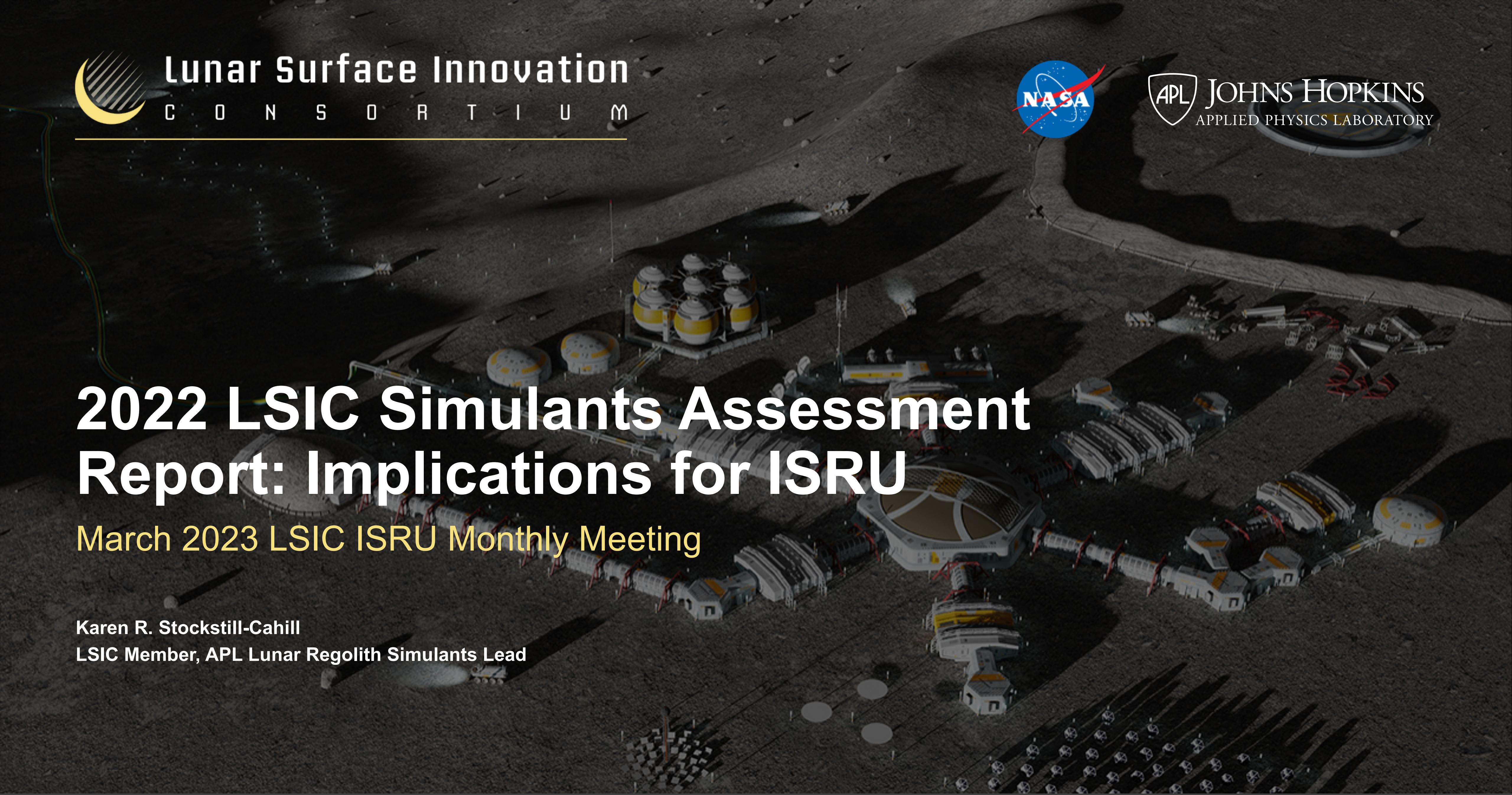

Lunar Surface Innovation
CONSORTIUM

2022 LSIC Simulants Assessment Report: Implications for ISRU

March 2023 LSIC ISRU Monthly Meeting

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LSIC Member, APL Lunar Regolith Simulants Lead

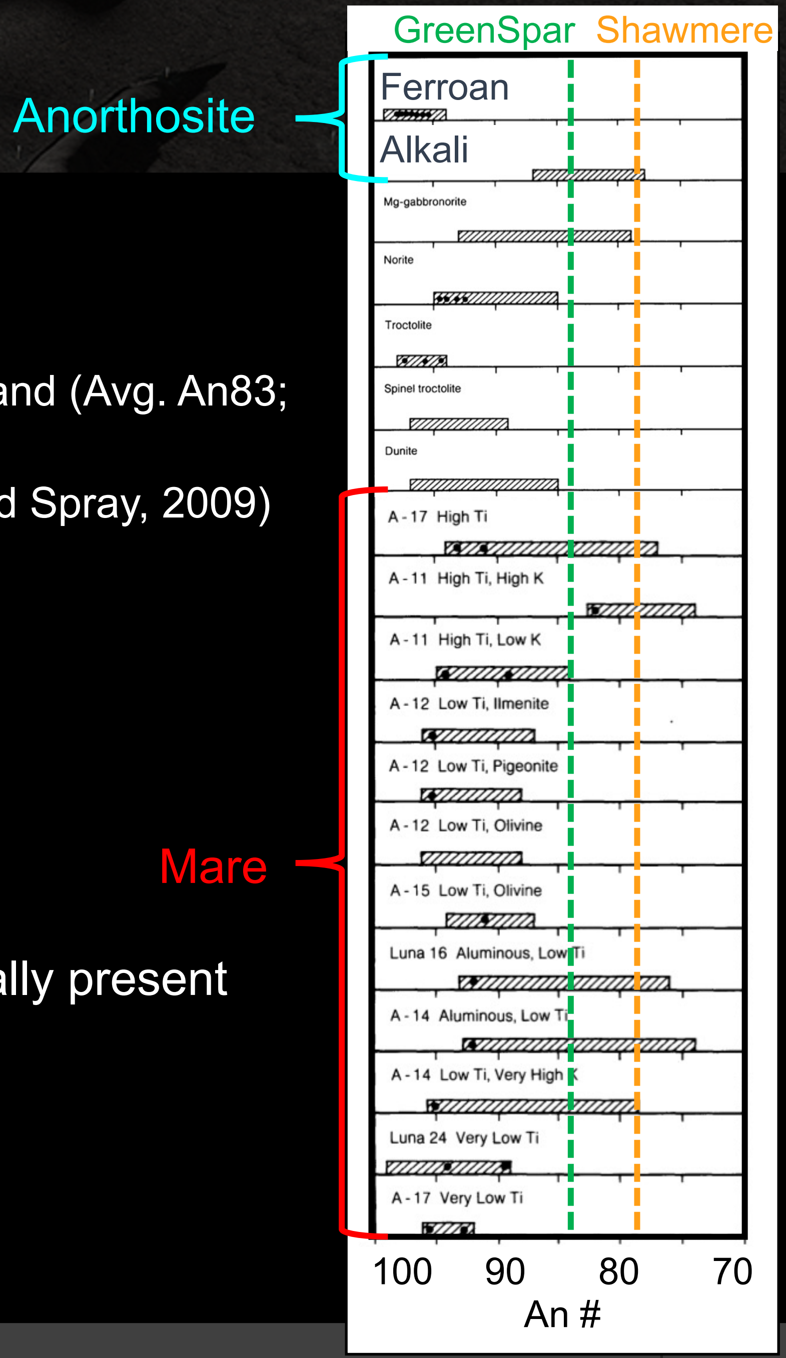
LSII | Lunar Regolith

- What is Lunar Regolith?
  - A complex mixture of particles that covers the lunar surface
    - Crystalline rock fragments
      - Highland - Anorthosite (>90% Plagioclase)
      - Mare - Basalt
    - Mineral fragments
      - Limited compositional range
      - Rims tend to be amorphous and contain nanophase Fe^0 ($npFe^0$)
    - Breccias
    - Agglutinates
    - Glass
  - Unique particle sizes and shapes!
    - Avg. Median particle size = 70 microns
    - Elongated particles, subangular to angular

