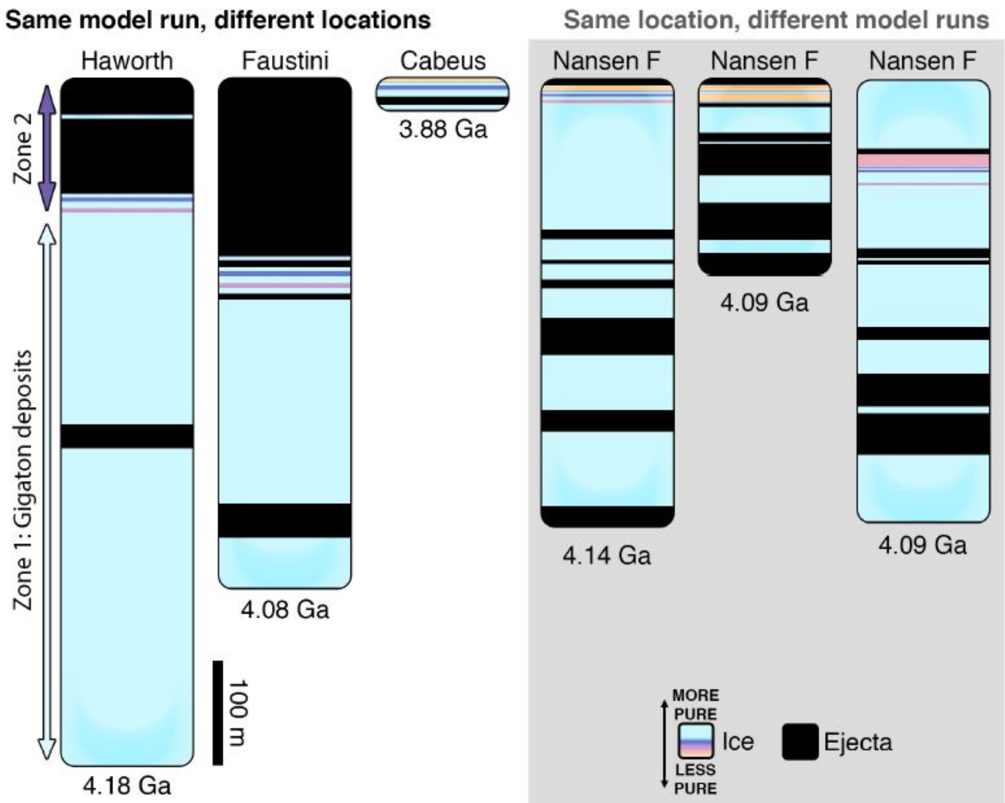



LAMP
LOLA
M3
LPNS
LCROSS
Radar
10 μm
1 m
>10 m
Surface ice
Shallow ice
Deep ice

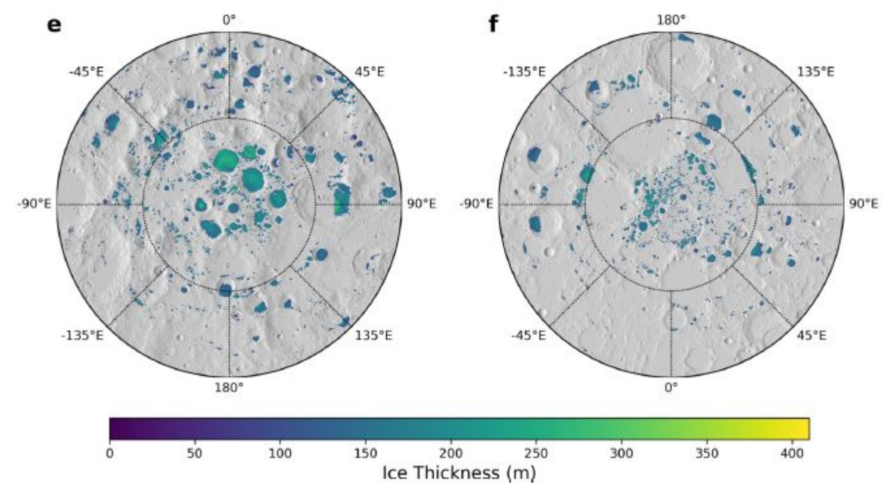


Lunar Volatile System





From Cannon et al. 2020



From Wilcoski et al. 2021

