THE SPECTRAL CHARACTERISTICS OF LUNAR AGGLUTINATES. Chanud N. Yasanayake[1], Brett W. Denevi[1], Bradley L. Jolliff [2], Samuel J. Lawrence[3], and Rebecca R. Ghent[4, 5], [1]Johns Hopkins Applied Physics Laboratory, Laurel, MD 20723, USA (chanud.yasanayake@jhuapl.edu), [2]Washington University in St. Louis, St. Louis, MO 63130, USA, [3]NASA Johnson Space Center, Houston, TX 77058, USA, [4]University of Toronto, Toronto, ON M5S 1A1, Canada, [5]Planetary Science Institute, Tucson, AZ 85719, USA.

Introduction: The surface of the Moon is constantly evolving, undergoing physical and chemical changes due to processes collectively known as space weathering. Of these processes, micrometeoroid bombardment and solar wind sputtering dominate. Although the effects of these two processes have been well studied through examination of lunar samples, laboratory simulations, and remote analyses of the lunar surface, there are still controversies about their roles in weathering the surface. For example, analysis of grain rims containing nanophase iron (npFe) has been interpreted to suggest they develop mainly through micrometeoroid bombardment [1], whereas remote analyses typically point to the solar wind as the dominant process in creating these rims [e.g., 2, 3, 4]. While once considered largely responsible for the spectral changes that occur with space weathering [5], agglutinates—fragments of minerals and microphase iron (mpFe) bound within a glassy matrix—are now at times overlooked in the fierce micrometeoroid vs. solar wind debate. This is despite the fact that the composition of mature soils (heavily weathered soils, as indicated by an I_s/FeO value >60 for the <250 µm fraction) is typically about half agglutinates. Micrometeoroid bombardment is clearly critical to the production of agglutinates, but does the solar wind also play a role—either by creating npFe rims that are recycled into the interiors of agglutinates as mpFe or by implanting protons that act as a reducing agent? How does the rate of formation of agglutinates compare to the rate of formation of npFe-bearing rims? Can we separately understand the roles of the solar wind and of micrometeoroid bombardment?

To better understand these issues, our current work focuses on the spectral characterization of agglutinates. We are studying lunar soil samples of varying composition, separating the agglutinates and gathering their reflectance spectra. These spectra will help us understand how the spectral characteristics of agglutinates vary with soil composition and will allow for improved modeling of agglutinate content in a variety of lunar soils.

Agglutinate Separates: Although agglutinates are a major component of mature lunar soils, their spectral characteristics have not been extensively studied. In fact, the only documented agglutinate spectra are from a single Apollo 11 soil sample [6, 7]. These spectra are insufficient to fully characterize the spectral properties of agglutinates, which may vary across the lunar surface based on factors such as soil composition and maturity. Additionally, they lack measurements of reflectance acquired under varying illumination and viewing geometries, which are needed for evaluating their effect on the lunar photometric function and for their inclusion in radiative transfer modeling.

Before isolating the agglutinates from the bulk soils, we sieved each soil to 125–250 µm, our size fraction of interest. We then sorted ~50 mg of agglutinates by hand using tweezers and a binocular stereomicroscope, identifying them by their distinct appearance: they are irregularly shaped, are brown in color, and have a surface texture that varies from rough to glassy, interspersed with mineral fragments (Figure 1).

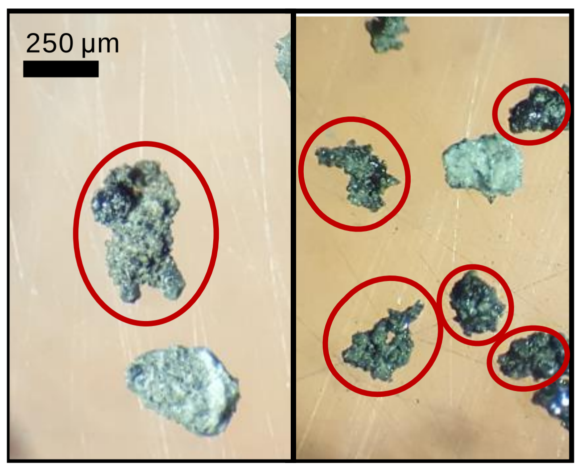

Figure 1. *Grains from the 125–250 µm size fraction of Apollo sample 14259 (agglutinates circled).*

