INTRODUCTION OF LCATS-1, A GEOTECHNICAL LUNAR REGOLITH SIMULANT FOR MULTI-PURPOSE UTILIZATION. D.M. Hooper[1], S.W. Ximenes[1], R. Wells[2], M. Necsoiu[3], E.L. Patrick[3], [1]WEX Foundation, 110 E. Houston Street, 7th Floor, San Antonio, TX 78205, [2]The University of Texas at San Antonio, 1 UTSA Circle, San Antonio, TX 78249, [3]Southwest Research Institute®, San Antonio, TX 78238. (dhooper@wexfoundation.org)

Introduction: The next decade should see a marked increase in the number of missions to the lunar surface. A key component of this activity is a well-defined and reliable regolith simulant required for the various scientific and engineering studies necessary for fulfilling the goals of lunar exploration programs [1]. In spite of this need, the amount of existent lunar material is both too valuable and too limited to be used in bulk or destructive research activities. This reality has driven the production of numerous lunar regolith simulants, many of which have been exhausted. To satisfy these needs, we have developed a practical lunar simulant called LCATS-1 (Lunar Caves Analog Test Sites). Within this report we begin the geotechnical description of this multi-purpose simulant.

Materials and Methods: The southern margin of North America experienced widespread alkaline magmatism during Late Cretaceous time, including a belt-like zone in southern Texas called the Balcones Igneous Province (BIP) [2,3]. The silica-undersaturated BIP contains a slightly greater percentage of feldspathoids (especially nepheline and leucite) than basalt and comprises isolated, monogenetic igneous centers that formed numerous sills, laccoliths, plug-like bodies, tuff rings, and lava lakes [2,4]. Raw simulant material was collected from the Vulcan Materials Company quarry in Knippa, Uvalde County, Texas (29.28°N, 99.65°W). It is black, dense, and aphanitic to slightly porphyritic. Commonly called "Knippa basalt", the petrologic classification of the igneous rock from the Knippa quarry is melilite-olivine nephelinite with accessory clinopyroxene (titanaugite), titaniferous magnetite, apatite, and biotite [2]. X-ray Diffraction (XRD) and X-ray Fluorescence (XRF) analysis of the LCATS-1 simulant is compared in Table 1 to previous analyses, lunar simulant JSC-1, and a lunar regolith sample. LCATS-1 was found to contain minor amounts of clay/phyllosilicate minerals, but these are interpreted to be weathering products. The lack of quartz and feldspar minerals, as determined by XRD, coupled with the very low silica content determined by XRF, suggests a mantle source for the Knippa igneous center.

Raw simulant is first processed at the quarry by a jaw crusher. To produce a desired simulant volume, subsequent grinding, milling, and screening reduces the Knippa basalt to the preferred grain-size range. Sieving is the final production step and we have selected the pan fraction and six practical mesh sizes to describe spectroscopy and geotechnical properties (Table 2).

Table 1. Major Element Chemical Compositions Expressed as Oxides in Weight Percent

Oxide	JSC-1 Simulant [5]	Knippa Quarry [2]	Knippa Quarry [4]	Apollo 12 Regolith, Sample 12001 [6]	Knippa Quarry [This Study]
SiO_2	47.71	37.59	38.31	45.7	33.47
TiO_2	1.59	3.89	3.54	2.7	3.00
Al_2O_3	15.02	10.36	10.18	12.3	8.34
Fe_2O_3	3.44	4.97	4.28	-	13.93
FeO	7.35	7.77	7.72	17.3	-
MgO	9.01	14.30	15.20	10.5	12.03
CaO	10.42	12.51	13.16	10.4	12.66
MnO	0.18	0.21	0.19	0.217	0.17
Na_2O	2.70	3.15	2.63	0.46	2.20
K_2O	0.82	1.23	0.96	0.24	1.32
P_2O_5	0.66	-	0.75	-	1.17

Table 2. Grain Size Classification and Description

Sieve Mesh Number	Screen Size (mm)	Phi Class (φ)	Size Terms
5	4	-2	Gravel (pebble)
10	2	-1	Gravel (granule)
35	0.5	1	Coarse sand
60	0.25	2	Medium sand
120	0.125	3	Fine sand
230	0.062	4	Very fine sand
Pan	Pan	Pan	≤ Coarse silt

Spectroscopy: Near Infrared Spectroscopy (NIR) was conducted and covered the spectral range of 0.35 to 2.5 microns. Laboratory measurements used the 7 sieving classes with 3 replicas and each replica contained 4 spectra. Spectra were collected at different angles (0, 90, 180, and 270 degrees). After standard calibration, data processing involved the typical format conversions, database generation, and corrections. Average spectra computed for each sieving class are presented in Fig. 1. Note the general darkening of the spectra with decreasing grain size until the finer size classes when the trend reverses so that the silty powder in the pan has the highest reflectance [7]. The presence of clay minerals and the iron content of olivine may affect the spectral response, but generally the diffuse reflectance of a powder sample is dependent on light scattering and particle size.

