CHARACTERIZATION OF LUNAR HIGHLANDS REGOLITH SIMULANTS IN PREPARATION FOR DRILLING AND SAMPLING INTO THE POLAR REGOLITH BY ESA's PROSPECT PACKAGE.

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Introduction: The Package for Resource Observation and in-Situ Prospecting for Exploration, Commercial exploitation and Transportation (PROSPECT) is in development by ESA for application at the lunar surface as part of international lunar exploration missions in the coming decade, including the Russian Luna-27 mission planned for 2021. PROSPECT will search for and characterize volatiles in the lunar polar regions to answer science questions and investigate the viability of these volatiles as resources.

Here we present the characterization of two lunar highlands regolith simulants: NU-LHT-2M produced by the United States Geological Survey (USGS) and NU-LHT-2M produced by Zybek Advanced Products. We use a range of complementary analytical and laboratory techniques at the University of Manchester and the University of Oxford to assess the similarities and differences in the two simulants including their particle size distributions, physical properties including texture and cohesiveness, and mineralogical make-up. Characterizations of regolith simulants like these are needed to assess their utility for testing drilling, imaging, and sampling packages like those on the ESA PROSPECT experiment [1].

Regolith Simulants: The USGS and Zybek NU-LHT-2M simulants were provided to the PROSPECT User Group (PUG) by Leonardo-Finmeccanica for the purpose of laboratory characterization. NU-LHT-2M is a lunar highlands simulant that was originally developed by the USGS to simulate the lunar highlands feldspathic regolith and has the chemical composition of the average of all Apollo 16 soils [2]. The bulk of the simulant material originated from the Stillwater Complex in Montana and included crystalline (65%) and glass (agglutinate 30% and 'good' glass 5%) components in proportions similar to the typical Apollo surface regolith value [2]. The particle size distribution of NU-LHT-2M was based on the average of 19 Apollo 16 surface soil samples and consists of particles from dust size to 1 mm [2]. As the USGS and Zybek simulants are derived from rocks of the same deposit and subject to the same milling and plasma-melting processes used to achieve the required grain size and glass component, they would be expected to have similar physical and spectral properties.

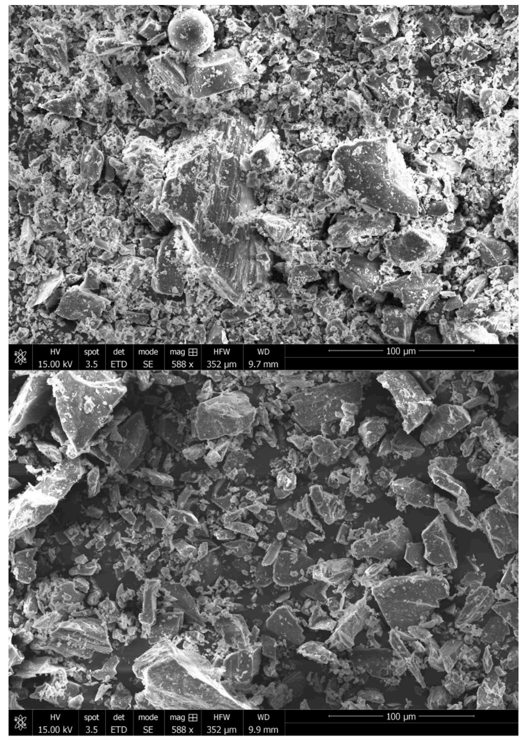

Figure 1. Higher magnification (×588) SEI of the heavily pressed grain mounts of **(Top)** USGS NU-LHT-2M and **(Bottom)** Zybek NU-LHT-2M.

Analytical and Laboratory Techniques: The bulk properties of the provided USGS and Zybek NU-LHT-2M simulants were characterized using complementary analytical and laboratory techniques.

University of Manchester. The grain shapes, sizes and interactions at the sub-millimeter scale as well as the composition were analyzed using a FEI XL30 Environmental Scanning Electron Microscope (SEM) using secondary electron images (SEI) and Energy Dispersive Spectroscopy (EDS). In order to perform the SEM and EDS analyses, the regolith simulants were mounted onto SEM sample stubs via an adhesive carbon sticky pad and then carbon coated. Six mounts per sample were created in order to investigate grain interactions: two heavily pressed grain mounts, two lightly pressed grains mounts, and two that were sprinkled directly onto the pad from a height of approximately 2 cm. In addition, to characterize the bulk spectral properties reflectance spectra were collected across the 4000 to 750 cm^{-1} spectral range using a Perkin-Elmer Spotlight 400 Fourier Transform Infrared (FTIR) spectrometer.

