EFFECTS OF METHANE CLATHRATES ON THERMAL AND SEISMIC PROFILES A. G. Maruasiak[1], M. P. Panning[1], S. D. Vance[1], E. Carnahan[2,3], M. A. Hesse[2,3], and B. R. Journaux[4]. [1]California Institute Technology, Jet Propulsion Lab, 8200 Oak Grove Drive, Pasadena CA 91109. marusiak@jpl.nasa.gov, [2]Department of Geological Sciences, The University of Texas at Austin, Austin TX. [3]Oden Institute of Computational Engineering and Science, The University of Texas at Austin, Austin TX. [4]Department of Earth and Space Science, University of Washington, Seattle WA.

Introduction: Methane clathrates are expected to be stable throughout Titan's surface ice shell (*1*, *2*). Methane clathrates may play a vital role in replenishing methane in Titan's atmosphere (*3*, *4*) and may also affect the habitability of Titan's subsurface ocean. Due to differences in thermal and physical properties of methane clathrates and pure water ices, the thermal and seismic profile of Titan will depend on the ice shell's composition. If the differences are significant, then a seismometer may be able to recover a seismic velocity profile that can help constrain the composition of Titan's ice shell. Here, we compare the thermal and seismic velocity profiles of Titan for a pure water ice, pure clathrate ice shell, and various clathrate lid models. We further compare the resulting seismic waveforms, created by AxiSEM (*5*) and InstaSEIS (*6*) software to determine methods and approaches for constraining composition through seismic investigations. Our results will be applicable to the upcoming New Frontiers class mission, Dragonfly (*7*), set to land on Titan in the 2030's.

Methods: To investigate the interior structure of Titan, we use PlanetProfile (*8*), an open-source software available on Github. Recently, PlanetProfile has been updated by integrating another open-source software, SeaFreeze (*9*), also available on Github. SeaFreeze can compute thermodynamic properties and seismic velocities of ice phases Ih-VII, including liquid water, as a function of temperature and pressures up to 2300 MPa, thus encompassing the entire expected range of Titan's hydrosphere and cryosphere. PlanetProfile creates one-dimensional self-consistent geophysical models that allow us to test how temperature at the ice-ocean interface and ice-shell composition can affect the thickness of internal ice layers, presence of high-pressure ices, and thicknesses of conductive and convective interiors.

For our simulations, we assume the ocean has a composition of 10% $MgSO_4$ and the temperature at the ice-ocean interface was 252 K, 262 K, and 266 K. These temperatures create ice shell thickness of 58 km, 85 km and 148 km, respectively. We assumed if high-pressure ices exist beneath the ocean, the composition is purely water ice. The silicate interior also remains the same across all models.

To calculate how methane clathrates may differ from pure water ice, we use parameters from the literature (*10–13*), to calculate properties including density, seismic velocity, and specific heat which are dependent on pressure and temperature. For methane clathrates thermal conductivity, we assume a constant value of 0.5 $W(m\ K)^{-1}$ (*14*, *15*). We began with end-member scenarios of pure water ice and pure clathrate surface ice shells. We then tested how clathrate lids will affect the ice shell thermal and seismic profiles.

Results: Our initial scenarios show that clathrates would greatly reduce the heat flux across the ice-ocean interface, increase the temperature of the convective regime, and increase the conductive lid thickness (Fig. 1).

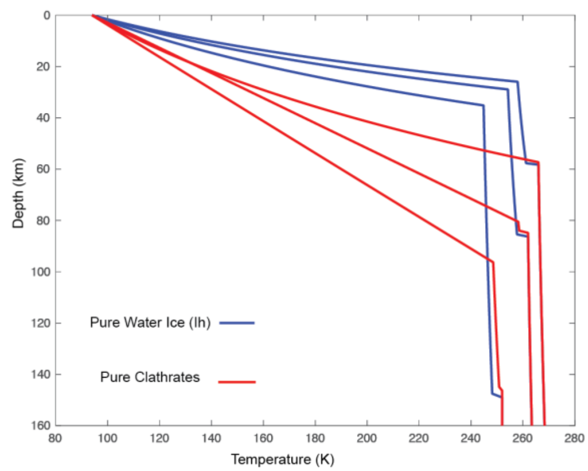

Fig. 1. Clathrates (red) have thicker conductive ice shells compared to pure water ice shells (blue). The temperature of the convective regime is also increased compared to pure water.

