CHARACTERIZATION SUMMARY OF JSC-1A BULK LUNAR MARE REGOLITH SIMULANT

Introduction

JSC-1A bulk lunar mare regolith simulant has been produced to support NASA's future exploration of the lunar surface. Simulant JSC-1A is part of a suite of three simulant materials labeled JSC-1AF, JSC-1A, and JSC-1AC that was created to match, as closely as possible, the composition of the previous JSC-1 lunar regolith simulant. Simulant JSC-1A matches the composition and grain size distribution of the original JSC-1 simulant as closely as practical. Simulant JSC-1AF ("fine fraction") has been processed by additional milling and sieving to possess a significantly smaller grain size in order to approximate the finer component of the lunar regolith where more than 50% of the gain sizes are below 20 microns. Simulant JSC-1AC ("coarse fraction") represents the coarser component of the lunar regolith and has grain sizes between 1mm and 5 mm. Like the original JSC-1 material, JSC-1A was mined from a commercial cinder quarry at Merriam Crater (35°20' N, 111°17' W), a volcanic cinder cone located in the San Francisco volcano field near Flagstaff, Arizona. Merriam crater is a volcanic airfall ash deposit of basaltic composition, and the commercial quarry is located on the south flank of the crater. The mined ash was processed by Dr. James Carter of ET Simulants, LLC, to produce these simulants. Processing of the ash to involves milling and sieving in order to achieve the desired grain size distribution. No chemical processing has been performed.

Information Contained Within

This document summarizes the characterization data for the first ton of the JSC-1A simulant. This characterization data consists of bulk chemistry and grain size distribution data. Characterization data for mineral chemistry, mineral identification was taken from the analysis completed for the JSC1AF and is noted within. For most purposes and due to the constant testing by the USGS, UCB and Orbitec, information provided in this document is sufficient and can be used for all of the JSC1A material manufactured by Orbitec for NASA Projects. However, please note that should the data for any particular ton vary significantly this data will be posted on the Orbitec website and provided to the JSC1A recipient.

Please also note that this document is being updated as additional characterization data is acquired by NASA, and refer to the document version number for the most recent data set. As additional characterization and property analyses of interest to the user are completed, they will be posted on-line at www.lunarmarssimulant.com.

Characterization data has been provided by the United States Geological Survey (USGS), NASA Marshall Space Flight Center, University of Colorado Boulder, Washington University, ST. Louis as well as several commercial analytical facilities.

Chemical Composition

The Wavelength-Dispersive X-Ray Fluorescence (WD-XRF) analysis was completed using six samples of JSC-1A to determine major element compositions. This data is presented in Table 1. This technique, like most bulk chemistry techniques, analyzes the elemental concentrations in the sample. The normal convention for data presentation uses oxide formulae from an assumed oxidation state for each element (with the exception of Fe which has been determined both by XRF and by titration) and oxygen is calculated by stoichiometry. For example, silicon is analyzed as an element but presented as SiO_2; it is important to understand that these are representations of the chemistry and do not represent actual phases or minerals in the simulant.

Table 1. Major Element Composition of JSC-1A

Oxide	Weight % (Average)	Standard Deviation	% Relative Standard Deviation
SiO_2	46.67	0.19	0.40
TiO_2	1.71	0.01	0.41
Al_2O_3	15.79	0.15	0.97
Fe_2O_3	12.5	0.09	0.74
FeO	8.17	0.05	0.63
MnO	0.19	0.00	-
MgO	9.39	0.22	2.37
CaO	9.90	0.07	0.71
Na_2O	2.83	0.05	1.62
K_2O	0.78	0.01	1.28
P_2O_5	0.71	0.01	1.23
LOI	<0.01	0.00	-
Total	108.64	-	-

The results of analyses by Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) and Inductively Coupled Plasma – Atomic Emission Spectrometry (ICP-AES) completed on six samples of JSC-1A to determine trace element composition are presented in Table 2.

Table 2. Trace Element Concentrations in JSC-1A

Element	Concentration (ppm, Average)	Standard Deviation	% Relative Standard Deviation
Ag	< 1	-	-
As	1.78	0.44	24.80
Ba	733.9	18.36	2.5
Be	1.22	0.04	3.61
Bi	0.06	0.02	30.27
Cd	0.10	0.00	0.00
Ce	93.53	1.56	1.66
Co	56.04	1.23	2.2
Cr	138.33	6.48	4.68

