PROPERTIES OF REGOLITH FROM EXPERIMENTS AT SMALL SCALE IN SEISMIC SIMULANTS: PORES[4] C. Braccia[1], N. C. Schmerr[1], W. Zhu[1], J.V. DeMartini[1], H. Lisabeth[2], N. Schörghofer[3], J. Richardson[1], D.C. Richardson[1], and M. Siegler[3], [1]University of Maryland, College Park, MD 20742 (cbraccia@umd.edu) [2]Lawerence Berkeley National Laboratory, [3]Planetary Science Institute.

Introduction: The lunar subsurface is a primary science target for future missions to the Moon and serves as a potential host location for resources such as water ice, void spaces for astronaut shelter, and important ore-bodies for in-situ manufacturing and building materials. The first tens of meters of the lunar subsurface are characterized by a poorly sorted, loosely consolidated, granular mixture of impact ejecta fragments, shattered local rocks, and dust[1,2,3]. Understanding variations in the structural properties of the deeper regolith requires a geophysical approach; here we investigate how the seismic signature of the regolith environment is affected by changes in material properties, such as when frozen in ice. This will be key for the subsurface exploration in future lunar surface missions.

The behavior of seismic waves in granular material deviates from a linear elastic model because granular materials can flow and behave like fluids. Within the granular material, stress is heterogeneously distributed, where the particles carrying the larger stress form a network of forces. This network of forces is referred to as a force chain, and studies suggest that energy transmitted through granular material has a transient behavior with increasing stress[4]. Because of this, seismic velocities are often slower than solid material for loosely consolidated material, such as lunar regolith, measured to have seismic velocities as low as 100 m/s[1]. The effects of lowered gravity and vacuum on the force chain path are poorly understood but highly relevant for the Moon and asteroids. We seek to understand these effects using a simulated test chamber that allows us to measure seismic velocity of regolith materials at low pressure and simulated gravity.

Experimental Setup: The experimental test chamber consists of a cylindrical 19-liter steel pot with a diameter of 300 mm and height of 310 mm and a 1.5 cm thick acrylic lid used to seal the simulant under vacuum (Figure 1). A 3 CFM oil pump is used to reduce the pressure to ~100 millibar. In order to simulate the forces acting on regolith at lunar gravity while on Earth, we use granulated cork that has a density of 150-300 kg/m³ and average grain size of 0.1-13 mm in diameter, creating equivalent gravitational forces. Glass beads are also used as a standard material in order to make comparisons to the properties of the cork.
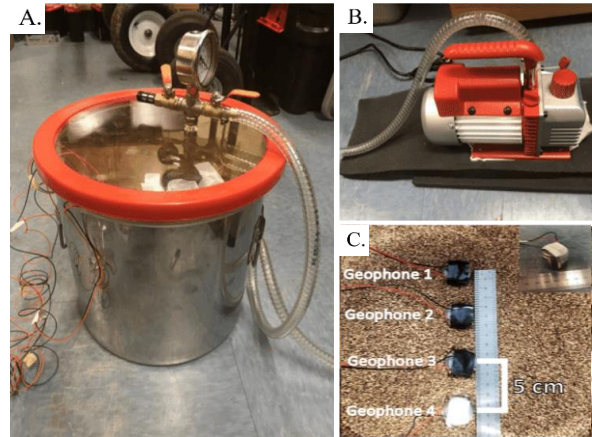

Figure 1. A) Test chamber setup showing both the steel pot and lid. B) Vacuum pump used to reduce the pressure within the chamber. C) Geophone (inset) arrangement and spacing used to capture seismic signature of the simulant material.

A gravity-driven weight consisting of a 5 mm metal ball bearing is used as an active source for the seismic experiments. The ball bearing is dropped into the simulant by removing the magnet from the lid and falls under gravity ~ 20 cm, imparting ~ 5 mJ of energy into the chamber. This chamber is partially filled with the regolith simulant and three to five R.T. Clark 525 Ohm 100 Hz Sercel Geophones are spaced evenly apart (5 cm separation), arranged in a linear formation and buried 1-2 cm beneath the cork simulant. The geophones are wired and pass through the vacuum seal at the lip of the container. When vacuum is reached, the source is released which sends seismic signals through the simulant that are captured by the geophones, allowing the velocity of the medium to be calculated.

