HYPERVELOCITY IMPACTS INTO MULTI-LAYER TARGET WITH AN ICE CRUST OVER A SUBSURFACE OCEAN K. H. McDermott[1], M. C. Cole[1], M. J. Burchell[1], [1]School of Physical Sciences, University of Kent, Canterbury, UK, CT2 7NZ, k.mcdermott@kent.ac.uk

Introduction: It has long been theorised that a subsurface ocean may exist below the ice crust surface of the icy moons of Jupiter, Callisto, Ganymede and Europa [1]. The presence of water below an ice crust may have substantial effect on cratering mechanisms that occur on the surface depending on the severity of the impact and the thickness of the ice crust. The Galilean moons have been well studied by flyby missions such as Cassini and Voyager 1 and 2, and a number of geological features thought to be linked to cratering have been observed. These features on the surface of Europa and other icy satellites include: (1) large multi-ringed shallow impact craters such as Tyre, Callanish and Mananian, formed as a result of impact bodies between 2- 4 km in diameter [2] thought to have penetrated the ice crust; and (2) chaos terrain characterised by broad areas where large blocks of original terrains occur in a structureless and hummocky matrix, with a texture that resembles detached ice bergs left to drift before the whole region refreezes.

These features vary in size and complexity, which may be linked not only to the variation in the size and speed of each individual impact but also to variation in the target surface parameters. Target surface parameters which can lead to variation in crater morphology include density, porosity, water content and internal strength (fracturing etc.).

The presence of a subsurface layer below an ice surface may result in the crater morphology differing from that produced in a solid ice target. The ice crust on Europa is thought not to be homogenous in thickness [3, 4], therefore the variation in the geological features linked to cratering may be the result of varying ice crust thickness at the impact sites. Here we investigate this effect by observing crater morphology produced in multi-layered targets in lab experiments, similar to the hydrocode modelling work previously reported by [5]. We report on the impacts into a target of water ice (thickness between 1 and 2 cm) over a liquid water sub-surface. These results are also compared with those at 5 km s^{-1} within abstract #**1219** at this meeting, in which similar experiments were conducted on a target of water saturated sand with a surface ice crust.

Experimental method: The impacts were produced using the two stage light gas gun based at the University of Kent [6]. 1.5 mm Al spheres were loaded into a nylon discarding sabot and fired at targets at a speed of ~ 5 km s^{-1}. Each target was prepared so that the required ice thickness would be completely frozen with few blemishes and no cracks to act as weakened areas of the target. The ice formed downward from the open top surface of a cylindrical flask of water, and the thickness required for each investigation was determined by varying the time interval the target remained within a -20°C environment. Once placed in the target chamber a metal ring cooled to -140 ^{O}C was placed on the target to prevent the edge of the target melting and the water inside escaping.

Results:

10 mm ice thickness:

The impact produced a bullet hole shaped penetration of the ice forming an irregular rounded hole in the ice with steep sides and no surrounding terrace. Secondary fracturing from the point of impact was complex and dense with numerous radial fractures extending away from the point of impact. A mixture of thin short and longer wider fractures was observed with the thin short group existing only around the crater. Away from the crater the longer fractures were connected by fractures parallel to the crater rim, together forming a spider web effect of numerous fractures that extending into the ice layer a few mm. All the impacts produced circular fractures, in this case two circular fractures were observed at the furthest edges of the target.

10 mm – 15 mm ice thickness:

There were 3 shots in this group and all produced penetrating fractures which have very similar diameters (40 – 50 mm). One crater produced at this speed contained a steep sided step terrace within the crater that extended a few mm away from the crater wall. Small thin fractures were common at the crater edge with larger radial fracture extending away and splitting as the fracture propagated through the ice. The fracturing was not as dense as that observed with the thinner ice targets with less spider webbing-like fractures. All these shots developed complete circular fractures about 30 – 40 mm away from the crater edge.

Solid ice (Standard): Uniform ice targets, 80 mm deep were used as a control (i.e. effectively semi-infinite ice tarets with no liquid sub-surface). The craters produced in these targets contain clear simple crater structures (see [7,8] for previous reports). The craters included numerous radial fractures extending away from the point of impact, often forming terraces as surface ice was removed away during the impact. In addition to radial fractures, which evened down from the ice surface as well as away from the point of impact, circular fractures were observed up to 5 cm away

from the point of impact. These fractures encompassed the whole crater and connected the radial fractures together. The circular fracture can be clearly observed, however such fractures often lie within the ice without reaching the surface. In the full ice targets this feature was only observed for impact speeds of 5 km s^{-1} and were absent at lower speed (also see abstract #**1219**). This feature bears a resemblance to the rounded fracture observed as part of the larger of Europa's craters such as Callenish crater, suggesting that this area of the Europa has a thick ice crust that was impacted without interacting with any subsurface medium. However this feature was not observed in the solid ice target impacted at 1 kms^{-1} suggesting that such a feature is not wholly a result of homogenous medium thickness but also the impact speed.

Discussion: The variation in the crater dimensions based on the ice thickness at the chosen speed of 5 kms^{-1} is the size of the bullet hole and the density of the fractures produced within the target. The densest fracturing and the widest crater was observed in the crater formed within the thickest (solid ice) target. The circular fractures that are observed in all 5 kms^{-1} shots may be a result of the limitations of the target being only 210 mm in diameter, however this has not been proven and larger area targets will be made to test this.

This work was initially done to see if a substrate below the ice crust would result in a difference in the crater produced. When compared to the result from abstract #**1219** it appears that for similar ice thicknesses there is little variation with the crater formed in the ice over saturated sand (abstract #**1219**) to that observed in the ice above the liquid water substrate (Fig. 1).

This may be because the saturated sand contained a high volume of water and therefore there is little density variation between the two substrates resulting in similar cratering and fracturing being observed. Future work will use basalt as the substrate and observe the cratering and fracturing rates within the ice to compare to this work.

So far this initial work has shown that the thickness of the ice has an effect not only on the size and depth of a crater but also the density of fractures related to the crater. However, these is little to no difference between the craters produced in the ice crust over water and water saturated sand, implying that currently the crater characteristics cannot aid in the possibly identification of the substrate material.

References: [1] Carr M. et al. (1998) *Nature 391*, 363-365[2] Zahnle K. et al. (2003) 263-289 [3] Turtle et al. (2001) *Science 294*, 1326-1328 [4] Schenk P. (2002) *Nature 417*, 419-421 [5] Bray V. et al., (2014) *Icarus 231*, 394-406 [6] Burchell M. et al. (1999) *Measurement Science and Technology 10*, 41 – 50. [7] Shrine N.R.G et al. (2002) *Icarus 155*, 475-485 [8] Fendyke S. et al. (2013) *Advances in Space Research 52*, 705-714

Figure 1: Comparison of the crater produced in an ice crust over water and that over saturated sand (# **1219**). Red symbols – Saturated sand; Black symbols – Water substrate. Circle – 80 mm thickness, Square – 30 - 50 mm thickness, Diamonds – 10 - 20 mm thickness Triangular – 1 - 10 mm thickness,. Error bars represent 1 σ standard deviation.