Cs	<5	-	-
Cu	58.7	1.82	3.11
Dy	4.71	0.1	2.2
Er	2.54	0.09	3.6
Eu	2.17	0.04	1.78
Ga	16.92	0.41	2.4
Gd	6.7	0.11	1.67
Ge	1.17	0.41	35
Hf	3	0	0
Ho	0.87	0.02	2.23
In	0.08	0.00	5.36
La	49.27	0.92	1.87
Li	7.33	0.50	6.82
Lu	0.31	0.01	2.42
Mn	1288.9	336.21	2.81
Mo	2.36	0.13	5.47
Nb	48.51	2.49	5.12
Nd	46.9	0.67	1.43
Ni	130.33	4.82	3.70
Pb	5.73	.1	1.74
Pr	11.43	0.2	1.72
Rb	9.75	0.19	1.92
Sc	30.81	0.7	2.26
Sm	7.3	0.15	2.12
Sn	1.24	0.14	11.44
Sr	802	25.54	3.18
Ta	1.88	0.08	4.0
Tb	0.92	0.02	2.13
Th	6.42	0.17	2.67
Tl	< 0.1	-	-
Tm	0.33	0.03	2.03
U	1.60	0.0	0.0
V	244	7.6	3.1
W	13.7	2.6	19
Y	25	0.4	1.8
Yb	2.23	0.08	3.7
Zn	97	2.6	2.7
Zr	140.7	3.8	2.7

Notes: Concentration expressed in parts per million (ppm) of the element, standard deviation is 1-sigma in ppm, and relative standard deviation is in percent.

Mineral Chemistry

Since the milling process does not significantly change the mineral chemistry of the mined ash JSC-1AF was used for this analysis.

Mineral chemistry has been determined by electron-probe microanalysis (EPMA) at Marshall Space Flight Center and at the USGS in Denver. Analyses were performed at 15 keV and 25 nA probe current, and minerals were analyzed at the center of the grain. Due to the fine grain size for some minerals (i.e., olivine and Ca-pyroxene) some contribution from the surrounding matrix has been observed due to electron scattering and secondary x-ray fluorescence. Elemental results are combined with oxygen calculated by stoichiometry for data presentation. Minerals are identified using the phase chemistry and results are also presented as the mineral formula. The data presented below are averages of approximately 25 analyses obtained from a number of discrete grains in the JSC-1AF samples, and represent analyses of plagioclase feldspar, Ca-pyroxene, olivine, and basalt glass. This mineralogy represents the dominant phases in JSC-1AF; note that several trace minerals such as titanomagnetite and chromite have also been identified. Other trace minerals may be present and are currently being analyzed. For EPMA data, Fe is assumed to be as Fe^{2+} and total Fe is presented as FeO* (i.e., FeO* denotes total Fe as FeO).

Chemical zoning is observed in the chromite grains. The olivine and Ca-pyroxene grains exhibit rim zoning at a scale too fine to determine with the electron microprobe.

The mineral compositions can also be described in terms of the end-member molecular components and are shown here as the average mineral composition as these components. These compositions are:

Plagioclase	$Anorthite_{70}$ — $Albite_{29}$ — $Orthoclase_{1}$
Ca-pyroxene	$Wollastonite_{45}$ — $Enstatite_{38}$ — $Ferrosilite_{22}$
Olivine	$Forsterite_{73}$ — $Fayalite_{27}$

These molecular component representations are short-hand notation. For example, the olivine composition shown is specifically $Mg_{1.46}Fe_{0.54}SiO_4$ (with components for Ca and Mn ignored).

Table 3. Mineral Chemistry Data for JSC-1AF

Oxide	Plagioclase	1 SD	Glass	1 SD	Ca-pyroxene	1 SD
SiO_2	49.80	0.63	46.11	0.53	47.18	2.08
TiO_2	0.10	0.03	2.80	0.22	2.47	0.70
Al_2O_3	31.87	0.71	14.92	0.65	5.56	1.59
Cr_2O_3	0.01	0.01	0.01	0.02	0.08	0.08
FeO*	0.85	0.11	12.66	1.08	10.31	0.94
MnO	0.02	0.02	0.22	0.02	0.22	0.04
MgO	0.15	0.06	5.07	0.49	12.31	1.22
CaO	14.19	0.54	9.98	0.63	20.27	0.66

Na_2O	3.22	0.26	3.96	0.23	0.58	0.15
K_2O	0.13	0.03	1.43	0.26	0.08	0.05
P_2O_5	0.02	0.01	1.02	0.17	0.28	0.20
Total	100.34	0.65	98.18	0.72	99.34	0.55

