Investigating the Effects of Composition on Granular Surface Area: Gas Sorption Analyses of High-Fidelity Lunar Highlands and Carbonaceous Chondrite Asteroid Regolith Simulants. J. Long-Fox[1], J. Perman[2], Z. . Landsman[3], A. Metke[4], D. T. Britt[5], [1]4000 Central Florida Blvd., Orlando, FL, 32816, jared.long-fox@ucf.edu, [2]Anton Paar QuantaTec 1900 Corporate Dr, Boynton Beach, FL 33426, jason.perman@anton-paar.com,, [3,4,5]4111 Libra Drive Rm. 430, Orlando, FL, 32816

Introduction: The amount of surface area per unit volume in a granular material directly impacts the physical properties of the material and how it interacts with its environment. Properties such as thermal and electrical transfer rates, dissolution rates, gas and moisture retention are sensitive to variation in surface area. These parameters are key in studies and processes that investigate and leverage the physical properties and mineralogical composition of planetary regolith, including lunar exploration and *in situ* resource utilization (ISRU) [1] as well as asteroid mining [2]. Each planetary body, and different sites on these bodies, is expected to have differing mineralogical composition and particle size distribution. These variations directly affect the amount of surface area (and therefore the physical properties) in the material and give insight as to how the regolith interacts with its environment, such as the formation of and interaction with the expected volatile-laden regolith in permanently shadowed regions (PSRs) of the Moon. In this study, Brunauer-Emmett-Teller (BET) gas adsorption analyses [3] are used to quantify the surficial properties of the lunar highlands regolith simulant, LHS-1, and carbonaceous chondrite asteroid regolith simulant, CI, produced by the CLASS Exolith Lab at the University of Central Florida.

Methods: LHS-1 and CI were chosen for this study because their composition (Tables 1 and 2, respectively) and particle size distributions are contrasting, and these differences are expected to be reflected in gas sorption analysis to quantify the surficial properties of the simulants. LHS-1 has an average particle size of 60 µm [4] and an uncompressed bulk density of 1.32 g/cm^3 [5]. CI has uncompressed bulk density of 1.10 g/cm^3 [6] and a larger average particle size than LHS-1, but the dispersal agent used in the particle size analysis breaks apart the larger, clumped simulant particles, giving skewed results. The mechanical breaking down of the larger regolith grains in CI is a result of the simulant manufacturing process in which water is added to CI and the mix is allowed to dry, and then the resulting clumps are then crushed to various sizes.

Table 1. Mineralogic composition of LHS-1 lunar highlands regolith simulant.

Component	Wt.%
Anorthosite	74.4
Glass-rich basalt	24.7
Ilmenite	0.4
Olivine	0.3
Pyroxene	0.2

Table 2. Mineralogic composition of CI carbonaceous chondrite asteroid regolith simulant.

Component	Wt.%
Mg-serpentine	51.3
Magnetite	10.0
Vermiculite	9.6
Olivine	7.0
Pyrite	7.0
Attapulgite	5.3
Sub-bituminous coal	5.0
Ferrihydrite	4.8

This study used nitrogen gas (N_2, formed from 99.999% pure liquid nitrogen with 77 K boiling point) as the adsorbate for isothermal analysis. To prepare the LHS-1 and CI samples for N_2 sorption isotherm analysis using the Anton Paar Autosorb iQ, the samples were loaded into glass sample cells (2.8143 g LHS-1, 2.5571 g CI) and placed on degasser stations to be heated at 343.15 K, for 32 hours to remove moisture obtained from ambient conditions. After degassing (dry mass 2.805 g LHS-1; 2.5049 g CI), a filler rod was added to the cell to reduce void volume before they were loaded onto the analysis stations. The isotherm analysis occurred at 77.35 K for both the sample with a measured analysis range from 0.025 to 0.99 relative pressure (P/P_0), and saturation pressure was monitored throughout the experiment.

Results: Surface area isotherms obtained from BET analysis for LHS-1 is shown in Figure and CI are shown in Figures 1 and 2, respectively. Table 3 gives the results of the linear fit of the truncated isotherm data for LHS-1 and CI to the BET equation.

