

# ICE IMPACT EXPERIMENTS WITH EPIC: VALIDATION OF RESULTS AND EXPLOSIVE PENETRATION OF A PRESSURISED WATER POCKET

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**Introduction:** Impact cratering provides a key mechanism for understanding the structure and evolution of planetary surfaces. On the icy satellites such as Europa and Enceladus numerical modelling of impact cratering has been used to make inferences about the thickness and structure of the ice shells [e.g. 1, 2, 3]. Laboratory experiments are an important counterpart to such numerical modelling efforts, providing essential data for benchmarking impact codes. Here we report on a set of preliminary impact experiments with water ice performed using the Experimental Projectile Impact Chamber (EPIC) at the Centro de Astrobiología.

EPIC has a 20 mm caliber single-stage gas gun powered by compressed N<sub>2</sub>. While the projectile speed is limited to around 400 m/s, and thus subsonic impacts, EPIC has the considerable advantage that the gun is fully orientable, allowing for testing at a variety of impact angles while maintaining vertical gravity on the target. This also allows for the use of targets involving liquid, which is the original purpose for which the facility was designed [4].

**Methods:** In total we performed 8 impact experiments of which 6 used simple, pure water ice targets. In addition, we had one target with a large lens of liquid water in the centre and one salt-water ice target that had partial melt spread roughly uniformly throughout. For this preliminary test run our impacts were mostly vertical, with two oblique impacts achieved by placing the target at an angle rather than rotating the gun. In all cases we used 20 mm, 5.7 g delrin projectiles, which would partially or totally disrupt on impact, with the impact speed varying over a narrow range from 365–387 m/s. The ice targets were either rectangular 55x45 cm, or circular 43.5 cm diameter and ranged in thickness from 4 to 11.5 cm. The targets were frozen in a commercial freezer at -20°C, however the ambient temperature in the facility was 10–15°C, which led to some unavoidable pre-impact fracturing in the blocks due to thermal expansion. Examination of an unused block also revealed a fracture running across the mid-plane of the sample, likely due to expansion while freezing, that was also found to be present in all of the experimental samples. Pre-existing fractures caused some distortion of the impact craters, but this did not significantly influence the results.

**Comparison to previous work:** In Figure 1 we compare the results of our vertical impacts into simple, pure water ice targets with previous work, which clearly show

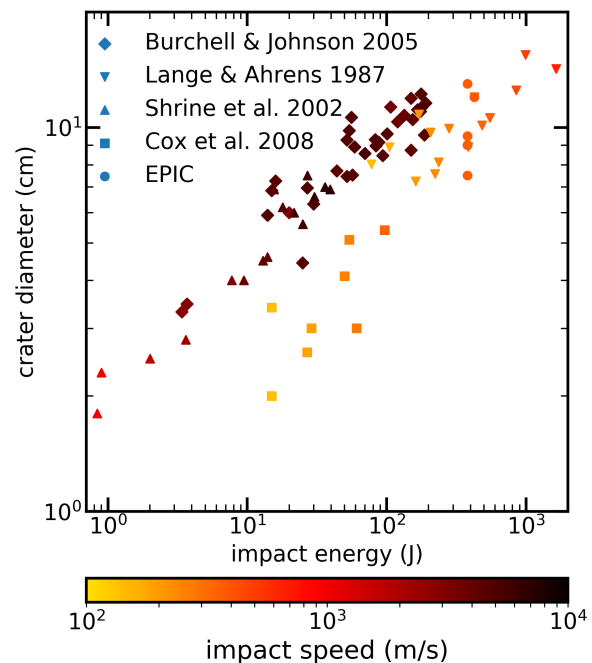


Figure 1: Comparison of the results of vertical impacts onto simple, pure water ice targets at EPIC with data from previous work [5, 6, 7, 8]. Points are coloured according to the impact velocity. The speed of sound in water ice is roughly 3100 m/s.

that the data from our impacts at EPIC are consistent with previous results. There is no clear distinction between subsonic and supersonic impacts. [6] and [7] used much smaller impactors (1.5 mm diameter) resulting in lower impact energies than our experiments despite the much higher impact velocities. [8] used ice sheets floating on water and some of the impacts shown partially penetrated the ice sheet, which is likely why some of their craters appear unusually small.

