Lunar Surface Innovation
CONSORTIUM

# 2022 LSIC Simulants Assessment Report: Implications for Dust Mitigation

## June 2023 LSIC Dust Mitigation Monthly Meeting

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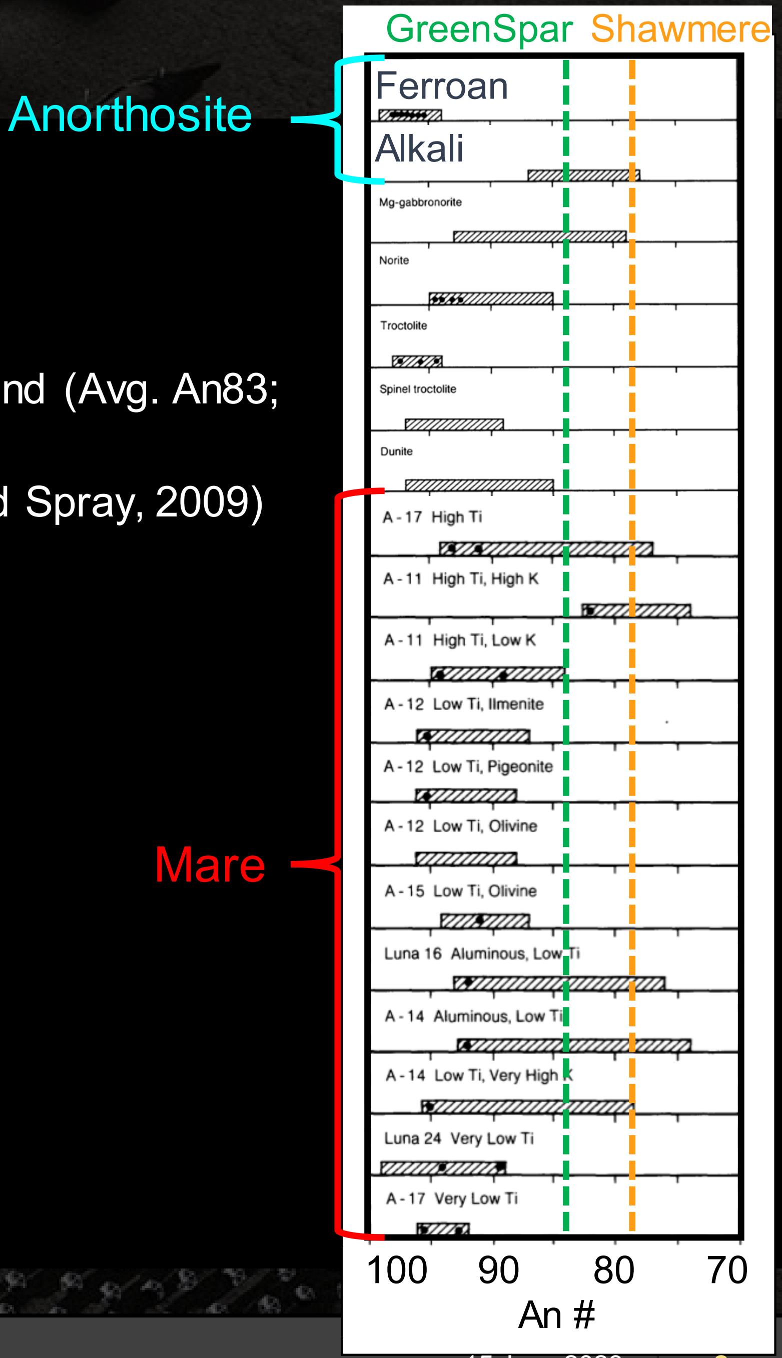
# LSII | Lunar Regolith

- 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** ($FeTiO_3$)

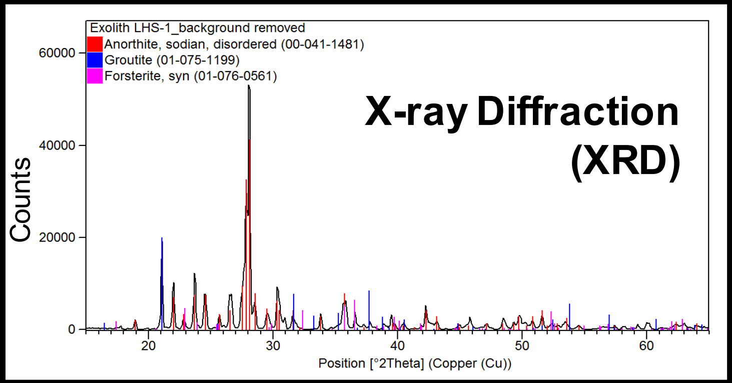
- **Missing unique components of Lunar Regolith**
  - **Agglutinates**
    - Some providers are making them in the lab
  - **Nanophase $Fe^0$ metal**
  - **Amorphous mineral rims**



