LUNAR SURFACE INNOVATION INITIATIVE: EVALUATING LUNAR SIMULANTS. K. R. Stockstill-Cahill[1] , A. C. Martin[1], C. M. Wagoner[1], S. R. Deitrick[2], and J. E. Gruener[2], [1]JHU Applied Physics Laboratory (11100 Johns Hopkins Rd., Laurel, MD 20723), [2]NASA-JSC/Jacobs (2101 NASA Parkway, XI4-JETS, Houston, TX 77058)

Introduction: NASA plans to return humans to the surface of the Moon and establish the first long-term presence on the lunar surface through the Artemis missions. This will require development of innovative technologies in areas such as construction of habitats, mobility, *in situ* resource utilization, generating power, and beyond. A critical aspect of this development and maturation of technology is testing under relevant lunar surface conditions, including in the presence of and using lunar regolith simulants.

Simulants are approximations of lunar regolith that do not reproduce all of the characteristics that the regolith exhibits *in situ* on the Moon. Simulants used for testing of lunar surface technologies need to be verified and validated to ensure that the impact of the differences between the simulants and the lunar regolith is understood, and the impact on the testing of the lunar technologies can be evaluated. As such, one of the roles of the Lunar Surface Innovation Initiative (LSII) at the JHU Applied Physics Laboratory (JHU-APL) is to work with the NASA simulant team to characterize and assess simulants and their components.

In 2020 and 2021, we evaluated commercially-available lunar simulants in terms of composition (mineralogy, bulk chemistry), particle size and shape, and availability and supply chain reliability. Lunar regolith simulants were compared to lunar regolith samples obtained by Apollo and other lunar missions. The results of the evaluation were published as a document [1] and made publicly available through the Lunar Surface Innovation Consortium (LSIC) website and confluence pages. The information gathered is also available through a portal located on the LSIC confluence site, which can be accessed by all LSIC members. (To join LSIC and access the portal, please see directions here.)

The JHU-APL LSII simulants team also worked with the NASA LSII simulants team to establish a Lunar Surface Working Group (LSWG) with a presence on the LSIC confluence site. Testing procedures developed by the community have a range of desired simulation characteristics, which requires a variety of lunar simulants to support these tests and careful selection of the appropriate simulant. The LSWG confluence space exists to support and enhance the exchange of lunar regolith simulant information, to share appropriate references and materials, and to encourage conversations between the LSII teams and community regarding the evaluation of lunar regolith simulants.

Methods: Methods used by the JHU-APL LSII simulants team for the evaluation of lunar regolith simulants included sieving the samples into 6 particle size fractions and weighing these fractions to determine a rough particle size distribution (PSD) by weight. In addition, simulants were characterized for particle size and shape present in samples using the Camsizer X2. Particle characteristics were compared to similar data collected for Apollo regolith samples.

Composition of the simulants were determined by various methods. We examined polished epoxy mounts of the 125-250 µm particle size fraction for each simulant using a Hitatchi TM 3000 tabletop Scanning Electron Microscope (SEM). Elemental maps were produced using the associated Bruker Q70+ silicon drift detector energy dispersive spectrometer (EDS) system. In addition, we examined bulk simulant powders using X-ray Fluorescence (XRF) to derive bulk elemental composition and X-ray Diffraction (XRD) to determine the number and rough amounts of crystalline mineral phases present in the sample. Additional details on the methodologies used are available within the assessment.

Finally, these results are combined with data collected by the NASA LSII simulants team and used within a user-friendly certification system to produce a "report card" on the simulant [2]. This system will aid community members in selection of appropriate simulants for their testing purposes.

Results: The most recent assessment looked at eight commercially-available simulants from four companies. These included the LHS-1 (highland) and LMS-1 (mare) simulants produced by Exolith, the OPRH3N (highland) and OPRL2N (mare) simulants from Off Planet Research (OPR), LHT-1 (highland) and LMT-1 (mare) simulants from Colorado School of Mines (CSM), and LHA-1 (highland agglutinate) and LMA-1 (mare agglutinate) simulants from Outward Technologies (OT). The assessment provides a detailed description of each company, their product and feedstocks, and anticipated availability.

Particle Size and Shape. All highland and mare regolith simulants exhibit a PSD within one standard deviation of an average Apollo regolith, although simulants contain a greater abundance of larger grains and have a steeper slope to their PSD curve (Fig. 1). Particle shapes of all lunar regolith simulants are more rounded than Apollo regolith grains (Figure 2).

Composition: Bulk Composition. The bulk composition for lunar regolith simulants are plotted with lunar regolith of the same class in Figure 3. Although similar geochemistry does not necessarily imply similar

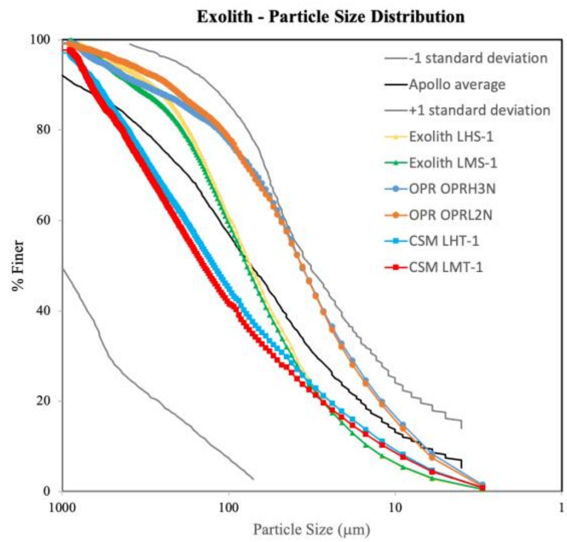

Fig. 1: PSD of lunar regolith simulants from [1] relative to an average Apollo regolith PSD.

