

# A Novel Method for Producing Icy Lunar Regolith Simulant



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# Summary

- Background of icy lunar regolith simulant efforts to date
- Discussion of first-principles ice morphology approach
- Granular icy lunar regolith simulant
- Pressure fused icy lunar regolith simulant (PFG)
- Production method
- Results
- Conclusions

# Background of Icy Lunar Regolith Simulant Methods

- Representative regolith simulants are critical for testing for activity on the lunar surface
  - This is equally critical for systems designed for operation in cold traps.
  - Requires the production of icy lunar regolith simulant
- Historically, all efforts to produce icy lunar regolith involve mixing liquid water with various regolith simulants, compacting, and freezing them
  - No first principles justification for this approach has been published

# Conventional Icy Lunar Regolith Simulant Definition

- Mixing liquid water with regolith wets the grains, fills interstitial spaces
  - When frozen, creates a continuous matrix, like permafrost on Earth
- Result is as strong as limestone, unlikely to be the case
  - Drives design solutions like drills, jackhammers; may be much weaker

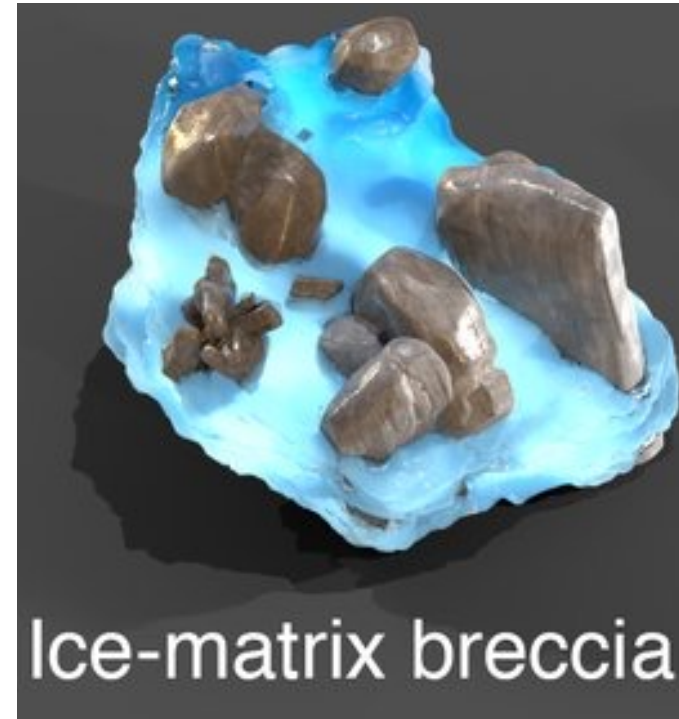
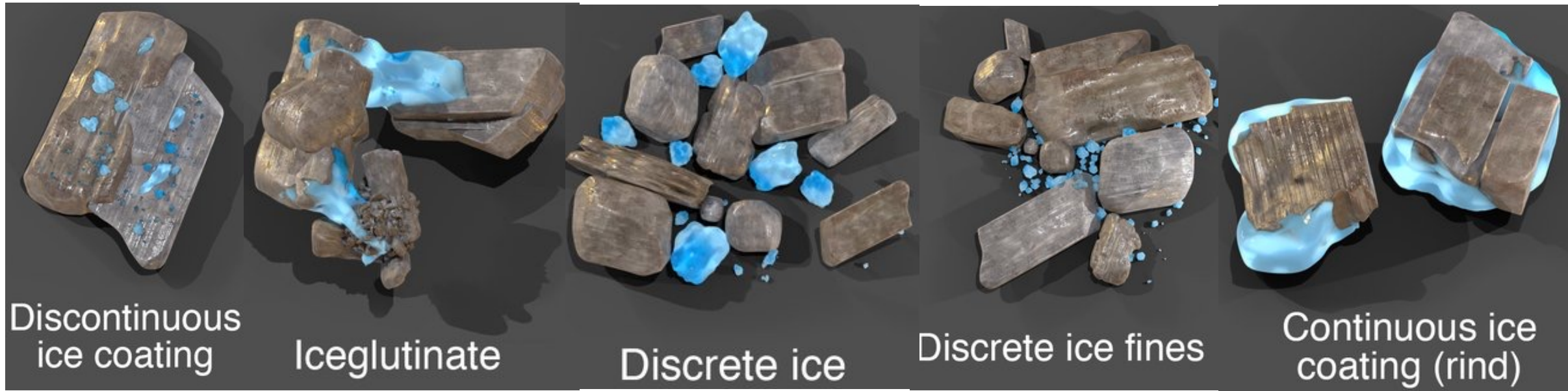


