LUNAR SOIL SIMULANT IN JAPAN 2018

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Emerging Frontier Division
SHIMIZU CORPORATION, JAPAN

Shimizu Corporation

- One of the top 5 Japanese construction companies
- Founded: in 1804
- Employees: 10, 672 in 2018
- Capital: JPY 74,365 million

Shimizu's 30-year History of Space Development

- 1987 : Established "Space Development Division"
- collaboration with US companies and agency
- 1988 : "Concrete Lunar Base" concept
- 1989 : "Space Hotel" concept
- 1995 : Manufactured the Lunar soil simulant "FJS-1"
- 1997 : Succeeded in on-orbit truss assembly
  - On-orbit experiment of Japanese Engineering Test Satellite VII (ETS-VII)

- 2000- : collaboration with JAXA using FJS-1
  - Wheel design, assembly and tests of a Lunar rover
  - Terramechanics study on terrestrial civil works (drilling, excavation, …)
- 2007 : "Lunar Resort" concept
- 2009 : "LUNA RING" concept

- 2010- : From "concept" to "practice"
- 2018 : Established "Emerging Frontier Division"
  - We will start business !!

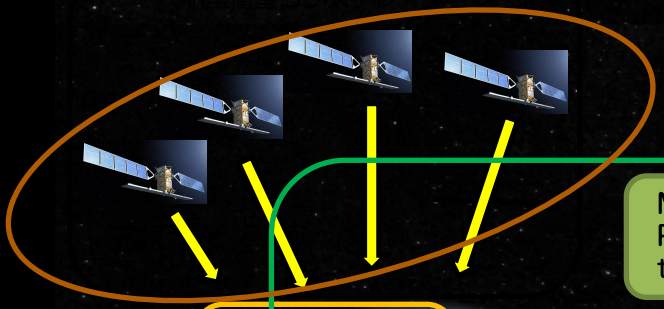
Emerging frontier division

New division since Apr. 2018

Mid-term

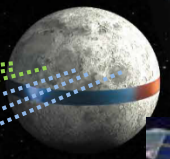
【Mission】
Realize Sustainable Lives on Earth

2. Satellite data service

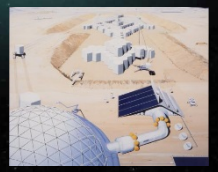


Microwave Power transmission

Short-term



Laser Power Transmission



Lunar Base
"Luna Ring"

1. Small rocket launch service

3. Lunar Development and Resource Utilization

Long-term

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FJS-1 as the Japanese standard lunar soil simulant

Need to test systems on ground before launch

Need to simulate lunar soil

Regolith Simulant

Mechanical properties
Mineral composition
…

Apollo data

ISRU
System Checkout
Soil-Machine interaction
Science
Dust investigation
…

FJS-1 is almost out of stock…

- We have been suppling FJS-1 to the Japanese space community, but it is almost out of stock…
- We decided to manufacture new lunar soil simulant and will supply to the community !!
- We plan to manufacture several grades of simulants for the various demands.