LSII | Lunar Regolith Simulants

- An approximation of Lunar Regolith
  - **Anorthite**
    - White Mountain Anorthosite (aka GreenSpar) from Kangerlussuaq, Greenland (Avg. An83; Gruener et al., 2020)
    - Shawmere Anorthosite Complex in Ontario, Canada (Avg. An78; Battler and Spray, 2009)
  - **Basalt** (providers often use glassy basalts to mimic the glass content)
    - (Previously) Black Lava Rock from Pebble Junction
    - San Francisco volcanic field (Arizona) basaltic cinder
  - **Ilmenite** ($FeTiO_3$)

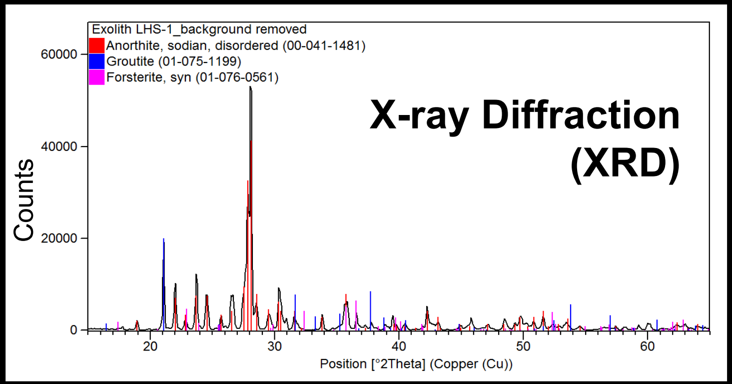
- Missing unique components of Lunar Regolith
  - Agglutinates, nanophase Fe^0 metal, amorphous mineral rims not naturally present
    - Some providers are making them in the lab
  - Nanophase Fe^0 metal
  - Amorphous mineral rims

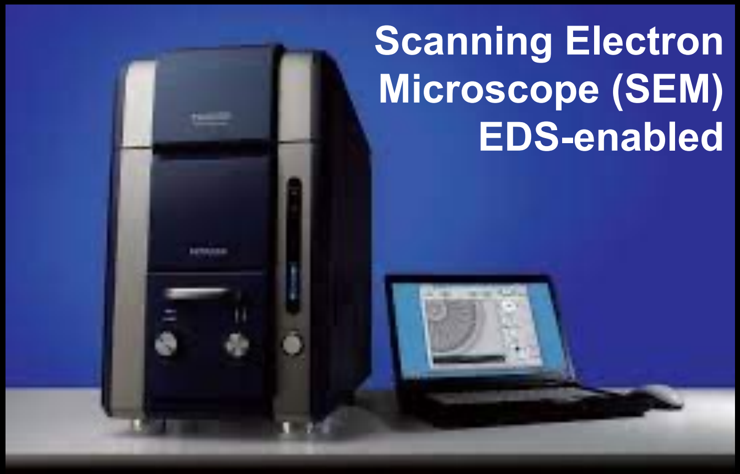


Lunar Simulants – Composition & Particle Size/Shape (2020,2021)

Bulk Composition (XRF, SEM)

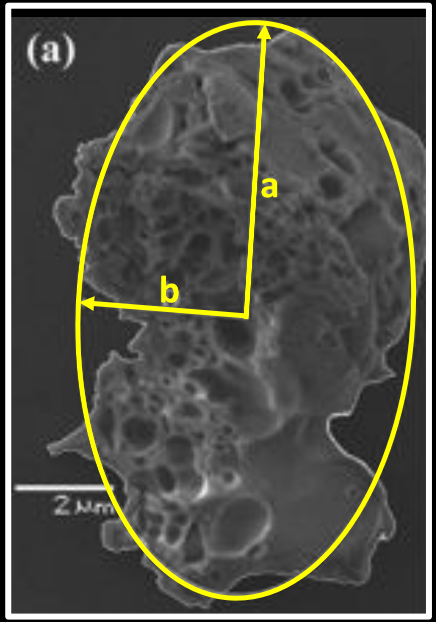
Mineralogy (XRD, SEM)





Particle Size Distribution (Sieve, Camsizer)

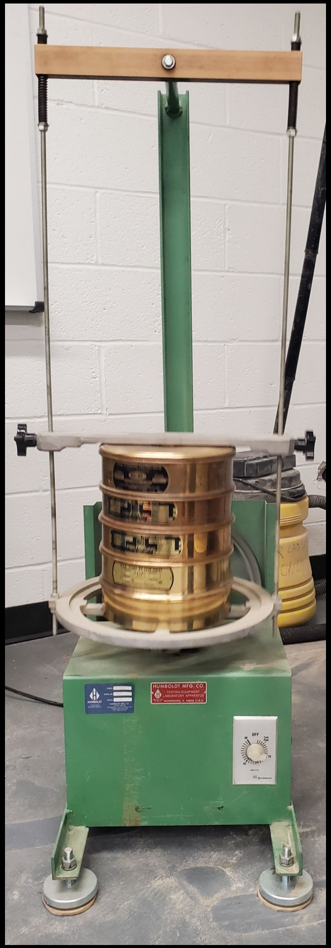
Particle Shape (Camsizer)



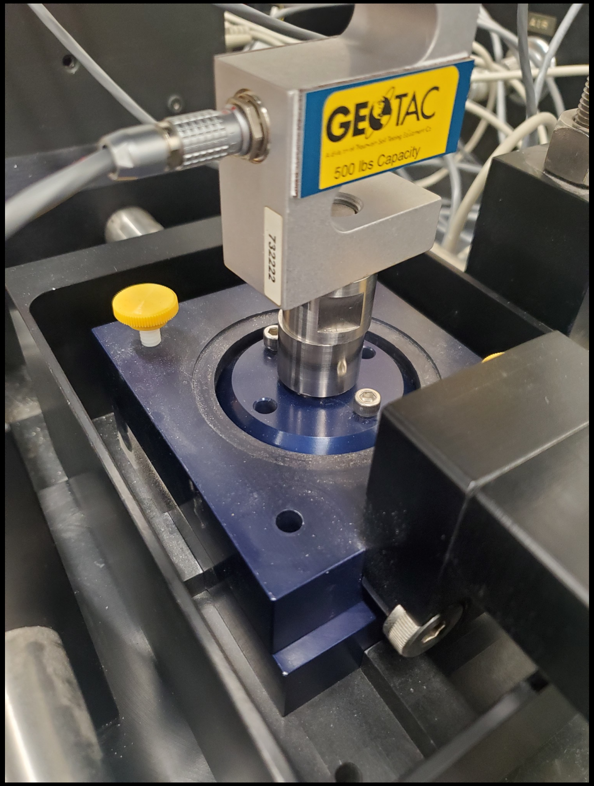
Aspect Ratio = a / b

Lunar Simulants – Geotechnical Characteristics (2022)

Particle Size Distribution (Sieve)



