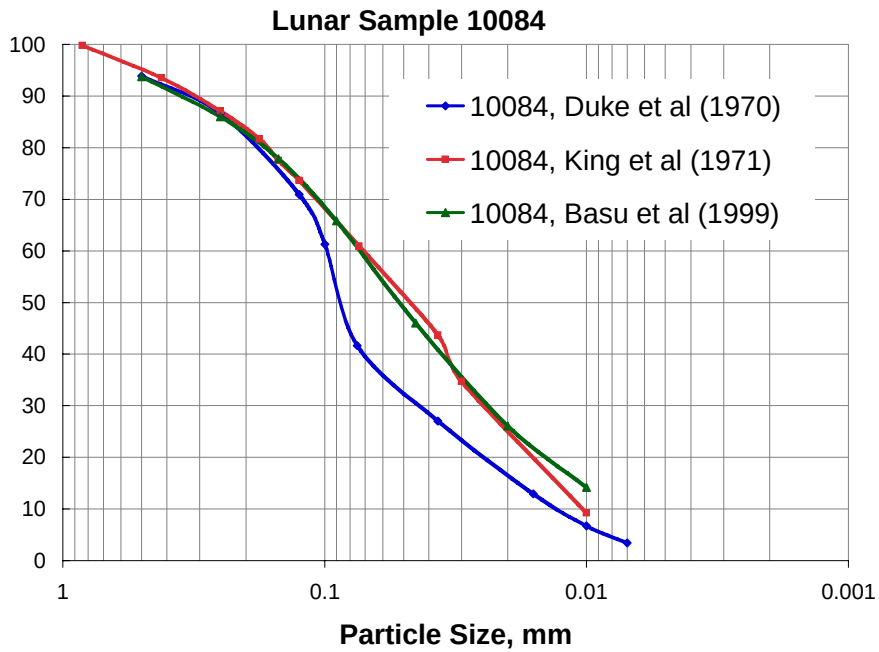
Minnesota Lunar Regolith MLS-1

Susan Batiste, susan.batiste@colorado.edu
Stein Sture, stein.sture@colorado.edu

Background: NASA image AS11-40-5878

Source for MLS-1

- Dr. Paul Weiblen and researchers at the University of Minnesota
  - Weiblen PW, and Gordon, KL. (1988) “Characteristics of a Simulant for Lunar Surface Materials”, *Symposium on Lunar Bases and Space Activities in the 21st Century*, Paper No. LBS-88-213, Houston.
- Bulk chemistry closely resembles Apollo 11 mare soil sample 10084
  - Basalt portion