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

## Bulk Composition (XRF, SEM)


## Mineralogy (XRD, SEM)

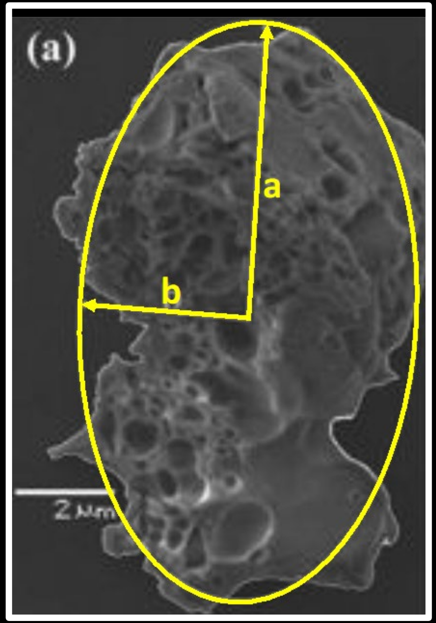




## Particle Size Distribution (Sieve, Camsizer)



## Particle Shape (Camsizer)

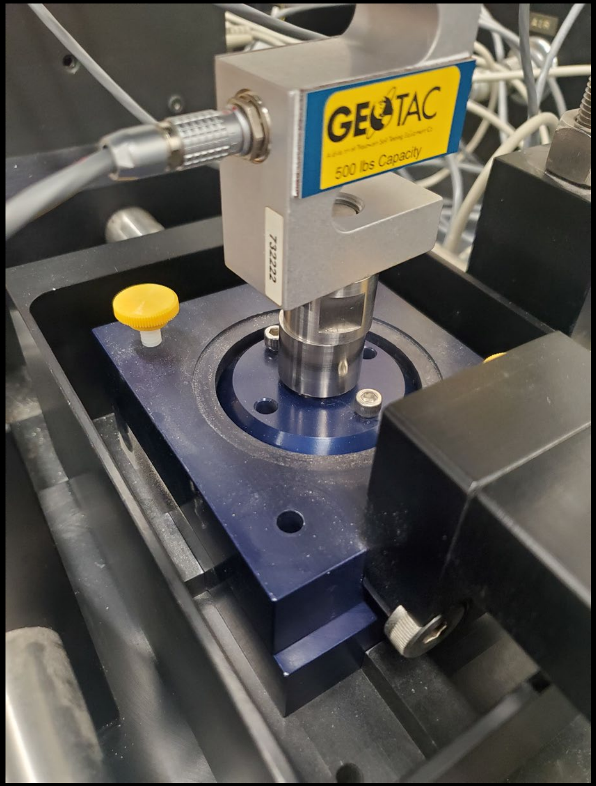



Aspect Ratio = a / b

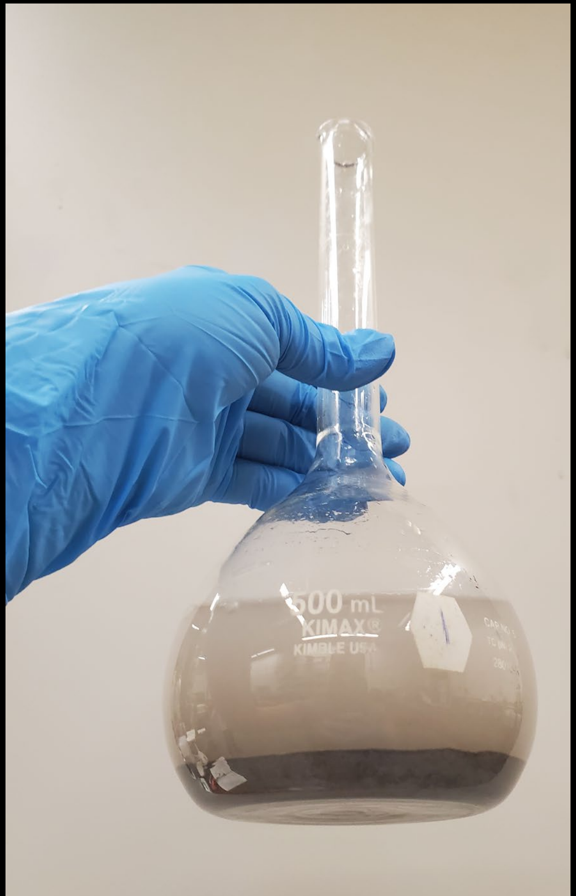
# Lunar Simulants – Geotechnical Characteristics (2022)