Direct Shear Strength



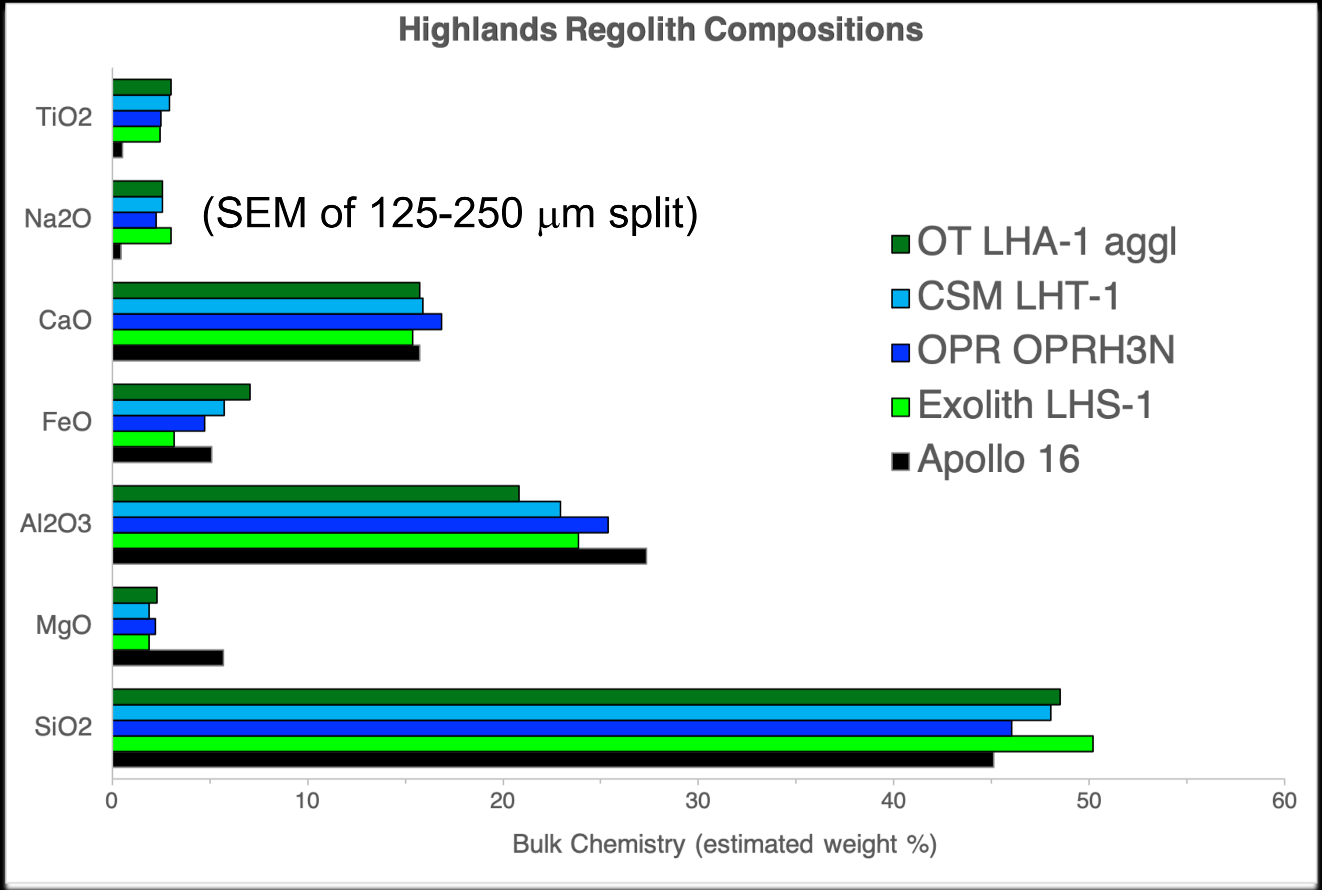
Specific Gravity

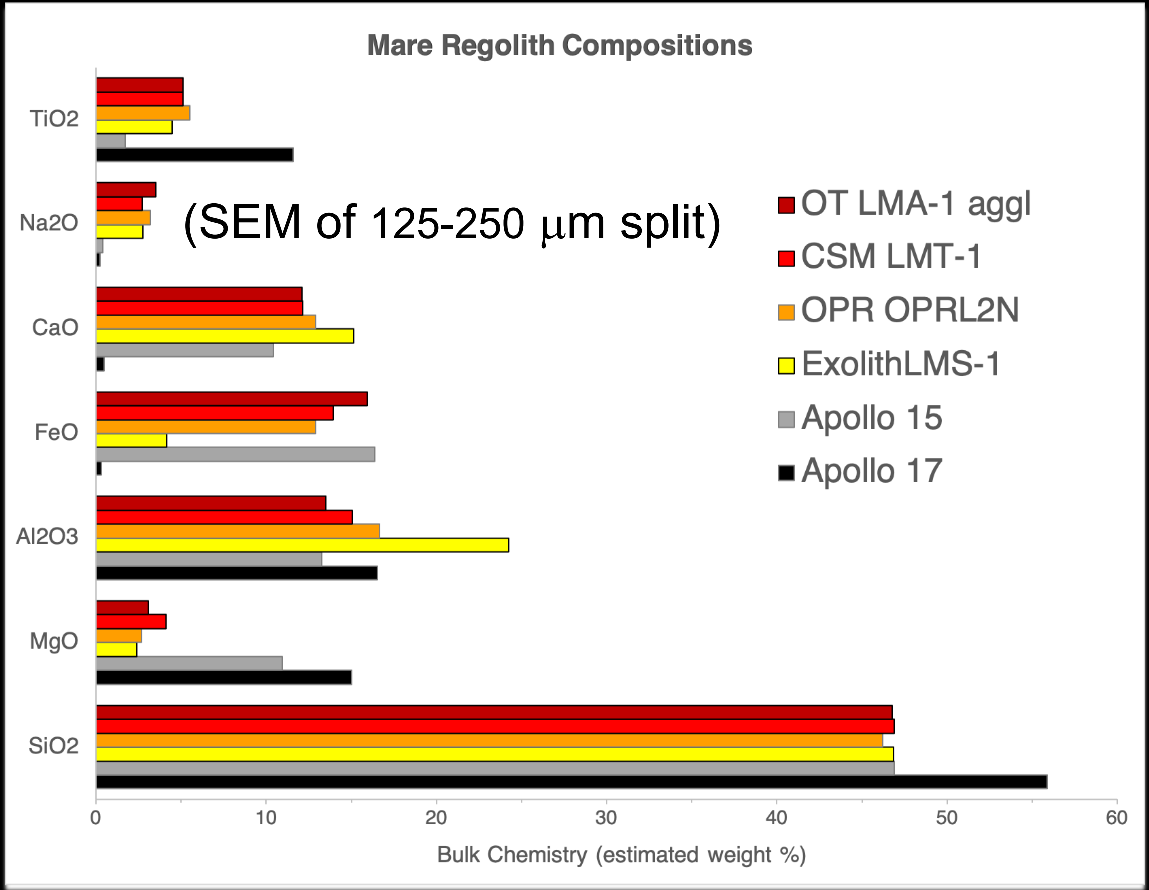
water pycnometry method

Min & Max Density

Lunar Simulants – Composition (2020, 2021)

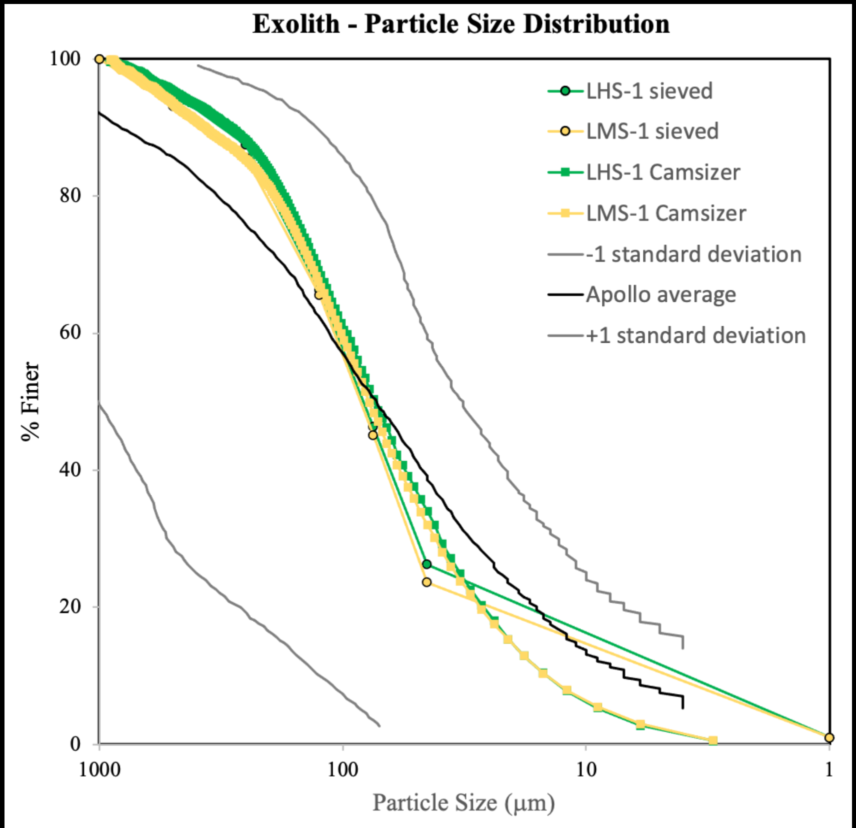
- **Bulk composition – XRF and SEM (Na_2O)**

