Simulant requirements

- Proper Mineralogy
  - Appropriate chemical composition
  - Absence of alteration minerals
- Optimal particle size distribution
- Appropriate shape distribution
- Major glass content
    - High quality (HQ) glass
    - Agglutinate (LQ) glass

Development approach

- Target average Apollo 16 lunar soil composition
  NASA conference pub 2255 (1982)
- Chemical analysis of starting constituents
- USGS blending program optimizes mixture
- Mixture is modified to include best
  mineralogical composition

Chemical composition starting materials

Sample ID	SiO_2	Al_2O_3	Fe_TO_3	MgO	CaO	Na_2O
Norite	49.4	23.72	4.07	8.17	13.6	0.84
Anorth.	48.6	30.9	1.54	1.47	15.9	1.7
Harz.	43.7	2.1	**13.1**	**38.3**	1.87	<0.2
Sand	47.7	22.1	6.2	10.5	12.5	0.9
Apollo 16	44.9	25.0	9.3	5.8	15.7	0.47

USGS

Components used

Material	Amount	% of total
Norite	38 lbs	30.0
Anorthosite	55	43.4
Hartzburgite	7.7	6.1
Ilmenite	0.92	0.73
Glass	25	**19.7**
HQ glass	5	(20)
LQ glass	20	(80)

USGS

Simulant preparation

- Starting material crushed <4 mm
  - Norite, Anorthosite, Hartzburgite,
- Grinding time experiments (ball mill)
  - Consistent size reduction
- Develop appropriate mixture of starting material
- Grind for specific time period (15, 45 min.)
- Blend as one batch
- Split using spinning riffler (200g aliquots)

USGS

LHT-1M composition

Oxide	Apollo 16	LHT-1M
SiO_2	44.9	47.6
Al_2O_3	25.0	24.4
FeO	8.4	4.3
MgO	5.8	8.5
CaO	15.7	13.1
Na_2O	0.47	1.4

USGS

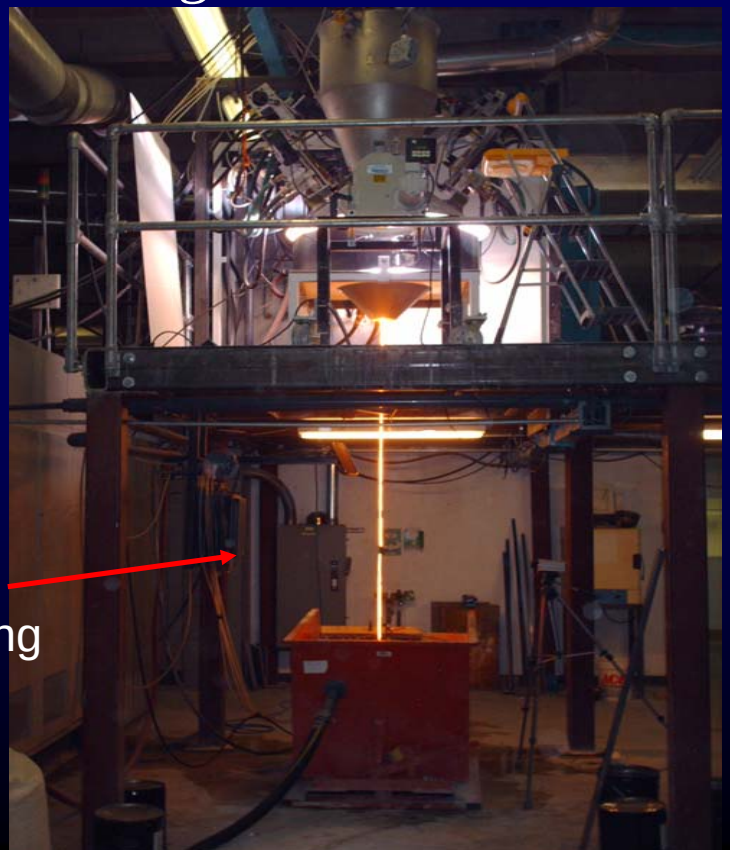
Glass production

- Need to develop technology for glass production
  - HQ glass
  - Agglutinate (LQ) glass
- High throughput 100's kg per day
- Excellent temperature control
- Able to handle geologic source material (powder)
- High temperature plasma