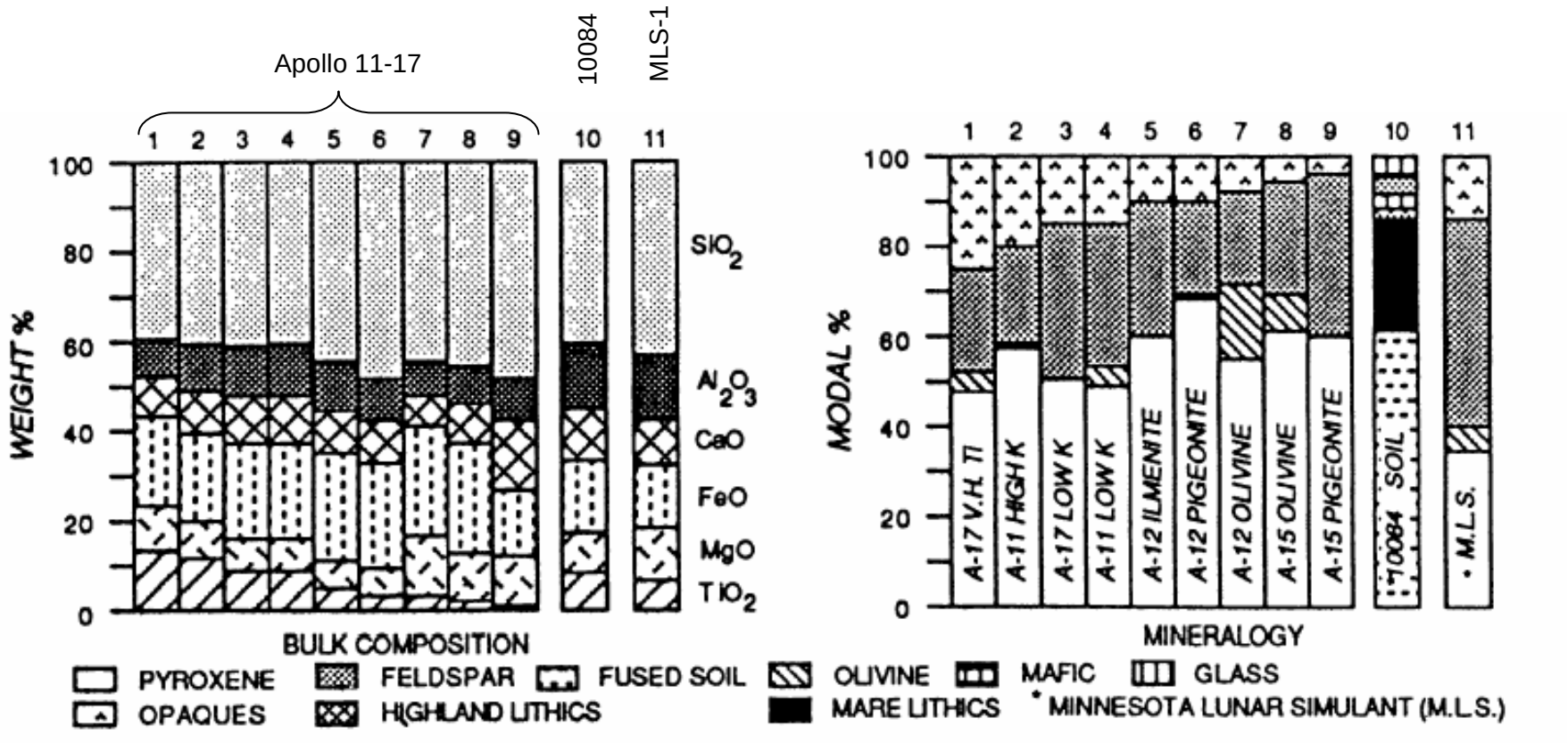
Quarrying and Processing

- Source location
  - Abandoned quarry in Duluth, Minnesota
  - 1-2 m thick sill of basaltic rock
  - Sill extends 50 m across a rock face
- Processing at University of Minnesota
  - Mechanically crushed and ground

MLS-1 Mineralogy

- High-Ti basalt
- Plagioclase, olivine, pyroxene and ilmenite
  - Crystallized simultaneously
  - Grain size similar to coarser lunar mare basalts
- Differences from Apollo 11 lunar mare
  - Less pyroxene
  - More feldspar
  - Small amount (<3% by vol) of biotite
  - Surface ferric iron (3.5% by wt)
    - Ilmenite and mafic silicates
  - 0.4% water
  - Surface oxidation
  - No glass or agglutinates (majority of 10084)