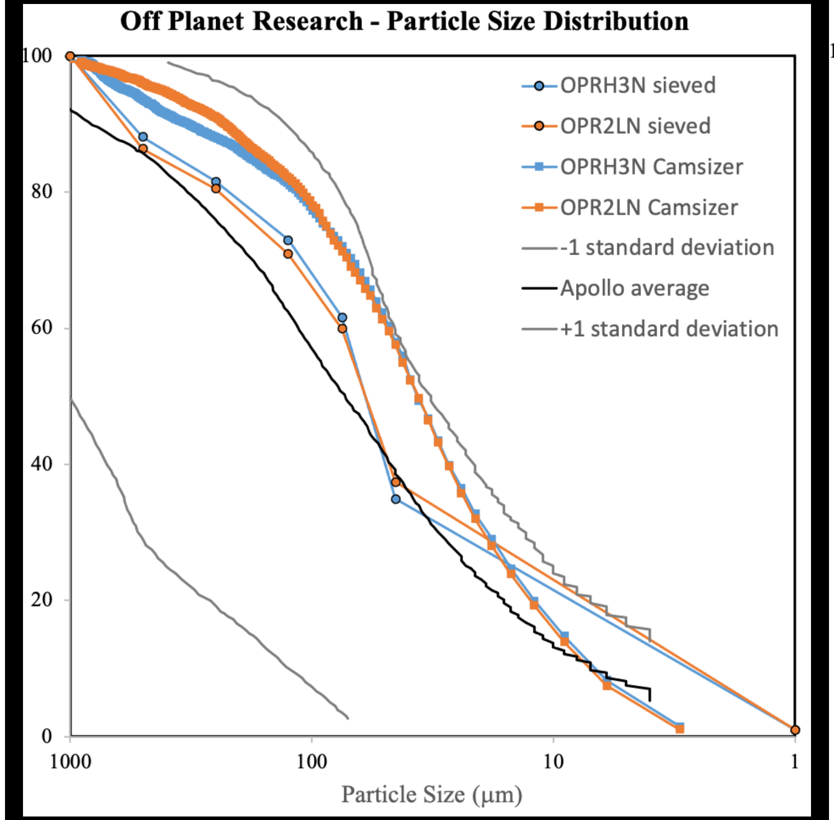


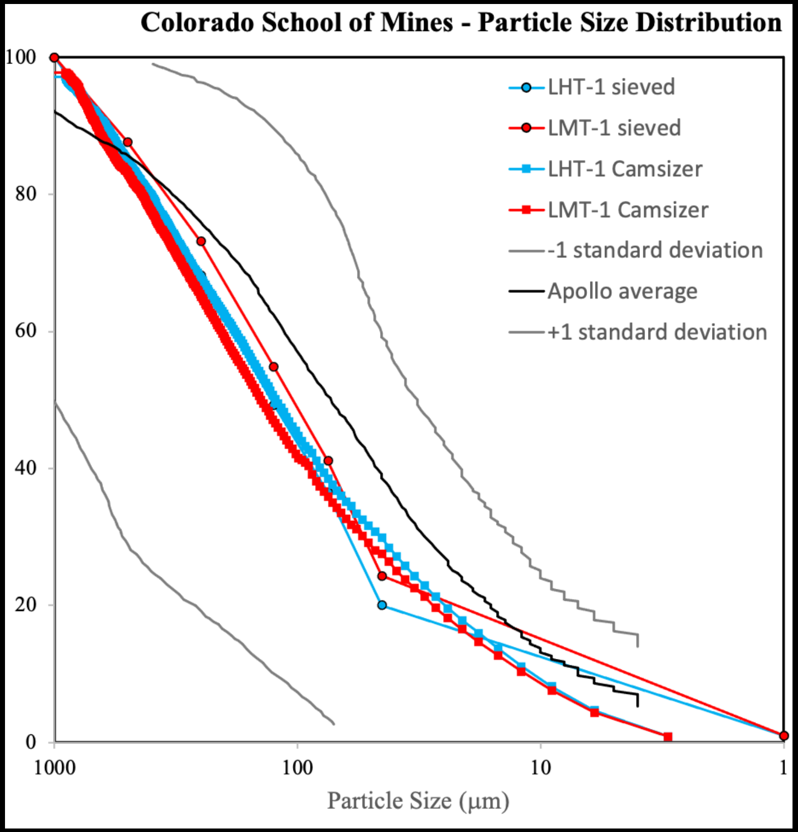


Lunar Simulants – Particle Size & Shape (2021)

- **Particle Size Distribution (PSD)**
  - Sieved materials (circles)
  - Camsizer system (squares)





