EXPERIMENTS WITH EXPLOSIVES AND ORDNANCE DISPOSAL DEVICES FOR THE SIMULATION OF SPECIFIC PROCESSES DURING SHALLOW-MARINE IMPACTS.

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Introduction: Most impacts on Earth strike a target covered by water. With increased interest in hazards from impact tsunamis, improved simulation softwares, and the discoveries of the now famous Chicxulub (Mexico) and Chesapeake Bay (USA) craters, the deep sea impact site of Eltanin (South Pacific), and the puzzling Alamo Breccia (USA), the interest for marine impact cratering has grown rapidly in recent years. Well-preserved marine-target craters such as Mjolnir (Norway) and Lockne (Sweden) have shown that marine impacts differ in many ways from land impacts (*e.g.*, crater morphology, melt and ejecta distribution, lithologies). The analysis of these differences often requires 3D modeling of oblique impacts into layered targets, something that is just beginning to be possible [1]. However, numerical modeling needs simplifications**;** on the other hand, some of the special features of the marine-target crater have complex origins. Hence, the analysis must be based on a combination of methods, all of which have their own limitations (*e.g.*, geological and geophysical studies, numerical modeling, laboratory experiments). In this paper we present preliminary results from experiments aiming to illustrate the formation of some of the special features noticed at Lockne and other marine-target craters.

The process of crater formation can be compared to an explosion, however with some important differences that concern the explosion [2] (*e.g.*, scaling problems, lack of projectile momentum, gas expansion instead of shock-driven excavation). There are also differences between the cratering from hypervelocity impacts and the mechanical push from the projectile in low-velocity impacts. This leads to different relations between the impactor properties and the resulting craters. In our study we are interested in certain aspects of the cratering that are not significantly affected by scaling differences. We have no access to a centrifuge, which is important for scaled experiments. Some issues regarding marine-target impacts that need special attention (*i.e.*, to be analysed with a combination of laboratory experiments, geological/ geophysical fieldwork and numerical modeling) are: 1. Excavation and modification of shallow water impacts (*e.g.*, crater concentricity at different water depths, separate ejecta curtains noticed in hydrocode modelings [1,3], shallow excavation flow of the outer crater), 2. Definition of crater diameters (transient crater, apparent crater), 3. Proportions between excavation and displacement zones; factors causing the excavation and displacement flows, 4. Dynamics of the resurge flow (e.g., the influence of channeling), 5. Dynamics of formation of ejecta flaps and their relation to the water depth; rupture of flaps developed in semi-coherent material and the relation to resurge gully formation; influence of the flap on the tsunami generation, 6. The reason for the absence of a structural uplift of the rim at the Lockne crater, 7. The effect of obliquity on shock propagation, concentricity, flap formation, ejecta distribution, and resurge.

The initial experiments described in this paper should be a step toward answers to the following questions: 1. What method is best suited for obtaining information relating to our general scientific objectives? 2. What method can be adopted in a controlled indoor environment? 3. What size of craters can we generate with the available methods, and what crater size do we need to obtain results within our main science objectives? 4. Will it be possible to recreate and analyze some of the features noticed in the geological and numerical studies of, first of all, the Lockne crater?

Experiments: The tests were performed in November 2003 in a half-spherical, 2.2 m wide, 1 m deep, outdoor test pit. The pit was lined with a plastic sheet, and then filled with a mainly middle-sand fraction beach sand. The humidity of the “dry” sand was not determined. Tests were performed with **“**dry**”** sand, water saturated sand, and saturated sand covered by a shallow water body. The tests were recorded with a high-speed digital camera (1000 frames/s), digital video camera (about 25 frames/s), and still-frame digital camera. We evaluated two methods for the production of the craters: 1. Trilite charge (detonation speed 6900 m/s), and 2. ordnance disposal device (standard CHUTA IB-060 gun) loaded with a 0.50 cal cartridge with 8 g single base powder that accelerates 4x7 cm cylindrical projectiles of, in this case, aluminium and steel to a maximum velocity of 2 km/s. The velocity of the aluminium projectile is 1.7 times higher than that for steel. The velocity is at a maximum about 10 cm from the gun, but is reduced with distance. The exact velocity was not determined in these preliminary tests.

