Engineer Research and Development Center

The In-Situ State: The Elusive Ingredient in Lunar Simulant

Ernest S. Berney IV
John F. Peters
Research Civil Engineers

NASA Involvement

- Modular Regolith Characterization Instrument Suite for Construction and In Situ Resource Utilization Surveys
  - Project Lead:
    - Dr. Jerome Johnson – CRREL
  - Mechanical Property Probe Lead
    - Dr. David Cole – CRREL
  - Geotechnical Property Lead
    - Dr. Ernest Berney – GSL
- In-Situ Investigation of Lunar Surface and Subsurface Material Properties

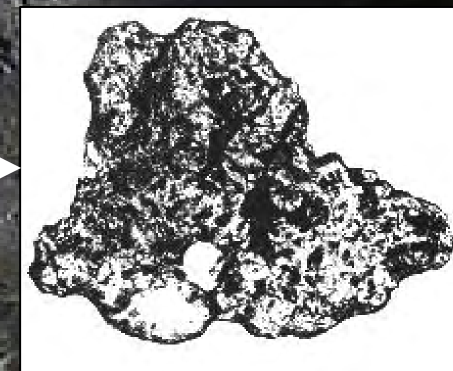
Key Issues

- Past Lunar Mission Exploration
  - Primarily shallow depths (< 0.5 m)
    - Shallow excavation (scoops)
    - Few deep probes
- New Lunar Missions
  - Primarily deep depths (2 m)
    - Deep probes – Coring
    - Excavation – Mining

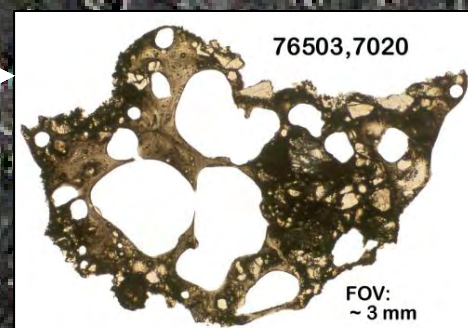
WHAT'S BELOW THE SURFACE?

Regolith Deposition

- Comminution (Meteor Impact)
  - Impact fragmentation
  - Mineral melting (Breccias)
  - Consolidation



- Agglutination
  - Melting
  - 30-50% of regolith



- Mixing
  - Interlocking of fragments, breccia and aggultinates

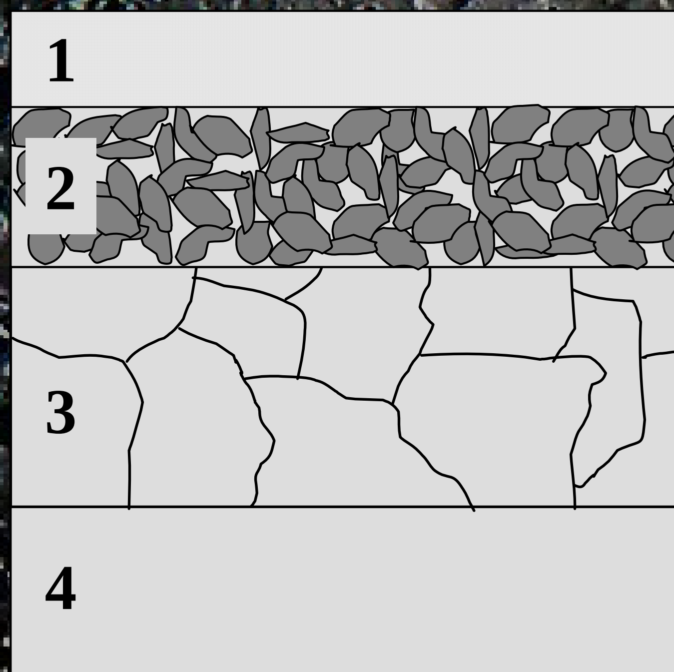
Structure

- Common in Terrestrial Soils
  - Loess
  - Glacial Till
  - Quickclays
- Present in lunar soils
  - Partial regolith induration ➔ *Quickclay*
  - Regolith breccia ➔ *Glacial Till*
  - Agglutinates ➔ *Loess*

Typical Lunar Structure

Intermediate layer, 2, represents complex response due to influence of structure on strength, compressibility and removal

Depositional Colluvium	Very loose material
Comminuted Regolith	Considerable structure and stability
Megaregolith	Very hard material at depth
Intact Bedrock	Beyond range of interest



What do we measure?

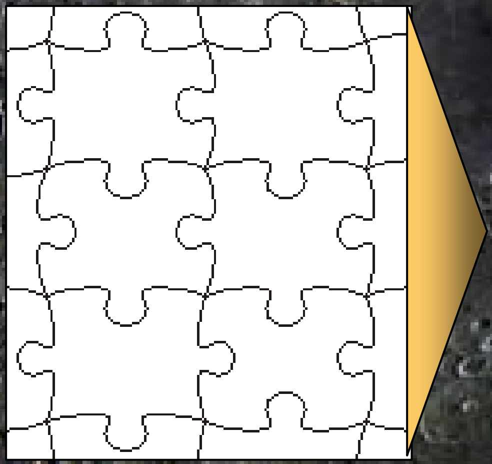
- Strength
  - Friction angle
  - Cohesion
  - Angle of Repose
- Compressibility
  - Indices
  - Modulus
- Rippability
  - Energy

All these properties have been measured from past missions on reconstituted material

WHAT'S MISSING ?

