PROBING THE EFFECTS OF SHALLOW LIQUID WATER ON CRATER FORMATION. M. R. Huffman[1], J. P. Kay[1], A. R. Rhoden[2], and A. M. Stickle[3], [1]The College of William & Mary, Williamsburg VA, 23185, [2]Southwest Research Institute, 1050 Walnut St., Boulder, CO 80304, [3]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, MD, 20723. (mrhuffman01@email.wm.edu)

Introduction: Bolides probe into the mechanical structures of planetary bodies, leaving behind craters whose morphologies and temporal evolution (e.g., relaxation) aid in constraining the thermal evolution and age of the body. However, much is unknown about how crater formation and modification differ on icy, ocean worlds versus rocky ones. Recent work has shown that the presence of an ocean under an ice shell may affect crater depth, which suggests that there may be a mechanism by which oceans can be identified from observed crater morphologies [1-3].

Europa, an ocean-bearing moon of Jupiter, may also have pockets of liquid water or icy slush within its ice shell. Liquid water has been implicated in the formation of large-scale (100s of km in diameter) chaos features as well as small-scale (<10 km) chaos, pits, and uplifts. Some models imply liquid water pockets may be present within the upper few km of the ice shell [4]. We explore the effects of shallow water pockets (i.e., sills) on impact crater morphologies, using the shock physics code iSALE. The goals of our work are to better understand crater formation on non-homogenous icy surfaces and to identify morphological characteristics that are diagnostic of low viscosity layers within an ice shell.

Methods: Many factors affect crater shape, including gravity, material properties of the crust and the impactor, impactor energy, and subsurface structure. Larger and faster impactors will excavate larger volumes of sub-surface material, which would change the morphology of the resultant crater. The thickness of the ice shell has been widely debated with estimates that range from 2km – 30km [3]. Previously, impact modeling has been used to estimate the thickness of the ice shell based on resultant crater morphology [5]. This study found that the ice shell must be greater than 4 km thick.

To investigate the influence of shallow subsurface complexities, specifically layer viscosity and depth, on Europan crater formation, we performed several impact simulations using the iSALE hydrocode (version iSALE-dellen) [6-8]. As part of this study, we are not aiming to reproduce any specific crater on Europa, but rather to examine a generic Europa-like body.

Here, we examine a variety of cases with a 1km thick liquid water layer at various depths (1km, 5km, and 10km) from the surface (Figure 1 & Table 1). We used a 0.62 km projectile made of water ice impacting at 15 km/s.

We selected impactor parameters based on typical values for Jupiter family comets because they are thought to be the source of the vast majority of craters on the Galilean satellites [9]. In our simulations, the model resolution is 31m per grid cell, to better illustrate the damage resulting from a small impactor. To keep the initial analysis simple, a small impactor size was chosen to ensure that craters remain in the "simple crater" category. Subsequent investigations will explore more complex crater morphologies.

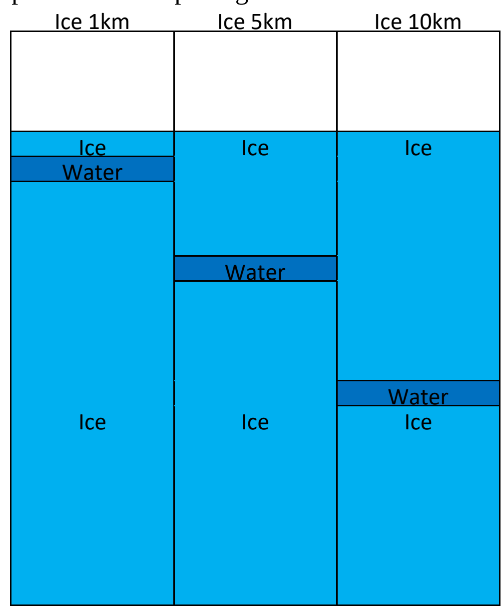

Figure 1: Schematic of layers used for model runs. The three models have a 1km thick water pocket at various depths (1km, 5km, and 10km, respectively), overlying more ice.