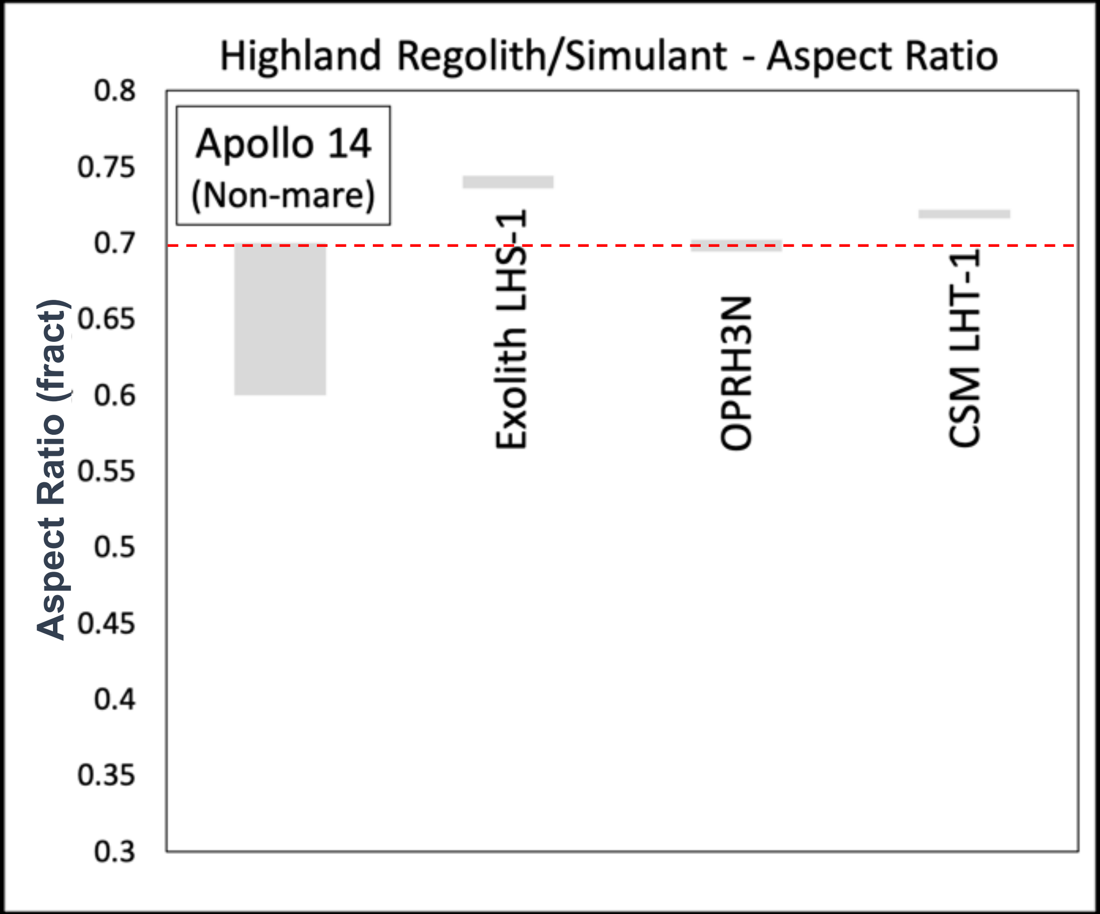


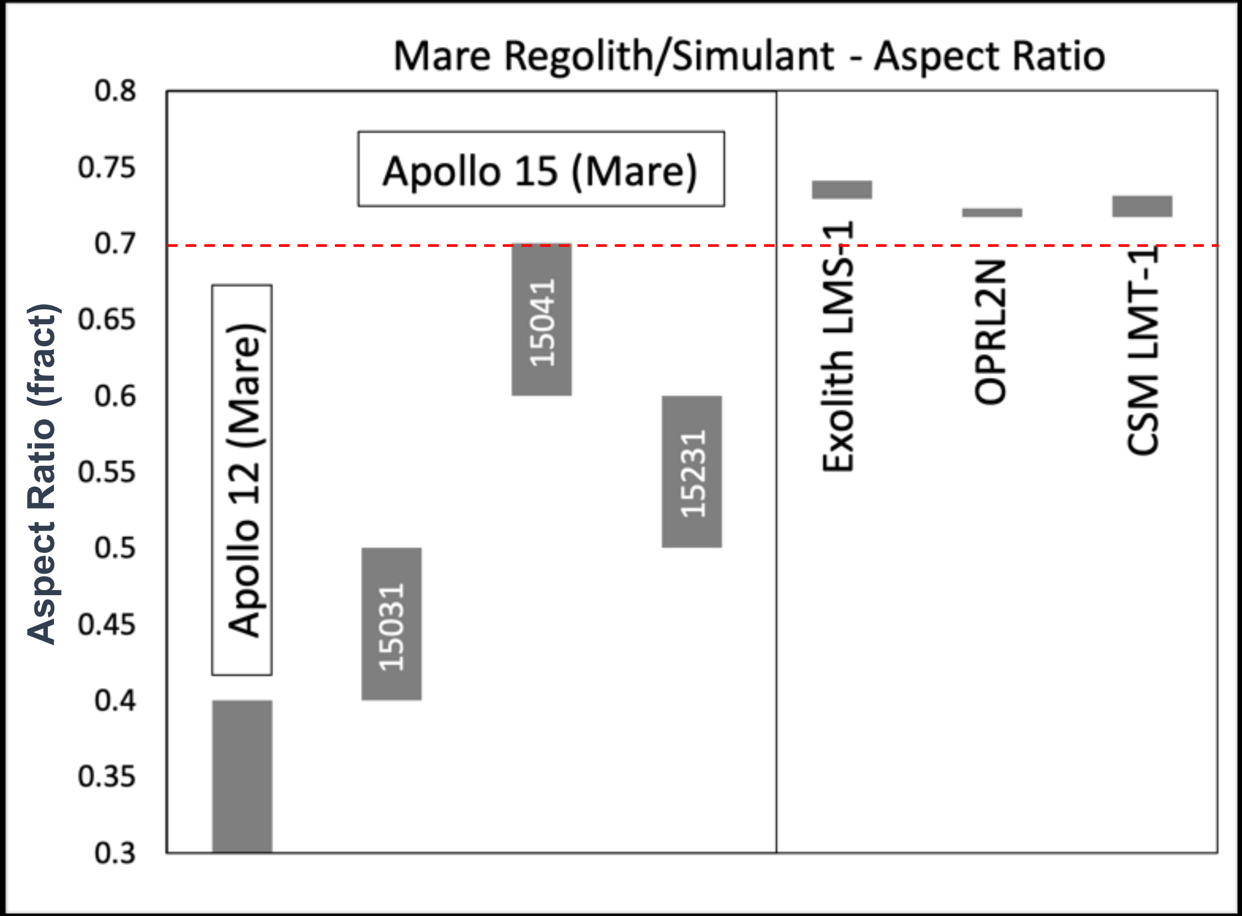
Lunar Simulants – Particle Size & Shape (2022)

- **Particle Size Distribution (2022)**

Lunar Simulants – Particle Size & Shape (2021)

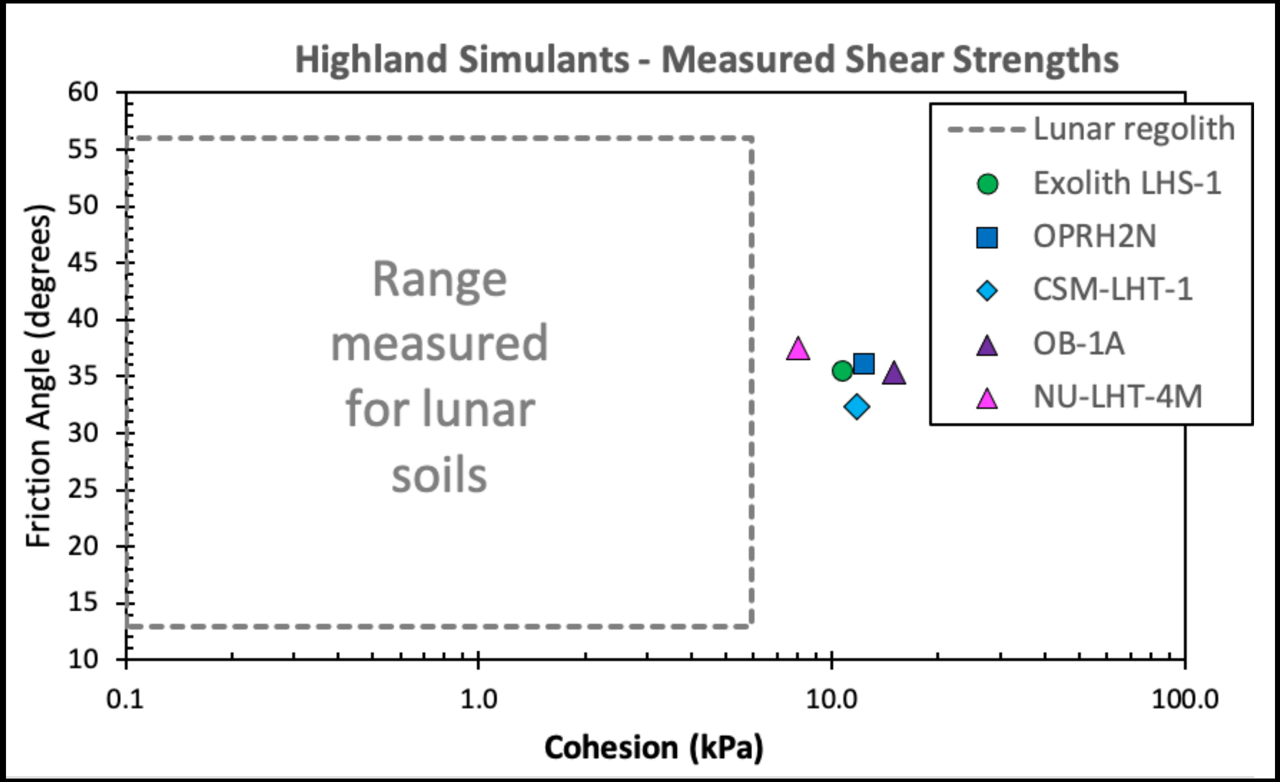
- **Particle shape – Aspect Ratio**
  - 1.0 = perfect sphere

