INFLUENCE OF A WATER LAYER ON THE IMPACT CRATERING PROCESS AND THE FATE OF THE PROJECTILE. D. J. Milner[1], E. C. Baldwin[2] and M. J. Burchell[1] [1]Centre of Astrophysics and Planetary Science, University of Kent, Canterbury, Kent, CT2 7NH djmilner26@hotmail.com, [2] UCL/Birkbeck Research School of Earth Sciences, University College London, Gower St, London WC1E 6BT.

Introduction: The standard model for impact cratering on the Earth currently reflects the case of sub-aerial impact events. This bias towards continental impact cratering is largely explained by the prevalence of sub-aerial craters found on the Earth's surface. Of the 170 documented Earth impact structures, only 33 structures and related deposits are recognized to have formed in a marine environment [1,2,3]. This can be explained by a number of factors such as the finite lifetime of the ocean floor (150-200 million years), a lack of detailed topography of the ocean floor, infilling of the crater with sedimentary layers and extensive crater rim erosion [2]. Currently the Earth's surface is approximately 70% covered by water, with almost 60% representing deep water environments [1]. Assuming this distribution has not greatly changed with time, the majority of impacts on the Earth can be expected to have occurred in marine environments. The standard model of impact cratering should be adjusted to reflect this.

It has previously been shown for marine impacts that at water depths far greater than the projectile diameter, no crater forms on the ocean floor [4,5,6]. The ratio of water depth W_d to projectile diameter P_d required to prevent crater formation is highly dependent upon the target material, with weaker unconsolidated material such as sand requiring a greater water depth to prevent cratering from occurring than a stronger and porous sandstone material [7]. This limit on cratering occurs because the projectile is significantly decelerated during its passage through the water layer, hence the impact energy on collision with the target basement is no longer sufficient to overcome the strength of the target material and produce an excavation flow field. Due to the reduction in impact velocity of the projectile with the basement rock, the shock pressures experienced by the projectile will be decreased and may also influence the chances of projectile survival. We thus investigate the effect the presence of a water layer has on the cratering process and projectile survivability.

Laboratory/numerical simulations: We use the University of Kent's two stage light gas gun [8] in conjunction with AUTODYN-2D computer models (based at University College London) to study the fate of the projectile. Experimental work used 1 mm dia. stainless steel 420 projectiles impacting into varying depth water layers overlying a crystalline basement rock. The projectile diameter and composition, water depth, impact velocity and impact angle were all varied [4]. The surviving projectile fraction was measured.

Simulations of the laboratory scale impacts were performed using AUTODYN-2D. The code has already been used at this scale for impacts on sandstone material underlying a water layer [9]. The Smooth Particle Hydrodynamics (SPH) solver was used for the simulations, with a resolution of 20 SPH particles per projectile diameter. AUTODYN-standard material models were used for stainless steel and water, while the Tillotson equation of state was used for granite, using inputs from [10]. Mechanical properties were derived from [11].

Results: The laboratory experiments demonstrated that a significant amount of the projectile can survive an impact event, the percentage of which is highly dependent upon the water depth, impact angle, impact velocity and projectile density, see Figure 1. As much as ~60% of the projectile can survive. The significant amount of material surviving the impact (compared to impact directly onto rock) illustrates the influence of the water layer. The projectile undergoes a lesser shock on entry into the water, decelerates whilst passing through shallow water depths and then experiences a consequently reduced shock when impacting the basement layer. To consider this further, a study of the velocity change in the water layer is made using the late-stage energy (LE) technique [12,13]. For a 1 mm diameter stainless steel 420 projectile impacting into a 5 mm deep water layer the projectile velocity is reduced from 5.49 km s^{-1} at entry to 1.72 km s^{-1} at the basement layer, and hence a peak shock pressure of approximately 40 GPa would be produced in the projectile during the impact event (reduced from 198 GPa if no water was present). At pressures of less than ~70 GPa the projectile should remain largely unmelted during the impact event [14]. Indeed, in our laboratory impact into a 5 mm deep water layer, 28% of the projectile was found to have survived.