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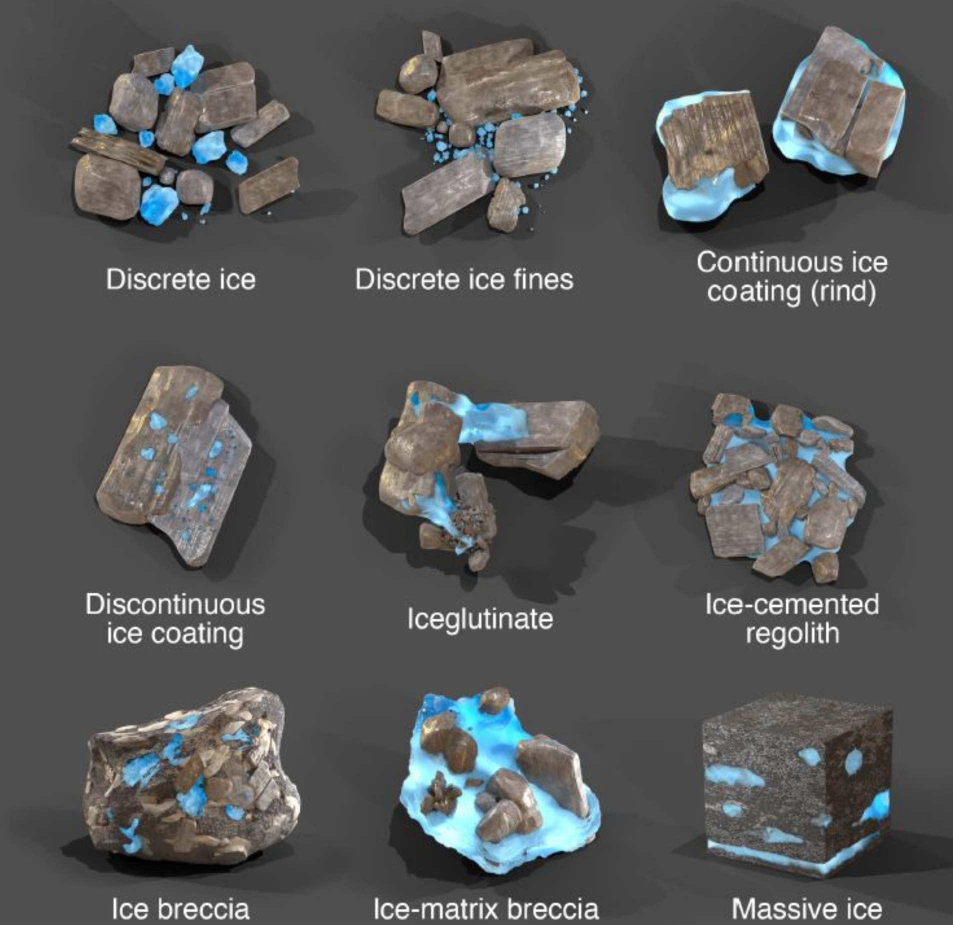


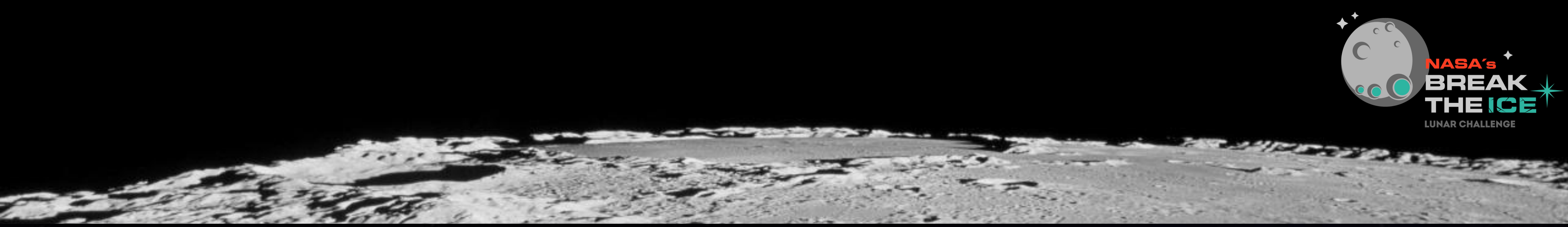
COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

Artwork by Lina Jakaite
strike-dip.com

The physical texture of lunar icy regolith is *unknown*.