Oxide	**Olivine**	**1 SD**	**Titanomagnetite**	**1 SD**
SiO_2	37.71	0.93	1.94	2.12
TiO_2	0.17	0.13	14.36	2.28
Al_2O_3	0.56	0.75	6.14	2.82
Cr_2O_3	0.01	0.02	1.05	2.03
FeO*	23.16	2.40	65.35	4.68
MnO	0.40	0.10	0.46	0.11
MgO	36.10	3.03	4.77	0.99
CaO	0.72	0.39	0.48	0.32
Na_2O	0.11	0.09	0.18	0.20
K_2O	0.06	0.07	0.09	0.11
P_2O_5	0.41	0.18	0.05	0.06
Total	99.42	0.75	94.88	1.30

Notes: These data are averages of approximately 25 grains for each mineral. Data are in oxide weight percent, and SD is 1-sigma standard deviation in oxide weight percent. The notation FeO* is total Fe calculated as FeO. Due to the fine grain size, some contribution has been observed from the surrounding matrix for olivine and Ca-pyroxene grains. Data from MSFC EPMA.

Mineral Identification

Since the milling process does not change the mineral composition of the mined ash JSC-1AF was used for this analysis.

X-ray Powder Diffraction Analysis

Simulant JSC-1AF has been characterized using X-ray powder diffraction analysis (powder XRD). The results of this analysis show that the following mineral phases are conclusively present in the simulant:

Plagioclase feldspar	Anorthite JCPDS search match, major mineral proportion
Amorphous phase	No JCPDS match, consistent with presence of basaltic glass phase
Olivine	JCPDS search match, minor mineral proportion
Ca-pyroxene	JCPDS search match, minor mineral proportion

The detection limit for powder XRD is typically at the level of ~ 1-2 modal percent. Further analysis of the powder diffraction is currently underway to evaluate trace mineral identification.

Electron-probe Microanalysis

The mineralogy of simulant JSC-1AF has been determined by electron-probe microanalysis by means of inspection of the mineral formula from quantitative analysis. The minerals identified by EPMA include:

Plagioclase feldspar	Major proportion
Basaltic glass	Major proportion
Olivine	Minor proportion
Ca-pyroxene	Minor proportion
Titano-magnetite	Minor to trace proportion
Chromite	Minor to trace proportion
Orthopyroxene	Rare

X-ray mapping results from EPMA and SEM analysis are in progress and will provide numerical values for the modal abundances of these phases.

Particle Size Distribution

Particle size distribution of JSC-1A was obtained by a particle size analyzer using laser diffraction on three samples. The average and mean particle size for the three tested samples of JSC-1A:

	Sample#1	Sample#2	Sample#3
Mean (microns)	196.8	184.7	181.6
Median (microns)	105	103.5	99.85

The particle size distribution curve is shown in Figure 1. The average differential volume of JSC-1A as a function of particle size and size categories are represented in Figures 2.