AUTODYN-2D has been utilized to model the laboratory impacts. The impact of a 1 mm diameter stainless steel 420 projectile into a 5 mm deep water layer at 5 km s^{-1} was modelled first; the projectile slowed to 1.2 km s^{-1} by the time it reached the basement, in good agreement with the laboratory data and the LE technique. A peak shock pressure of 17 GPa was produced in the projectile when impacting the target rock (reduced from 222 GPa if no water was present); with a peak shock pressure of 88 GPa when traversing the water layer. The average peak shock pressure experienced across the projectile throughout the entire impact process was 15 GPa. The results of further modeling will be reported at the conference, including more laboratory impacts and larger scale impacts, to suggest the effect of a water layer on the fate of the projectile at a planetary scale.

Planetary scale impacts: It is widely accepted that the majority of the projectile is vaporized during an impact event. The results here, however, imply that in a marine impact there is a significant reduction in shock pressure with corresponding increase in survival of the projectile material. Consider an impact into deep water. The Eltanin impact site is believed to represent the impact of a 1 km diameter asteroid into a 4.7-5 km deep ocean. From examination of deep sea sediment cores taken around the impact site a first order estimate of the overall surviving mass at this site was predicted as $2x10^{12}$ kg [15,16,17]. This was a controversial prediction, due to the relatively few samples they obtained over such a large area. Based on scaling of results from the laboratory data we predict survival of $1.3x10^{12}$ kg of meteoritic material [4]. Note that this only indicates the total surviving mass and not the size/distribution of the material.

Conclusions: We have shown that with the presence of a water layer the fate of the projectile is not as simple as in the case of the sub-aerial impact events. A significant amount of material survives a laboratory scale impact event. The effect of impact angle, velocity, varied water depth and projectile density are important, as is the strength of the target material e.g. more material survives a vertical impact into less dense and weaker materials than denser crystalline rock. Utilizing AUTODYN-2D, we have seen that the passage of the projectile through the water layer can be modelled computationally and closely matches the analytical LE calculations.

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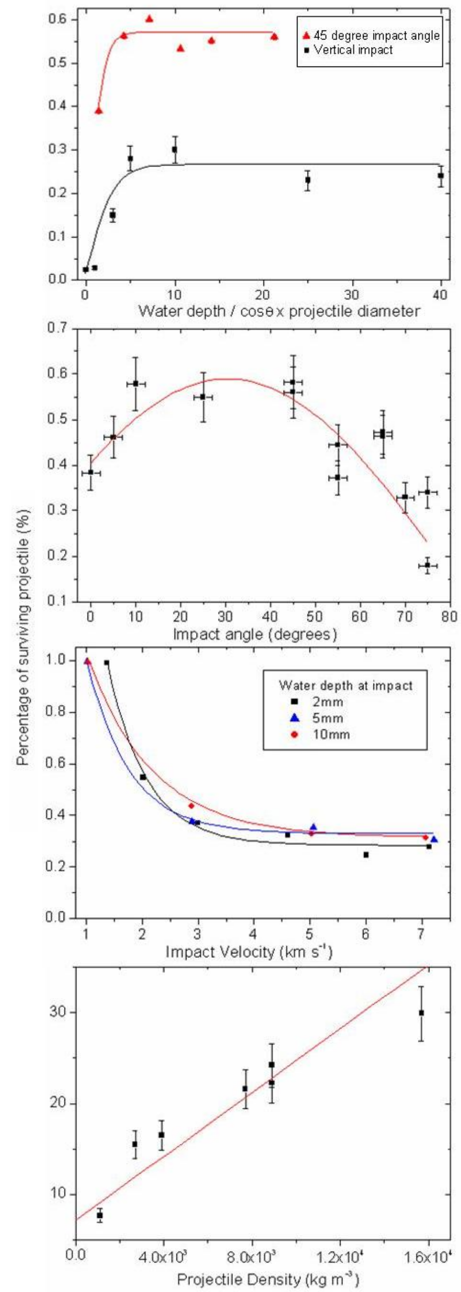

Fig. 1. Change in surviving projectile mass as water depth, impact angle, impact velocity and projectile density are varied.