The change in thermal profile will result in changes in the seismic velocity profile (Fig. 2). At the surface, where pressure and temperature are the same in all models, clathrates have lower compressive wave velocities (V_P) and shear wave velocities (V_S). At greater depths (> 25 km), pure water ice models have lower temperatures than pure clathrates. Where both compositions convect, clathrates have slower V_P but faster V_S, resulting in smaller ratios of V_P/V_S.

The change in velocity structure will affect the arrival times and observable distances of seismic phases

(Fig. 3). The software, TauP (*16*), was used to compute the travel-time moveouts using the output models from PlanetProfile. For models with the same ice shell thickness, models with a clathrate composition had later arrival times at short distances (<2º epicentral degrees). For distances > 8º, the clathrate models predict earlier arrival times. Reflections off the ice-ocean interface were observable over slightly different distances and had differences in arrival times. For a 58 km thick shell, *S* reflections are observable at 26.4-51.5º for clathrates and 25.8-50.9º for pure water ice models. The arrival times for the reflections differed by ~ 2.5 seconds for events with the same epicentral distances.

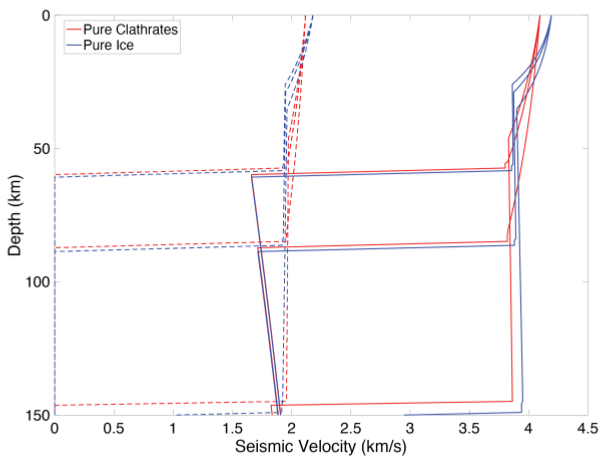

Fig. 2. Seismic velocities for pure clathrate models (red) and pure water ice models (blue). Shear wave (dotted) and compressive wave (solid) for clathrates are initially slower in the near surface (<25 km depth), but become faster where clathrates remain conductive while water ice convects.

In addition to the changes in arrival time and observable distances. There were also small differences in the amplitudes the seismic waveforms. Waveforms from nearby events (< 2º epicentral distance) would have greater amplitudes if the ice shell was composed of clathrates. If the events at occurred at greater distances (e.g. 30º), then an ice shell composed of pure water ice would produce greater amplitudes.

Summary: If clathrates are present in Titan's ice shell, their effects on Titan's thermal and seismic profile may be observable. The differences on individual waveforms are subtle. Low uncertainties in arrival times (<1 s) of seismic phases and the distances (<1 º) at which the event occurred would be ideal. Low uncertainties in individual events would allow for a more accurate seismic velocity structure recovery.

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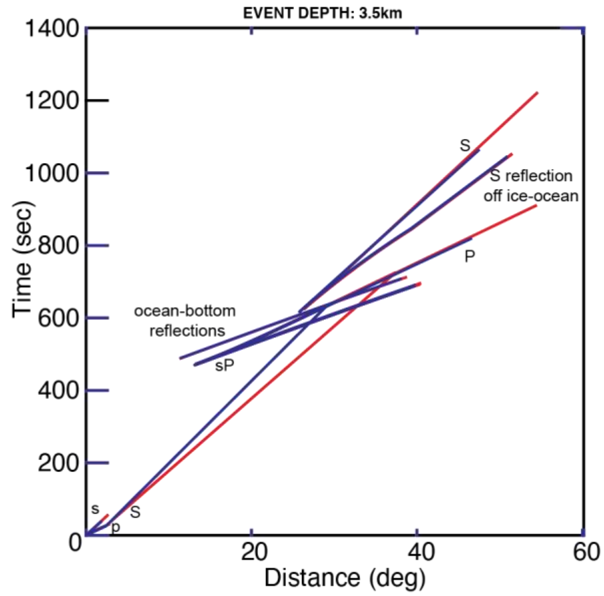

Fig. 3. Travel-time moveout curve for pure clathrate (red) and pure water ice (blue) shell models with 58 km thick surface shells. Created using TauP software.

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