TESTING DOMAL FORMATION MECHANISMS ON CERES. D. Y. Wyrick[1], D. L. Buczkowski[2], and H. G. Sizemore[3], [1]Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78238, dwyrick@swri.org; [2]Johns Hopkins Applied Physics Lab at; [3]Planetary Science Institute.

Introduction: The dwarf planet Ceres, located in the asteroid belt, defied pre-Dawn mission predictions by presenting a more complicated geologic history than expected, throwing many hypotheses on its origin and formation back for reconsideration. Ceres' has been postulated to have significant water however; recent findings from Dawn have raised new questions about Ceres' internal structure and composition. Current Ceres data suggest a likely differentiated dwarf planet with a strong lithosphere (although still ice-rich), with signs of geological activity, including evidence of resurfacing, bright salt deposits, and potential cryovolcanism [1,2,3,4,5]. However, the evidence for significant stores of near surface water ice is still lacking: crater relaxation models suggest limited ice (<40% by volume) can be present in the near subsurface [6] and observations of sublimation features are surprisingly rare [7]. An intriguing clue into Ceres' subsurface may be found in the observation of large domal features found globally, but not uniformly across Ceres [8]. These uplift features may represent solid-state mass migration such as salt doming [8] or cryomagmatic activity [8,9], both of which inform Ceres' internal state and composition.

This project seeks to extend our current understanding of the underlying mass migration creating the domal features in order to provide constraints on several competing hypotheses for the composition and mobility of Cere Using the Dawn Framing Camera (FC) data, we are analyzing the domes and domal uplift regions (and associated geologic features) on Ceres to constrain the volume, depth, and shape of the subsurface mass migration that created them. In general, these domes and uplift regions show morphometric signatures similar to both salt doming (solid state) and cryomagmatic plume (liquid-to-solid state) tectonics, suggesting similar terrestrial analyses can provide estimates of the mass geometry and thickness of the deformed host rock units.

Scaled physical analog experiments are being performed to constrain the underlying properties of the mass movement and the deformation patterns that arise for direct comparison to Ceres. In this study, we are agnostic to the composition of the mobile material, focusing instead on the geophysical and geometrical behaviors in the subsurface. The subsurface mobility of material produces surface deformation features such as fracture patterns and dome slopes that are unique to one geophysical processes or the other (or conversely, some characteristics are common to all domal forms), which provide constraints on the underlying geometry of the subsurface mobile material and the volume of displaced rock above. Determining the specific styles of subsurface mass movement will, in turn, constrain the subsurface composition and formation hypotheses of Ceres' shallow subsurface. We hope to increase the current understanding of the underlying mass migration creating these domal features in order to provide constraints on several competing hypotheses for the composition and mobility of Ceres' shallow subsurface.

Methodology: Our experiments test the evolution of mass migration and characterize the strain produced by varying planform shapes, topographic peaks and slopes, and crustal thickness. These experiments are designed to mimic data observations made by the Dawn mission of the domal surface expression. We use a wet clay cake as an analog for Ceres' brittle upper crust. The clay cake is a precisely controlled mixture of kaolin, silicate mineral fines and water [10] and is similar to that used in earlier experimental modeling studies of Ganymede [11]. It is composed mainly of kaolinite particles (<0.005 mm in diameter) and water (~40% by weight) and has a density of 1.55–1.60 g cm-3. Its coefficient of internal friction is ~0.6, with a cohesive strength is ~120 Pa [10,12,13]. For cryomagma experiments, dry Oklahoma #1 sand, sieved to 500 µm, is used as the main analog for the brittle upper crust. This material behaves in a time-independent manner at the low strain rates used in the experiments and its material properties and behavior have been well-documented [12,13,14,15,16]. Paraffin wax is used as a magma analog as it is capable of preserving the three-dimensional structure of the intrusive body relative to the surrounding host rock. The paraffin is kept liquid at 66°C [150°F] until injected into the overlying dry sand pack, which is cooled with dry ice. An average of 300 cm3 of wax is injected in the experiments over 1 to 3 seconds before cooling and hardening of the magma body.

Preliminary Results: Preliminary efforts are exploring the role of layer thickness on the fracture patterns that arise from domal uplift. Layer thickness is varied between 1.5 to 5 cm thickness (representing ~1.5 to 5 km of crustal material). Stratigraphic unit thickness controls the degree of curvature, and thus can influence the overall dome morphology. Fracture development over the domes is documented as a function of layer thickness for comparison to Ceres' domal fractures.

Experiments to test the effects of a freezing lens of water and the mobility of low viscosity/low density materials are being explored as new results from the Dawn mission emerged (Fig 1). We also have planned a number of set planform shapes, including a circle, ellipsoid, and "ribeye". Planned efforts include testing the effects of varying uplift magnitude and shapes. For these models, the rate of vertical uplift will be controlled to mimic the asymmetrical domes found on Ceres. Careful layering and placement of thin rubber sheeting is used to retard the inflated bladder to create asymmetric uplift in the models. Also, injection experiments designed to model the effects of magmatism on domal shapes are planned. These models will be performed using cold, dry sand layers of 4-10 cm thickness. Liquid paraffin wax is injected under pressure under the sandpack through rubber tubing. The wax injects and solidifies within seconds of emplacement and the sandpack is then wetted and dissected to determine the surrounding host rock deformation. The fracture patterns are then used for comparison to domal features on Ceres to determine what effect magmatism has on the overall deformation pattern

Fig 1. Centimeter-scale analog experiment a subsurface ice lens freezing to create a signature pattern of extensional fractures.

References: [1] (Bowling et al., LPSC 2016, #2268, [2] Castillo-Rogez et al., LPSC 2016, #3012, [3] Krohn et al., LPSC 2016, #2001, [4] McCord et al., LPSC 2016, #1607, [5] Pieters et al., LPSC 2016, #1383, [6] Bland et al., *Nature Geo* (9), 538-542, 2016, [7] Sizemore et al., LPSC 2016, [8] Buczkowski et al., 2016 [9] Ruesch et al., 2016 [10] Eisenstadt & Sims, 2006, [11] Sims et al., 2014, [12] Withjack et al., 1990, 1995; [14] Cloos, 1968; Withjack and Jamison, 1986; [15] Krantz, 1991.

Acknowledgement: This research is supported under the NASA Discovery Data Analysis program # 80NSSC17K0457.