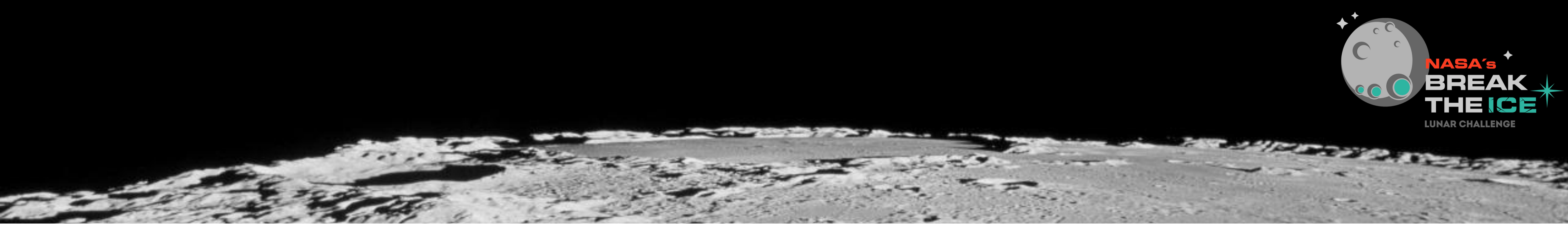
However, we can consider the geologic processes operating and make predictions about what's possible.

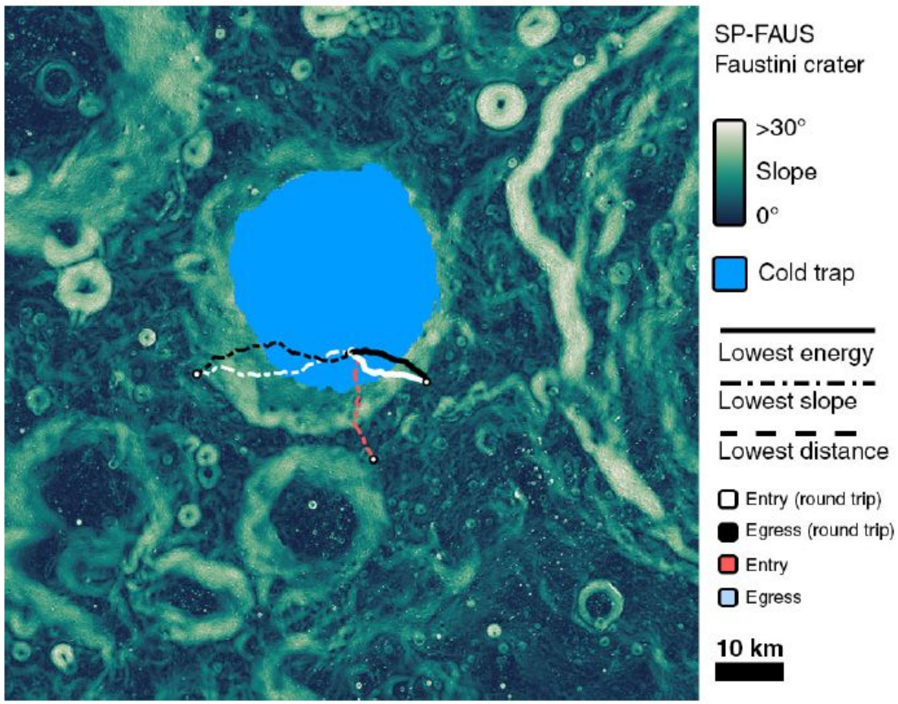
The textures on the left are probably all present to some extent, but their relative prevalence is not constrained.

