ROCK PHYSICS: LINKING SEISMIC SPEEDS TO POROSITY AND ICE OF ANALOGUE MATERIALS IN PLANETARY SYSTEMS. L. Adam1 J. Charoensawan1, D. Meek1, K. van Wijk2, Luca Paolini2, Shanice Mascarenhas1.

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Introduction: The field of rock physics studies how physical properties of solid materials (e.g. rock, ice) and fluids influence the geophysical properties of rocks. Rock physics for radar applications on planetary systems exists [1]. However, there are few studies that target elastic (seismic) wave rock physics specifically for planets and moons [2]. Seismic data combined with laboratory experiments and numerical models provide the direct clues to the geological understanding of planets and moons. With the deployment of past and future seismometers on the Moon and Mars, P- and S-wave velocity and attenuation data need to be interpreted in terms of the physical properties of rocks at such locations and at pressure and temperature conditions that resemble those on Mars and the Moon. Other than meteorites, we do not have Martian rock samples and thus Earth analogues should be used. For the Moon, limited samples restrict direct experimental measurements of wave speeds. However digital rocks and numerical models can be used to predict the physical properties of rocks. This abstract provides a brief overview of rocks physics approaches for linking seismic waves to the physical properties of analogue (or real) rocks from planetary systems.

Experimental methods: Wave propagation [3] and resonant [4] ultrasound methods are the most common ways to estimate wave speeds or elastic parameters (e.g. Young’s. modulus and Poisson’s ratio) of rocks. Transducers are commonly used but have limitations, especially when resembling extreme temperatures in planetary environments. The non-contacting nature of laser ultrasound systems [5] allow measurements at frozen and hot environments. No matter what experimental approach is taken, rocks samples are required.

The shallow (< 300 m) subsurface of the western Elysium Planitia on Mars where the InSight lander sits since 2018 is interpreted to be composed of highly porous sedimentary rocks over and underlaying a possible basalt layer [6]. In the nearby Kalpin crater [7], layering of sedimentary rocks of different friability are observed. At Gale crater, near surface rocks are sedimentary, porous [8] and sampling by NASA’s Curiosity rover [9] shows that rocks are weak with porosities in the range of 40% [15]. To date, how do the geological properties of Mars-analogue poorly-lithified and porous rocks translate into seismic wave properties have not been studied. Such analogue sedimentary rocks can be found in the Waitematā Group in Auckland. Porosities of such samples range from 18-52%, with a direct correlation to lithification. The P- and S-wave speeds on dry Waitematā sandstones are within the range of near surface P- and S-wave speeds measured by InSight [10,11] (SEIS, Figure 1). Moreover, the presence of ice in the pore space in such weak rocks also predicts the InSight seismic models.

![Figure 1. The range of NASA’s InSight P- and S-wave near surface models from seismic signals is shown in grey. Symbols are laboratory data on dry porous and variably-lithified Mars-analogue samples. Values inside the plot are porosity. SEM images of three samples of different porosities/lithification are shown. Three samples are saturated with ice as shown by the light blue symbols.](image)

![Figure 2. P-wave speeds measured with a laser ultrasound system for a poorly lithified Waitematā sandstone (porosity=58%). Measurements are performed dry and with two level of relative humidity (RH).](image)
Numerical methods: In this section we briefly explain two approaches for predicting seismic wave speeds numerically. Such approaches are suggested if: 1) no real or analogue rocks from planetary systems are available for use in the experimental methods, 2) digital images of real rocks from planetary systems are available and/or 3) there is no knowledge of the geological properties of the rocks of interest.

Effective media models. Porosity and pore shape are the most important controls on seismic wave speeds. Effective media theories and models describe the rock as a combination of minerals and idealized shapes of pores. These pores shapes are mathematically described by spherical, ellipsoidal and penny-shaped pores. Examples of such theories and models are the Kuster and Toksöz, Mori-Tanaka, Differential Effective Media and the Self-consistent (SC) approximation. SC models [12,13] have been used to predict P- and S-wave speeds in the Martian crust, but all the porosity is assumed to come from one pore shape. For two rocks with the same porosity, a rock with spherical pores has a much higher wave speed than with elongated ellipsoidal cracks. Therefore, care on the selection and mixture of pore shapes is needed. Such mathematical models are commonly unconstrained and should be used for predicting ranges of possible wave speeds. The main pitfall of such models for predicting real rocks is that these are composed of a range of idealized pore shapes, each contributing differently to porosity. In addition, regolith and sedimentary rocks are more complex to model than basaltic rocks because of the granular nature of those materials.

Computerized tomography x-ray images of real Moon rocks. Wave propagation via finite element approaches [14], for example, can be performed on 2D and 3D images of rocks such as SEM or x-ray CT (computerized tomography, XCT) datasets. Apollo missions Moon rocks and meteorites have XCT data for which such numerical models can be computed. In addition, such images can be segmented (Figure 3) to extract the real range of pore shapes to model P- and S-wave speeds with effective media models. In addition, XCT or SEM images can be modified, such as adding water or ice to the pore space to predict wave speeds.

Conclusion: Elastic wave rock physics is at its infancy for planetary system applications. Identifying and experimentally measuring wave speeds and attenuation in planetary system analogue rocks should be a priority. The pressure and temperature subsurface conditions on Earth cannot be extrapolated to Mars or the Moon, therefore, experiments and numerical models should focus on predict seismic properties at extreme pressure and temperature conditions.

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