## Particle Size Distribution (Sieve)

## Direct Shear Strength




## Specific Gravity

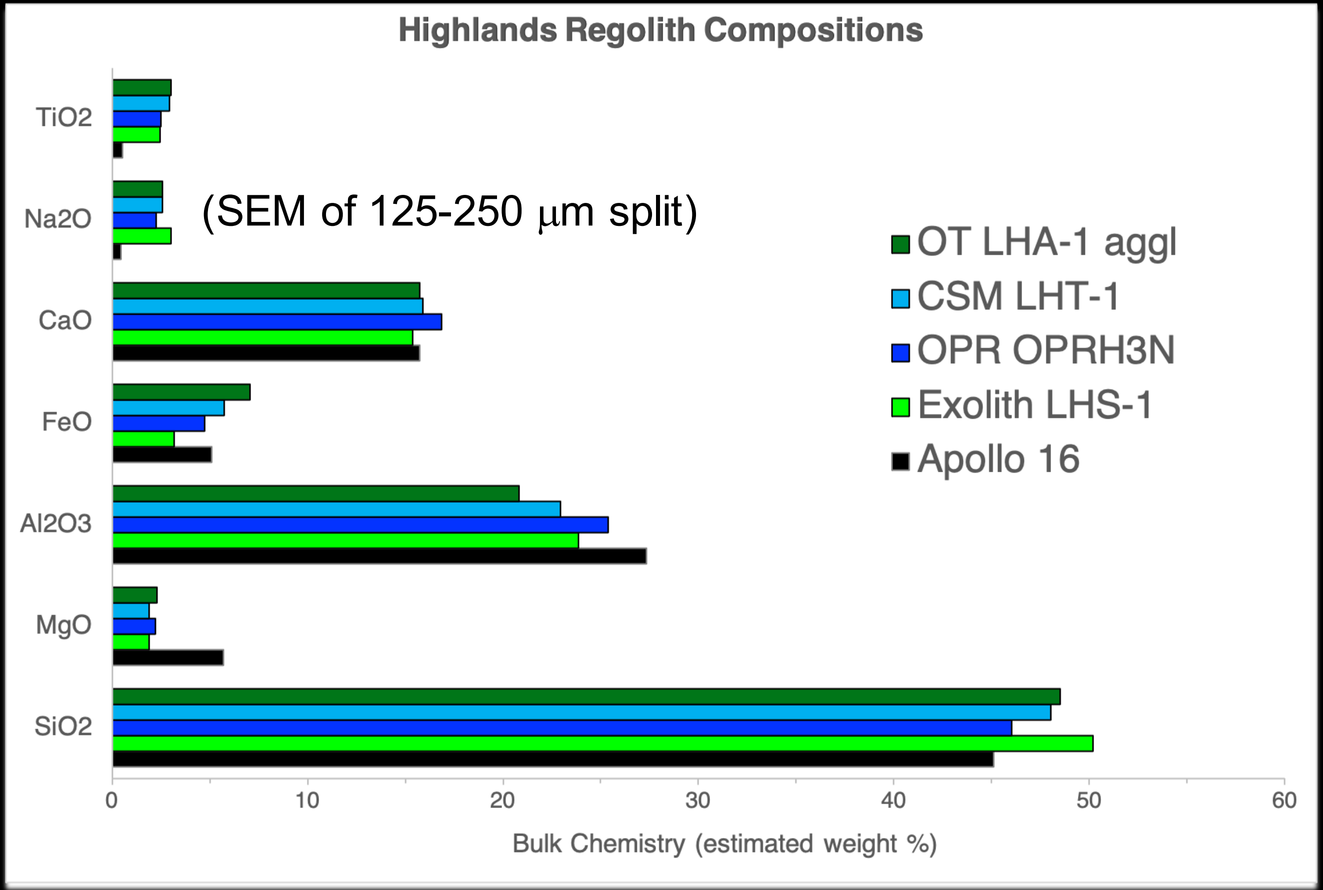


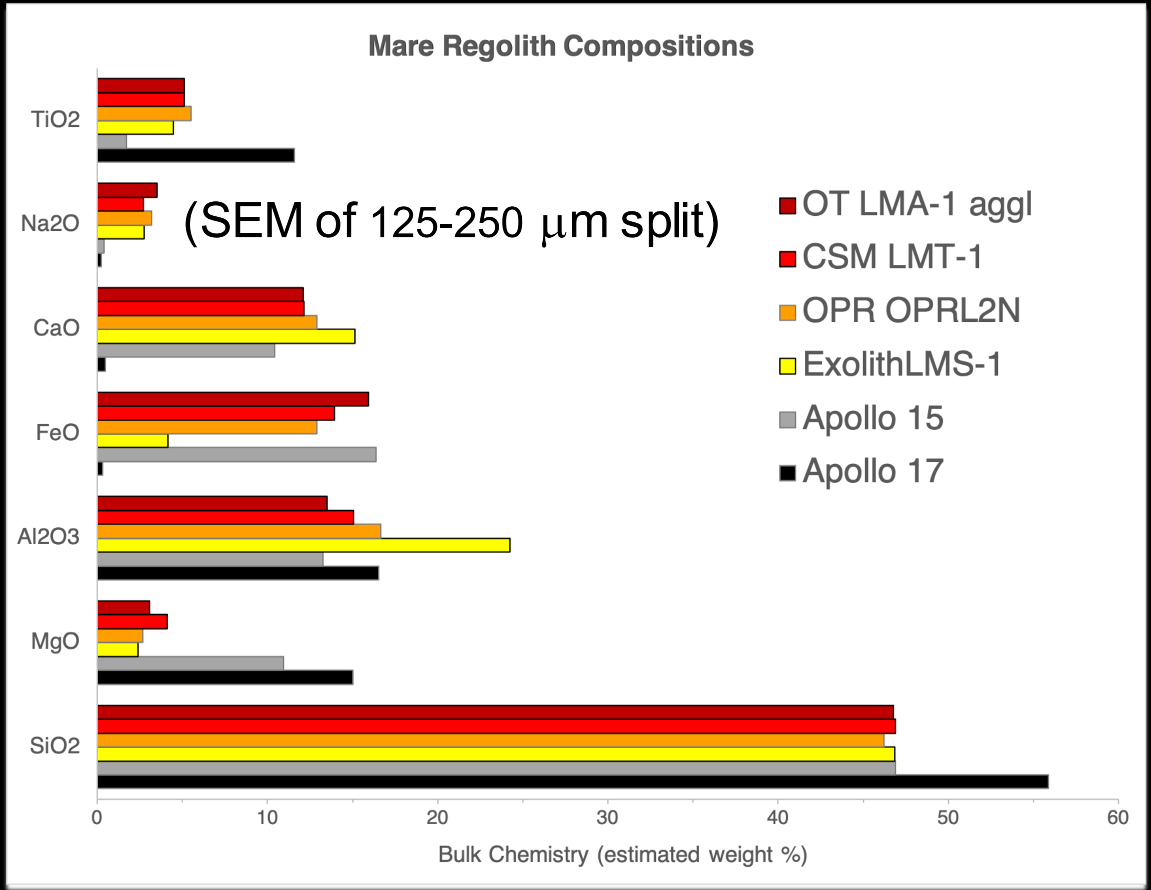