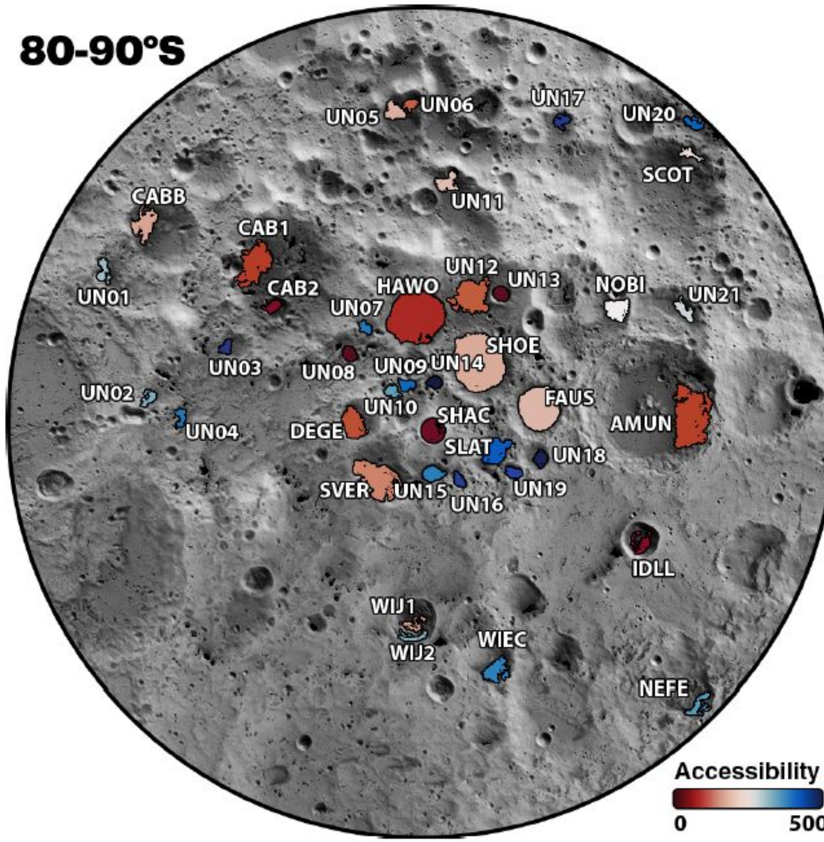


VIPER launching late 2024

NSS Neutron Spectrometer
TRIDENT Drill (1 m)
MSolo Mass Spectrometer
NIRVSS Spectrometer

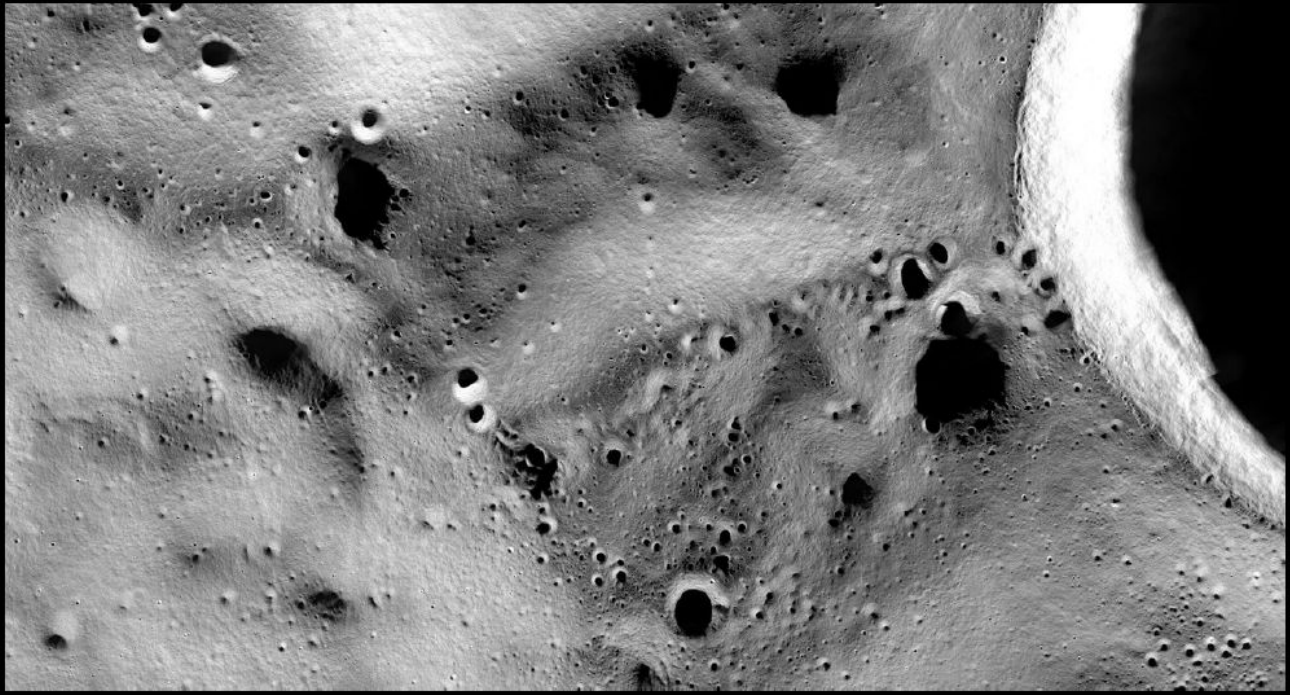


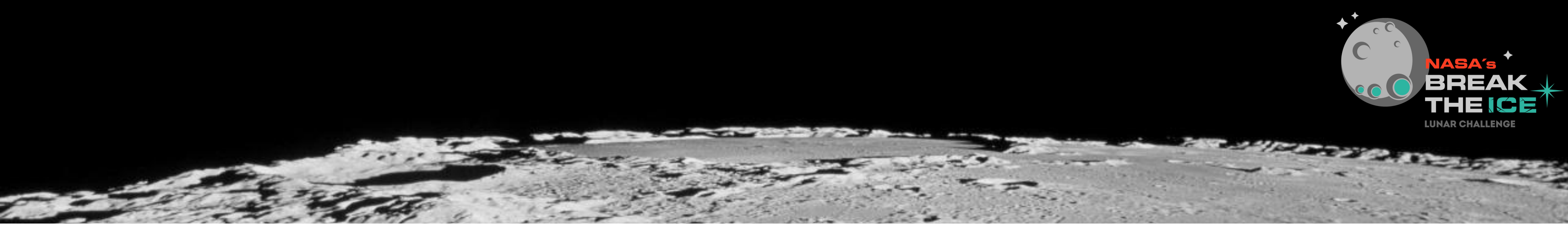




Cannon and Britt 2020b

VIPER Landing Site





Simulating the UNKNOWN

Pete Carrato

Simulating the UNKNOWN

It is a Challenge to create a Challenge.