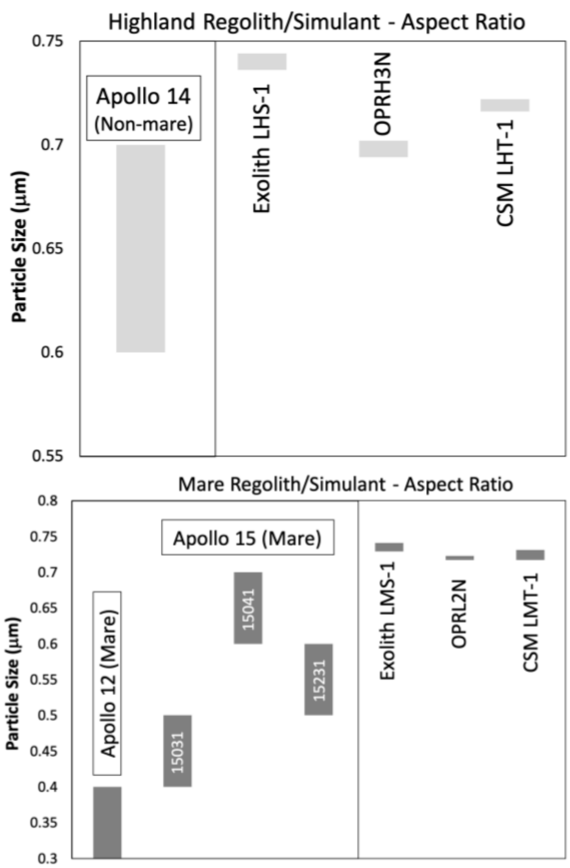

Fig. 2: Aspect ratio of lunar highlands [3] and highland simulants (top) and of lunar mare regolith [3] and mare simulants (bottom).

mineralogy, it can be useful to understand inherent differences that could impact some testing. We see a fairly good match in bulk composition to lunar regolith, however there are some important differences to note. First, the Na_2O content of all the simulants is much higher relative lunar regolith (Fig.3). This is due to the sodium-rich nature of terrestrial plagioclase. The simulants also contain more TiO_2 and less MgO than measured in lunar regolith (Fig. 3), although we note that the values measured have the greatest uncertainty for the XRF measurements [1].

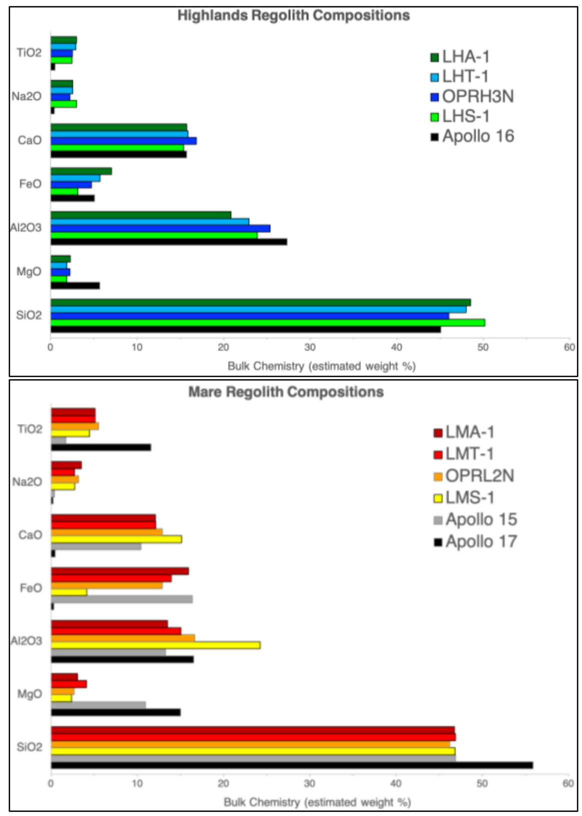

Fig. 3: Bulk compositions (XRF & SEM data) for lunar highland regolith and highland simulants (top) and lunar mare regolith and mare simulants (bottom).

Conclusions: The evaluation of a simulant is specific to its application and all users should carefully consider the needs of their application when selecting a regolith simulant. Simulants from current simulant providers should meet the needs of most users and most providers have the willingness and capability to adapt their product to the users need given sufficient lead time. We recommend consulting a lunar geologist or regolith expert when selecting the appropriate simulant.

References: [1] Stockstill-Cahill *et al.* (2021) JHU-APL LSII Report. [2] Deitrick and Cannon (2021) 11th PTMSS-SRR.[3] Carrier *et al.* (1991), *Lunar Sourcebook*, Cambridge Univ. Pr., pp. 475–594.