AN EXPERIMENTAL SETUP TO MEASURE THE ELASTIC WAVE VELOCITIES OF FROZEN ROCKS: APPLICATION TO MARS. M. J. Heap[1], L. Griffiths[1], J. I. Farquharson[1], P. K. Byrne[2], S. Mikhail[3,4], C. R. Cousins[3,4] and P. Baud[1], [1]Institut de Physique de Globe de Strasbourg (UMR 7516 CNRS, Université de Strasbourg/EOST) 5 rue René Descartes, 67084, Strasbourg, France, [2]Planetary Research Group, Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, North Carolina, USA, [3]The School of Earth and Environmental Sciences, Irvine Building, The University of St. Andrews, UK, [4]The Center for Exoplanet Science, The University of St. Andrews, UK.

Introduction: Vast water-carved Martian landscapes serve as a testament that large bodies of surface liquid water existed on Mars in the geological past [1-9]. However, the present–day Martian surface is dry and dusty [10] and water is largely restricted to the polar ice caps, subsurface cryosphere [11-12], and seasonal Recurring Slope Lineae (RSL), likely brine seeps [13-14]. The average surface temperature of Mars is below the freezing temperature of water (ranging from -150 to 20 °C) and, as such, subsurface water exists as both as ice water and as liquid water. The position of the subsurface liquid–ice water interface likely varies in both space (latitude: [15]) and time (seasonal variations).

Since ice meltwater [16] and volcano–ice interactions [17] have been cited as plausible habitats for life on Mars, an improved understanding of the subsurface liquid–ice water interface, and how it changes with latitude and season, may help pinpoint likely locations for subsurface microbial life on Mars, as well improve our knowledge of the Martian hydrological cycle [18]. While the Martian surface has been extensively mapped and analysed, both remotely and in situ, the crustal subsurface is still poorly understood. In particular, two episodic surface features have subsurface origins: RSL and methane gas emissions. Seasonal brine seeps have been proposed to cause RSL features [13-14], while methane release could be attributed to subsurface microbial activity (methanogenesis), water–rock interaction, or methane clathrates. Understanding these subsurface processes requires knowledge of the nature of water–ice and frozen brines within the subsurface, and how they can be detected. Detection of subsurface ice and/or frozen brines also has implications for present–day habitability, which is restricted to the Martian crust due to inhospitable surface conditions. Brine composition has implications for microbial habitability, even where water activity is permissive [19]. Distinguishing frozen brine from pure water would therefore be a further way to constrain present–day habitability on Mars, particularly in relation to RSL features.

NASA's InSight lander, equipped with a seismometer that will probe the Martian subsurface, is due to arrive on the surface of Mars in November 2018. The InSight mission therefore offers the opportunity to map the subsurface liquid–ice water interface. Crucially, however, knowledge of the elastic wave velocities of dry, water–saturated, and frozen basalt (the most representative rock type: [20]) currently eludes us. Sparse published data on sedimentary rock and granite have shown that frozen rocks are characterised by systematically higher velocities [21]. New data on basalt are therefore an essential pre–requisite for interpreting the seismic signature of the interface between liquid water and ice water in the subsurface. Here we describe a project to provide, for the first time, laboratory measurements for the elastic wave velocities of dry, water/brine–saturated, and frozen basalt (from Mount Ngauruhoe, New Zealand). Combining the measurements with theory will provide velocity profiles (with depth) for the Martian subsurface for a range of different scenarios (porosity, temperature).

Experimental setup: Elastic wave velocity measurements are made using a uniaxial compression apparatus (Figure 1). The setup contains two piezoelectric transducers housed inside upper and lower steel pistons within the uniaxial load frame. A signal generator applies a pulse to the emitting transducer on one side of the rock sample and the pulse is received by the transducer at the opposite end. The wave velocities are calculated from the sample length and the time delay between the generated and received signals viewed on an oscilloscope.

