IMPACT EXPERIMENTS ON MULTI-LAYER TARGETS WITH AN ICE CRUST.

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Introduction: Remote sensing is a significant tool that has identified numerous geological features on planets, moons, asteroids and comets within our solar system. One of the more common evidence features in images are impact craters preserved on surfaces including ice moons and ice bearing regions of other celestial bodies. It has long been theorised that in the depths of Europa and other Jovian ice moons lay liquid water oceans [1]. It is thus interesting to ask if the morphology of craters exposed on the ice crust can provide an indication to the subsurface density or the thickness of the ice crust.

Features on the surface of Europa for example 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.

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 based on computer simulations of observed crater features e.g., [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].

Accordingly, we have been investigating the variation in crater morphology with the density of the subsurface material by firing 1.5 mm Al projectiles at a range of targets.

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 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. The ice was then placed over a subsurface material and then placed in the target chamber. A metal ring cooled to -140 °C was placed on the target to prevent the edge of the target melting and the water sub-surface inside escaping.

Impacts directly into water ice targets have been extensively researched [e.g. 7, 8] which provided a method for producing clear unblemished ice targets that was then modified for this study.

Results:

Ice over Water:

Impacts into ice above liquid water were conducted at 5 km s^{-1} with variations of ice thickness between 5 - 50 mm, with a constant total target depth of 80 mm. The craters produced formed two groups: those that punctured through the ice crust (penetrative) and those in which the crust thickness was sufficient to contain the craters (non-penetrative). The penetrative impacts were recorded in ice crust thicknesses up to 19 mm. The impact produces a rounded, steep sided hole in the ice crust. Around the edges of this hole multiple radial fractures were observed with longer fractures extending away into the target up to 100 mm. In ice thicknesses over 10 mm circular factures were also observed around 50 mm from the edge of the target. The diameter of the penetrative hole increased with ice thickness.

The non-penetrative impacts produced larger rounded craters, with radial cracks extending away into the target both across the surface and down into the ice crust

Ice over Sand:

Impacts into a target of ice placed in contact with a saturated sand basement were conducted with a range of ice thicknesses from 5 – 30 mm at three different speeds 1, 3 and 5 km s^{-1}. At 5 km s^{-1} the crater morphology was similar to that observed in the ice over water targets with penetrative impacts occurring in ice thicknesses up to 20 mm. Deep craters were preserved in the sand below the bullet hole/crater in the covering ice. The depth of the crater within the sand remained constant for thicknesses of the ice crust up to 17 mm. Between 5 and 7 radial fractures spanning from the point of impact were observed in each shot. Circular factures were only observed in one target. For ice thickness greater than 20 mm the impact resulted in extensive damage to ice crust which remained in place above the base. The impact crater was only recognizable from the white crushed ice at the point of impact but the radial features were so numerous that perpendicular fracturing joined them together creating a spider web like fractured surface across the whole target surface.

At the lower speeds (1 and 3 km s^{-1}) no circular features were observed and the radial fractures were less common, forming long well defined fractures in the crust.

Ice over basalt:

For a distinct change in subsurface densities and to simulate ice over primitive chondritic/basalt material as can be found on asteroids or the surface of Mars, basalt was the final subsurface material tested. Ice thicknesses of 10 -17 mm and impact speeds of ~5 km s^{-1} were used. The craters produced in the ice were significantly different to those previously described. There was no penetration through the ice to the basalt. The ice instead is crushed onto the surface of the basalt forming a large shallow crater in the ice with a complexly crushed center and no exposed basalt. Radial cracks are common place and cause damage of the ice beyond the crater.

Solid Ice:

Impacts into a solid ice target (80 mm depth) were conducted at speeds of 3 and 5 km s^{-1} as a standard to compare with the other targets. The craters produced in these targets have s deep central pit surrounded by a spall zone, and can including a number radial fractures. Circular fractures were always observed in the solid ice target at an impact speed of 5 kms^{-1}. At lower impact speeds the craters were much smaller, with fewer radial fractures.

Implications:

The variation in crater morphology is obvious between the targets with basement layers on the one hand of basalt on the other hand water and sand basements. This indicates that during an impact into ice, the density or hardness of the subsurface material does result in a differing crater morphology if the contrast is great enough. The more interesting outcome of this initial work is that the thickness of the ice crust has a positive correlation with the size of impact crater produced in the ice over water and ice over sand targets. In the case of ice over basalt targets the size of the crater remains constant within error for ice thicknesses between 12 – 17 mm at a given speed. From these results the shape of the crater can provide evidence of the nature of the subsurface material. With further development of this work, the size of the crater and the fractures associated with it may provide insights about the thickness of the ice crust.

The geological features associated with impact cratering also mainly differ with increasing impact speed and ice thickness rather than the subsurface material. The circular faults observed away from the point of impact are bear 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 km s^{-1} suggesting that such a feature is not wholly a result of homogenous medium thickness but also the impact speed. The circular fractures that are observed in all 5 km s^{-1} shots may also be a result of the target being only 210 mm in diameter, however this has not been demonstrated yet and larger area targets will be made to test this.

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