LUNAR AND MARTIAN USABILITY OF A SEISMIC, WHEEL-BASED, SENSOR SYSTEM TO DETECT SHALLOW WATER-ICE. J. M. Lorenzo1, M. P. Zanetti2, H. F. Haviland3, P. M. Bremner2, S. Karunatillake1, G. P. Tsolfias3, T. A. Douglas4, A. J. Gerner5 1Dept. Geology and Geophysics, Louisiana State University, S. Campus Drive, Baton Rouge, LA 70803, gllore@lsu.edu; 2NASA Marshall Space Flight Center, 320 Sparkman Drive, Huntsville, AL 35820, michael.r.zanetti@nasa.gov, heidi.haviland@nasa.gov, paul.m.bremner@nasa.gov, 3University of Kansas, Geology, Ritchie Hall, room #354B, Lawrence, KS 66045-7613, tsoflias@ku.edu, 4U.S. Army Cold Regions Research & Engineering Laboratory, 9th Avenue, Building 4070 Fort Wainwright, AK, USA, thomas.a.douglas@usace.army.mil, 5Lunar Outpost Inc., 2830 East College Avenue, #106, Boulder, CO, aj@lunaroutpost.com

Introduction: On the Moon, cold-trapped, subsurface H2O-ice in permanently shadowed regions may be key to understanding the evolution of volatiles in the solar system [1]. On Mars, climate cycles are recorded by polar [2] and mid-latitudinal ice sheets [3]. As well, shallow ground ice, can potentially record atmosphere-regolith volatile exchange across the critical zone [4]. Detailed prospecting of near-surface (<1 m), planetary resources such as H2O ice, may be assisted by mapping high-resolution seismic properties using a transferrable array of piezo-accelerometers rigidly mounted to the interior of rover wheels. This can complement electromagnetic methods, such as ground penetrating radar [5] whether deployed in orbit on in situ.

Methods: By limiting the number of horizontal-component sensors to one per rover wheel we can reduce overall power, mass and electronic complexity, while using a trailing rover wheel to carry a highly controllable electromagnetically vibrating horizontal shear source (<1 kHz). Because we focus on the collection of surface wave data instead of reflected or refracted arrivals we carry several advantages: Love waves (1) generally display a relatively high natural signal-to-noise ratio and so require fewer sensors than seismic reflection surveys which rely on strong impedance contrasts among soil horizons. (2) Surface wave amplitudes decay far more gradually than refracted body waves given the same distance of travel between source and sensor and (3) they also can be used to detect low-velocity zones.

Seismic data quality is potentially affected by mechanical wheel resonance, inefficiencies in wheel-to-ground sensor and source coupling, seismic attenuation, and seismic velocities of the materials traversed.

Field Sites: We evaluated a single wheel and a composite-test article with 6 wheels of 2 different sizes in 3 different substrates: (1) a dry, laboratory sand tank, (2) frozen, intact loess within the U.S. Cold Regions Research and Engineering Laboratory’s Permafrost Tunnel near Fairbanks, Alaska, and (3) in the Lunar Regolith Terrain (LRT) field at NASA Marshall Space Flight Center, in Huntsville, AL. The LRT is an outdoor planetary analog environment that contains 500 tons of lunar regolith simulant confined within a 38 m x 38 m area with a depth range between ~13 cm and 1.2 m) The Lunar regolith simulant is of JSC-1A [6] feedstock material (volcanic cinder sand sourced from Meriam Crater, Flagstaff, AZ) with representative geotechnical, geochemical, and optical properties of lunar mare basalt. The permafrost research facility is an accessible terrestrial analog to cryospheric processes on Mars [7].

Results: In both laboratory and field regolith analogs, wheel resonance does not affect the fundamental mode used for inversion of phase-velocity-frequency data. However, the effects of resonance from the frame of the rover prototype have not yet been evaluated. For cases of low seismic velocities in loose granular material (50 m/s) as well as high attenuation (Q < 6), wavelengths are at least 1/2 length of a rover (1 - 2 m) and

Figure 1. (A) The NASA Marshall Space Flight Center, Lunar-Regolith Terrain field. (B) Each of the 6 wheels in the prototype carries a high-frequency (kHz) horizontal-component accelerometer. A reversible horizontal electromagnetic shaker transfers motion to the underlying ground via a trailing wheel with variously-oriented grousers. Source-receiver distances range between 0.43 m and 1.04 m (C) For comparison, 24 conventional high-frequency geophones (100 Hz corner frequency) lie horizontally to capture horizontal-component seismograms. Geophones are oriented E-to-W spread over source-receiver offset ranges 5 cm to 2.35 m. Performance is rated within 12% of factory specifications. For both (B) and (C) opposite-polarity horizontal blows are used to generate two data sets at each shotpoint location. These data are differenced to remove unwanted converted P-waves.
By contrast, in the case of frozen loess in the underground field site, wavelengths can exceed array dimensions by at least a factor of 2. However, in these cases, where the presence of H2O ice soils appears to increase the shear modulus, the measured changes in seismic attenuation are also readily noticeable [8]. We are able to use the very sensitive, narrow range of mechanical resonant frequencies (~1 kHz) in one of the wheels as a sensitive detector to lateral attenuation changes.

At the LRT, the regolith simulant displays very low apparent Vs values (Figures 2 and 3) based on both conventional 24-channel geophone array data. Dashed lines represent interpreted fundamental modes using in preliminary inversions (Figure 3). In the case of H2O ice soils, approximately spatially unaliased. By contrast, in the case of frozen loess in the underground field site, wavelengths can exceed array dimensions by at least a factor of 2. However, in these cases, where the presence of H2O ice soils appears to increase the shear modulus, the measured changes in seismic attenuation are also readily noticeable [8]. We are able to use the very sensitive, narrow range of mechanical resonant frequencies (~1 kHz) in one of the wheels as a sensitive detector to lateral attenuation changes.

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Figure 2. Dispersion images (phase-velocity versus frequency) for (A) 6-sensor rover prototype (Figure 1A) and (B) conventional 24-channel geophone array data. Dashed lines represent interpreted fundamental modes using in preliminary inversions (Figure 3).

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Figure 3. Preliminary inversion models from velocity dispersion trends (Figures 2A and 2B respectively). Only for the purpose of comparing (A) wheel-mounted sensor data and (B) conventional geophone-data, the inversion parameterization [9] uses highly unrestricted values for Vp, Vs, Poisson’s ratio, and medium density. The best 1000 models are shown for a range of model misfits.

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