Photo Credit: Dr. Kevin Cannon

# Possible Icy Lunar Regolith Morphologies



- Ice is deposited to cold traps from vapor to solid phase
  - Impact gardening over geologic timescales mixes and ice layer into underlying regolith
- Potential fusion between grains possible via vapor deposition, impact shock at depth



# Granular Icy Regolith Simulant

1. Shave Ice
  2. Progressively sieve to below 500  $\mu\text{m}$
  3. Mix with freezing regolith simulant
- Liquid water never in contact with regolith



Granular Icy Regolith (Credit: Kevin Cannon)

# Pressure-Fused Granular (PFG)

- PFG is a tailorable icy regolith simulant
  - Strength can be selected by moderating icy content and applied pressure
- Actual icy morphology is unknown, PFG allows wide range of properties to be tested
- Apply pressure to granular, fuse ice grains to regolith
  - Greater pressure results in greater degree of fusion

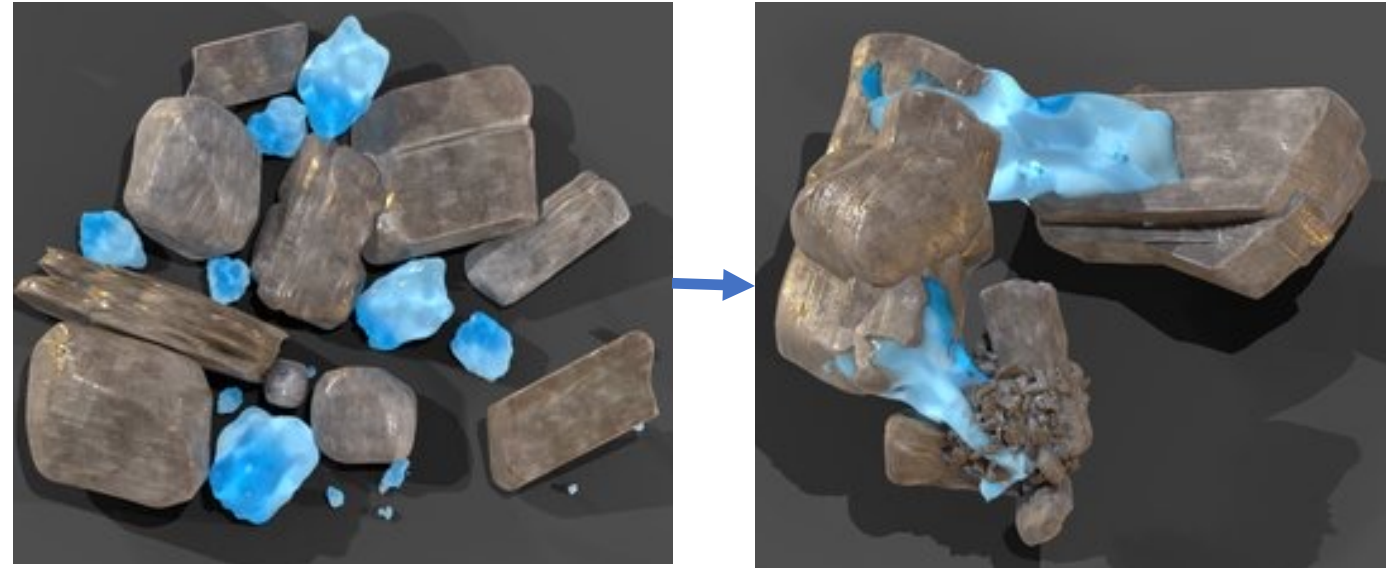
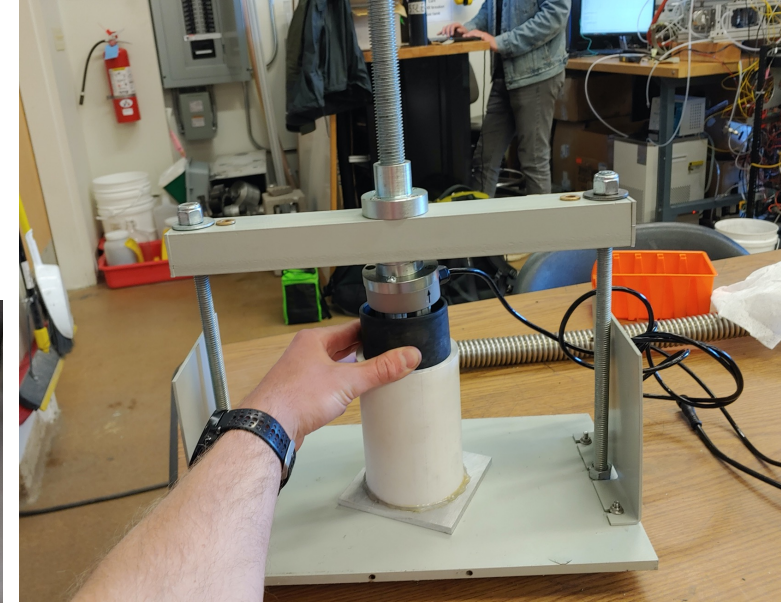