University of Oxford. The bulk composition, dominant particle size, and thermal properties were analyzed using thermal infrared (TIR) spectroscopy. TIR emissivity measurements were made under Earth-like (ambient) and simulated lunar environment (SLE) conditions in the Simulated Lunar Environment Chamber (SLEC). The experimental setup and calibration of SLEC have been previously described by Thomas et al. [3]. TIR spectra were collected using a Bruker IFS66v FTIR spectrometer at a resolution of 4 cm^{-1} from ~2400 to 400 cm^{-1} (~4 to 25 μm).

Results: The USGS simulant has a greater proportion of fine material compared to the Zybek simulant (Figure 1). While the bulk mineral compositions of the simulants are similar, Manchester EDS and FTIR spectra show the mineral proportions of the finest size fraction in each are different. The finest fraction of the USGS simulant is plagioclase-rich in nature, while the finest fraction of the Zybek simulant is a mixture of plagioclase, olivine, and pyroxene similar to the average composition of Stillwater anorthosite.

The USGS and Zybek simulants we have studied also differ in their physical properties, in particular their cohesive nature. As seen in Figure 1, the finest size fraction (< 30 μm) in the USGS simulant is highly cohesive in contrast to the more loose sediment nature of the Zybek simulant. This may be due to the largely mono-mineralic nature of the fine fraction, or it may be due to the smallest minerals (<1 μm in length) being more fibrous in shape (i.e. having 1 long and 2 short axes) and having a greater surface area, allowing for more cohesion between grains. The Zybek sample behaves more like a loose sediment with a low cohesive strength because its finest size fraction is not cohesive either due to its poly-mineralic nature or the absence of a fibrous component.

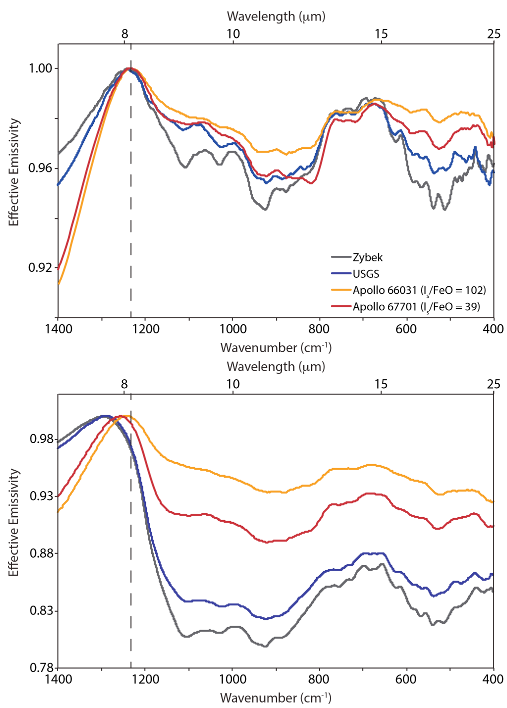

Figure 2. (Top) Ambient spectra of the two NU-LHT-2M simulants and two Apollo 16 bulk lunar soils of varying maturity. **(Bottom)** SLE spectra of the same samples. The dashed line highlights the position of the CF under ambient conditions.

As seen in Figure 2, both simulants are of similar bulk composition to Apollo 16 soils as their Christiansen Features (CF), an emissivity maximum indicative of composition [4], are at similar frequencies as are other diagnostic features in the ambient emissivity spectra. Under SLE conditions, the emissivity spectra of the simulants show a larger shift to higher frequencies of the CF and a larger increase in the spectral contrast between the CF and the fundamental vibration bands than the Apollo 16 soils. These results suggest the thermal properties of the simulants differ from the actual Apollo 16 soils. In addition, reflectance and emissivity spectra of the USGS and Zybek simulants corroborate the SEM analysis that both are spectrally dominated by the finest particle size fraction as demonstrated by: (1) the appearance of a transparency feature near 800 cm^{-1} and (2) the increase in depth of the feature at higher frequencies than the CF. The spectra also show that the Zybek simulant is of a coarser particle size fraction than the USGS simulant, and both NU-LHT-2M simulants are of coarser particle size fractions than Apollo 16 soil 66031 and 67701.

Future Work: Further analysis is needed to better constrain the differences observed in the USGS NU-LHT-2M and Zybek NU-LHT-2M simulants including: (1) repeat SEM and spectral measurements of the simulants; (2) constrain the particle size distribution of each simulant using multiple techniques; (3) further EDS analyses of the finest size fractions; and (4) compositional analyses of the fibrous material in the USGS simulant.

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