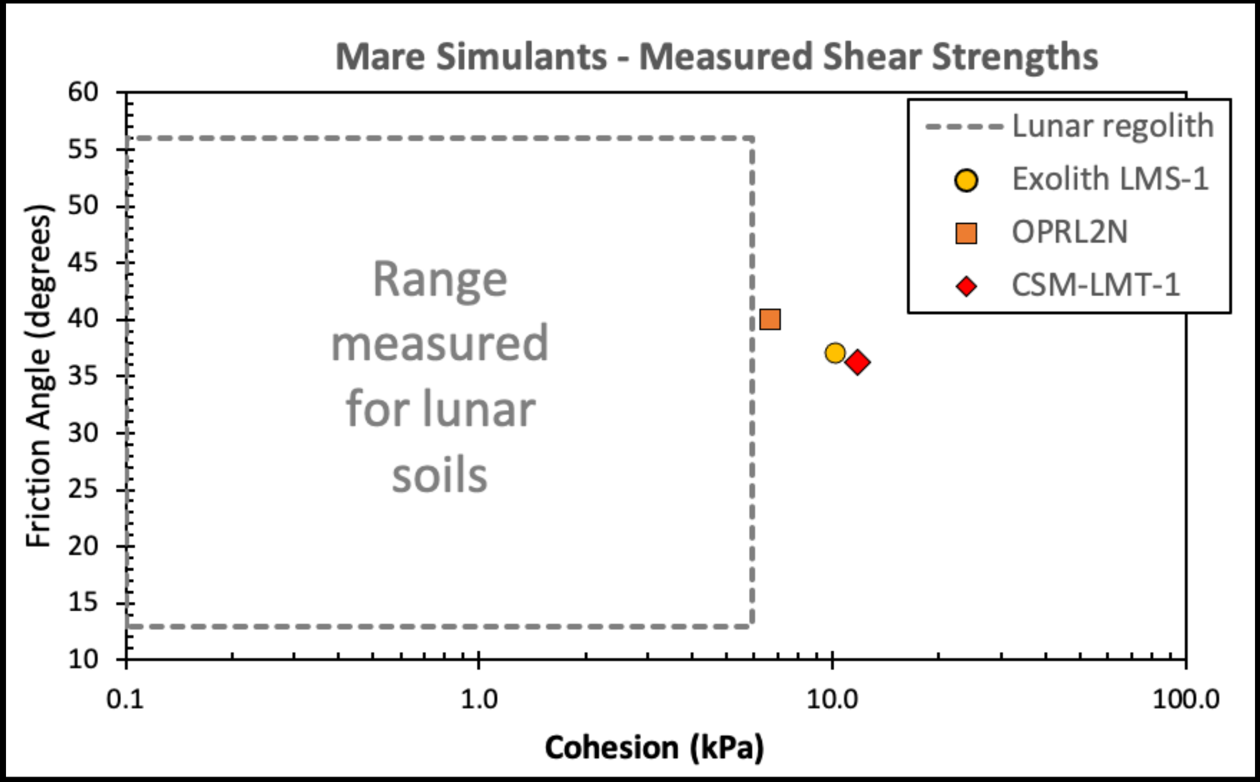




Lunar Simulants – Shear Strength (2022)

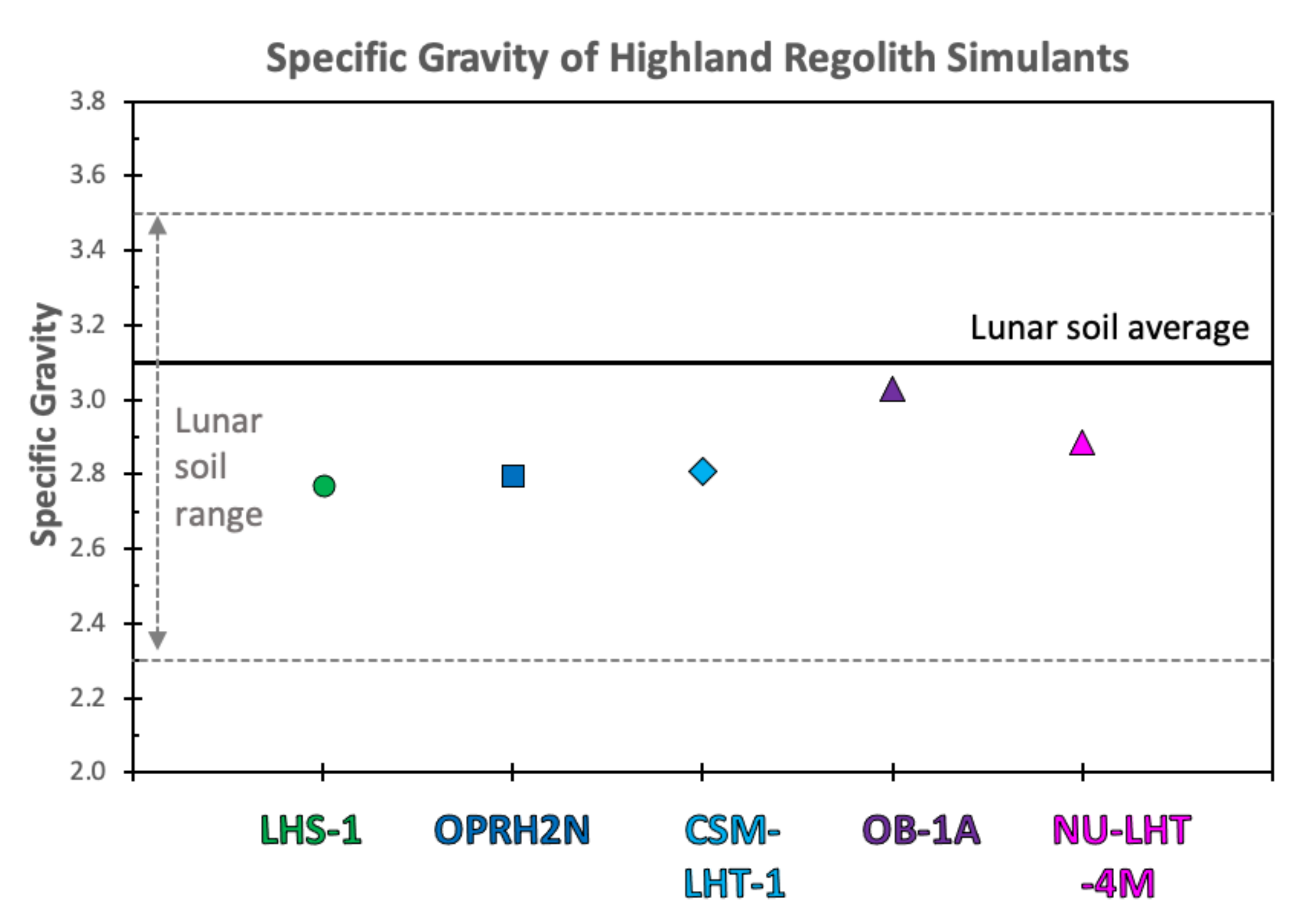
- **Direct Shear Strength measurements**
  - Friction angles within range measured for lunar soils
  - Cohesion exceeds that measured for lunar soils

