Breaking the Ice! An Investigation of Impact Cratering Mechanisms that occur on Icy Moons with Subsurface Oceans.

K. H. Harriss[1], C. Fisher[1] and M. J. Burchell[1], [1]School of Physical Sciences, University of Kent, Canterbury, Kent CT2 7NH, UK. Email: K. Harriss@kent.ac.uk

Introduction:

Ice is a dominant material found on many different surfaces in the solar system from the permafrost on Mars [1] to minor bodies and making up the surface of moons [2] orbiting the outer giant planets. Therefore, understanding the geological processes that occur within this environment and bodies is important in improving our understanding and developed plans for future missions and exploration of such landscapes and worlds. One of the geological processes that are common on all bodies no matter of age; size or location within the solar system is impact cratering [3]. Previously, there have been multiple investigations into impact cratering on ice targets of different composition [4, 5, 6], and porosity [7] but the ice targets have usually been homogenous. Recent work began to investigate heterogeneous ice target [8] recreating the type of ice covered environments that have been observed in the solar system including ice over water to represent icy bodies with subsurface ocean, the theorized structure of icy moons including, Europa [2]. The work presented here is a continuation of investigations of impact cratering on heterogeneous ice target. We have investigated the variation in crater morphology and associated features such as radial and circular fractures formed when impacting a liquid-filled ice sphere (Fig. 1). It is found that the thickness of the ice crust has a correlation with the crater morphology and the extent of associated features.

Experimental method:

Making the ice spheres:

Three types of ice spheres have been impacted (Figure 1):

1. Solid ice spheres,
2. Hollow ice spheres filled with water,
3. Hollow ice spheres filled with water and a solid core.

The ice spheres were formed by placing a water-filled balloon into a plastic spherical mould and slowly freezing in a -25°C environment. The balloon is encased in insulation allowing the ice to freeze from the outside inwards creating a liquid-filled ice sphere. This method allows the ice that makes up the crust to remain bubble-free forming clear unaltered ice as the gas and impurities remain in the liquid creating an ice layer with negligible porosity.

Impact experiments:

The impact experiments were undertaken using the Light Gas Gun (LGG) facility at the University of Kent [9]. A 1.5 mm glass sphere was used as the projectile for consistency and a range of impact speed between 1 km s^{-1} and 3 km s^{-1} have been investigated (Table 1) with a range of ice thicknesses.

Table 1: Impact parameters for each ice sphere target. SIS: Solid Ice Sphere; WFS: Water Filled Sphere; WFSwC: Water Filled Sphere with Core

Target Type	*Impact velocities*	*Ice thickness*
SIS	1 – 5 km s^{-1}	N/A
WFS	1 – 5 km s^{-1}	25 mm
WFSwC	1 – 3 km s^{-1}	7 – 40 mm

Results:

Variation in Crater Morphology:

As with previous investigations, there is a direct correlation between the impact crater diameter and the thickness of the ice layer that is being impacted.

However, for different impact velocities, the relationship changes as the shock pressure increase. At 1 km s^{-1} for the ice thicknesses that we have investigated so far there appears to be no correlation between the ice thickness and the cater morphology with the crater diameter remaining constant around 50 mm, suggesting that even at a normalized ice thickness (ice thickness / projectile diameter) of 5 the ice shell is acting as a semi-infinite body. This needs to be directly compared to a solid ice sphere. For impact velocities of 2 km s^{-1} and 3 km s^{-1} there is a positive correlation between crater morphology meaning that the ice crust is not acting as a semi-infinite body as observed for 1 km s^{-1}.

Fracturing:

In addition to the major craters that form as a result of impact cratering events the shock wave passes through the target at different speeds depending on the medium and results in deformation of the target forming fractures in the surface. In most cases, regardless of ice thickness, both radial fracture and circular fractures are observed within the ice crust. The fractures have the largest plane thickness (perpendicular to the target surface) close to the crater which often resulted in sections falling away from the target seconds after impact. In some cases where the ratio between ice thickness and shock pressure was sufficient all the fracture planes extended the thickness of the ice crust resulting in complete disruption and breakup of the target.

In the cases where the fractures do not extend beyond the thickness of the ice crust the target remains whole. The radial fractures occur in a similar orientation as that observed in other brittle materials including glass [10]. Circular fractures form parallel to the crater wall (Fig. 1). In some cases, large circular fractures occur towards the back of the target away from the impact crater. In one case the crater morphology and location and length of the distal circular fracture have a similar ratio to that of the Odysseus crater and the Ithaca Chasma that is observed on the icy moon Tethys. This requires more investigation but it shows that in the lab features similar to those observed on actual icy bodies can be recreated.

Initial Conclusion:
This work is ongoing and is attempting to aid in our understanding of icy moons from remote sensing analyses alone. This work has shown that impact crater morphology can be used to gain an idea of the thickness of the ice layer which can aid in other investigations such as the search for habitable environments. This work will continue to investigate impacts into these whole bodies including a more detailed study into the effect a solid core may have on the product produced by a large impact cratering event.

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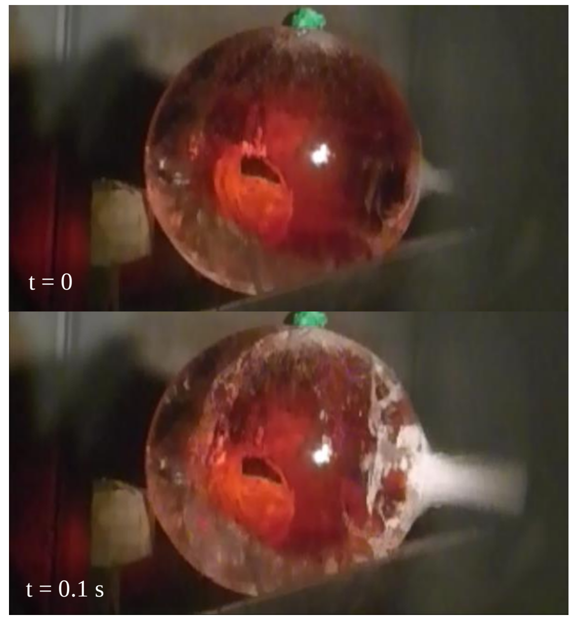

Figure 1: Still from video of 1.97 km s^{-1} impact showing the point of impact (t = 0) where fractures have yet to form and t = 0.1 s where the circular and radial fractures have formed. The red interior is the result of dying the internal water with food coloring.