USGS

Plasma Technology

- Remotely-coupled transferred arcs
  - Non-conductive material rapidly heated / cooled
  - Extreme thermal gradient
  - Power density - 140 MW/m^3
- Glass exit temperatures 1,300–1,925 °C. Up to 150 kg/hr
- Plasma temperatures 13,000˚K to 21,000˚K
  - Typically run at 600 to 1,200 amps



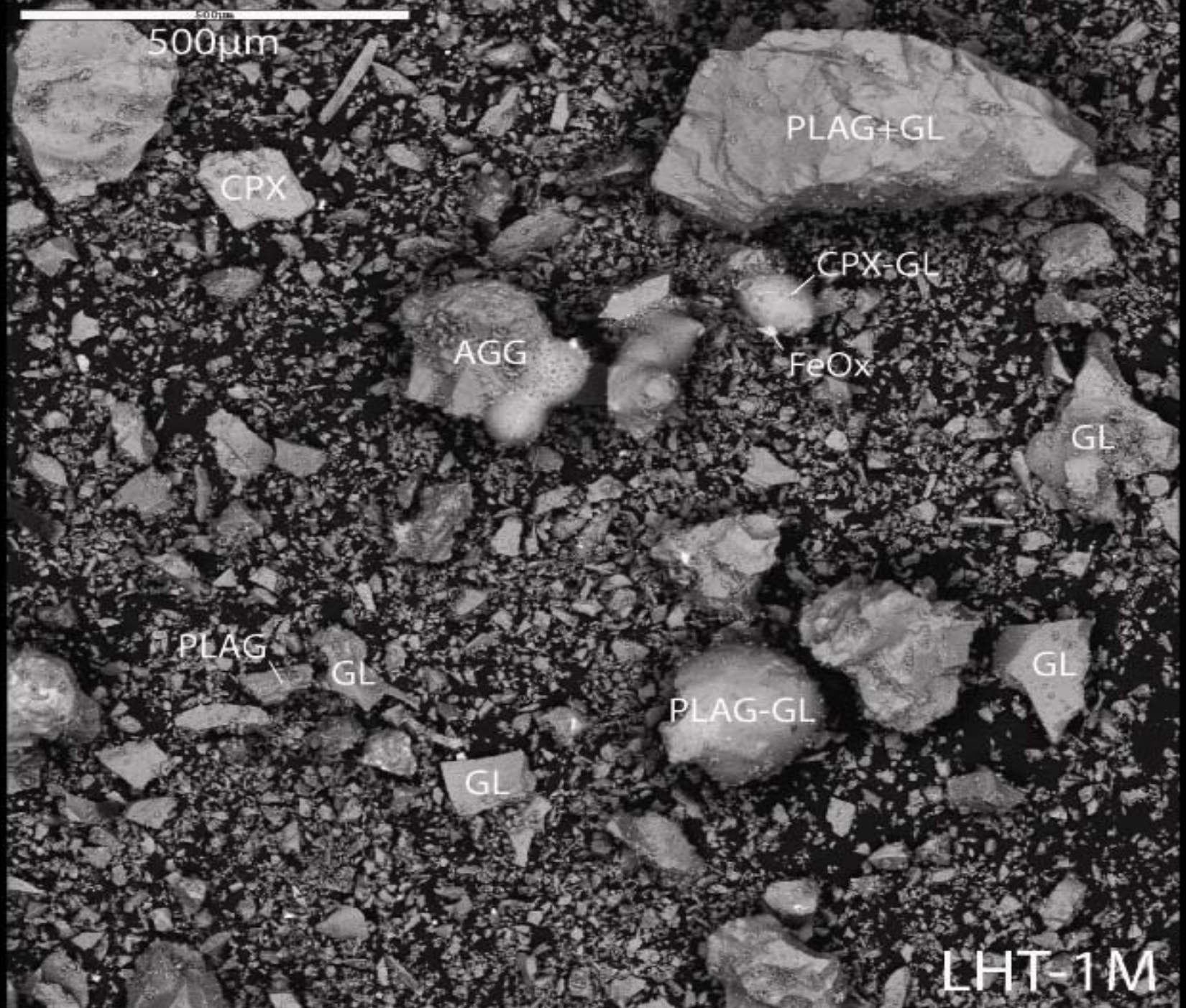
LHT glass manufacturing

Agglutinate production

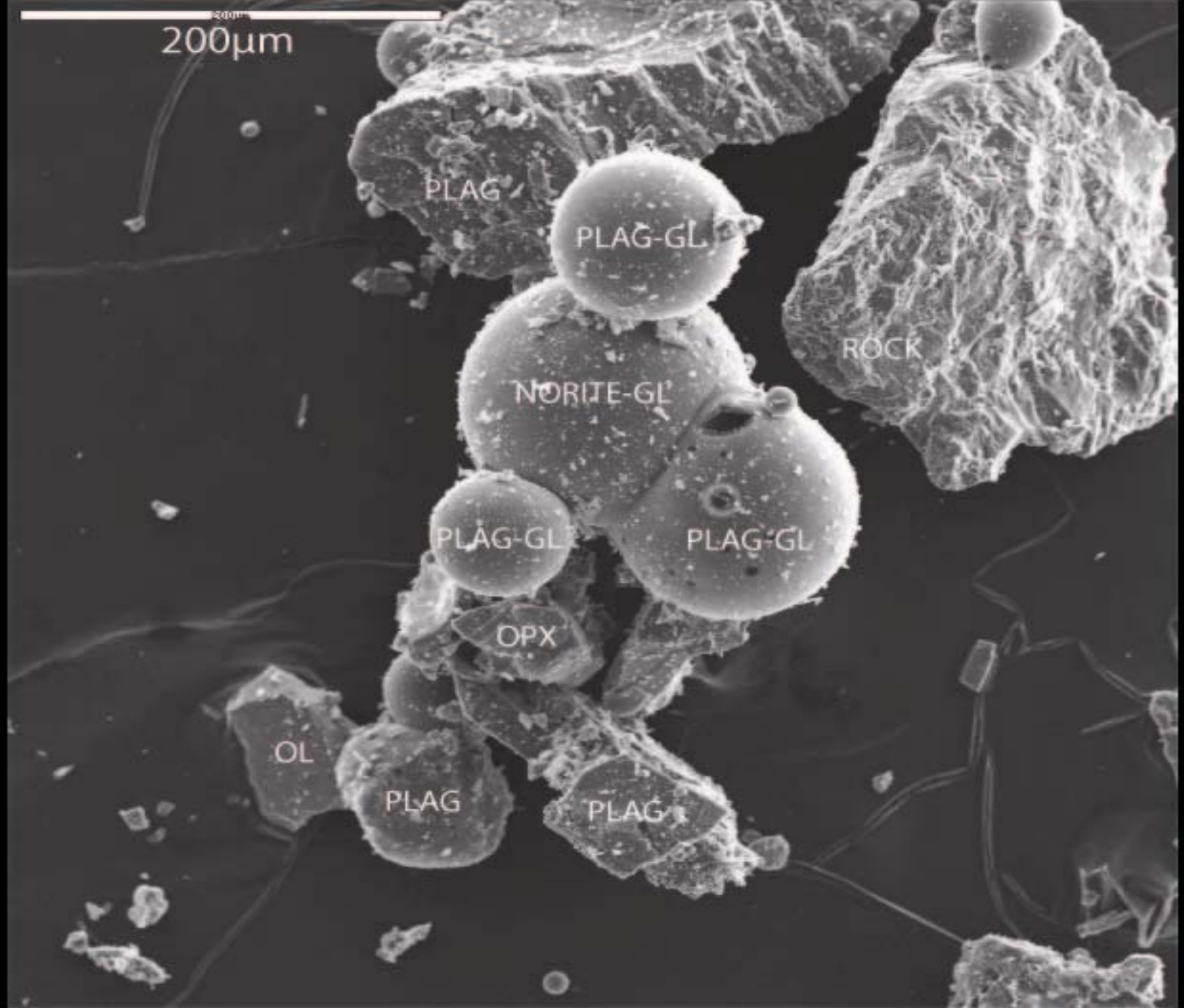
- Partially melted material
- Irregular internal structure, vesicles
- Very friable
- Production rates at 50+ kg (110+ lbs) per day