First tests. Dry target and Trilite charge. **1**. 50 g charge (rectangular block 29x45 mm) 10 cm above the sand. Vertical ignitor. Generated a 37 cm wide, 3 cm deep (top of rim to apparent crater floor), shallow, “peak-ring” crater (from the shallow burst, not target rebounce). **2**. 100 g (2x50 g) charge 10 cm above the sand. Horizontal ignitor. Crater of similar shape as above, but 50 cm wide and slightly deeper (3.5 cm). Rim height 1 cm. **3**. 100 g (2x50 g) charge directly on the sand surface. Horizontal ignitor. 70 cm wide, and 17 cm deep, slightly conical crater. Rim height 1.5 cm. **4**. 50 g charge buried at 10 cm depth. Vertical ignitor. Generated 100 cm wide, and 20 cm deep crater. Rim height 2 cm.

The craters generated by these explosion experiments had sizes and morphologies of interest for our objectives. However, the fire and smoke cloud prevented observations of the cratering process. Hence, the experiments were continued using the gun.

Continued tests. Gun. **5**. Dry target. Aluminium projectile (235.5 g, flat point) shot from 40 cm above the sand surface. Generated 64 cm wide and 13 cm deep crater. Rim height 2 cm. The projectile was buried 15 cm below the apparent crater floor. **6**. Dry target. Steel projectile (686 g, flat point) shot from 40 cm above the sand surface. Generated an almost identical crater as experiment 5 (65 cm wide and 13 cm deep). Rim height 2 cm. The projectile was buried 56 cm below the apparent crater floor. **7**. Saturated sand. Less than 0.5 cm water depth. Steel projectile (686 g, flat point) shot from 40 cm above the sand surface. Generated a surface blast in the early part of the excavation stage. The blast removed the surface water to an extent of about 60-70 cm from the centre. During this phase there were also noticed several water escape vents (like miniature geysers) in the sand surface to a distance of about 50-60 cm from the point of impact. A distinct, 25-30 cm wide crater formed in the wet sand. It lacked a raised rim and did not collapse until it was reached by a resurge of surface water. Once again saturated, the initial crater collapsed and left a shallow, 44 cm wide, flat floored crater with a 3 mm high rim. The rim was crossed by numerous small furrows from the water resurge. **8**. Saturated sand covered by 10 cm water. Aluminium projectile (235.5 g, flat point) shot from 40 cm above the sand surface. Problem with the high-speed camera. Test repeated. **9**. Repetition of test 8 (but this time with 212 g, rounded tip projectile). Video camera recordings from test 8 and 9 and high-speed video recording from test 9 show how water is ejected at a steep angle (Fig.1). At an early stage of the excavation water is steaming in a zone around the growing water cavity. Based on comparisons with numerical simulations [1,3] we assume this to be due to cavitation in a zone of pressure release. Although some water is ejected to 1-2 m above the impact point, the main part of the ejected water forms an approximately 1 m wide and 50 cm high cupola. This water falls back almost vertically. The water ejecta does not cause any noticeable wave outward from the crater. Any wave generation is due to oscillations from the crater collapse. There is no significant central peak of water. The cupola of water prevents visibility of the cratering of the substrate that must occur at the centre of the growing cavity. The resulting apparent crater in the substrate consisted of a 25 cm wide, shallow, flat floored crater surrounded by a 30-40 cm wide, 1 cm thick, flat-topped zone of ejecta. We assume that, initially, a crater similar to the fresh crater in experiment 7 is formed, but that it suffers severe modification during the resurge of the water. The wide ejecta zone may indicate a larger volume of ejecta than in experiment 7 (= larger initial crater?).

Conclusions: The objectives set up for the initial experiments were fulfilled. The gun is more suited for continued tests than the explosive charge**.** The crater sizes are large enough to allow analysis of the features listed in our main science objectives and, notwithstanding the limitations of the method, we can see that it should allow us to tackle our science objectives from yet another angle. Observations such as the initial blast and water escape surrounding the crater in experiment 7, the lack of an elevated rim and the weak resurge furrows in the same experiment, and the water cavity/inner crater formation in experiment 8&9 indicate that comparisons can be made with large scale marine-target craters such as Lockne. The tests will continue in an indoor facility that allows a better control of the target environment and documentation of the experiments. We will try to create a gun that allows oblique impacts, not least because this may allow us to film the cratering from vertical view.

References: [1] Shuvalov, V. et al. (2004) *Impact Studies*, (in press). [2] Melosh (1989) Oxford Univ. Press, New York, 1-245. [3] Ormö J. et al. (2002) *J. Geophys. Res.* 107, E11.

Fig.1. Impact into 10 cm deep water.