Each Level is a bespoke event that will never be repeated.

Icy regolith simulation is the most common source of inquires from Teams.

Required Attributes

- Addresses the technology gaps

  Large quantities

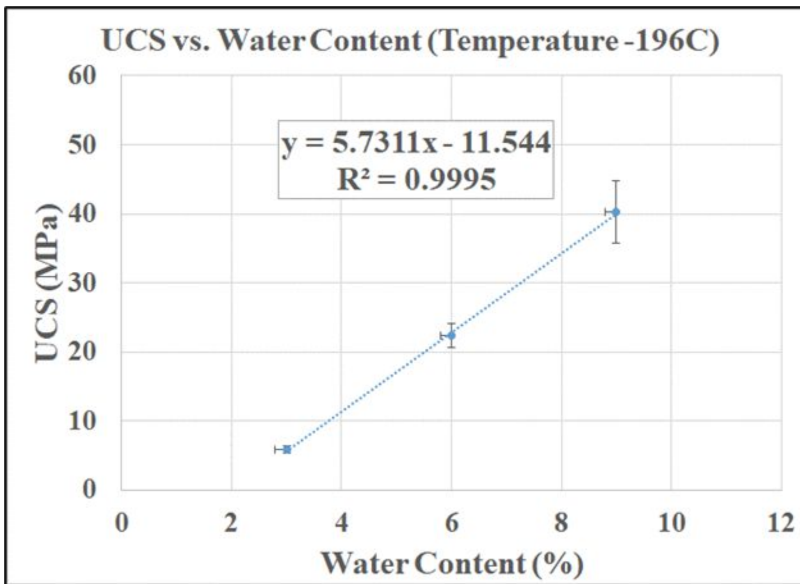
  Excavate

  Transport

- Simulates lunar condition

  Icy regolith deposit

Icy Regolith



Reference:
1) ASCE Earth and Space, April 2021
2) Estimation of Effects of Varying Moisture Condition and Temperature on Strength Properties of Icy Lunar Regolith in Cryogenic Environments, Liu et al

Icy Regolith

- Mechanical properties are critical for BTIL

  Particle size distribution

  Strength – BREAK THE ICE

  Density

  Abrasion

  Void ratio

  Etc.

Strength of Icy Regolith

A wide range of possible strengths, from permafrost to a loosely cemented granular mixture.