USGS

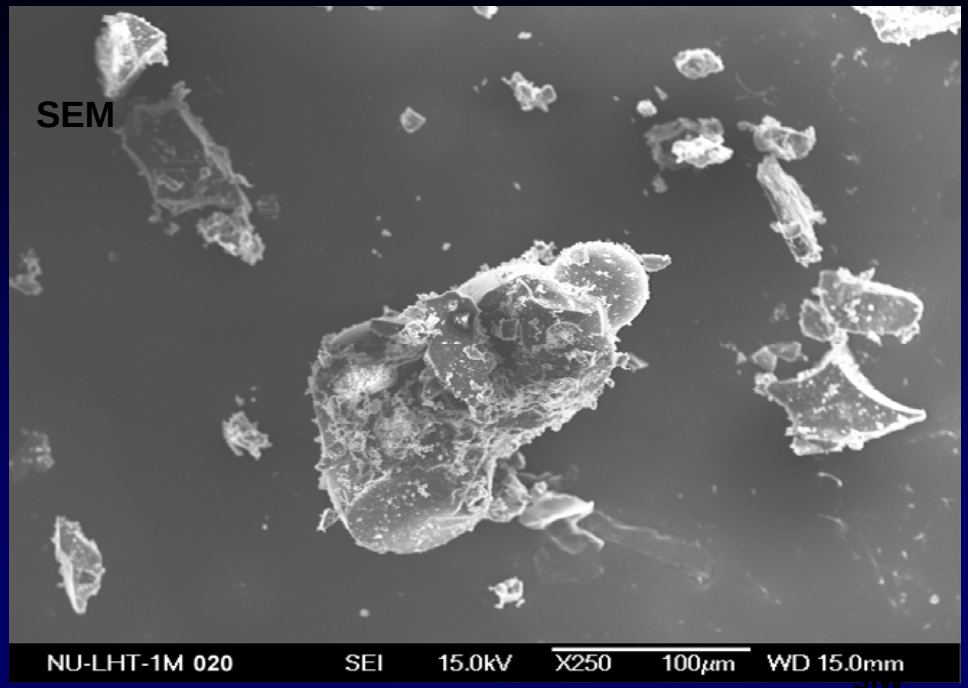
Video

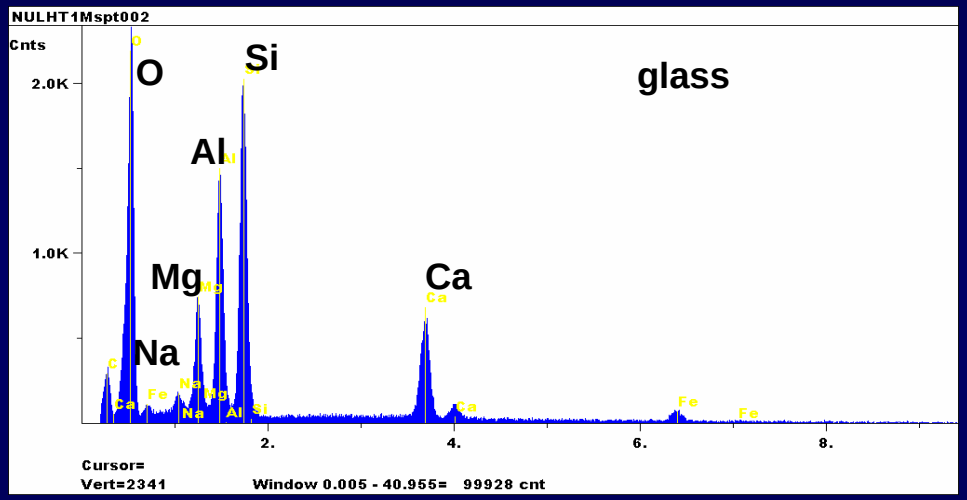

500µm
PLAG+GL
CPX
CPX-GL
AGG
FeOx
GL
PLAG
GL
GL
PLAG-GL
GL
LHT-1M

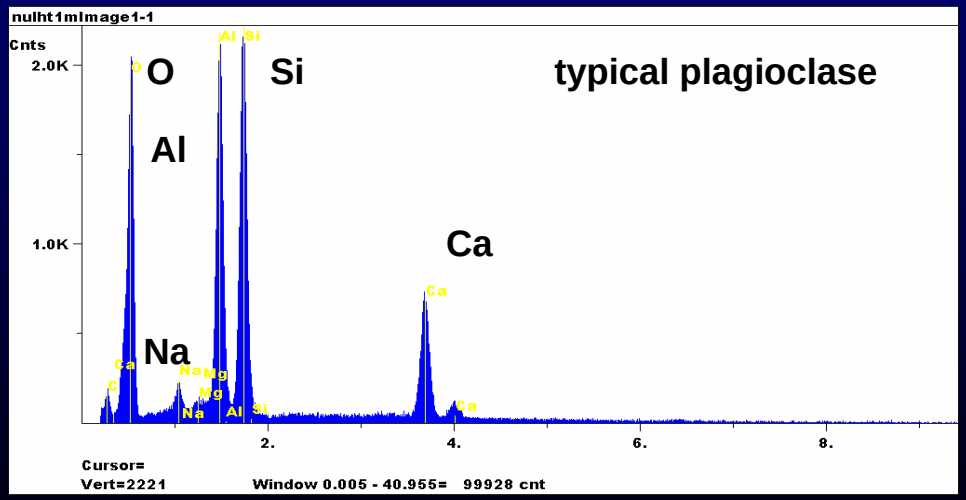
15kV
X37 500µm
USGS LHT-1


200µm
PLAG
PLAG-GL
ROCK
NORITE-GL
PLAG-GL
PLAG-GL
OPX
OL
PLAG
PLAG

Glass spherules are rare to isolated. This one is firmly attached to larger vesicular glass.
Glass has Mg-rich highlands composition regardless of shape, and is homogeneous.
No inclusions have been identified in glass.
Nothing found in sample that looks like agglutinate.
Found isolated ilmenite(?), a Zr-rich grain, and a grain consisting of Si, Al, C, and O.