Photo Credits: Kevin Cannon

# Pressure Fused Granular Production Method

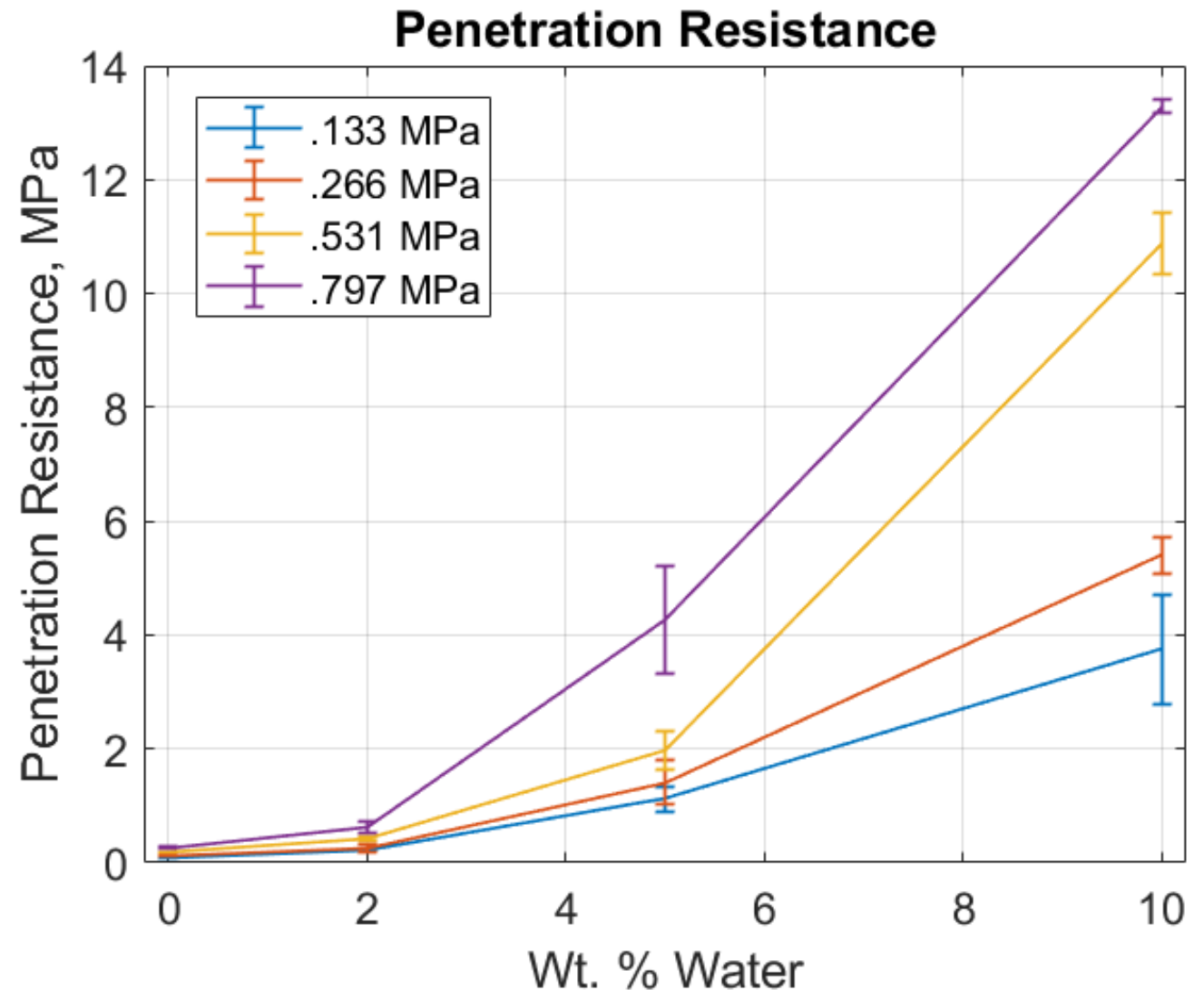
1. Create granular icy regolith simulant
2. Pour into cylinder
3. Press with piston
4. Maintain isostatic pressure for 10 minutes
  - In this study, 4 applied pressure and 4 water wt. % were used
  - Container diameter: 4.06"
  - Sample height: ~4"