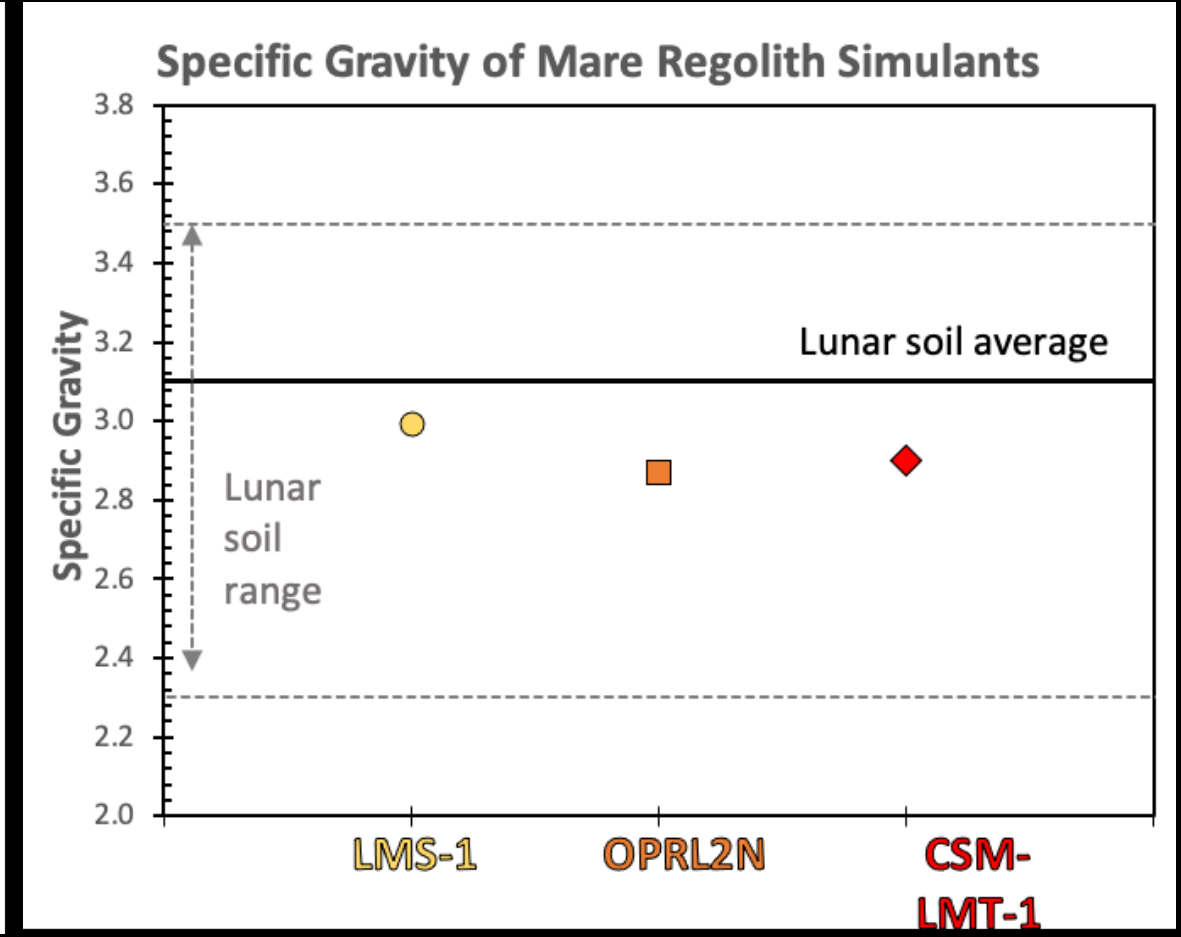




Lunar Simulants – Specific Gravity (2022)

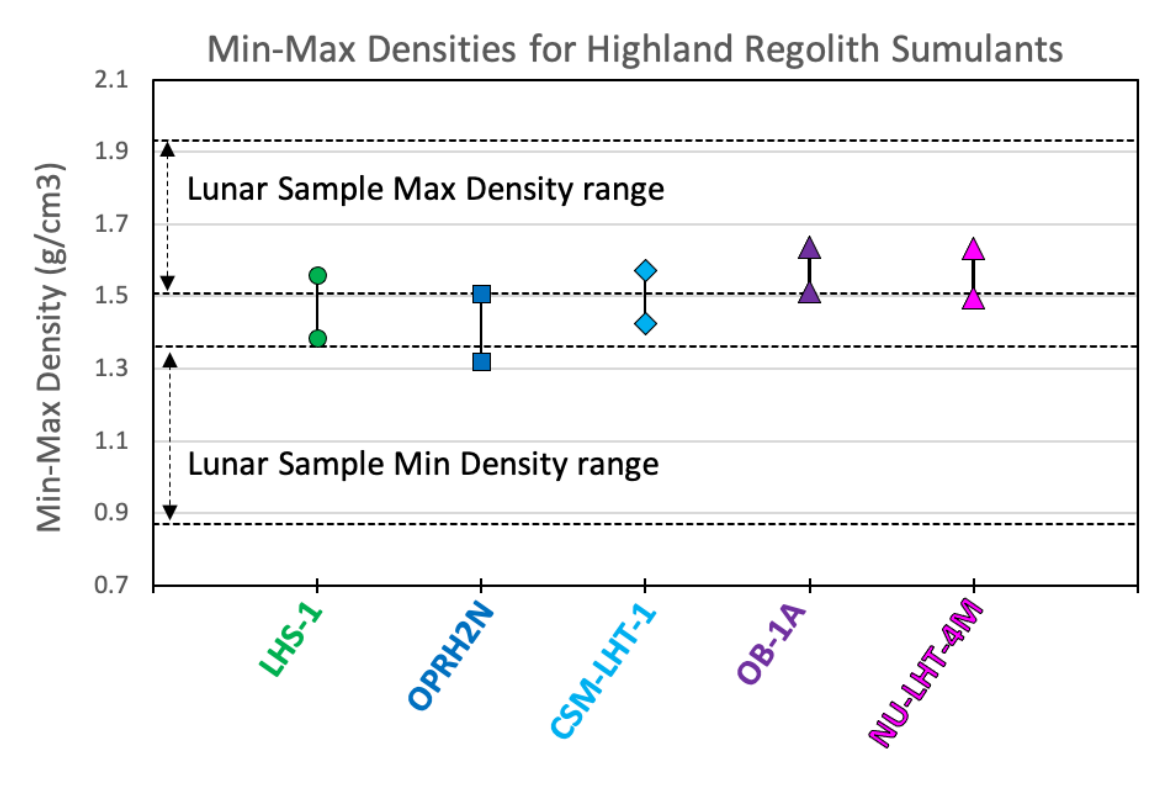
- **Specific Gravity**
  - All simulants have specific gravity values within the range observed for lunar soils