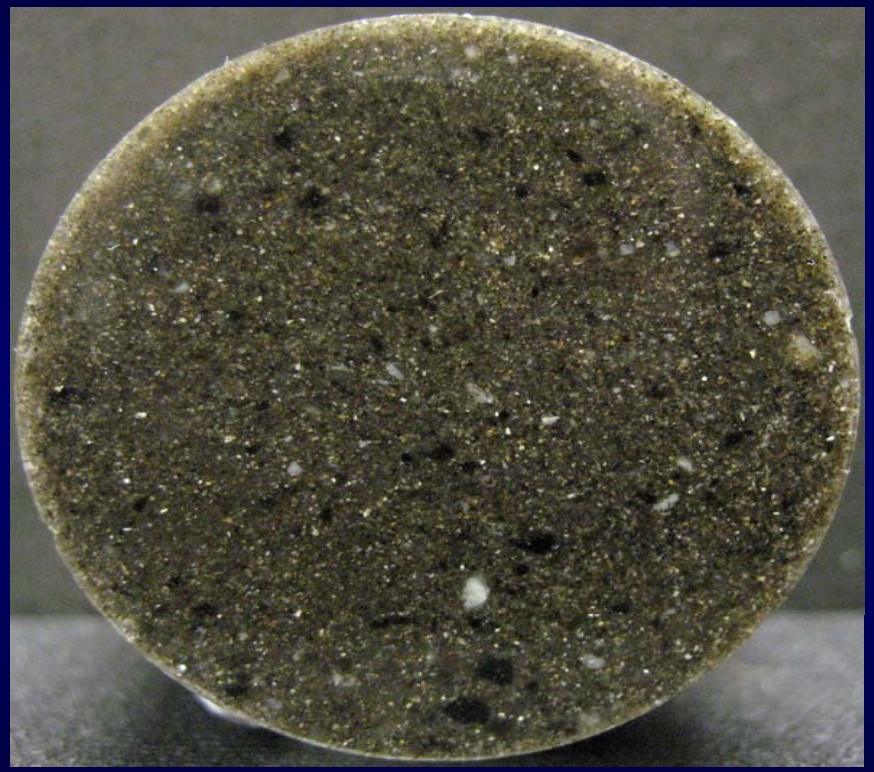
Glass constituents (in order of decreasing peak height, which qualitatively correlates to abundance): O, Si, Al, Mg, Ca, Na, Fe.

Composition is excellent approximation to those of many lunar highland impact glasses .

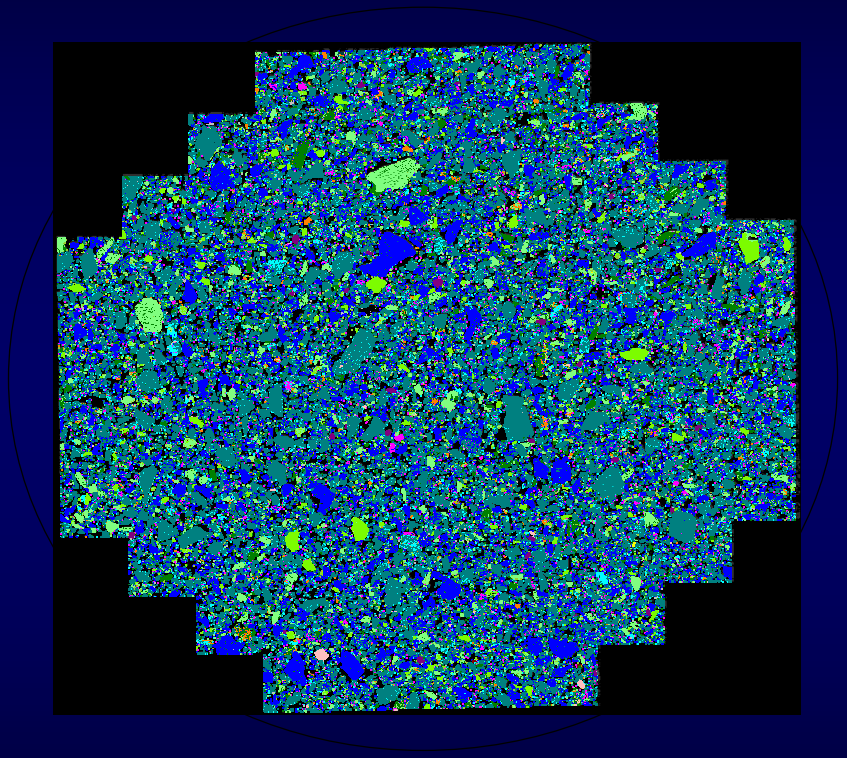
System overview

QEMSCAN® uses advanced e-beam technology from Carl Zeiss and combines this with high resolution BSE and SE imaging, and state-of-the-art Energy Dispersive Spectrometers. It integrates these using iDiscover software to provide a solution capable of identifying most rock-forming minerals in just milliseconds