Influence of Structure

- Strength increases
  - Maturity
    - overconsolidation,
    - induration
  - Aggregate interlock
- Compressibility varies
  - Stiff initial response
  - Collapse potential
    - void ratios higher than simulant
    - natural formation prevents achievement of most stable configuration



Links particles like a jigsaw puzzle

What does this mean to ISRU

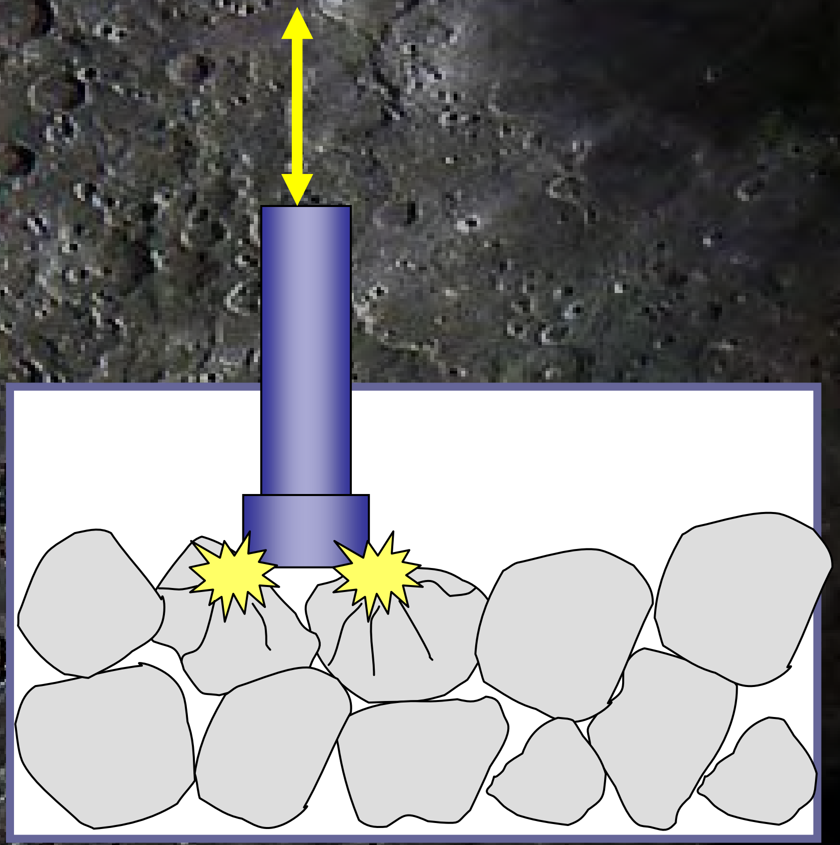
- Higher energy requirements
  - Probe insertion
  - Rippability/Excavation
  - In-situ strength
- Durability
  - Abrasion
- Drillability
  - What tools work best on the moon
  - What materials should the tools consist of

Current Lab Formation

- **Not representated by simulant compaction**
  - **Lacks natural interlock**
  - **Lacks induration of mature regolith**
- **Oxidation of terrestrial basalt simulant alters surface texture from lunar basalts**
- **Need to create structure with in-situ material !**

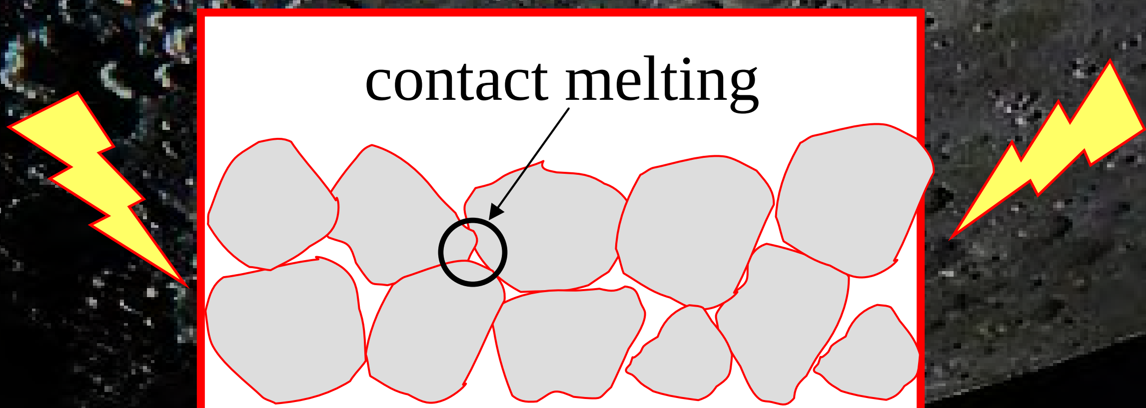
Creating Structure

- **Crushing of larger aggregate in-situ**
  - Can create impact framentation
  - Fill gaps with compacted regolith
  - Allows for larger void structure



Creating Structure

- Cementatious agents
  - Creates bonding within compacted aggregate
  - Simulates induration or melting
  - Allows for increased resistance to excavation
- Heating
  - Temperature indurate simulant
  - Heat activated epoxy resin coatings



Why should we care?

- *Energy* is the #1 Issue
  - Conservation is critical to mission success
- We do not want to underestimate
  - Limits the potential of extra-terrestrial instruments
  - Can cause premature failure
- Cost $$ if we are wrong

What to do?

- Literature can tell us ranges of influence between in-situ and reconstituted terrestrial material
  - Provides factor of safety in instrument design for added resistance
- Attempt to simulate structure in laboratory environment
- Use of DEM to predict behavior of soil structure

Conclusions

- New lunar missions seek to explore deeper into the subsurface
- Structure of in-situ regolith will play a role in affecting exploration
- There is a need to account for structure in development of simulant/additives

Questions?