A COMPARISON OF KINETIC IMPACT AND LASER IRRADIATION SPACE WEATHERING EXPERIMENTS. L. M. Corley[1], J. J. Gillis-Davis[1], and P. H. Schultz[2], [1]Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Mānoa, 1680 East-West Road, Honolulu, HI 96822, [2]Department of Earth, Environmental and Planetary Sciences, Brown University, 324 Brook Street, Providence, RI 02912, (lmc44@hawaii.edu).

Introduction: Various laboratory experiments attempt to simulate the space weathering process. Laser irradiation experiments replicate the optical effects of space weathering and produce submicroscopic iron (SMFe) [1-4]. Impact experiments replicate regolith comminution, chemical fractionation, and agglutinate formation [5, 6]. However, space weathering is a complex process that yields complex effects. Whether and to what extent these experiments can accurately reproduce the spectral and physical changes has yet to be fully examined. We compare and contrast the results from laser irradiation and kinetic impact experiments to determine: 1) if the two types of experiments produce similar spectral effects, and 2) if either technique or a combination of the two produces space weathering effects similar to those observed in lunar regolith.

Methods: We created a highlands regolith analog for use in both experiments. The simulant is a powdered (<75 µm) mixture of 85% Stillwater plagioclase (An_{80}), 10% orthopyroxene ($Wo_1En_{69}Fs_{30}$), and 5% San Carlos olivine (Fo_{90}). Laser irradiation experiments were performed under vacuum at ~10^{-5} mbar, with a 1064-nm pulsed laser. Pulse energy is 30 mJ and pulse length is 5-7 nsec at 20 Hz, which simulates µm-sized micrometeorite impacts. The beam was rastered across 0.5 g of the sample at 1-min intervals for a total of 40 minutes (1,440 J or 2,880 J/g), equivalent to approximately 500 million years of space weathering on the lunar surface.

Kinetic impact experiments were performed with the 0.30 cal light-gas gun at the NASA Ames Vertical Gun Range (AVGR). The target was 42 kg of the same highlands analog. A series of 16 individual shot experiments were done on the same target material over a 5-day period. The projectile was a ¼-inch Pyrex sphere that was fragmented into random small shards by firing it through a thin, 1.5-mil Mylar film as it entered the target chamber, which had pressures of ~10^{-1} mbar. The average crater size produced by all projectiles in a shot was 18 cm in diameter and 4 cm deep. The average velocity of each shot was 5.52 km/s, and the average energy per shot was 4,543 Joules (for a total of 72,688 J). As a whole, the target received 1.7 J/g. Only the middle third of the target was impacted with projectiles; therefore, there energy distribution relative to mass was ~5.2 J/g. For comparison, the lunar surface receives ~5-10 $J/m^2/yr$ from micrometeorites [7]. Three grams of material were collected after each shot, and the crater was reset after every third shot so that projectiles would not penetrate to the bottom of the target basin.

Reflectance measurements of all samples were taken with an Analytical Spectral Devices FieldSpec 4 spectrometer, which measures reflectance from the ultraviolet to near-infrared (0.35-2.5 µm). Spectra were acquired with a 30° incidence angle and 0° emission angle. Reflectance was measured relative to Spectralon standards. Samples were examined with the Hitachi S-4800 Field Emission Scanning Electron Microscope (SEM) at University of Hawai'i at Mānoa.

Results: Laser irradiation replicates lunar-like spectral response to the space weathering environment [8-10]; which includes decreased albedo, reddening of the spectral slope, and reduction of the strength of absorption bands (Fig. 1). This observation is confirmed by laser weathering experiments of a lunar highlands sample [11]. The grain morphology (i.e. shape, melt deposits splashed onto grains) are comparable to lunar soil grains (Figs. 2 A & C), and SMFe was contained in silicate amorphous rims. However, the laser weathering experiments do not produce agglutinates or vapor-deposited nanophase Fe by iron micrometeorite vaporization [12].

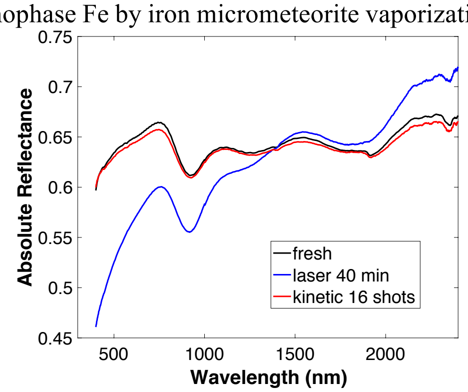

Figure 1: Absolute reflectance of fresh highlands analog and analog weathered by laser irradiation and by AVGR impacts.

