ANALYZING SURFACE STRUCTURES ON I CY SATELLITES: A PHYSICAL ANALogue MODELING APPROACH. E. J. Leonard¹, A. Yin¹, R. T. Pappalardo², D. A. Patthoff², and J. Lin¹. ¹University of California Los Angeles, Earth, Planetary and Space Science, erinleonard@ucla.edu, ²Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

Introduction: The existence of global oceans on some icy satellites—Europa and Enceladus, for example—implies the presence of a ductile warm ice layer. However, the role of such a ductile layer in controlling icy-surface deformation has never been systematically investigated nor quantified. We aim to address this issue by combining previous observations from geomorphological mapping of surface features on icy bodies [1] with a unique two-layer analogue model containing an overlying brittle layer and a ductile creeping layer.

Although analogue models have been widely used for tectonic studies on Earth [2], they have only rarely been adapted to the studies of the icy-surface deformation [cf., 3] Using the analogue experimental approach and analyzing the effects of a subsurface ductile layer, we will gain understanding of different formation mechanisms for surface features and aid in reconstructing the resurfacing history of icy satellites such as Europa.

Procedure: The basic analogue model consists of a ductile, lower viscosity layer underlining a cohesive brittle layer. We initially use therapeutic putty with a measured viscosity of about 10⁴ P•s for our ductile layer and fine-grained sand for our brittle layer. We chose these materials for our initial experiments because they will scale up properly to conditions on Europa. For example, if we scale with the cohesive strength of our sand (~60 Pa) and use well accepted values for Europa [4], we get a scale where about 1 km on Europa corresponds to 1 cm in our model, or 10⁻⁵ scale factor [5].

To set up the experiment, we first layer the putty into a low-walled box. Because the putty is ductile, but still fairly viscous, we let it relax to a flat surface over the course of a few days before adding the desired amount of sand. We also create a 1 cm x 1 cm grid of blue marker sand on top of the experiment to aid us in keeping track of how much extension or contraction is occurring.

For experiments where we want to simulate extensional processes, we eliminate one of the box walls causing the ductile material to flow out, creating uniform contraction in the brittle surface layer.

Initial Results: We began the analogue experiments by varying the thickness of the brittle layer, 0.25 cm, 0.5 cm, and 1.0 cm, to study the effects on the surface features. The experiments are run over the course of about 6 hours, scaling to 10³ yrs on Europa [2]. By varying the thickness of the brittle layer, we are effectively studying the effect of varying heat flux on the surface morphology. For example, an icy body with a higher heat flux would have a thinner ice shell and therefore a thinner brittle layer.

Extension. In the extension experiments, we see the spacing of resulting normal faults in the brittle layer increase with the increasing thickness of the brittle layer (Fig. 1). We expected this result based on past work on normal fault spacing on Earth [6, 7]; thus this

Figure 1: Analogue model with 2-cm thick putty layer below a brittle sand layer that is 0.25 cm (A), 0.5 cm (B) and 1.0 cm (C) thick, respectively, under ~30% extension. Note that the structural spacing and morphology vary with a sand-layer thickness. Common scale.

Figure 2: Preliminary data from extensional experiments using sand (see Fig. 1). The average normal fault spacing is ~1.4 times the depth of the brittle layer.
The experiment serves as a conceptual test for our analogue model.

However, from the preliminary data, we get an average normal fault spacing of ~1.4 times the depth of the brittle layer (Fig. 2). This is lower than what is expected for Earth [6], and we will explore this discrepancy further as the experiments progress and in the future work.

**Compression.** In the compression experiments, we see an increase in the wavelength of resulting folds with the increase in the thickness of the brittle layer (Fig. 2). The smallest scale folds occur when the brittle layer is thin which is in agreement with previous computer models [8] and high-resolution observations of Europa’s surface [1]. However, kilometer scale folds are also potentially present on Europa, indicating that the brittle layer, and thus the heat flow, may have changed over time (Fig. 4).

**Future Work:** As we continue to develop our model, we will make many improvements to the experimental variations. The first variable we intend to introduce is different brittle materials. The conditions on the surface of icy satellites such as Europa are relatively unknown and some properties, such as porosity, could even vary across the surface [9]. By testing a variety of brittle layer materials in our analogue model and analyzing any effects on resulting surface structures, we could potentially place limitations on the surface conditions as the time of surface structure formation.

Additionally, in order to further delve into the relationship of surface structures with the presence of a ductile layer, we plan to vary the viscosity of the ductile layer by selecting different model materials. We will also introduce a more realistic brittle-ductile transition. In our current model, the transition is abrupt, with the brittle material directly in contact with the ductile material. In order to include a more realistic transition we will introduce a third layer, a mixture of the two materials, in between the two current layers. This additional layer would represent the brittle-ductile transition and allow us to analyze whether the nature of this layer has an effect on the resulting surface structures.

For icy satellites with a recognized resurfacing history, we will run experiments with multiple episodes of deformation. For example, since Europa is thought to have a very young surface, on the order of 60 million years [10], it must have active or recently active resurfacing mechanisms. Thus, Europa’s surface today is made up of the superposition of these resurfacing events or else pre-existing structures are completely erased. We can compare and analyze these two possibilities in the analogue model by creating multiple episodes of extension or compression and analyzing the resulting surface features.

**Implications:** By creating a two-layer analogue model for icy satellite surface deformation, we will gain insight as to how the brittle surface and the ductile subsurface interact on these bodies to form the surface structures that we observe. This interaction has implications for the resurfacing history of such bodies and could potentially reveal current or past ice shell thicknesses when the surface structures formed. Additionally, we will be able to constrain the rheology and mechanisms controlling the formation of surface structures on icy bodies such as Europa.

**References:**