Eranti Engineering Oy Cold Weather Engineering

Realistic Constraints

- Affordable
  Not lunar simulant
- Achievable

  Not maintained at -196 C
- Available

  Not limited to Tier 1 Research Facility
- Reliable

  Not new technology
- Repeatable

  Not limited by testing methods

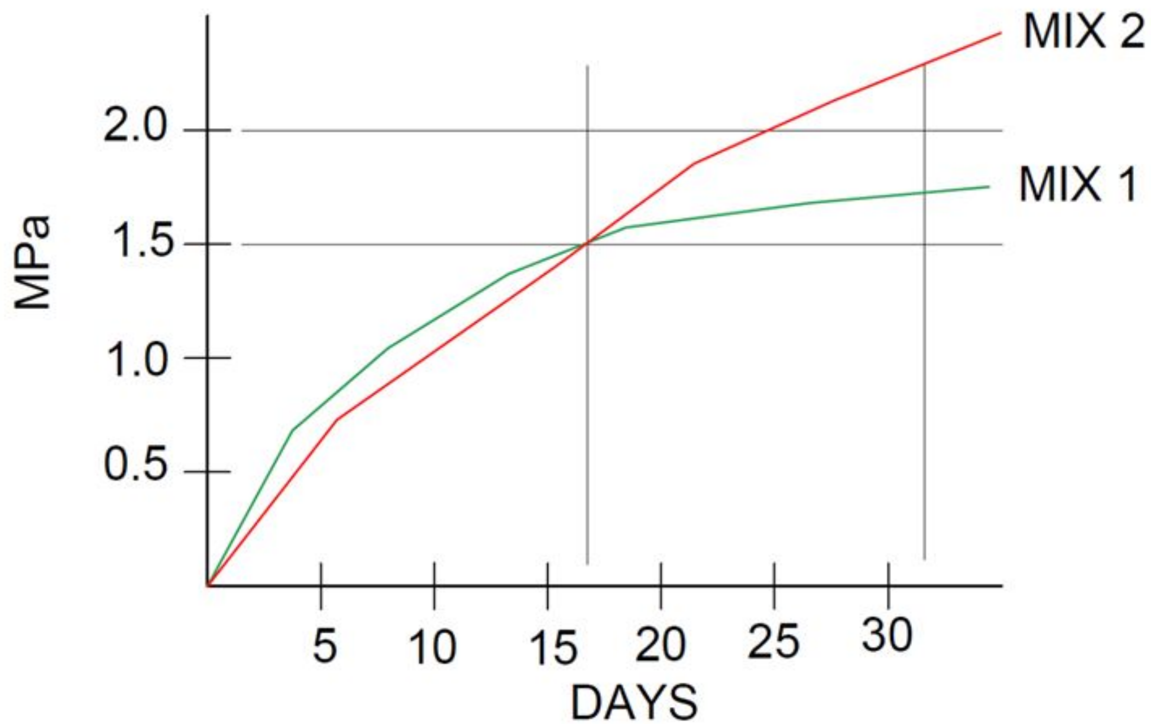
BTIL Simulation

- Consolidated Low-Strength Material – ACI 229-R
- Fillcrete
- Flowable Fill
- Low strength concrete

CLSM Mixture

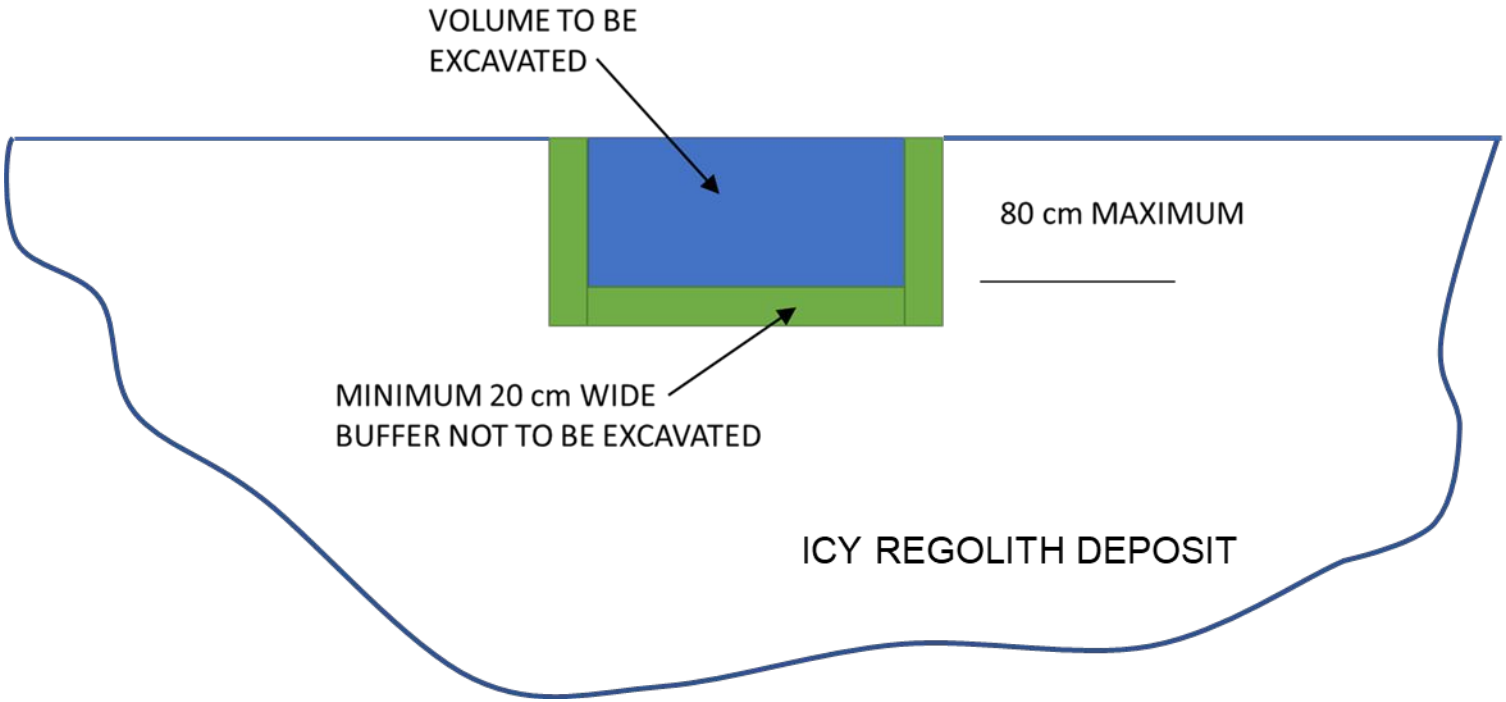
Use CLSM with one required physical attribute, unconfined compressive strength.

