SEISMIC EXPERIMENTATION TO FURTHER UNDERSTANDING OF MARTIAN REGOLITH-ICE. A. Bates[1], J. M. Lorenzo[1], S. Karunatillake[1] [1]Louisiana State University Dept of Geology and Geophysics, (abate15@lsu.edu).

Introduction: Prior workers have hypothesized the various states and stability regimes of regolith-bound H_2O-ice on Mars based on the diffusion of atmospheric water vapor into the porous martian regolith (1–4). Such models primarily use fluctuations in the orbital dynamics of Mars, especially obliquity variations, to determine periods of thermophysical stability of ice as a function of latitude. As Mars' obliquity changes, the stability regimes for ice change, resulting in latitudinal transfer of ice through vapor diffusion (1, 5). However, ice may remain metastable at shallow depths within the mid-latitudes (~55°) even during low obliquity, as verified by satellite observations (6, 7). In addition to poorly constrained metastability, the quantity of ice found at lower latitudes exceeds what could have accumulated solely through available atmospheric vapor through the previous obliquity cycle (1, 6).

To understand seasonal controls and identify key regions of regolith ice accumulation, future in situ missions must capably investigate the martian subsurface. We are developing a novel and effective, yet non-invasive, method using high frequency seismic waves, because they reveal shallow subsurface physical properties. While many physical parameters of the martian regolith have been constrained (8, 9), past works mostly overlook the utility of seismic data to define the shallowest velocity structure of the martian regolith in the presence of H_2O in any state (9). Furthermore, the capability of underlying rock physics models to accurately constrain the seismic velocities of regolith-ice mixtures has yet to be applied to Mars. Testing the ability of these models to provide the necessary conceptual characterization of porous media on different planets is essential before in-situ seismic exploration can advance.

The burgeoning nature of martian near-surface seismology still has many unknowns regarding the physical and chemical parameters that could potentially affect shallow seismic velocity profiles. Therefore, we examine the applicability of modified contact theory, to explain the observed velocities.

Methods: Using contact theory (CT) and cement contact theory (CCT) following (10), we predict p- and s-wave velocities for the upper 5 meters of martian regolith. Contact theory estimates seismic velocities based on wave propagation through grain contacts and is thus dependent on the number of grain contacts, the physical properties of the grains, and the pressure the grains themselves are subjected to (i.e., depth of burial) (10). As such, CT provides a baseline estimate of p- and s-wave velocity in the absence of any volatiles or cement affecting grain contacts, which would be similar to the conditions expected at the InSight landing site (8, 11). Cement contact theory estimates velocities in a similar manner to CT, but with the addition of cement at the grain contacts. Cement at grain contacts affects the overall stiffness and density of the 2-grain system, which affects the p- and s-wave velocities through the medium. CCT has been used in terrestrial studies to effectively model velocities in permafrost environments (12) and should prove effective in a martian setting.

For our input parameters using CT, we employ the Reuss Lower bound technique (10) to estimate the bulk and shear modulus of a "grain" which consists of an aggregate of minerals typical of martian soil, based on bulk mineralogy from Gusev crater (13). We use a coordination number of 9, typical for spherical sand grains (10), a composite density of all the material phases in the system (i.e., grains, air, cement), and a porosity of 0.7, which is higher than what is expected for random packing of spherical grains (9) for the purpose of achieving overlap between InSight velocities and those estimated in this study. For CCT, the input parameters remain the same as before, however our porosity value is 0.35, and the amount of cement is limited to 43% of that available void space, as CCT is most effective at modeling velocities of systems with cement not exceeding a porosity of 0.15 (12). The portion of cement in the void space increases linearly with depth in this study and the cement is limited to pure ice.

Results: As noted in the methods section, a porosity of 0.7 is used for the void space in our CT estimations. This is roughly the lowest porosity value that results in

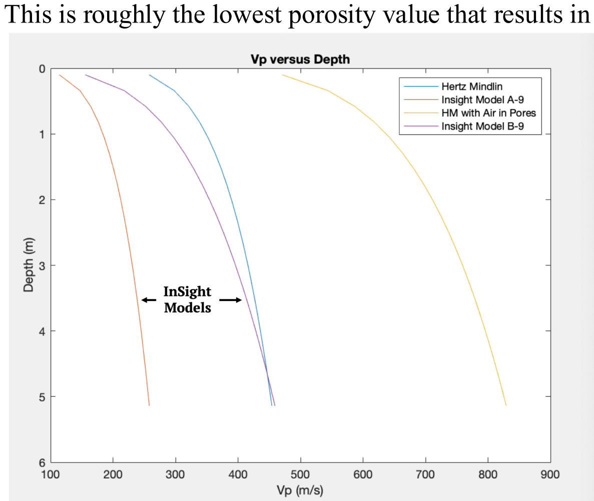

Figure 1: P-wave velocity for the upper 5 meters of martian soil. The InSight models are labeled and the velocity profile predicted by CT is indicated by the blue curve. When we account for the air in the pore space, we generate the yellow curve.