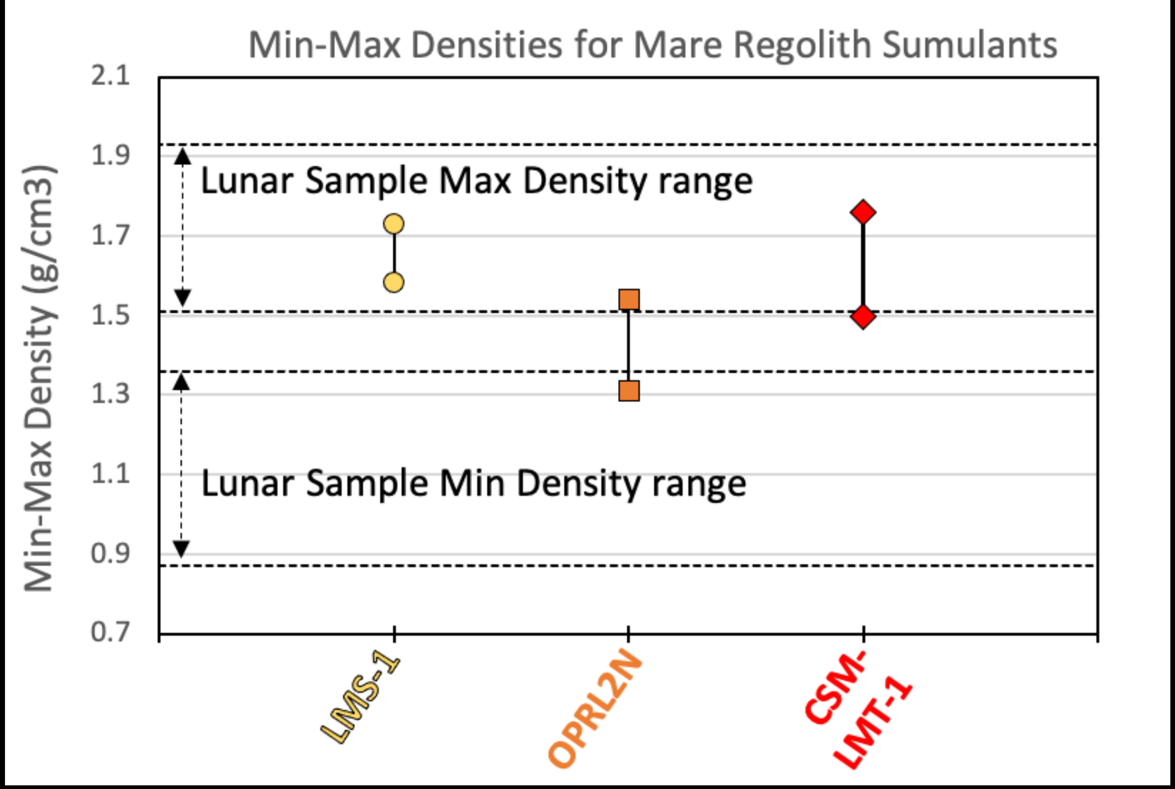




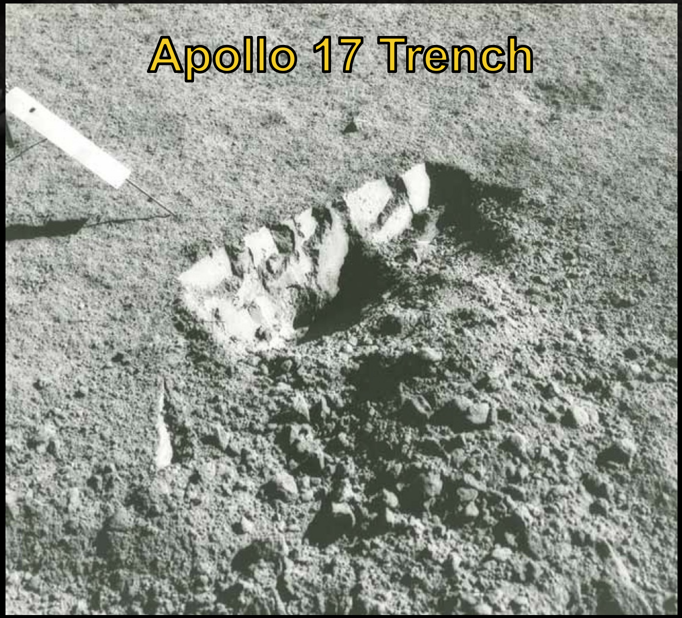
Lunar Simulants – Min & Max Density (2022)

- **Minimum and Maximum Density**
  - Maximum density values for all simulants fall within the range measured for lunar soils
  - Minimum density values for simulants exceed the range measured for lunar soils, except for OPRH2N (highland) and OPRL2N (mare) simulants





LSII | ISRU Considerations

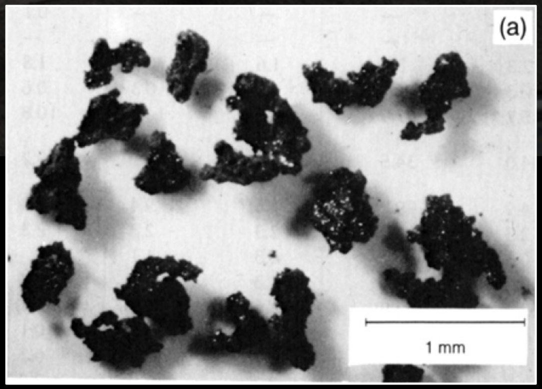


- **The evaluation and utility of a simulant is specific to its application**
  - Melting/microwaving regolith requires high compositional fidelity
    - Difference in Na content may be important
      - Petrologic modeling suggests large differences in viscosity of the liquid produced by melting
      - Small changes in the melting temperature due to Na differences
  - Material durability studies would require high fidelity in particle shape & size
    - Lunar particles tend to be very angular and “interlock” so they have unique behavior
- **Regolith simulants and even lunar regolith do not necessarily behave in the same way on Earth as they would on the Moon**
  - Solar wind implants volatiles on lunar surface (reactivity, cohesive forces, etc.)
  - Nanophase Fe^0 results in magnetic properties in lunar regolith
  - Lower confining stresses at lunar surface
    - We attempted to compare our data to only earth-based measurements on lunar regolith

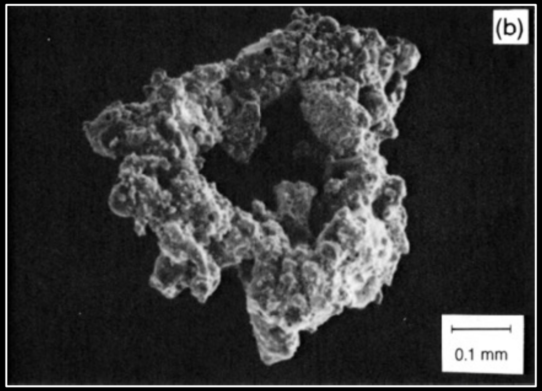
LSII | ISRU Considerations

- **Lunar regolith simulants from current simulant providers could meet the needs of most users**
  - You can add components to increase fidelity in appropriate areas
    - Synthetic Materials & Glasses
    - Psuedo-Agglutinate Simulant
    - Magnetic susceptibility materials

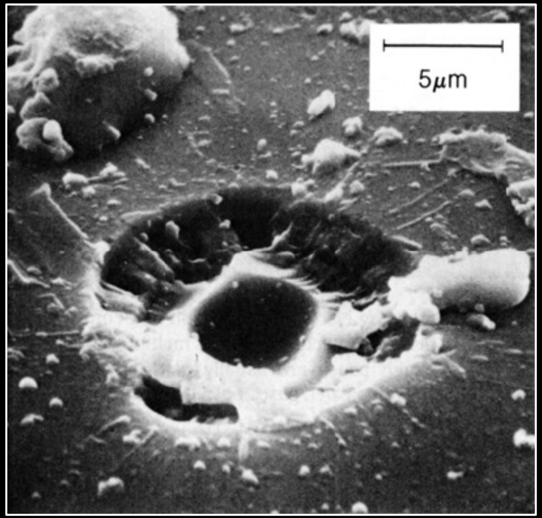
- **For advanced (high TRL) testing related to ISRU needs, it may be wise to compare results using a simulant with and without pseudo-agglutinate simulant, and potentially even a lunar soil (in the lab or on the lunar surface).**



Apollo 11 agglutinates separates (NASA Photo S69-54827; Fig. 7.2a of McKay et al., 1991).



Close-up of agglutinate particle (NASA Photo S87-38812; Fig. 7.2b of McKay et al., 1991).



Micrometeoroid impact crater on the surface of a lunar soil particle (Fig. 7.8 of McKay et al., 1991).

Lunar Simulants Working Group (LSWG)

- **LSWG on LSIC Webpage** (under Our Work)
  - Info on APL & NASA Simulants Teams, Assessments & Databases, Pubs
  - Links to Wiki, Simulants Portal, & Simulants Survey
  - https://lsic.jhuapl.edu/Our-Work/Working-Groups/Lunar-Simulants.php

- **LSWG Confluence Page** (requires LSIC membership)
  - Space for LSIC members to share simulant information
    - Annual Simulant Assessments
    - Relevant Publications
  - Lunar Simulants Portal - data collected on lunar simulants, provider info
  - APL & NASA Simulants Teams
  - https://lsic-wiki.jhuapl.edu/display/LSWG/Lunar+Simulants+Working+Group+Home

Please email Karen.Stockstill-Cahill@jhuapl.edu **to be added to new LSWG List Serve**
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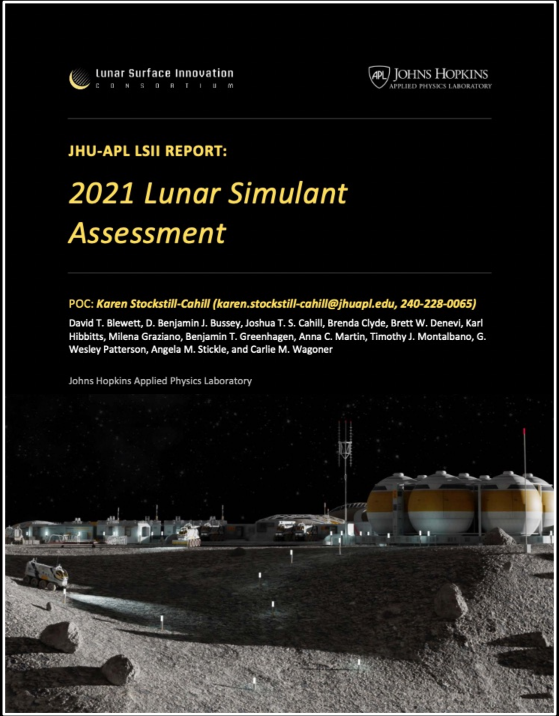
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JHU-APL LSII REPORT:

2021 Lunar Simulant Assessment

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