water pycnometry method

## Min & Max Density

# Lunar Simulants – Composition (2020, 2021)

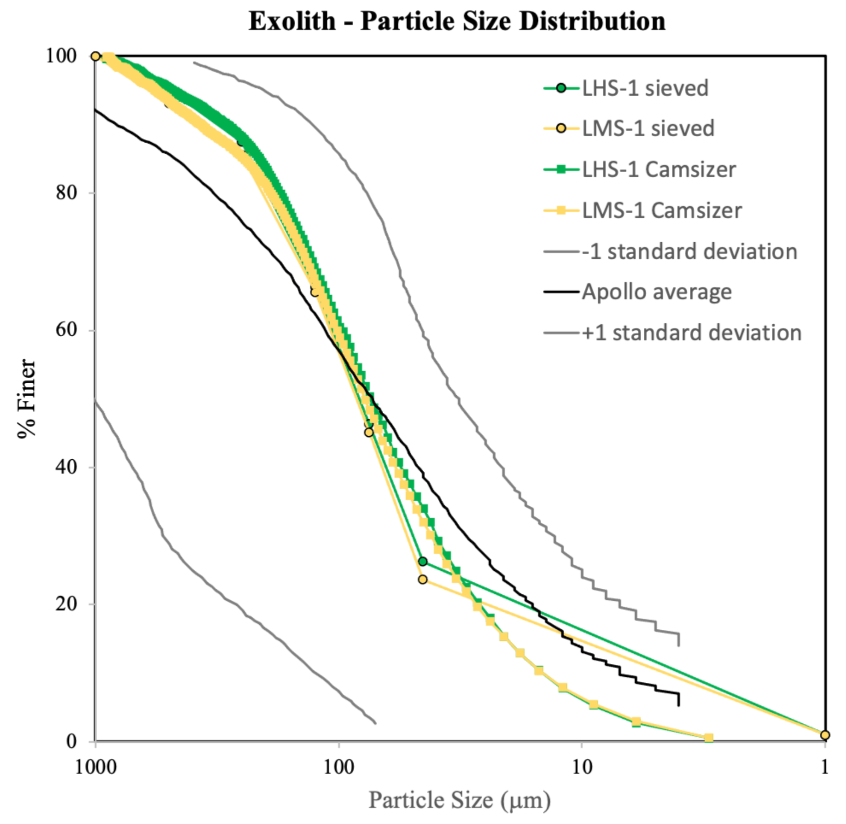
- **Bulk composition – XRF and SEM ($Na_2O$)**