Mineralogy: Apollo Regolith & MLS-1

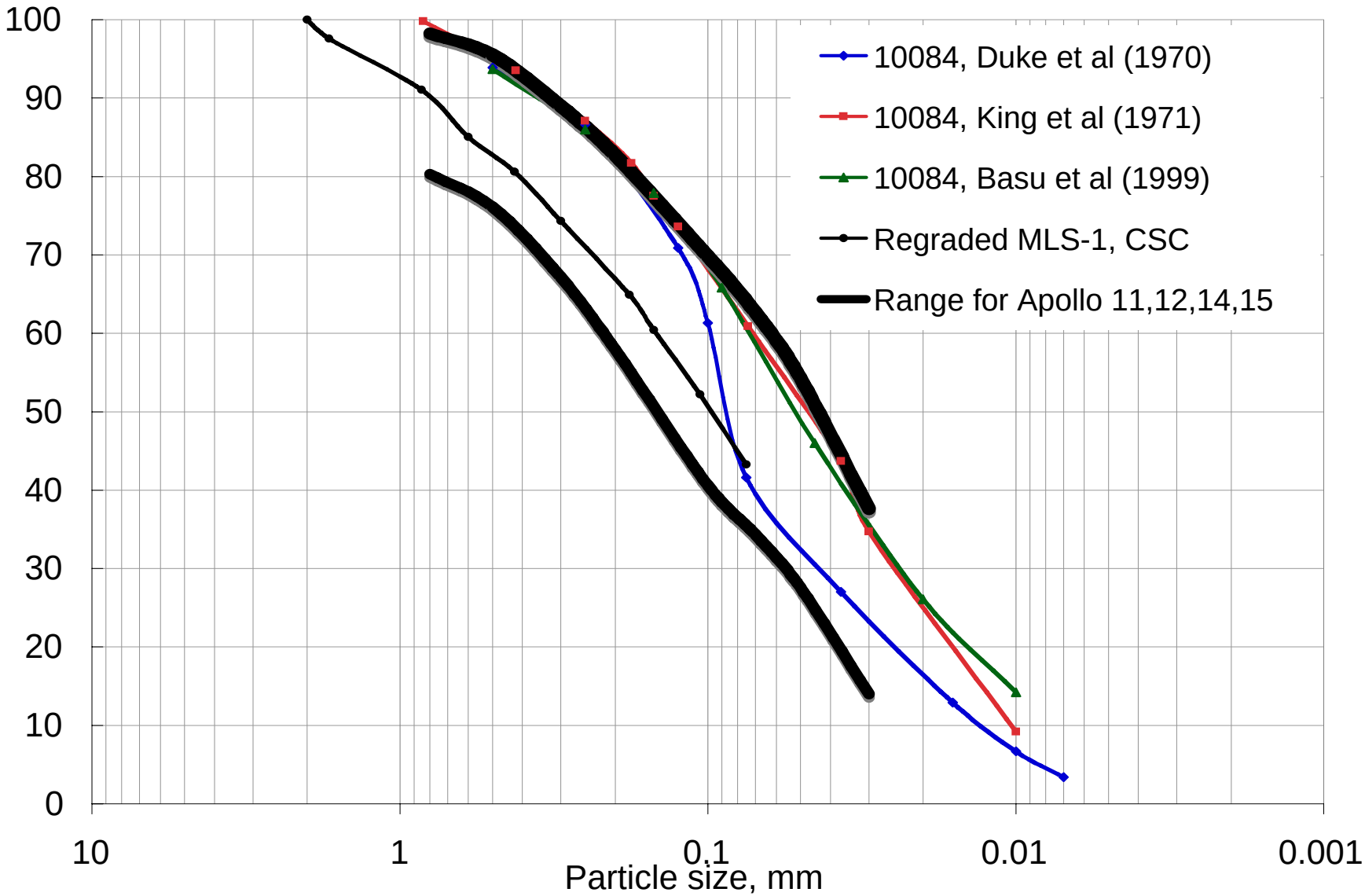


Weiblem&Gordon (1988), from Papike et al., (1976, 1981)

CU-Boulder Processing

- Apollo 11 sample 10084 forms upper bounds of grain size distribution curve for Apollo samples
- MLS-1 was further processed at CU-Boulder to fall within band of grain size distributions
  - Sieved into respective grain sizes
  - Course material ground in a rodding mill
    - By USBR in Denver
    - Needed to obtain enough fines
      - 40% of lunar regolith is smaller than #200, or 75μm)
  - Recombined

MLS-1 Grain Size Distribution



Mechanical Properties 1

- Specific Mass: 3.2
- Unit weight (particle-void composite)
  - ρ_{max}, g/cm^3: 2.07-2.20
  - ρ_{min}, g/cm^3: 1.48-1.60
- Conventional triaxial compression