Today's contents

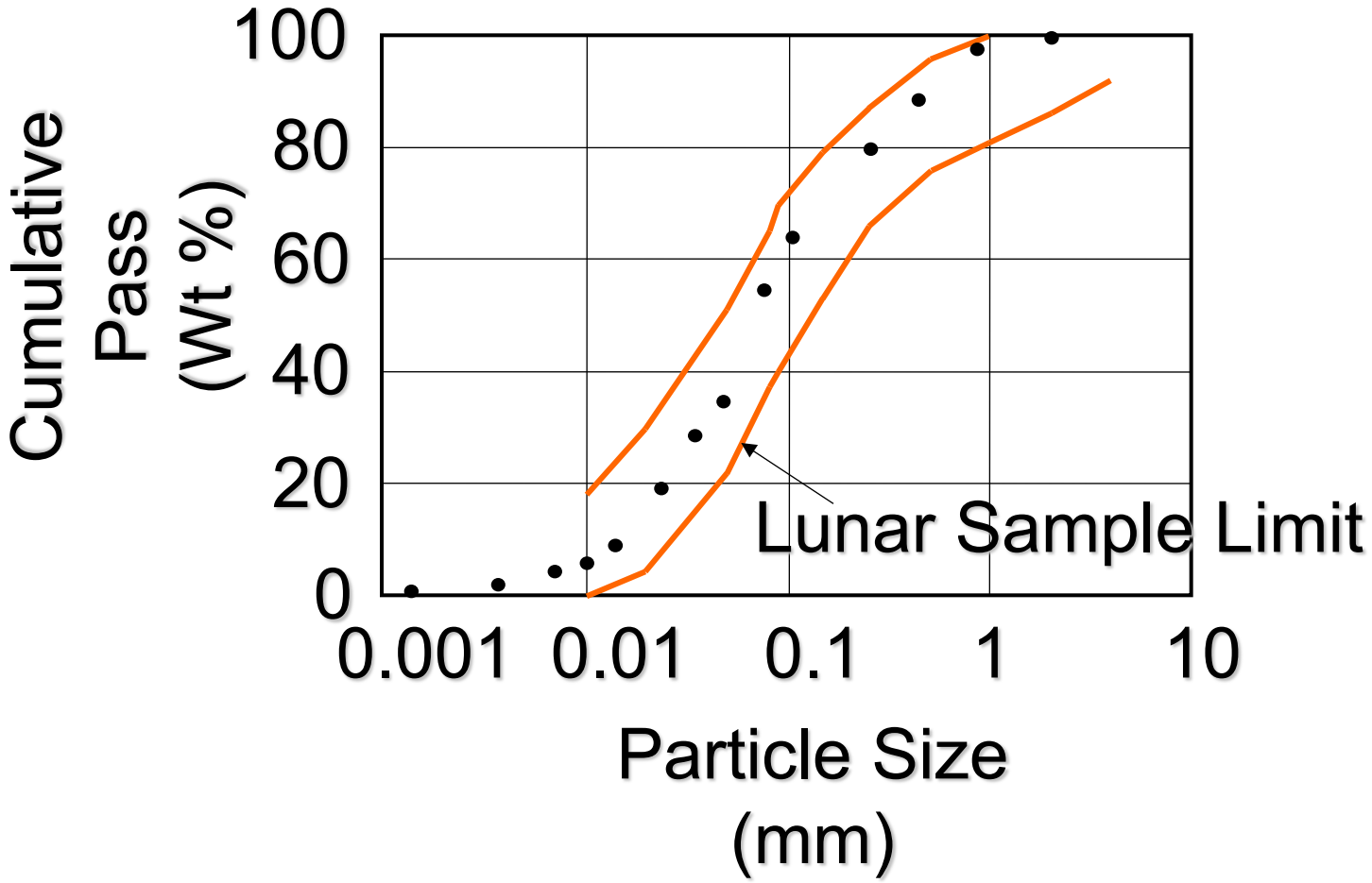
- Looking back on the Japanese standard lunar soil simulant, "FJS-1" and other types of simulants
- Applications of FJS-1 to researches
- Current Status of new simulants

Looking back on FJS-1 and other simulants

Features of Lunar Soil Learned from Apollo Samples

Silica Content	Lower than Ordinary Terrestrial Soils
Titania Content	Higher (Mare Region)
Free Iron	Contained
Ferric Oxide	Not Contained
Alkali	Lower
Organic Substances	Not Contained

Particle Size Distribution of FJS-1



Mechanical Property of FJS-1

	Lunar Sourcebook	FJS-1
Particle Density	2.3 - 3.2 (3.1)	2.7 - 3.0 (2.9)
Bulk Dens.（ton/m^3）	1.45 - 1.79	1.40 - 2.00
Internal Friction（°）	30 - 50	30 - 40
Cohesion（kPa）	0.1 - 1	0 - 8
Size Range（μm）	0.1 - 2000	0.1 - 2000
Median Size（μm）	70	70
Elongation	1.32 – 1.38	1.31 – 1.40

Other types of simulants

Simulants in lunar highland regions (Kohyama)

FJS-1 (Mt. Fuji)

Simulant in lunar mare regions (Oshima)