One mixture constraint, no light-weight aggregate.



CLSM Placement

Placed in a continuous process lasting less than 8 hours.



NASA's BREAK THE ICE
LUNAR CHALLENGE

CLSM – aka Flowable Fill

Javeed Munshi

Controlled Low-Strength Material - CLSM

Flowable/low grade self levelling concrete

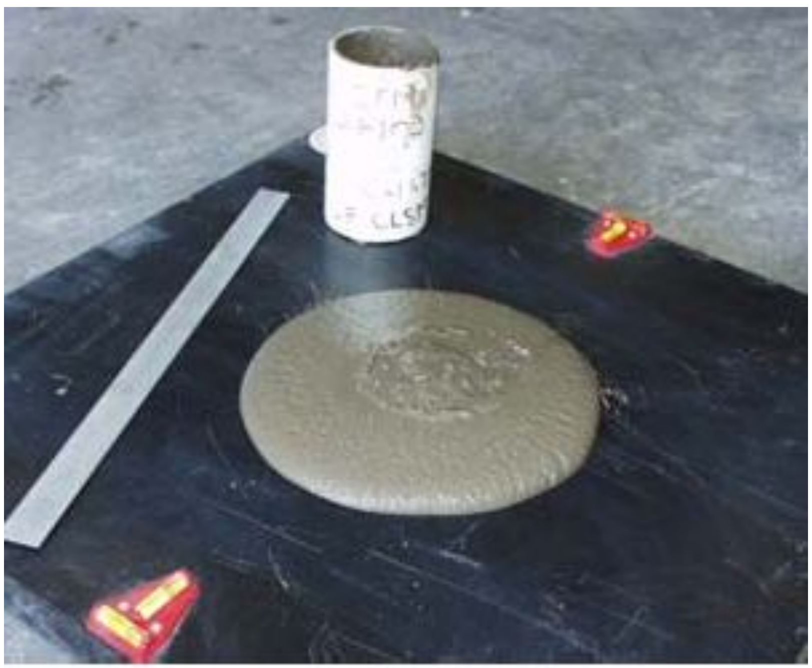
Cement+Fly Ash+Sand+Water +Admixtures

ACI 229R or AASHTO

R3.9 CLSM Air Generating Admixture – Dispensed and mixed into the CLSM, the admixture produces a stable air content between 15 and 30%. Some of the benefits of entraining air in CLSM is it controls strength development and reduces the water content, bleeding, shrinkage, and settlement.

CLSM

Flow of 6-8 inches



CLSM

Comparison

Properties	Typical CLSM	Compacted Earth Fill
28-Day Compressive Strength	< 2.1 MPa [< 300 psi] *	< 0.3 MPa [< 50 psi]
Density	1840-2320 kg/m^3 [115-145 pcf]	1600-2000 kg/m^3 [100-125 pcf]
Placement	Self-leveling, no equipment needed	Mechanical compaction

Strength of Icy Regolith

Setting and Hardening

Setting time is the time when the CLSM transitions from fluid-state to hardened-state [< 24 hours]

Hardening time is when CLSM has sufficient bearing capacity to support construction loads [up to 2-3 weeks]

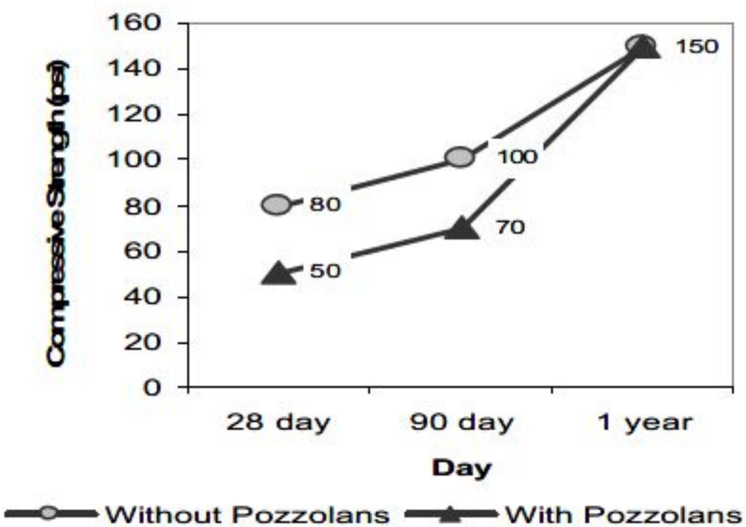
Excavability

R3.3 Excavatability-The excavatability Of hardened CLSM can generally be divided into two categories:

1) Unconfined compressive strength < 150 psi is considered to be EXCAVATABLE by hand tools and conventional machinery such as backhoes.
2) Unconfined compressive strength > 150 psi is considered to be NON-EXCAVATABLE.