**Explosive penetration of a pressurised water pocket:** One of our targets had not completely frozen and still had a substantial water pocket in the centre of the block (Figure 2A). When the impactor penetrated the surface ice layer an explosion was observed that disrupted most of the ice above where the water pocket had been, leading to a much larger crater/area of disrupted ice than for the blocks that were completely solid (Figure 2D). Figures 2B and 2C are snapshots during the impact, show-

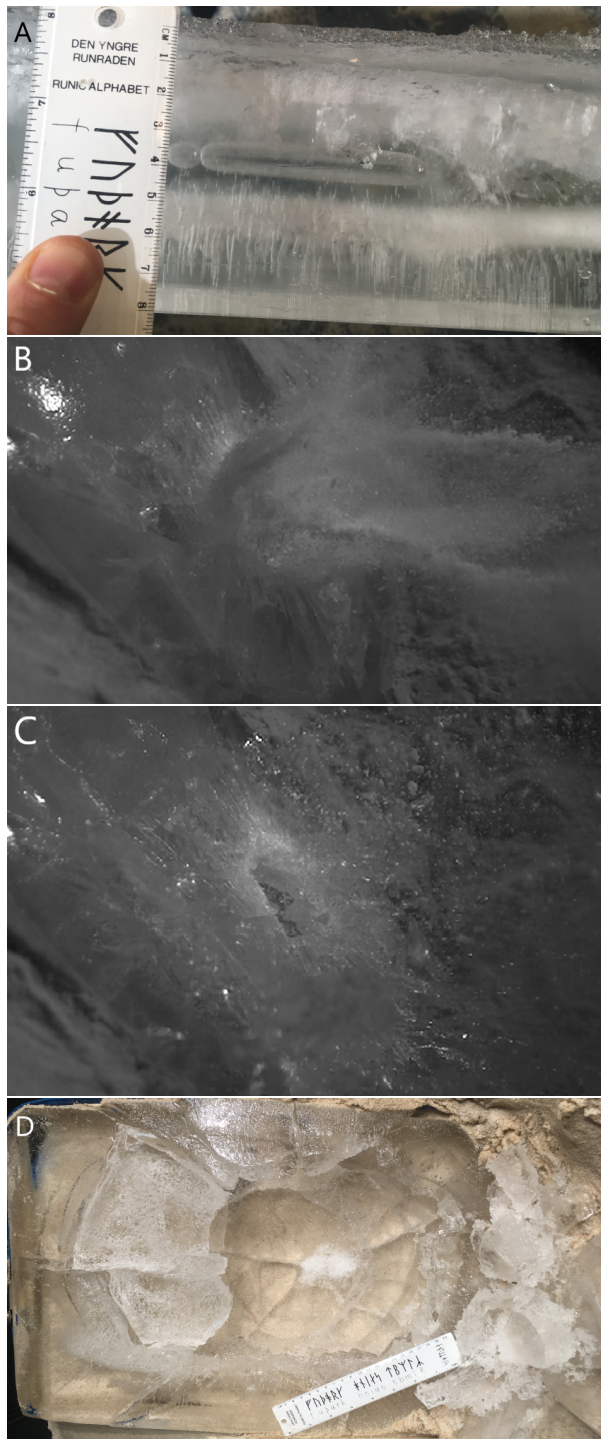


Figure 2: Images showing ice block before impact with water pocket in the centre of the block (A), snapshots during the impact (B, C), and after impact (D). Note that the block was inclined so gravity caused the fragments to fall down out of the impact site (to the right in images B-D).

ing the expansion of the oversized ejecta curtain (B) and the whole crater area beginning to detach and lift (C). The area of disruption was roughly 24 cm in diameter whereas for the completely solid targets the craters were between 9 and 13 cm in diameter for the same impact energy. This includes a completely solid target with roughly the same thickness as the top layer of the target with the water pocket.

We hypothesise that, due to the expansion of ice as it freezes, the water in the pocket had become pressurised. When the impactor penetrated and fractured the upper layer of ice this resulted in a sudden and catastrophic release of the pressure in the water pocket which further disrupted the ice.

This is particularly interesting in the context of Europa and the formation of Chaos terrain. The exact mechanism involved in the formation of Chaos terrain is not yet fully known, but a key line of investigation is the possibility of sills of liquid water within the ice shell [e.g. 9, 10]. If a sill of liquid water forms within the ice shell and becomes cut off from its deep source then as it begins to freeze the remaining water would become pressurised. An impact into this pressurised water pocket would then likely lead to much greater surface disruption than expected given the impact energy, as we found in our experimental case. Whether this would lead to something resembling Chaos terrain, or an alternative unusual impact structure is a topic worthy of further study.

**Conclusions:** We have validated EPIC for use with water ice targets, demonstrating agreement with previous experimental work. In addition, we noted an interesting explosive behaviour when impacting a target that contained a substantial pocket of liquid water, likely due to the pocket being pressurised. In future work we will perform additional experiments at a range of impact angles, taking advantage of the orientability of the EPIC gas gun, and continue to investigate targets with water pockets.

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