Chemical compositions

	Highland regions			Mare regions			
	#1	#1	#2	#1	#1	#1	#2
	Apollo-16	NU-LHT-1M (NASA)	Kohyama (Shimz)	Apollo-12	JSC-1A (NASA)	FJS-1 (Shimz)	Oshima (Shimz)
SiO_2	45	46.6	47.49	46.3	46.8	49.14	44.4
TiO_2	0.54	0.115	0.14	3	2.44	1.91	5.54
Al_2O_3	27.3	21.55	22.59	12.9	13.9	16.23	12.6
FeO	5.1	*5.08	*8.53	15.1	*12.1	*13.07	*16.1
MnO	0.3	0.09	0.17	0.22	0.21	0.19	0.36
MgO	5.7	9.5	10.24	9.3	5.6	3.84	7
CaO	15.7	12.6	8.02	10.7	10.5	9.13	9.7
Na_2O	0.46	0.965	1.65	0.54	3.89	2.75	2.09

*The values of simulants are the sum of FeO and Fe_2O_3

#1: NASA MSFC measurement
#2: Shimizu's measurement

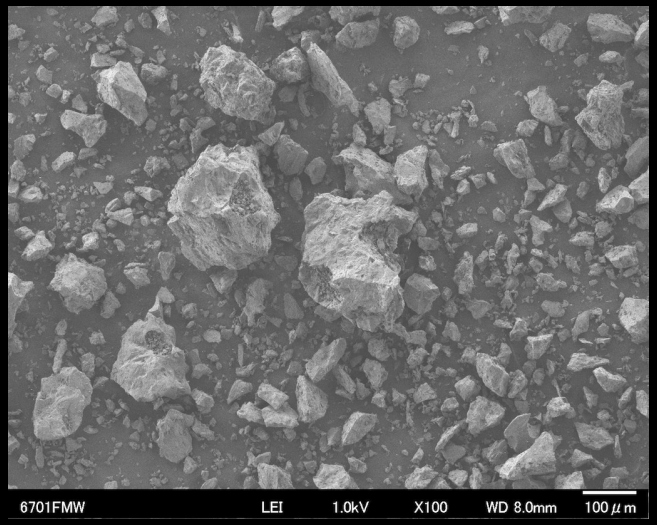
Mineral compositions

	Highland regions			Mare regions			
Minerals	Apollo-16 64001/2	NU-LHT-1M (NASA)	OB-1 (Canada)	Aopllo 11 & 12	JSC-1 (NASA)	FJS-1 (Shimz)	MLS-1 (Univ. of Minnesota)
Plagioclase	43-44	51.87	44.35	11-15	32.47	48.78	25.45
Clinopyroxene	0.6-0.7	8.95	2.95		14.67	24.39	35.86
Orthopyroxene	~2.5	6.76	0.19		0.65	1.37	1.37
Total pyroxene	~3	15.71	3.14	25-37	15.32	25.76	37.23
Olivine	0.8-0.9	5.79	6.27	2-10	18.29	4.94	1.06
Glass	44-46	24.07	43.22	31-45	30.86	7.15	22.29

Source：NASA MSFC

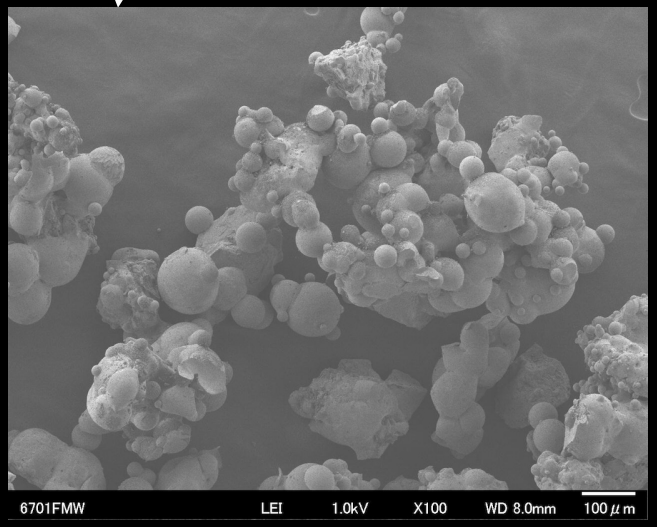
- Apollo-16 data came from QEMSCAN® analyses of sample No. 64001,6031 and slices of 64002,6019.
- Apollo-11,12 data came from SEM EDS analyses of sample No. 10084,1618, 12030,122, 12001,7 (provided by Prof. Taylor at the Universityty of Tennessee)