Simulant Properties: LCATS-1 has a specific gravity of 3.14 and a melting point of 1100° C. Particles of each sieve fraction are attracted to ceramic and

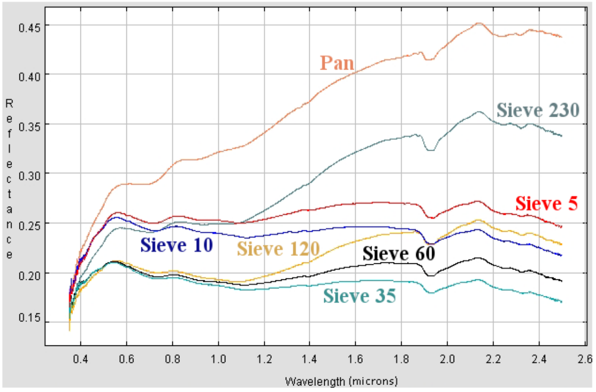

Figure 1. Average of NIR spectra.

neodymium magnetic discs. As a lunar regolith simulant, we have identified a grain size range of 40–70 microns (0.04–0.07 mm) as desirable for most applications and activities. Table 3 encapsulates measurements of bulk density—volumetric density including solid material, open and closed pores, and interparticle voids—which is lowest for coarse granular material and fine powders. This corresponds, respectively, to the pebbles captured by sieve 5 and the silty powder in the pan. Angle of repose measurements specified in Table 3 are also highest for these same two sieve fractions, decreasing to the fine sand fraction of sieve 120, which does not interlock as well as the other size classes. The silty material of the pan is noteworthy for the extent that it clumps together at over-steepened angles.

Table 3. Simulant Properties

Sieve Mesh Number	Bulk Density (g/cm^3)	Angle of Repose/Funnel Test (degrees)
5	1.57	42.2
10	1.62	38.8
35	1.70	33.1
60	1.60	37.3
120	1.62	26.5
230	1.67	30.8
Pan	1.41	44.6

Particle shape (roundness), described in Table 4, was based on standard visual charts and consists of subdivisions ranging from very angular (VA) to well rounded (WR) [8,9]. Sixty to 70 percent of each sieve fraction was very angular to angular, an anticipated result considering the particles were manually crushed and never exposed to natural erosion, abrasion, and/or transport by wind, water, or ice. Roundness (and related sphericity) measurements are intended for cobble- and pebble-size clasts [8,9]; therefore, measurements were not conducted for the finer sieve fractions due to increasing difficulty in making accurate measurements with both hand lens and binocular microscope.

Conclusion: We have produced a lunar regolith simulant called LCATS-1 to support education, scientific research, and engineering studies. The simulant is being used for: (i) In Situ Resource Utilization (ISRU) lesson plans, (ii) bricks for rocket exhaust blast tests, (iii) 3D printing, (iv) dust measurements in a simulated lunar environment, (v) telescope mirrors, and (vi) a lunar terrain sandbox called the "Lunar Surface and Subsurface Robotics Mobility Test Bed" (Fig. 2). We conclude that LCATS-1 is a viable simulant closely resembling lunar properties for scientific and engineering research.

Table 4. Particle Morphology (Roundness) Expressed as Percentage of Measured Grains

Sieve Mesh Number	VA	A	Sub-A	Sub-R	R	WR
5	30	30	10	20	5	5
10	35	30	15	10	5	5
35	40	30	15	10	5	0
60	30	40	20	5	5	0

Figure 2. Simulant test bed with modeled lunar skylight and student robot with attached CanSat.

Acknowledgements: LCATS material discussed in this abstract is based upon work supported by NASA under award Number NNX16AM33G. Opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Aeronautics and Space Administration.

References: [1] Sibille L. et al. (2006) NASA Tech Rpts 2006-214605. [2] Spencer A. B. (1969) *J. Petrology 10*, 272–306. [3] Griffin W. R. et al. (2010) *J. Geology 118*, 1–21. [4] Barker D. S. et al. (1987) *Geol. Soc. Amer. Special Paper 215*, 293–304. [5] McKay D. S. et al. (1994) Engineering, Construction, and Operations in Space IV, Amer. Soc. Civil Eng., 857–866. [6] Papike, J. J. et al. (1982) *Rev. Geophysics and Space Physics 20*, 761–826. [7] Hooper D. M. and Necsoiu M. (2014) *Frontiers in Geotechnical Engineering 3*, 1–9. [8] Powers M. C. (1953) *J. Sediment. Petrol. 23*, 117–119. [9] Lindholm R. (1987) *A Practical Approach to Sedimentology*, Allen & Unwin.