	Density, ρ, g/cm^3	Confining Stress σ_3, kPa	Friction Angle, ϕ, deg
Lunar Regolith	**1.89**	**26.0**	**48.8**
(Scott, 1987)	**1.71**	**52.6**	**40.7**
MLS-1	**1.90**	**13.8**	**49.8**
	1.90	**34.5**	**48.4**
(Perkins, 1991)	**1.70**	**34.5**	**42.9**
	1.70	**68.9**	**41.4**

Combined friction, cohesion data

- Comparing data based on density
- Friction angle for ρ=1.7-1.75 comparable
  - Lab tests were performed at relatively high confining stress
  - Future tests should use comparable stress

Material	Depth, cm or Conf. Stress, kPa	Density, g/cm^3	Cohesion, kPa	Friction Angle, deg
Lunar Regolith	0-15 cm (0-0.1 kPa)	1.50	0.52	42.0
	30-60 cm (0.2-0.4 kPa)	**1.75**	**3.0**	**54.0**
MLS-1	**1.72 kPa (360 cm)**	**1.70**	**0.10**	**51.4**
	1.72 kPa (200 cm)	2.17	1.5	62.3

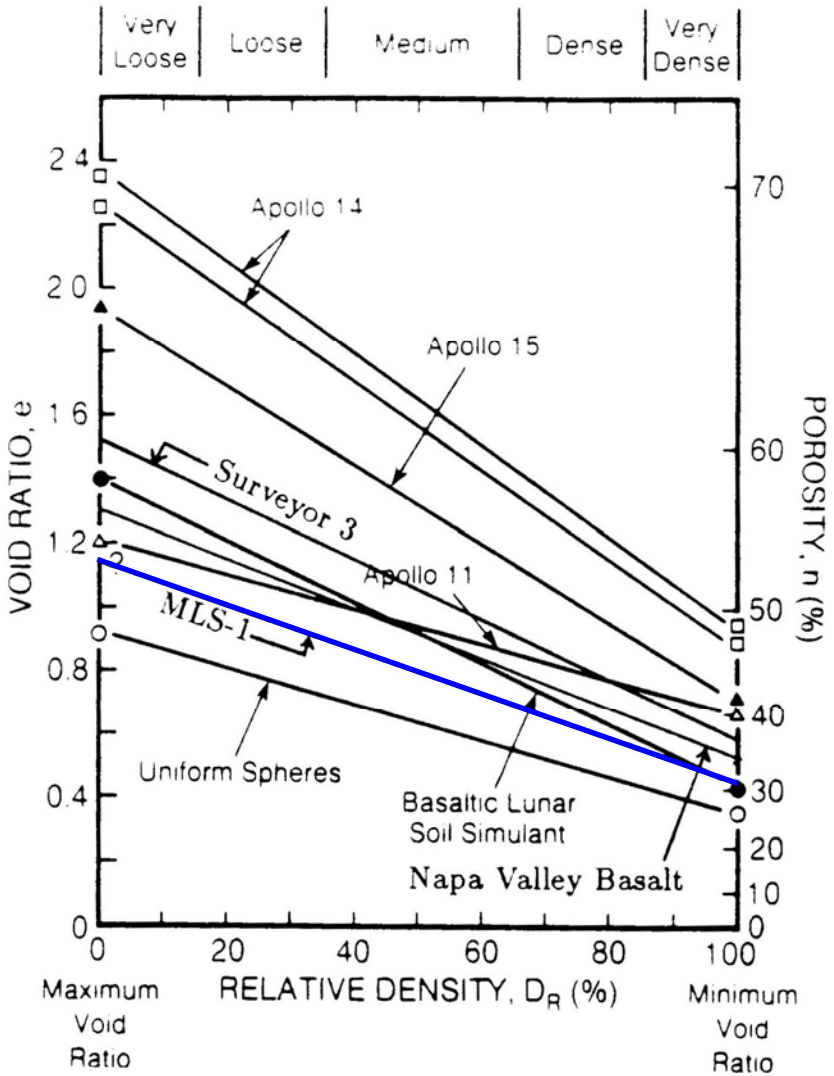
***In situ* data**

For K_o=0.25 | **Direct shear** | **Triaxial (CTC)**

MLS-1 Composition

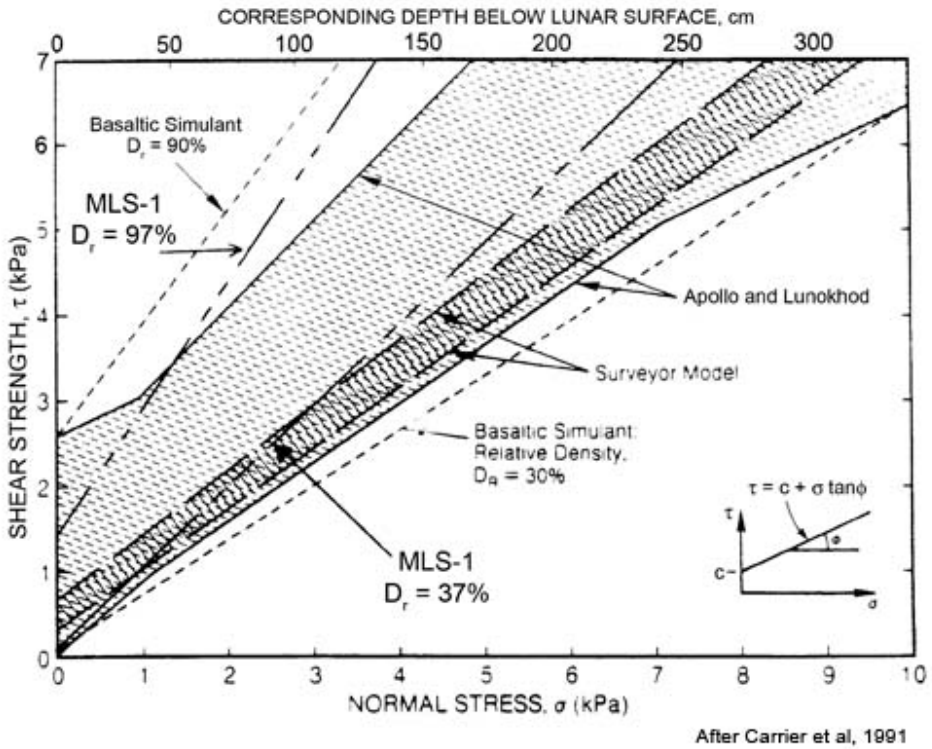
- No glasses
  - Lack of glasses is not considered to have a significant impact on engineering properties
- No agglutinates
  - May be significant as they are easily broken
- UM attempted agglutinate production by passing MLS-1 through a plasma torch (6000C)
  - Did not produce the intricate and delicate shapes of the agglutinate particles

Density Range of MLS-1



- MLS-1 minimum void ratio
  - Slightly more dense than lunar soils
  - Static compaction
    - Same method as Apollo 11 and Surveyor 3 samples
- MLS-1 max void ratio
  - Not as loose as lunar regolith
    - Due to lack of agglutinates, which have highly irregular shape
  - Close to Apollo 11 data
    - Possible test error suggested
      - No agglutinate data with tests

Mohr-Coulomb Peak Strength



D_r= 97% ➲ 2.17 g/cm^3

D_r= 37% ➲ 1.90 g/cm^3

- MLS-1 strength properties tend to bracket in-situ regolith values
- Cohesion intercept for dense MLS-1 is low in comparison to regolith
- MLS-1 deficiencies that may lead to low cohesion
  - Electrostatic charging
  - Agglutinate particles
    - Highly angular, interlocking cohesion

Conclusions

- MLS-1 is a reasonable simulant of the lunar basalt
  - Similar chemistry
  - Similar engineering properties
  - Lacks the cohesion properties of lunar regolith
- For a more-realistic simulant for engineering
  - Add agglutinates to MLS-1
  - Perform check cohesion and friction properties