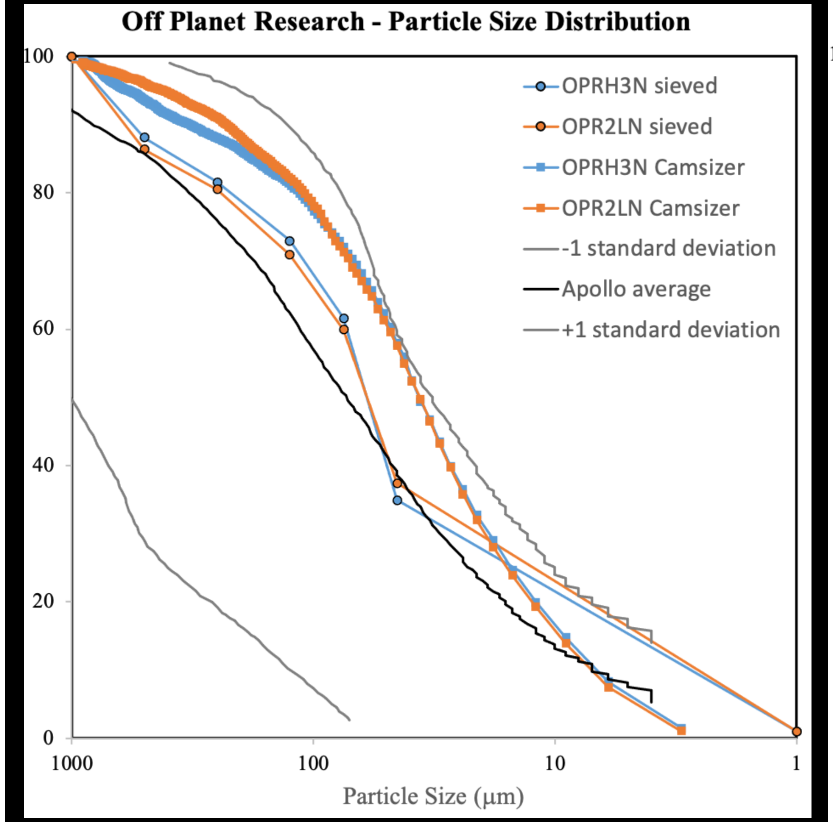


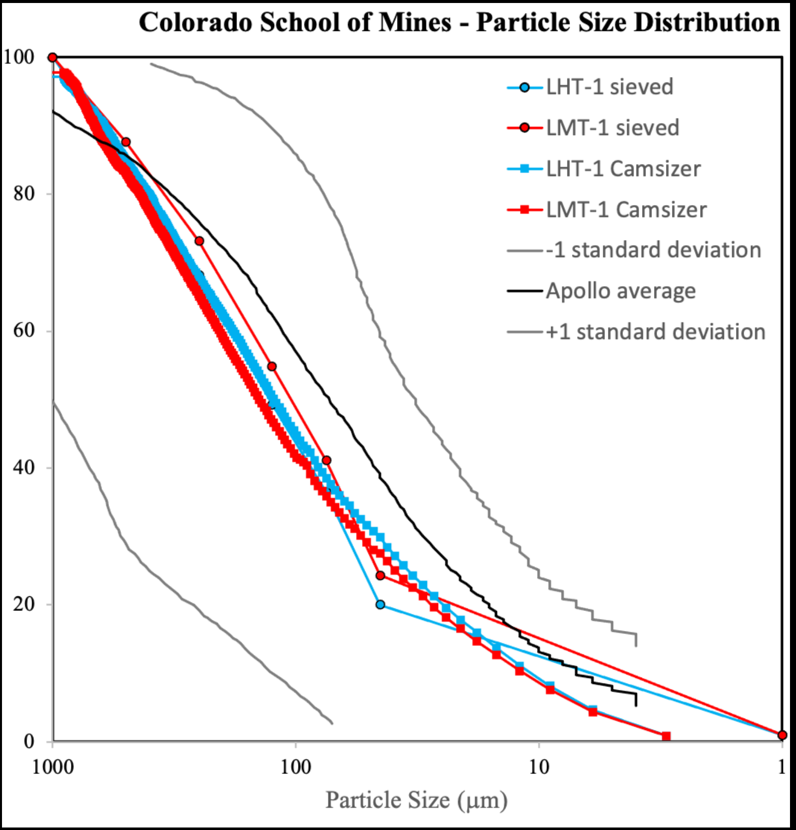



# Lunar Simulants – Particle Size & Shape (2021)

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



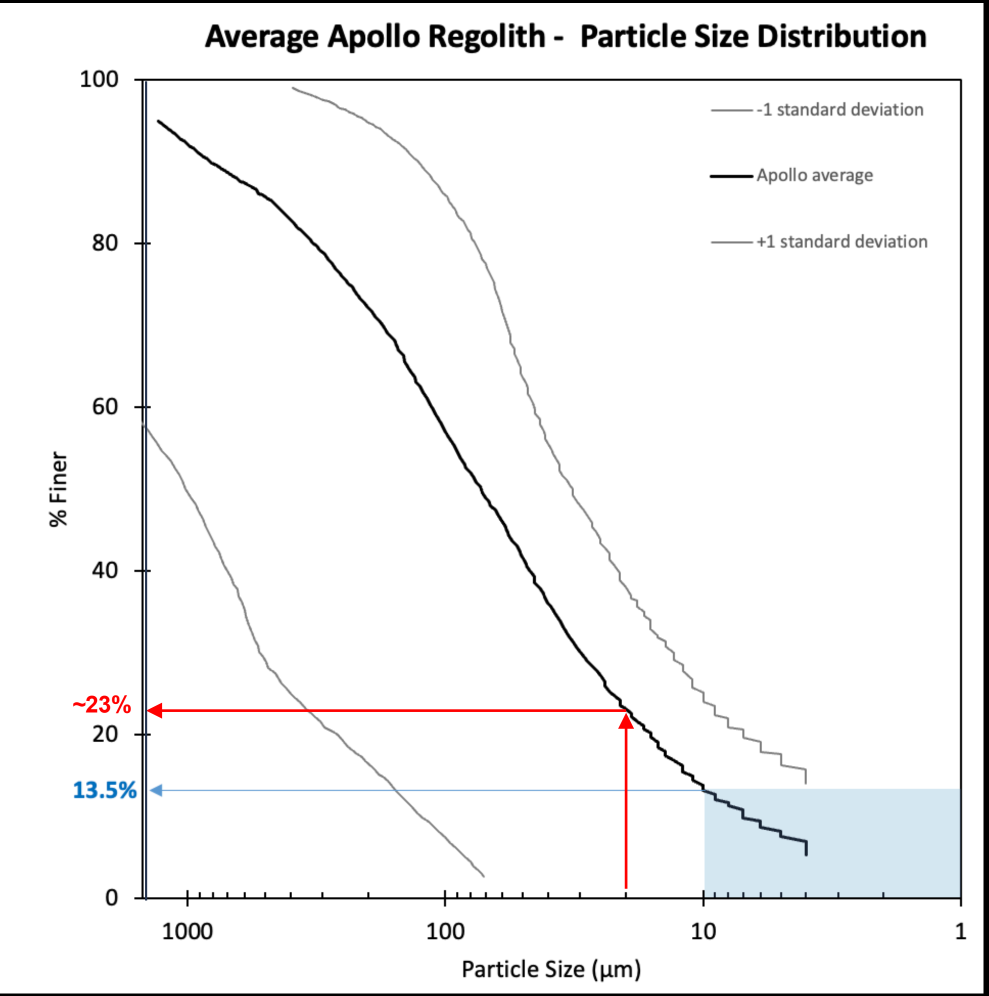



# Lunar Regolith = Dust + Bigger Stuff

- NIH study (Pohlen et al, 2022) says the respirable fraction of lunar dust is divided into:
  - Ultrafine: <0.1 um
  - Fine: 0.1 – 2.5 um
  - Coarse: 2.5 – 10 um

  ~13.5% by mass
- Rickman & Street (2008)
  - Material < 20 um
  - Poorly characterized

  ~23% by mass
- Note: Sieving skews the particles to the larger since many fines cling to larger particles