Unlike the laser experiments, the kinetic impact experiments produced agglutinates, most of which were a few mm to one cm in size (Fig. 3). Agglutinates did not appear darker than the fresh simulant. The surface of the target material beyond the impact zone darkened gradually over the series of experiments due to the deposition of carbon from vaporized sabot material or black powder used in the primary stage of the light-gas gun. This component was reduced by a blast suppression system, but it could have been mitigated further by placing a large plate with an opening near the chamber entrance.

The center of the target, which was impacted repetitively by 16 shots, exhibited little to no lunar-like spectral changes (Fig. 1). A slight darkening and reduction of absorption bands occurred, but there was no significant spectral reddening. This suggests that carbon is the spectrally-neutral darkening agent and that there is no SMFe. SEM secondary electron images did not reveal impact melt on any of the analyzed grains, only smaller grains adhered to the surface of larger grains likely due to static forces (Fig. 2B).

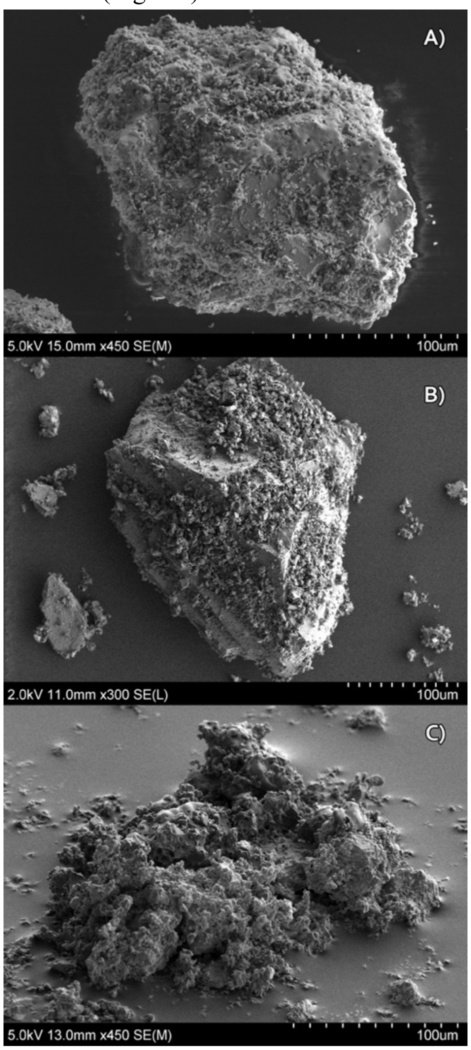

Figure 2: Secondary electron images of grains from A) analog after 40 min of laser irradiation, B) analog from AVGR after 16 shots, and C) Apollo 16 highlands soil 65701.

Discussion: Although the AVGR is useful for studying crater formation and morphology and creating agglutinates, the kinetic impact experiments with our experimental setup are not suitable simulations to study space weathering spectral changes. Our 5 days of experiments represent only 7,000 to 15,000 years of space weathering by micrometeorite bombardment. AVGR impact experiments have demonstrated the creation of melt/vapor deposits [13] and vaporization of iron [14]. However, the impact velocity at AVGR (~6 km/s) is considerably lower than micrometeorite impact velocities into the lunar surface (~16 km/s). Hence, much less energy is partitioned into vaporization as would occur for a micrometeorite impact on the Moon.

Figure 3: Agglutinates made in the AVGR experiments.

In contrast, laser irradiation experiments replicate spectral changes comparable to space weathering on geologic timescales. In our experiments, the highlands analog became darker, redder, and lost spectral contrast as a function of laser irradiation. The absence of agglutinates is a weakness in the ability of laser irradiation to simulate lunar space weathering, as agglutinates comprise ~60% of mature lunar regolith [15], contribute to darkening the spectra, and are the major carriers of much of the SMFe in a lunar soil [8-10]. However, during laser irradiation, enough melt may adhere onto a grain that it effectively acts like an agglutinate and contributes to darkening. Studies are needed to confirm this hypothesis. Additionally, we plan to perform laser irradiation on our samples from AVGR that contain agglutinates to investigate if the presence of agglutinate material enhances the darkening produced by laser weathering.

Conclusion: The difference in weathering effects between the two experimental setups relates to two factors: First, energy density is important. AVGR experiments partition less energy into vaporization than laser irradiation. Hence, the laser experiments produce a higher vapor to melt ratio than the AVGR experiments. Second, AVGR impacts may disperse any generated vapor over a large surface area, which results in particles having negligible SMFe containing vapor deposits.

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