QEMSCAN® Results



Digital photograph of a 30mm diameter polished block



QEMSCAN® false-coloured, digital particle mineral map montage of a polished block

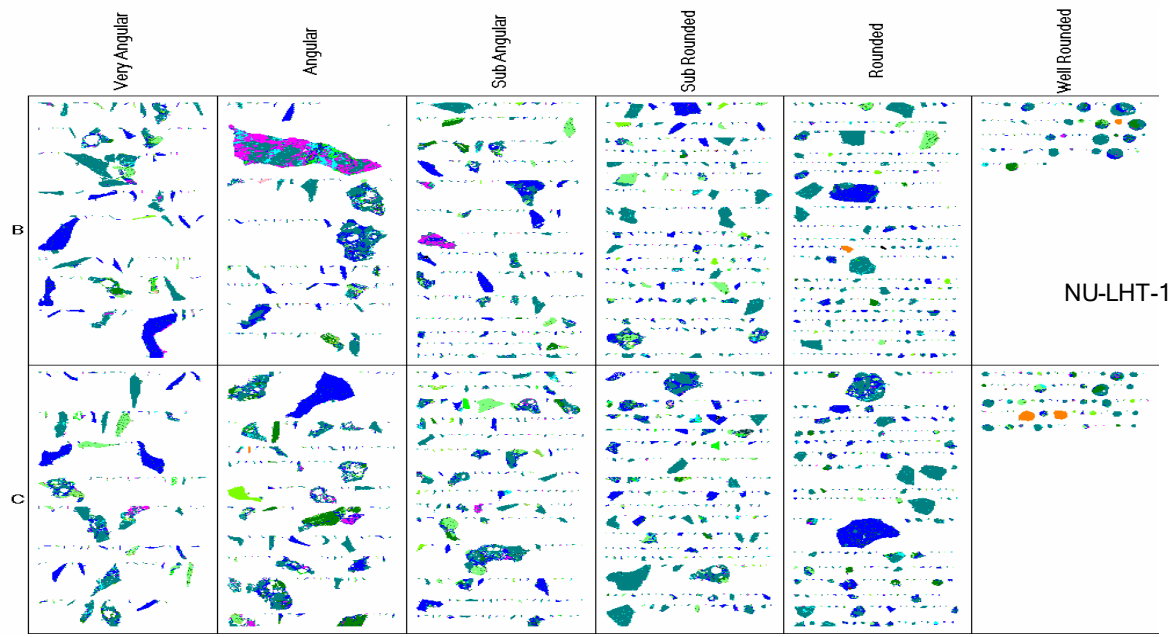
USGS

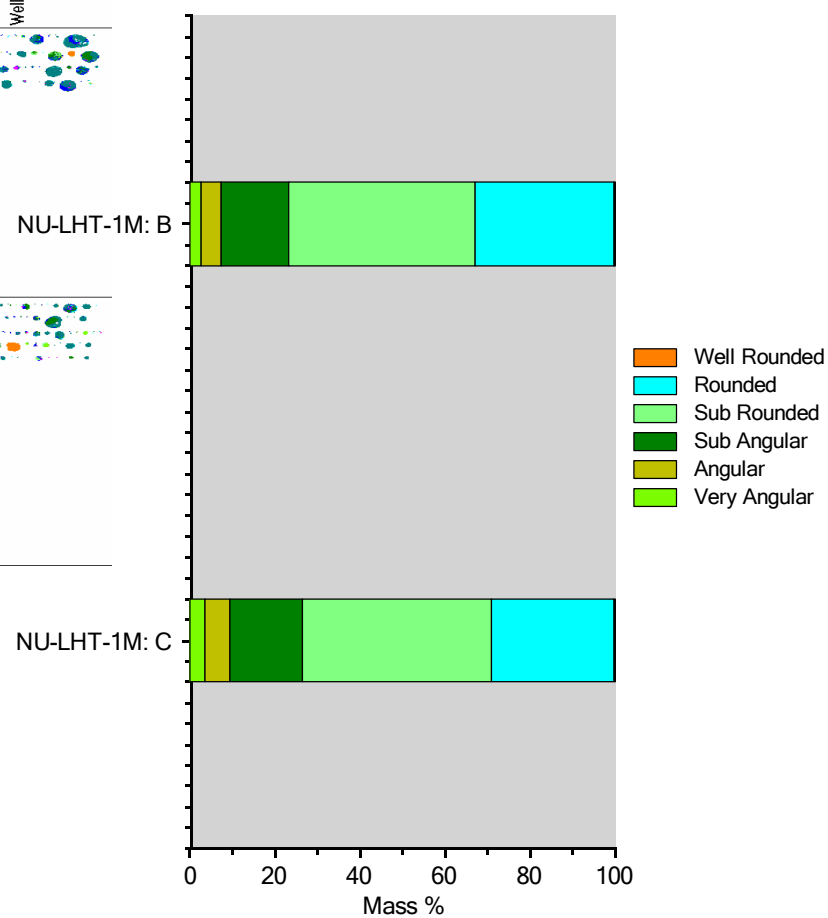
Modal Composition and Repeatability

	NU-LHT-1M:C	NU-LHT-1M:B
CaMgFe Glass	26.0	26.8
MgFeAl Silicate	0.5	0.5
Ca Al Silicate Glass	1.7	2.2
Mg Silicates	1.3	1.4
Olivine	3.5	3.6
Orthopyroxene	7.6	6.8
Clinopyroxene	8.3	8.2
K Feldspar	0.1	0.1
Plagioclase (An60-An100)	45.6	44.6
Plagioclase (Ab-An60)	4.1	4.1
Quartz	0.2	0.2
Ilmenite	0.6	0.4
Chromite	0.1	0.1
Magnetite	0.1	0.3
Iron	0.0	0.5
Others	0.3	0.4
Total	100	100

USGS

Simulant Particle Shape - Quantified





	NU-LHT-1M: C	NU-LHT-1M: B
Very Angular	3.5	2.5
Angular	5.8	4.8
Sub Angular	17.2	15.9
Sub Rounded	44.3	44.0
Rounded	29.1	32.6
Well Rounded	0.2	0.2
Total	100	100

USGS

Production plans

- Create a prototype material NU-LHT-2M
  - Improvements from LHT-1M effort
  - Addition of minor minerals - fidelity
  - Nanophase iron in agglutinate?
  - More spheroids
- 900 – 1000 pounds
- Expected completion date 1-1-08

USGS

U.S. Geological Survey
National Aeronautical and Space Administration
Certificate of Analysis
Lunar Highlands Type simulant (Pilot)
NU-LHT-1M

Material used in the preparation of this pilot simulant material was collected under the direction of the USGS in 2007 from the Stillwater Mining Company, located near Nye, Montana. A variety of samples from the mining operations and locations adjacent to the mine were obtained which are believed to represent the various geologic rock types found in the highlands region of the moon. The USGS performed a basic separation of the starting material by visual inspection, followed by blending of selected aliquots based on chemical and mineralogical considerations. Glass and agglutinate production using material from the Stillwater mine was performed at Zybeck Technologies Inc. using a high temperature plasma melter. Glass and mafic components were then combined, processed and bottled at the USGS. Information presented below is based on analyses preformed at the USGS, Bureau of Reclamation, and Horiba Instruments Inc.

Element	Mean	s.d.
Al, %	12.9	1.0
Ca	9.38	0.40
Fe (II)	2.55	0.01

Oxide	Mean	s.d.
Al_2O_3, %	24.4	3.5
CaO	13.1	0.56
FeO	3.30	0.012

Acknowledgements

- Stillwater Mining company - Dave Ryckman
- JSC collaborators

  John Lindsay, Sara Nobel, Susan Wentworth
- Horiba instruments, shape/size analysis
- Zybeck Advance Products – Mike Weinstein
- Intellection - Alan Butcher

USGS