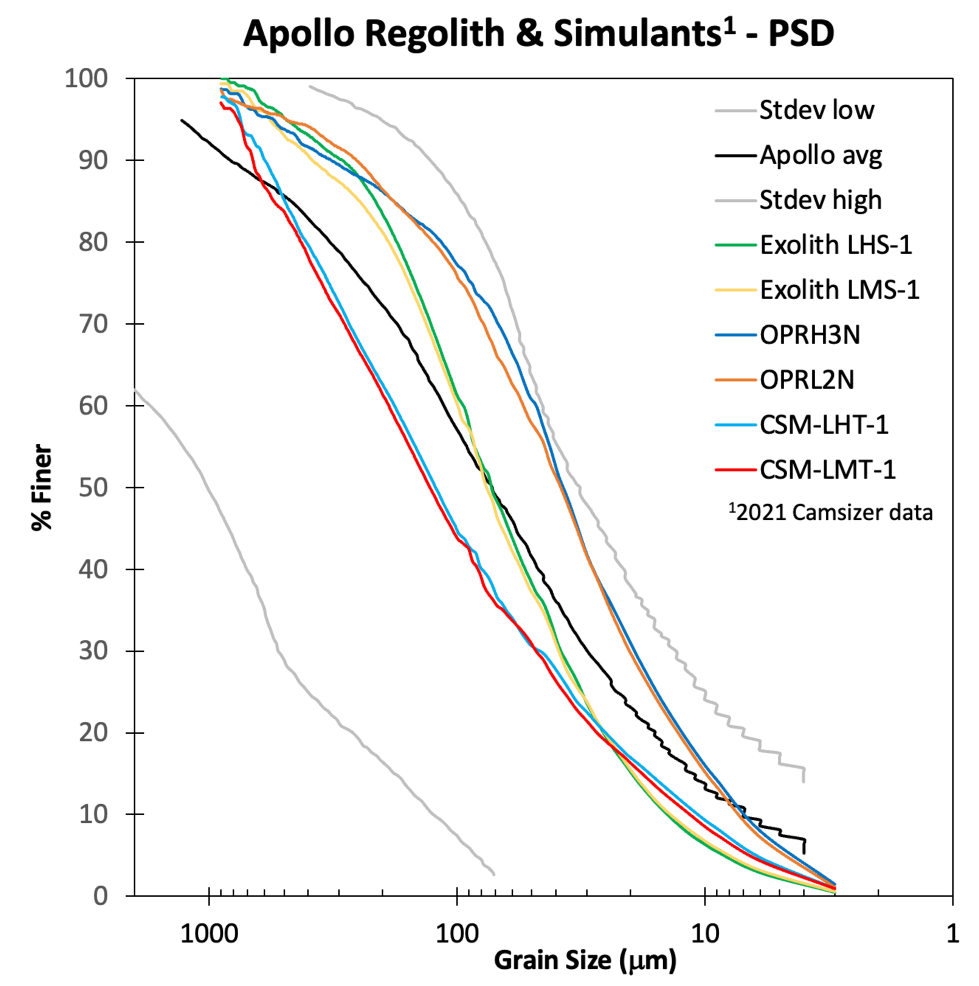



Pohlen et al. (2022) *Overview of lunar dust toxicity risk*, NPJ Microgravity, v. 8, no. 55, doi:10.1038/s41526-022-00244-1.
Rickman & Street (2008) *Some Expected Mechanical Characteristics of Lunar Dust: A Geological View*, https://www.nasa.gov/sites/default/files/atoms/files/staif2008_rickman_street.pdf.

# Lunar Regolith Simulants = Dust + Bigger Stuff

- Simulants - fairly good match to PSD of average Apollo regolith
  - All plot within 1 stand deviation (gray lines)

| Calculated % finer than: | | |
|---|---|---|
| | 10 µm | 20 µm |
| **Apollo avg** | 13.5 | 23.1 |
| **LHS-1** | 6.3 | 15.2 |
| **LMS-1** | 6.8 | 15.5 |
| **OPRH3N** | 16.0 | 31.0 |
| **OPRL2N** | 15.1 | 29.7 |
| **CSM-LHT-1** | 9.3 | 16.9 |
| **CSM-LMT-1** | 8.5 | 16.3 |




- Note: Sieving skews the particles to the larger since many fines cling to larger particles
  - This may be less of an issue for Camsizer?

# Lunar Simulants – Particle Size & Shape (2022)

- **Particle Size Distribution (2022)**

Size split: 74um 74-149um 149-297 um 297-500 um >500 um

# Lunar Regolith – Composition vs. particle size?

- Does lunar regolith show compositional changes in various particle size splits? YES!!!
  - McKay *et al*. (1991) "Polymineralic and lithic (rock) fragments dominate the coarser size fractions. In contrast, the finer soil fractions are enriched in feldspars and glassy phases." (Ch. 7 of LSB)
  - Heiken (1975) *Petrology of Lunar Soils* (Rev. of Geophysics & Space Physics) – typical Apollo 17 mare regolith

**Components***

Agglutinates
Basalt, equigranular
Basalt, variolitic
Breccia
  Low grade, brown
  Low grade, colorless
  Medium high grade
Anorthosite
Cataclastic anorthosite
Norite
Gabbro
Plagioclase
Clinopyroxene
Orthopyroxene
Olivine
Ilmenite
Glass
  Orange
  'Black'
  Colorless
  Brown
  Gray, 'ropy'
Other