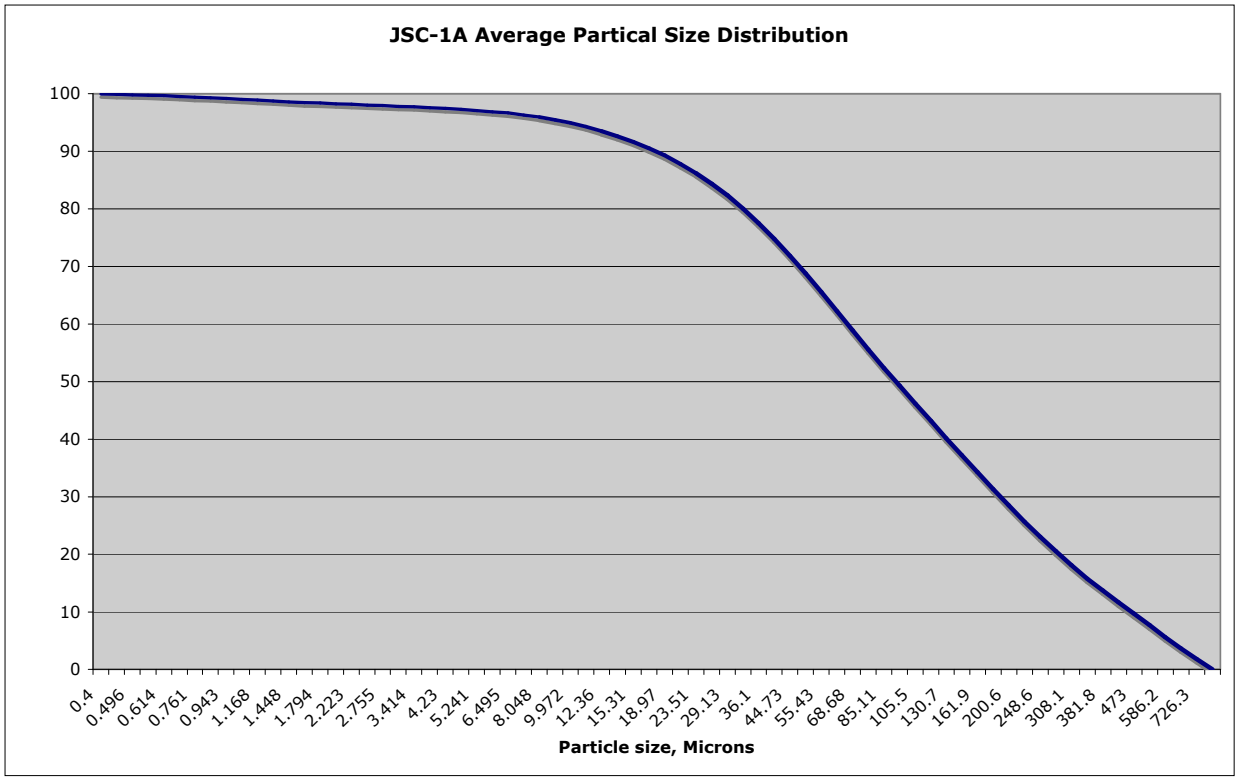

Figure 1. Average Particle Size Distribution for JSC-1A

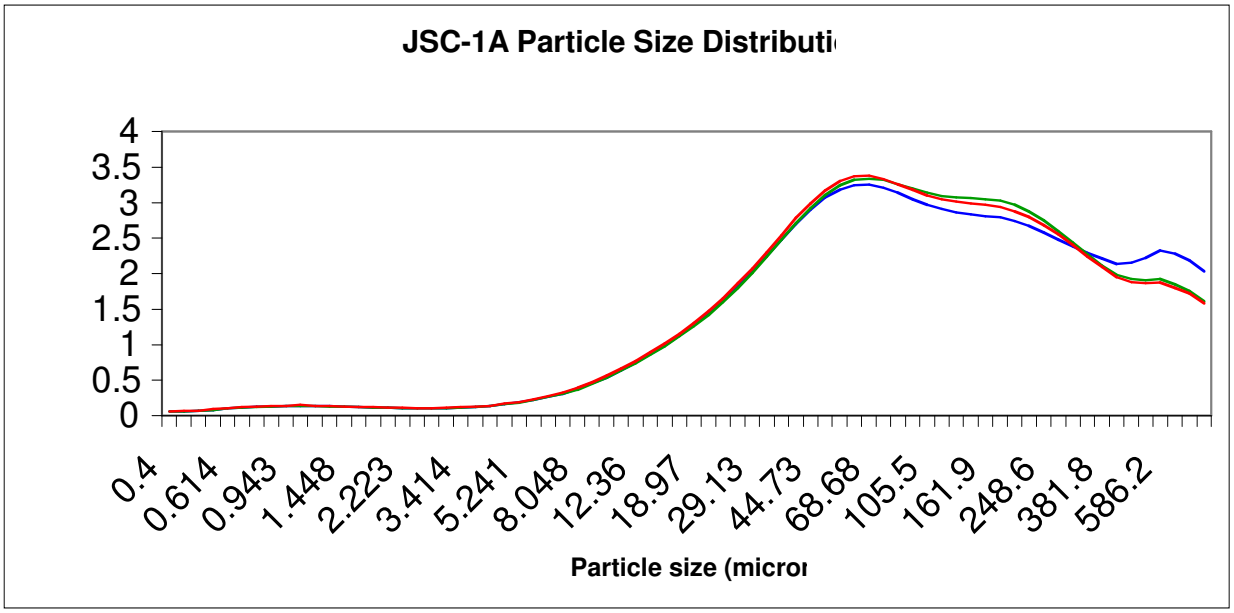

Figure 2. JSC-1A Average Differential Volume Distribution as a function of particle size for three random samples of simulant

References and Links

Taggart, J. E. Analytical methods for chemical analysis of geologic and other materials, U.S. Geological Survey, Open-File Report 02-223, U.S. Department of the Interior, 2002. Web link http://pubs.usgs.gov/of/2002/ofr-02-0223/

Contact Information

Lunar Regolith Simulant Distribution

Marty Gustafson
Lunar Mars Simulant
c/o Orbitec
1212 Fourier Drive
Madison, WI 53717

Web site: http://www.lunarmarssimulant.com/

Characterization Document Contacts

Simulant Project Scientist
Dr. Doug Rickman
doug.rickman@nasa.gov

MSFC ISFR/ISRU/Dust Project Manager
Carole McLemore
carole.a.mclemore@nasa.gov

MSFC ISFR/ISRU/Dust Dep. Project Manger
John Fikes
John.fikes@nasa.gov