some overlap between CT estimated velocities and those estimated by the InSight team (8). Assuming the physical properties of the grain(s) are fixed, the main input parameters that can be adjusted are porosity and the mineralogical abundances that constitute our "grain." The amount of clay in relation to the overall porosity of a sand-grain system has been shown to decrease the overall compressional wave velocity (14), however, an unreasonable abundance of clay, > 20 wt.%, is needed to create a CT velocity profile that overlaps with the InSight models. Increasing the porosity alone will result in overlap between the CT velocity profile and the InSight ones, and there is also room to vary the clay abundance and porosity a reasonable amount to achieve overlap.

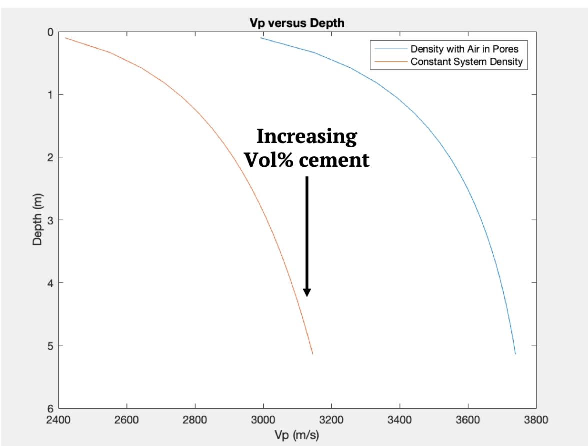

Figure 2: P-wave velocity for the upper 5 meters of martian regolith that is cemented by ice. The relative ice content increases with depth. The orange curve represents the velocity profile with an assumed constant density of 2400 kg/m^3, whereas the blue curve uses an average density per depth interval of the 3 phase (cement, grains, air) system.

Our velocity profiles for an ice-cemented regolith are an order of magnitude higher than the velocities predicted by CT, Fig. 2. These estimates of velocity are consistent with other studies that examine p-wave velocity as a function of ice content (12, 15, 16).

Discussion: Contact theory's effectiveness to predict velocities in granular media on Mars is somewhat unclear. While there are some unknowns surrounding the nature of the regolith at InSight, the simplicity of CT does also work against it. The added complexity of low density martian air within the unoccupied pore space is difficult to account for in CT (Fig. 1). This coupled with an uncharacterized mineralogy could be reasons to explain the lack of overlap between the InSight and CT velocity profiles.

Despite these unknowns, CCT shows consistency with prior terrestrial studies (Fig. 3) examining ice-cemented media. The velocity increase with increasing vol% cement s hows an exponential trend similar to prior works (15, 16). As such, we believe that CCT could be used to accurately predict velocities in martian permafrost settings.

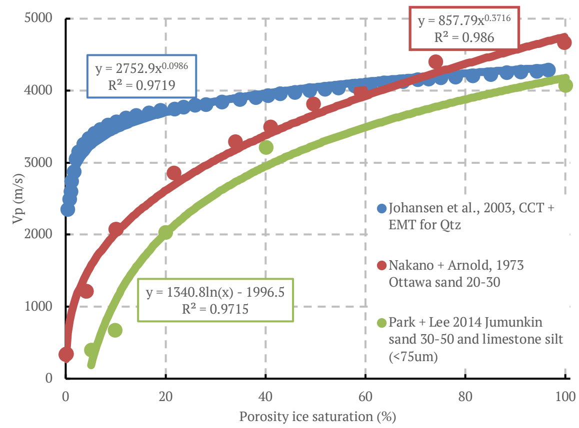

Figure 3: Summary of results from prior works examining ice content versus p-wave velocity. The red and green curves are from experimental studies and have similar exponential increases whereas the blue curve is modeled using CCT and effective medium theory. The key takeaway is that for ice vol% below 20, there is a substantial increase in the p-wave velocity.

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