CLSM – How to specify

Graph R6.3: An example of compressive strength development for CLSM mixtures.



California Bearing Ratio - When required, the CBR value shall be specified by the ENGINEER. The ENGINEER may elect to specify a minimum 28-day compressive strength in place of specifying a CBR test.

Unit Weight - When required, the unit weight shall be specified by the ENGINEER. The manufacturer shall be permitted to select and proportion the ingredients of the CLSM mixture to meet specified requirements.

Penetration Resistance - The ENGINEER may elect to specify a minimum penetration resistance (ASTM C403), hardening time, proof rolling, drop ball test (ASTM D6024), or proof that the CLSM mixture will support an individuals weight.

CLSM - Testing

8.0 QUALITY CONTROL

8.1 Sampling - ASTM D 5971

8.2 Compressive Strength - ASTM D 4832

8.3 Unit Weight - ASTM D 6023

8.4 Flowability - ASTM D 6103

8.5 Air Content - ASTM D 6023

8.6 Permeability - ASTM D 5084

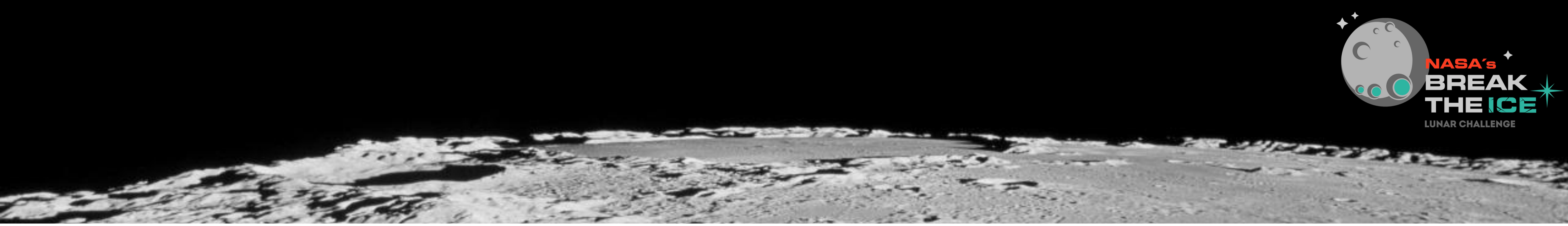
8.7 California Bearing Ratio - ASTM D 1883

8.8 Penetration Resistance - ASTM C 403

CLSM – Where to source from?

Ready mix suppliers can produce to the required specs

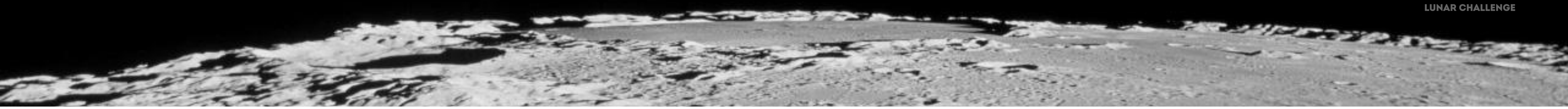
Controlled by standard NRMCA certifications and QA/QC protocols



Q&A

SUBMIT YOUR QUESTIONS VIA THE Q&A CHAT BOX

Next Steps



- Complete the required paperwork and submit the supporting documents and forms by September 30, 2022

- Stay Connected

  Challenge Website: https://breaktheicechallenge.com/

  @NASAPrize

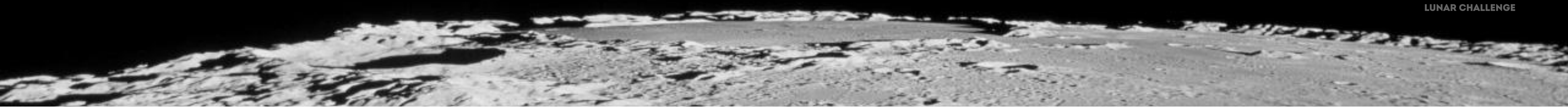
  @NASAPrize

  /NASAcc

- Questions: Email at admin@breaktheicechallenge.com

NOTE*: Any questions or inquiries sent to any other contact or sent directly to any of the Challenge Administrators will not be answered. This includes NASA, NASA Centennial Challenges, NASA Centers, and NASA Tournament Labs.*

Ollie



THANK YOU