Results and discussion: Figure 2 shows results for three different simulations: a) a 0.62 km projectile impacting into ice with a 1 km deep low-viscosity layer, b) a 0.62-km projectile impacting into ice with a 5 km deep low-viscosity layer, and c) a 0.62 km projectile impacting into ice with a 10 km deep low-viscosity layer. Damage and yield strength fields are shown 50 sec after the impact. There is a major difference between the 1km depth and the 5km and 10km depths, as the bolide penetrates through the top ice layer and the low-viscosity layer. The two craters of the 5km and 10km depths are similar sizes, but there are some differences in target damage, yield strength, and crater morphology observed when a low-viscosity layer is closer to the surface. The depth of the low-viscosity layer also affects the volume of fall back material that remains in the crater, even in the two deeper layers. The fallback material will, however, be proportional to the size of the impactor. Larger impactors will probe deeper into the crust than smaller projectiles, which increases the influence of a potential low viscosity layer at depth.

With our current model resolution and impactor size/velocity, there does not appear to be a major change in the d/D ratio beyond the presence of fall back material. This is something we will explore in further simulations. Note that the edge effects are likely due to the size of the simulation, and do not affect the crater size itself. In future simulations, we will increase the model size to reduce these effects further.

Future work: For follow up work we would like to investigate the effects of differing viscosities and depths. In addition, we would like to explore a larger range of impactor sizes, angles (only possible in iSALE 3D), and velocities.

Table 1. Summary of initial model setup conditions

		Ice 1km	Ice 5km	Ice 10km
Layer 1	Thick (km)	1	5	10
	Visc (Pa*s)	1E+22	1E+22	1E+22
Layer 2	Thick (km)	1	1	1
	Visc (Pa*s)	0	0	0
Layer 3	Thick (km)	17	13	8
	Visc (Pa*s)	1E+22	1E+22	1E+22

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References: [1] Carr et al., (1998) Nature 391, 363-365. [2] Pappalardo et al., (1999) JGR Planets 104, 24,015-24,055. [3] Billings S.E. and Kattenhorn S.A., (2005) Icarus 177, 397-412. [4] Schmidt et al., (2011) Nature 479, 502-505. [5] Turtle E.P. and Pierazzo E., (2001) Science 294, 1326-1328. [6] Amsden et al., (1980) Los Alamos National Laboratories Report, LA-8095:101p. [7] Collins et al., (2004) Meteoritics and Planetary Science, 39:217--231. [8] Wünnemann et al., (2006) Icarus, 180 514-527. [9] Zahnle et al., (2003) Icarus 163, 263-189.

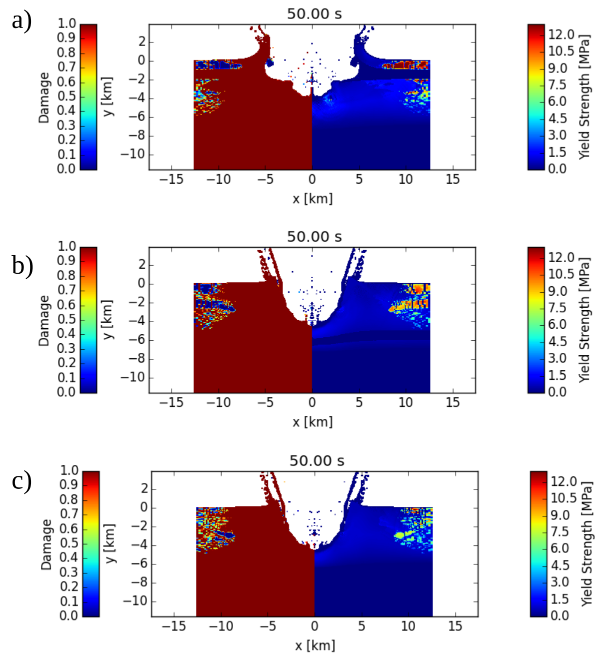

Figure 2: Three of our sample model results. a) A 1km thick liquid water layer 1km deep, b) a slightly deeper liquid water layer (5 km), c) a liquid water layer at 10km deep. In each of the figures, the Damage caused by the bolide is plotted on the left (out of one) and the Yield Strength is plotted on the right (MPa). For consistency, we plotted each simulation after 50 seconds.