# Results

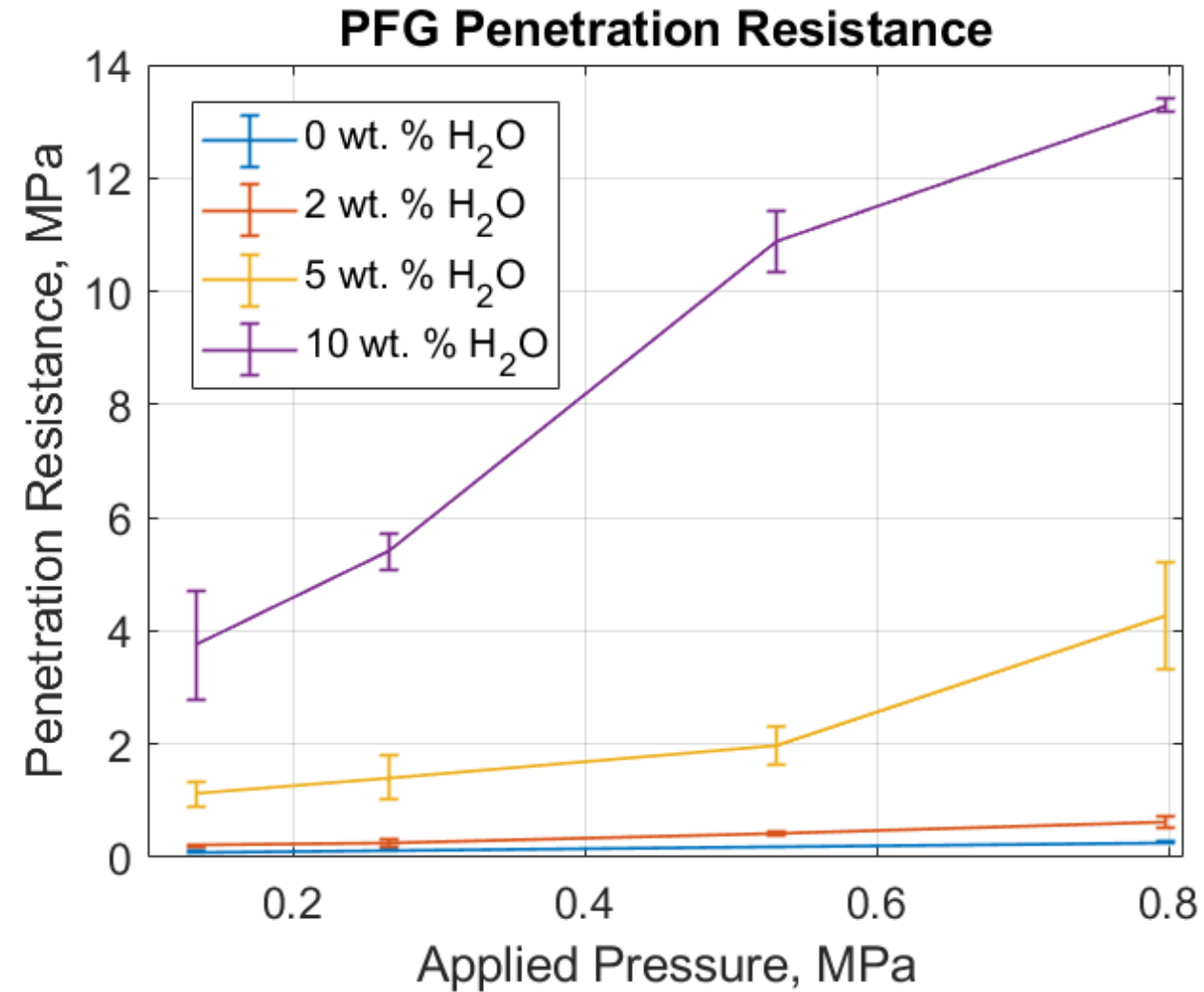
- Penetration resistance measured with 10 mm diameter flat head penetrometer
  - Max reading taken in 5 mm of penetration
- Observed strong relationship between water content and penetration resistance
- High tailorability of strength



Error bars  $\pm 1 \sigma$

# Penetration Resistance Results

- Very little strength capability observed for lower wt. % samples (0% + 2%)
  - Drastically increased strength for higher water content
- Greater than 3-fold difference in penetration resistance achievable with 6-fold increase in applied pressure



Error bars  $\pm 1 \sigma$

# Conclusions

- Pressure Fused Granular icy regolith simulant is highly tailorable, allowing a wide range of possible terrains to be tested
- Desire that Pressure Fused Granular is further developed, used in testing drills, excavators, rovers, and water extractors
- Next steps:
  - Further investigation of PFG
    - Thermal properties, additional mechanical properties
  - Increase scale
    - Vehicle testing