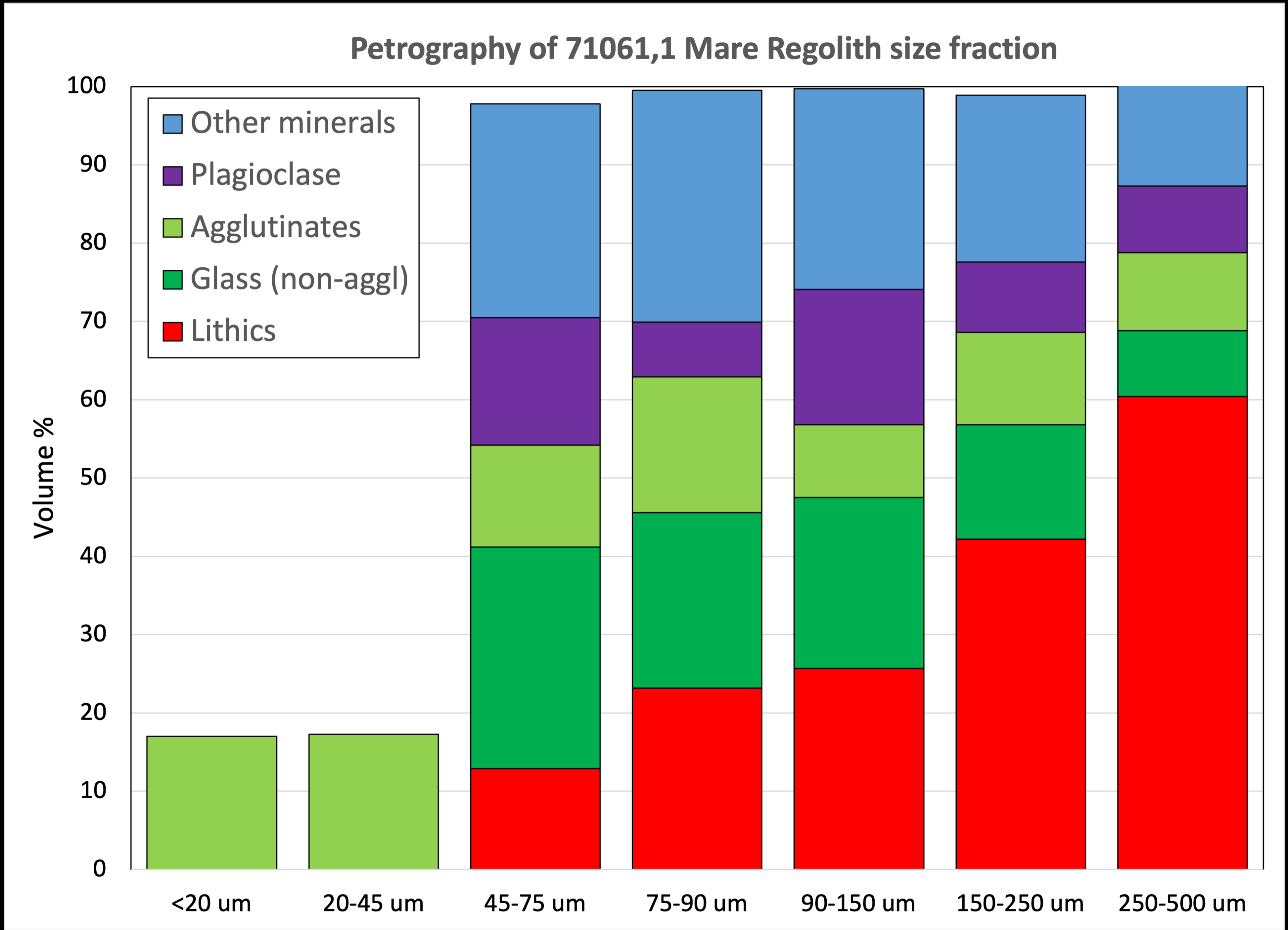
TABLE 4*a*. Petrography of a Series of Size Fractions From 71061,1, a Typical Apollo 17 Mare Soil

| | Petrographic Description, vol % | | | | | | | Visual Estimate in Lunar Receiving Laboratory | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Components* | <20 μm | 20–45 μm | 45–75 μm | 75–90 μm | 90–150 μm | 150–250 μm | 250–500 μm | 0.5–1 mm | 1–2 mm | 2–4 mm | 4–10 mm |
| Agglutinates | 17.0 | 17.3 | 13.0 | 17.3 | 9.3 | 11.8 | 10.0 | 10.0 | | | |
| Basalt, equigranular | | | 9.0 | 15.0 | 19.6 | 30.9 | 51.5 | 65.0 | 100.0 | 100.0 | 100.0 |
| Basalt, variolitic | | | 0.6 | 1.6 | | 3.4 | | | | | |
| Breccia | | | | | | | | | | | |
| Low grade, brown | | | 1.0 | 4.0 | 3.6 | 5.1 | 6.9 | | | | |
| Low grade, colorless | | | 0.3 | 1.3 | 0.6 | ... | ... | 5.0 | | | |
| Medium high grade | | | 1.0 | 1.3 | 1.6 | 2.8 | 1.5 | | | | |
| Anorthosite | | | ... | ... | 0.3 | ... | ... | | | | |
| Cataclastic anorthosite | | | 1.0 | ... | ... | ... | ... | | | | |
| Norite | | | ... | ... | ... | ... | ... | | | | |
| Gabbro | | | ... | ... | ... | ... | 0.5 | 5.0 | | | |
| Plagioclase | | | 16.3 | 7.0 | 17.3 | 9.0 | 8.5 | | | | |
| Clinopyroxene | | | 21.3 | 26.3 | 21.0 | 17.4 | 10.8 | | | | |
| Orthopyroxene | | | ... | ... | ... | ... | ... | | | | |
| Olivine | | | ... | ... | ... | 0.6 | ... | | | | |
| Ilmenite | | | 6.0 | 3.3 | 4.6 | 3.3 | 2.3 | | | | |
| Glass | | | | | | | | | | | |
| Orange | | | 7.6 | 5.0 | 6.3 | 4.5 | 0.8 | | | | |
| 'Black' | | | 18.7 | 10.6 | 9.6 | 5.1 | 6.1 | 5.0 | | | |
| Colorless | | | 1.0 | 1.0 | 1.3 | ... | 1.5 | | | | |
| Brown | | | 0.3 | 5.2 | 4.6 | 3.3 | ... | | | | |
| Gray, 'ropy' | | | 0.7 | 0.6 | ... | 1.7 | ... | 10.0 | | | |
| Other | | | 2.0 | ... | ... | 1.0 | ... | | | | |
| Total number of grains counted | 300 | 161 | 300 | 300 | 300 | 178 | 130 | 20 | 100 | ? | ? |
| Wt % of total sample for each size fraction | 17.98 | 12.21 | 8.39 | 3.0 | 8.66 | 7.04 | 7.08 | 3.44 | 6.15 | 6.74 | 10.16 |

Sample 71061,1 was taken from Station 1 on the mare surface. Agglutinate versus nonagglutinate grains were identified by using a scanning electron microscope in size ranges of <20 and 20–45 μm. The >10-mm fraction made up 9.42% of the sample.