The P– and S–wave velocity of the samples are first measured dry (with samples vacuum–dried at 40 °C prior to measurement). The uniaxial press applies a small servo-controlled stress (0.1 MPa) to the sample during the experiments, ensuring a constant coupling between the transducers and the sample, for better comparison between measurements. Elastic wave velocities are then assessed for water–saturated and ice–saturated samples. The velocities of the water– and ice–saturated samples are measured inside a steel container sufficiently large to contain the sample and the ends of the pistons (Figure 1). First, this container is filled with deionised water and the sample, vacuum-saturated with deionised water, is placed between the pistons. The water-saturated velocities are then measured on each sample as before.

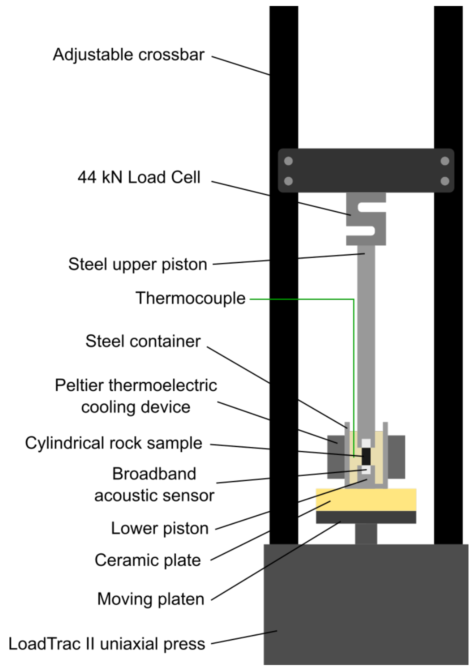

Figure 1: Schematic of the experimental device at the University of Strasbourg. (Illustration is not to scale.)

The ice–saturated measurements utilises the same steel container. Two Peltier thermoelectric cooling plates, attached to either side of the steel container (Figure 1), cools oil contained within the steel container to a range of subzero temperatures. The cooling plates are powered by two power supply packs and controlled with two temperature controllers. The samples are first vacuum–saturated with deionised water and placed inside a freezer. Once frozen, the samples are placed between the pistons. Both sample and pistons are therefore contained inside a bath of oil with a temperature below 0 °C. The ice–saturated velocities are then measured on each sample as before. Water– and ice–saturated experiments will also be performed with brines of differing salinity.

Modelling: Laboratory measurements are inherently scale–dependent. The elastic wave velocity of rock containing a pore fluid (i.e. air or water) or another solid (i.e. ice) can be calculated theoretically [21]. Combining the measurements from this study with theory allows for the comprehensive, empirically calibrated modelling of rock with different porosities, matrix moduli, saturation conditions (i.e. temperatures), depths, and pore fluid pressures. Therefore, our study provides velocity profiles for the Martian subsurface for a range of different scenarios against which future in situ measurements can be compared.

Prospectives: The data generated by this project will provide insights into the following aspects of planetary crusts, with an emphasis on that of Mars: (1) elastic wave velocity profiles (with depth) for the Martian subsurface for a range of different conditions (including, but not limited to, temperature and porosity); (2) experimentally calibrated constraints on the lower limit for the detection of water ice in the Martian lithosphere using seismological measurements from the InSight mission; (3) a dataset for refining the interpretation of seismic data collected by InSight; (4) a better understanding of the Martian hydrological cycle, with attendant implications for potential habitable environments on and within Mars; (4) an improved view of the distribution of frozen and liquid water within Mars, which may provide context for the transient methane observed in the Martian atmosphere; (5) an expanded understanding as to how efficiently terrestrial planetary bodies can store water: our dataset will help inform InSight measurements to determine how much water is still stored within the Martian crust; and (6) a useful database with which to better characterize measurements for the polar regions of Earth (e.g., the Antarctic seismic datasets), as well as other subsurface water ice reservoirs and regions that see seasonal ice cover (such as ice cap-covered volcanoes).

Combining planetary remotely sensed and in-situ data with laboratory measurements is a potent tool for investigating extraterrestrial geological phenomena. We anticipate that this project can be extended to worlds other than Mars, and will foster yet further interactions between those who measure rock physical properites in the laboratory and those who primarily employ spacecraft datasets.

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