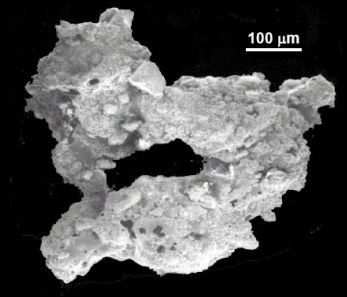
Agglutinate



Oshima
(mare region simulants)

Processing
(plasma torch)





Agglutinate

Agglutinate trial manufacturing

Applications of FJS-1 to Researches

Machine-soil interaction

FJS-1 used to investigate the traversability of lunar rovers

(c JAXA)

Machine-soil interaction

FJS-1 used to investigate excavations on the moon

Low Bulk Density

High Bulk Density

3.5 Feet Robot Arm with Bucket (4-DOFs)

Machine-soil interaction

FJS-1 used to investigate drilling on the moon

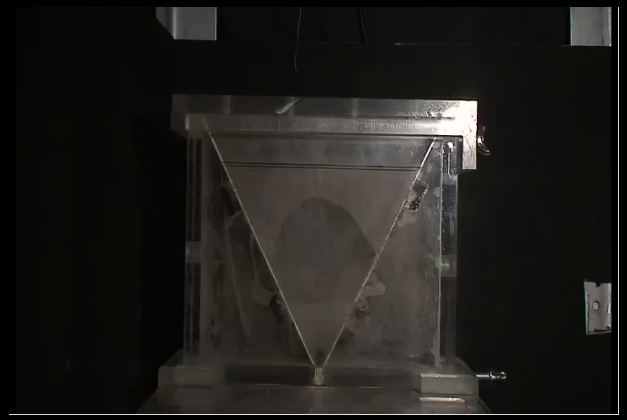
Experiments In vacuum camber

Hopper in lunar gravity

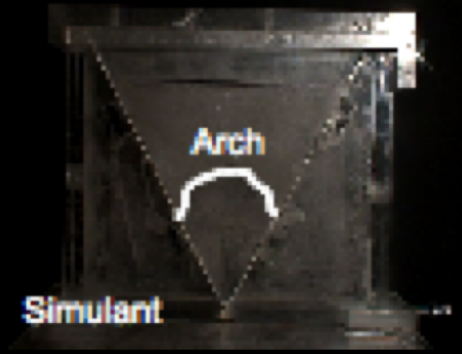
FJS-1 tested in parabolic flight

Standard sand in 1G

Standard sand in 1/6G

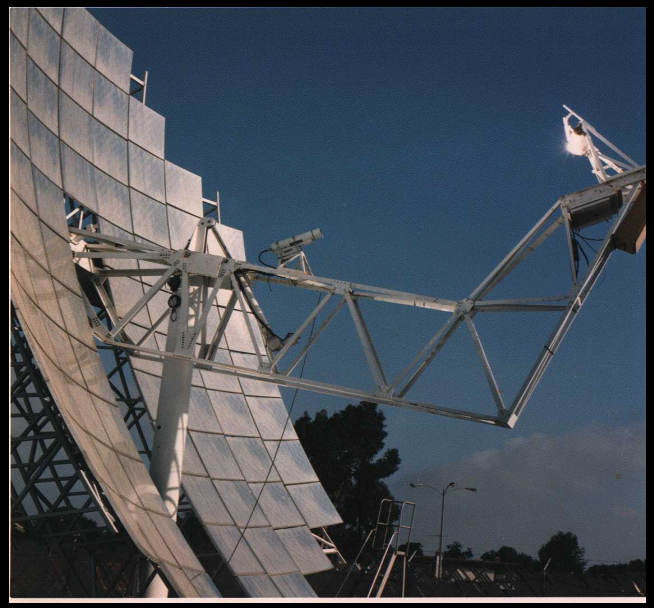


FJS-1 in 1G

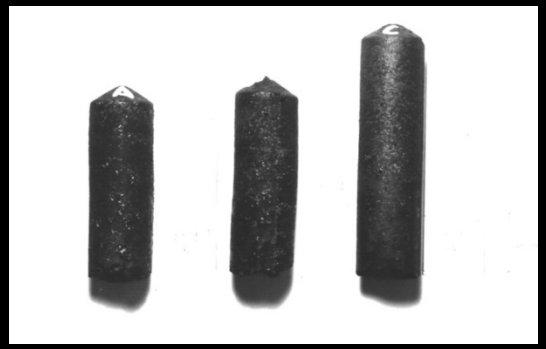


FJS-1 in 1/6 G

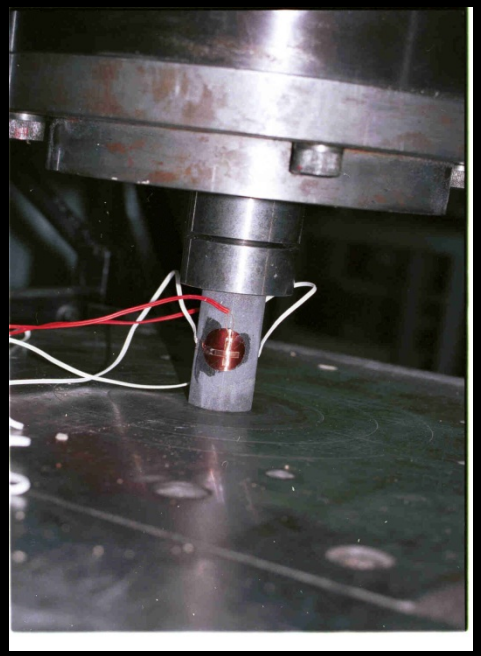
In-Situ Resource Utilization



Solar Concentrator
(at Boeing, Huntington Beach)



Cast Basalt
Specimens