Ideally, we would focus on a smaller size fraction (~10–20 µm), as the spectra of small particles are more representative of bulk soil spectra [6]. However, in this case our method of manual separation requires that we choose the larger 125–250 µm size fraction, where the grains do not cling to one another as much and are more feasible to manually sort. To ascertain the effect of using the 125–250 µm size fraction instead of a smaller one, we will magnetically separate a range of size fractions of agglutinates out of one sample and compare their spectra. This magnetic separation method is an efficient way of separating out agglutinates [8], but we choose to primarily separate agglutinates by hand instead since magnetic separation can incorrectly separate non-agglutinate material with large Fe grains while leaving out agglutinates with plagioclase-like composition [9].

In our study, we examine agglutinates in six Apollo soil samples: 62231, 14259, 15041, 79221, 67461, 61141 (Table 1). These six samples were all studied previously by the Lunar Soil Characterization Consortium (LSCC) [10, 11, 12], providing data on their mineralogy, chemistry, maturity, and spectral properties. Four of these samples are mature soils of varying composition (low-Fe highlands, moderate-Fe highlands, low-Ti mare, and high-Ti mare). The remaining two samples consist of one submature soil (I_s/FeO >30, <60) and one immature soil (I_s/FeO <30), both from the lunar highlands. The differing compositions and degrees of maturity among these samples will allow us to determine how and if these two factors affect the agglutinate spectra.

Soil	Maturity (I_s/FeO)	FeO (wt%)	TiO_2 (wt%)	Composition
62231	Mature (91)	4.9	0.6	low-Fe highlands
14259	Mature (85)	9.5	1.8	moderate-Fe highlands
15041	Mature (94)	14.2	1.8	low-Ti mare (basalt)
79221	Mature (81)	14.0	6.4	high-Ti mare (basalt)
67461	Immat (25)	4.2	0.3	low-Fe highlands
61141	Submat (56)	5.3	0.6	low-Fe highlands

Table 1. *Characteristics of selected lunar samples* [10, 11, 17].

Reflectance Spectra: Agglutinate reflectance spectra are being collected at the Reflectance Experiment Laboratory (RELAB) at Brown University [13]. Their Fourier transform infrared spectrometer will be used to obtain spectra from 2–25 µm at 4 cm^{-1} spectral resolution. The bidirectional spectrometer will be used to gather ultraviolet–near-infrared spectra (0.32–2.55 µm) at 10 nm spectral resolution at multiple geometries (incidence angles ranging from 5° to 70°, emergence angles ranging from -70° to 60°). This wide range of geometries will allow us to test for differences in the relative forward- and back-scattering properties of agglutinates from the lunar highlands versus maria, as has been proposed by Sato et al. based on resolved Hapke parameter maps of the lunar surface [14].

Future Work: Approximately 50 mg of agglutinates have been manually separated from three samples. After isolating agglutinates from the remaining samples and collecting their spectra, we will use this new information to further our main goal of studying the roles and weathering rates of micrometeoroid bombardment and solar wind sputtering. Electron microprobe analysis of the agglutinates will yield their composition, which along with the spectral data will help us incorporate agglutinates into a radiative transfer model [15]. This will improve on previous radiative transfer models, which have suffered in accuracy from a lack of data on agglutinates and difficulties modeling their spectral effects. For example, Denevi et al. found that using empirical parameters to account for agglutinates resulted in their model often estimating agglutinate abundance at 0%, even for agglutinate-rich mature soils [16].

The improved model will be used to estimate agglutinate abundance at varying locales on the lunar surface based on their reflectance spectra in order to provide constraints on their rates of formation. We will additionally search for differences in formation rate with latitude and within lunar swirls, as solar wind flux decreases with increasing latitude and is mitigated within swirls [2, 4].

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