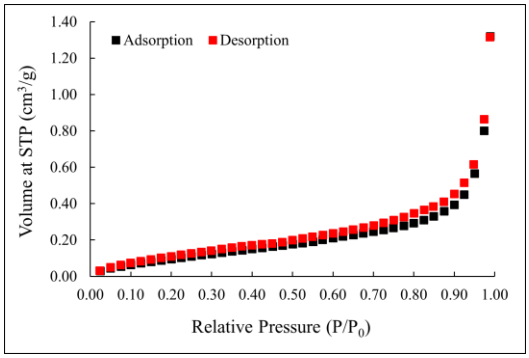

Figure 1. Surface area isotherm for Exolith Lab LHS-1 lunar highlands regolith simulant gathered using the Anton Paar Autosorb iQ.

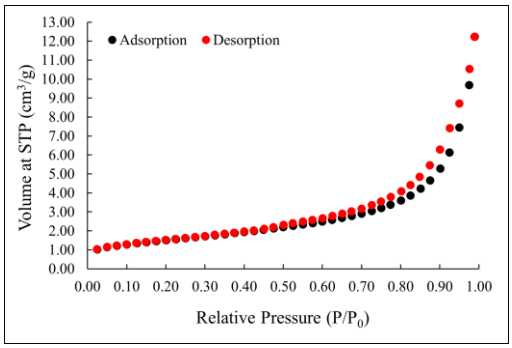

Figure 2. Surface area isotherm for Exolith Lab CI carbonaceous chondrite asteroid regolith simulant gathered using the Anton Paar Autosorb iQ. Note the change in vertical scale from Figure 1.

Table 3. Results of the analyses performed on isotherms of LHS-1 and CI.

	LHS-1	**CI**
Range of P/P_0	0.125-0.275	0.07-0.226
Number of data points	7	7
Surface Area (m^2/g)	0.474	5.402
C constant	9.294	120.157
R^2	0.99947	0.999972
Pore Volume (cm^3/g) at ~0.95 P/P_0	8.74×10^{-4} cm^3/g	1.151×10^{-2} cm^3/g

Discussion: The isotherms from these samples exhibited Type II characteristics (non-porous) and the hysteresis observed in the LHS-1 and CI adsorption and desorption isotherm data may be due to simulant porosity (voids between particles) rather than the surficial characteristics of the mineral grains themselves. The total surface area per unit volume of CI is over an order of magnitude higher than that of LHS-1 and the total pore volume of pores less than ~40 nm in diameter is two orders of magnitude higher in CI. Given the compositions of both simulants and the clumped nature of CI, the relatively high surface area and pore volume of CI are expected, as serpentines have comparatively low density, trioctahedral layer structures [8], and carbon-rich compounds may exhibit high surface areas per unit volume compared to other materials [9], as does ferrihydrite [10]. LHS-1 is composed solely of magmatically-derived mineral grains, has no carbon or serpentine content, relatively dense crystal structures, and has a smaller average particle size than CI. Since particle size is inversely proportional to surface area, mineralogy plays a significant role in determining the specific surface area in geologic materials, stressing the importance of mineralogical accuracy in planetary regolith simulants. Given the sensitivity of surface area to mineralogy, this study demonstrates the requirement of a high mineralogical fidelity regolith simulant for accurate reproduction of the physical properties of planetary regolith, including heat and electrical transfer and gas and moisture retention for studies that involve asteroid mining [2], investigate the lunar water cycle and lunar ISRU processes [1].

Conclusions: Failure to account for the varying physical properties of planetary regolith, even from site to site on the same planetary body, endangers mission success and safety, as well as scientific and engineering merit. This study highlights the sensitivity of specific surface area of geologic materials to mineralogy using high mineralogical fidelity lunar highlands (LHS-1) and carbonaceous chondrite asteroid (CI) regolith simulants produced by Exolith Lab. This sensitivity means that care must be taken to accurately reproduce target regolith mineralogy in terrestrial studies, or personnel and hardware safety, ISRU and mining process efficiency, and scientific results will be negatively impacted.

References:

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