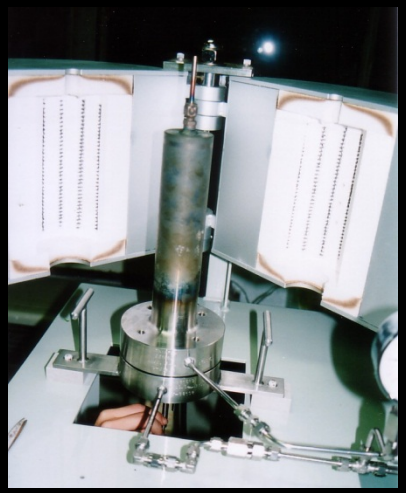
Strength Test of
Cast Basalt

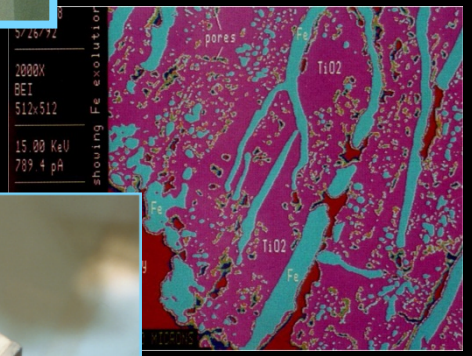
Cast Basalt – Construction Material

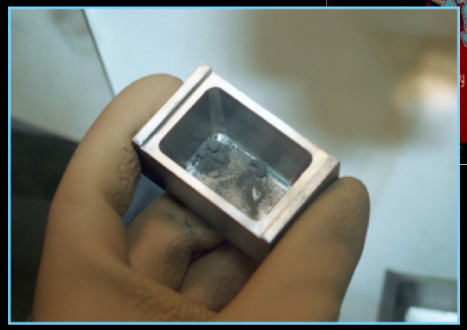
In-Situ Resource Utilization

(Apollo 17 sample No. 70035)

H_2 Reduction Reactor (for FJS-1)







Reduced Apollo Sample

*NASA-Carbotek-Shimizu

Current Status of New Simulants

Raw materials

- Raw materials of new simulants are collected from the region around Mt. Fuji.
- New simulants will contain more glass than FJS-1

Candidate #1

Candidate #2

Planned Schedules

- June, 2018
  ➔ Finish analyzing raw materials
- August, 2018
  ➔ Finish test crushing
- November, 2018
  ➔ Finalize entire process
- December, 2018
  - Ready to be delivered !!

Summary

- The Japanese standard lunar soil simulant “FJS-1” is almost out of stock.
- We started to manufacture new simulants.
- New simulants will be ready to the space community by the end of 2018.

End


Today's Work, Tomorrow's Heritage
SHIMIZU CORPORATION
SHIMZ