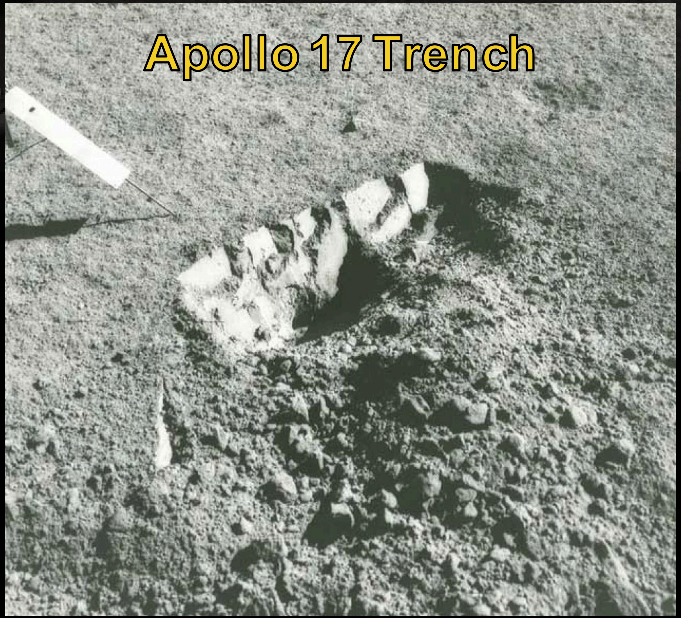
* The <20-μm fraction is 83% nonagglutinate; the 20- to 45-μm fraction is 82.7% nonagglutinate.

# Lunar Regolith – Composition vs. particle size?




- Graphic produced from Heiken (1975) Table 4a for a typical Apollo 17 mare regolith
  - 130 – 300 grains were counted for each size split
  - 3 -18 wt % of size split
- Lithic fragments dominate the larger size fractions
  - 40 vol. % or more
- Glass & Plagioclase enriched in the finest size fractions
  - 45 vol. % or more

# LSII | ISRU Considerations



(Fig. 7 in Carrier 2005)

- **Much of what we know about regolith and simulants are characteristics of BULK samples**
  - Differences in composition exist between grain size splits
    - Visible differences in simulants
    - Documented in at least two Apollo 17 regolith samples
    - This trend suggests that the dust will have more plagioclase & glass, less lithic fragments
  - There may be differences in grain shapes by size as well
- **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 (not in situ measurements)

# Lunar Simulants Working Group (LSWG)

- **LSWG on LSIC Webpage** (under Our Work)
  - https://lsic.jhuapl.edu/Our-Work/Working-Groups/Lunar-Simulants.php
  - Assessments under “Assessments & Databases” tab
- **LSWG Confluence Page** (requires LSIC membership, link on main page)
  - https://lsic-wiki.jhuapl.edu/display/LSWG/Lunar+Simulants+Working+Group+Home
  - Assessments under “LSWG Resource Library” => “Recent Simulant Assessments & Reports”

Simulant Teams
Assessments
Publications
Resources
And More!!!

## Lunar Simulant Data Repository

Created by Andrea Harman, last modified by Karen Stockstill-Cahill on Jan 19, 2022

**Introduction**

Spurred by the Constellation Program, a 2010 report from LEAG and CAPTEM (Simulant Working Group, 2010) presented findings on the lunar regolith simulants that were available at that time (e.g., JSC-1, JSC-1A, NU-LHT) and their strengths and weaknesses for various uses. Excellent summaries of the history of, and the shortcomings of these simulants were presented by Taylor and colleagues (Taylor and Liu, 2010; Taylor et al., 2016). In the intervening decade, new simulants have become available that specifically address the limitations of the previous iterations. Here we present information on several simulants from this new generation, including new analyses of their particle size–frequency distribution, particle morphology, and composition, and their potential suitability for specific uses.

**Introduction and Background**

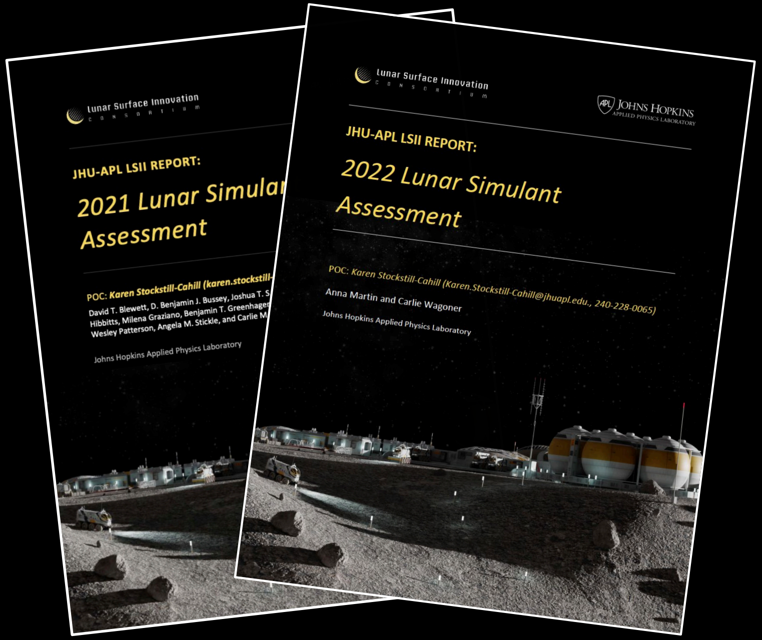
**Methods used for Lunar Simulant Assessments**

**Assessed Lunar Highland Simulants**

**Assessed Lunar Mare Simulants**

**Assessed Lunar Agglutinates Simulants**

**Lunar Simulant Providers included in recent Assessments**



# LSWG Speaker Series starts TODAY!!!

**Speaker:** Dr. Doug Rickman

**Title:** "The Art of Simplification: Making the choices that allow simulants to be made, chosen, and used."

**Date/Time:** June 15th, 2023 at 1 pm ET

**Please email**
Karen.Stockstill-Cahill@jhuapl.edu
**to be added to new LSWG List Serve**
Format: henry@somewhere.com Henry Brown

SCAN ME!

**Meeting ID**: 161 580 7672

**Passcode**: 828569

Meeting link at:
https://lsic-wiki.jhuapl.edu/display/LSWG/Lunar+Simulants+Working+Group+Home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