Results: The experiment performance was first demonstrated for several different locations across The University of Maryland's campus as background noise affected our ability to interpret the results. Power spectra were compared between multiple locations in order to establish the best environment with a reduced background noise. Ten runs were conducted at each location and an average and smoothed average were calculated. Location 1 has a spike in background noise at ~30 Hz and a slightly elevated background noise of -9.05 dB. Location 2 has a slightly lower background noise of -8.44dB, likely due to location 2 being further from

anthropogenic noise, making location 2 the more ideal location for experiments.
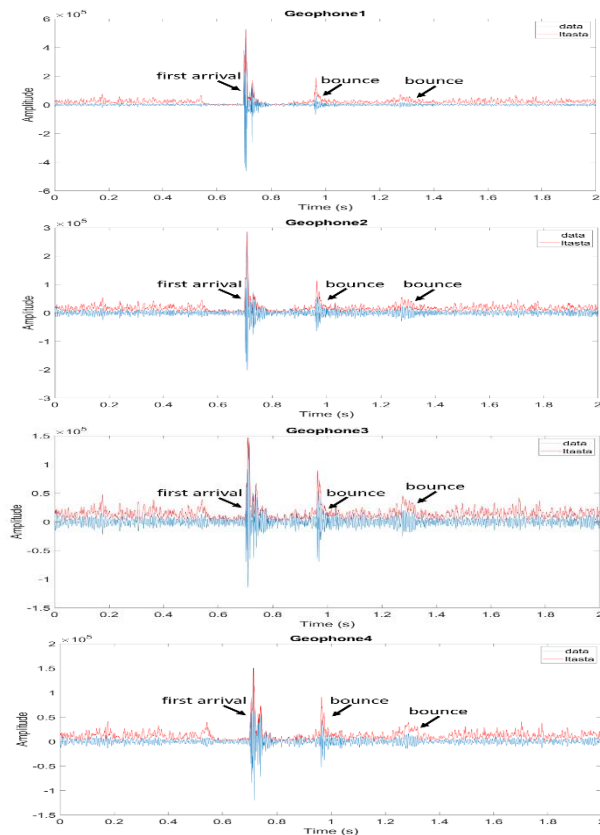

Figure 2. Results from the vacuum test chamber experiments showing the seismic waveforms. The test material for this experiment was glass beads. This experiment was done at 100 millibar pressure with 4 geophones spaced linearly 5 cm apart and a source located ~ 3 cm from the first geophone.

In our experiments, we measure seismic velocity by finding the first arrival of the P-wave. Additional signals are from where the ball-bearing source bounced within the chamber. Figure 2 shows travel time picks for an operator selected first arrival that used an automated short-term average, long-term average ratioing method[5] for the glass beads simulant. The slope of the resulting travel time picks is determined with linear least squares regression and provides an estimate for the P-wave velocity for the medium (Figure 3).
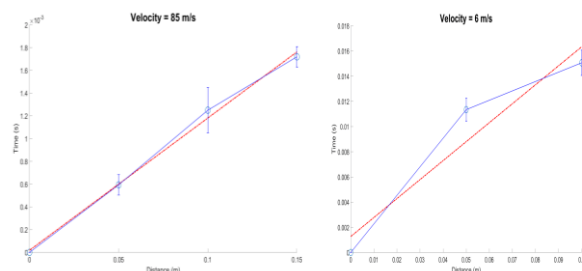

Figure 3. Travel-time curve calculated from the P-wave first arrival picks for the glass beads (left) and the cork simulant (right). First arrivals of the P-wave from an automated picking algorithm (blue) are selected at each geophone station. A linear least squares regression (red) is used to determine the material velocity.

The calculated velocity of the glass beads, ~85 m/s, is similar to that of lunar regolith.

In a second set of experiments, waveforms are captured using a similar experimental setup but with cork as the simulant instead of glass beads. The P-wave arrivals are picked using an identical method and travel time curves are created. The calculated velocity for the cork simulant is ~6 m/s.

The expected seismic signature of a solid material may be calculated if the material properties are known using the following equation:

$$V_p = \sqrt{\frac{K + 4/3G}{\rho}}$$

where K = bulk modulus, G = shear modulus and ρ = density.

For granular material, seismic velocities are not as easily estimated using calculations based solely on material properties because of the material's ability to behave inelastically. The estimated velocities based on the equation above for the glass beads is ~6300 m/s and for cork is ~400 m/s, two orders of magnitude higher than the captured velocities in the test chamber. This indicates that there is likely another factor, outside of material properties, controlling the seismic signature of regolith material.

References: [1] Kovach, R.L., Watkins, J.S. (1973) The Moon 7, 63–75. [2] Gangi, A.F., Yen, T.E. (1979) The Moon and the Planets 20, 439–468. [3] Nunn, C., Garcia, R.F., Nakamura, Y. et al. (2020) Space Sci Rev 216, 89. [4] McBeck, J., Mair, K., Renard F. (2019) J Geophysical 124, 9, 9920-9939. [5] Trnkoczy, A., (1999) NMSOP-2.