THE EFFECT OF ASTEROID SHAPE, VELOCITY AND TARGET MATERIAL ON ASTEROID SURVIVABILITY. R.W.K. Potter[1], G.S. Collins[1], D. Elbeshausen[2] and K. Wünnemann[2], [1]Impacts and Astromaterials Research Centre, Dept. Earth Science and Engineering, Imperial College London, London SW7 2AZ, UK, ross.potter04@imperial.ac.uk; [2]Museum für Naturkunde, Leibniz Institute at the Humboldt University, D-10099 Berlin, Germany.

Introduction: In typical hypervelocity asteroid impacts on Earth the majority of the asteroid is either vaporized or melted, with little or no evidence of solid fragments left behind within the impact crater. Original asteroid fragments have been located in distal locations [1,2]; however, the recent discovery of an unmelted 25cm fossil meteorite, and many sub-millimetre solid fragments, within the Morokweng impact crater, South Africa [3], has shown that solid projectile fragments can survive the impact process and remain within the crater. Impact velocity, angle and target material have all been shown to affect asteroid survivability [4,5,6,7]; however, the reason for the survival of such a large un-melted clast at Morokweng is unclear. The survivability of asteroid fragments during impact is also of importance for the possible transfer of primitive life and organic compounds between planets [8,9,10].

Method: Using the two-dimensional iSALE hydrocode [11,12], we studied the effect of projectile shape, velocity and target material on asteroid survivability. Because of the two-dimensional nature of the iSALE code, only 90° impacts could be simulated. We simulated impacts of a 1.5km radius dunite asteroid using a resolution of 150 cells per projectile radius (CPPR). An ANEOS-derived equation of state table for dunite [13] was used to represent the projectile material, as dunite is a useful proxy for asteroidal material due to its ultra-mafic composition [5]. The simulations were timed to cover the propagation of the shock wave through the projectile, its reflection at its rear, and the following unloading of the asteroid. As the shock-induced stresses in the asteroid and target are so high during this phase of cratering, material strength was neglected in all simulations.

We investigated three variables: asteroid shape, impact velocity and target material. The standard model we used was a spherical asteroid impacting vertically into a non-porous granite target at 20km/s. From this model we then varied, independently, asteroid shape, impact velocity and target material, keeping all other variables constant. Asteroid shape was varied from a sphere to both a prolate and oblate spheroid (with respect to the axis perpendicular to the target surface) by varying the ellipticity. To investigate the effect of impact velocity, we varied velocity between 5 and 30 km/s, and to investigate the effect of target material we simulated impacts into granite, porous quartzite and water targets.

To quantify impact survivability we measured the volume of the asteroid that remained solid after shock loading and release. According to [14] incipient melting and vaporization of non-porous dunite occurs upon release from shock pressures in excess of 135GPa and 186GPa respectively. Hence, we analyzed our simulations to calculate the proportion of asteroid material that did not experience shock pressures above these limits. The proportion of the asteroid that experienced peak shock pressures <135GPa was considered to have remained solid and hence "survived" the impact.

Oblique impact simulations using a three-dimensional version of the iSALE hydrocode [15] are ongoing to investigate how impact angle influences the results presented here.

Results: In agreement with previous work, our modeling results show that impact velocity (Fig. 1) has a large effect on asteroid survivability. At impact velocities near escape velocity (12km/s), 61% of material remained solid after impact. This decreased dramatically to 24% at 15km/s, 5% at 20km/s and only 1% at 30km/s. The surviving solid material originates from a shell on the backside of the asteroid (Fig. 2).

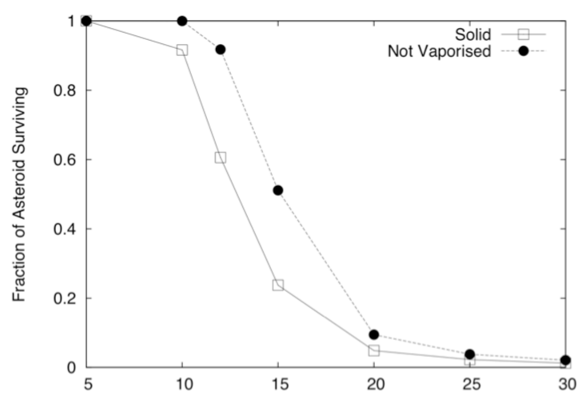

Figure 1: The effect of impact velocity on the fraction of the asteroid that remains solid (squares), or does not vaporize (circles), during impact.

Our 20 km/s impact results can be compared to previous studies of dunite impactor survivability in vertical 20 km/s impacts using the CSQ III [16] and CTH [5] hydrocodes. The 3D CTH simulations used a resolution of 50 CPPR, and between 151 and 165 trac-

tracer particles to track the fate of asteroid material. In this case, 0% of the asteroid remained solid after impact (in fact, the whole asteroid experienced shock pressures in excess of the threshold for incipient vaporization, 186GPa). The 2D CSQ simulations used a resolution of 40 CPPR. In this case, 10% of the asteroid remained solid after impact. Thus, our result of 5% survivability in a 20 km/s impact using iSALE (2D) is intermediate between the two estimates based on previous 2D and 3D calculations. These differences might be explained by a combination of: (1) the higher resolution used in our simulations; (2) the use of two orders of magnitude more tracers in our simulations, which allowed us to resolve low-end pressure levels more accurately; (3) the different equations of state used in each calculation (the iSALE and CSQ simulations used ANEOS, the CTH simulations used SESAME); (4) intrinsic differences in each code (e.g. 2D vs. 3D).

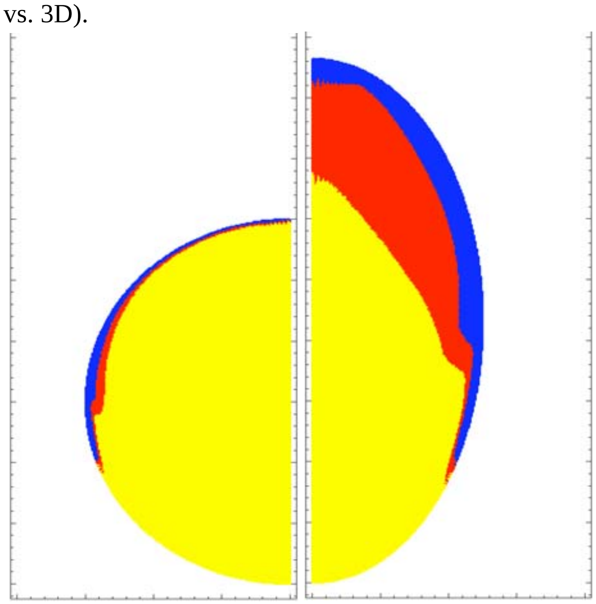

Figure 2: Provenance of asteroid material that experienced different shock levels during impact (blue-solid; red-partially molten; yellow-partially vaporized) for spherical and prolate spheroid (shape factor = 1.73) impactors.

Impactor shape can also have a significant effect on survivability. The proportion of the impactor surviving an asteroid impact (thereby not being shocked above 135GPa) decreases as impactor shape becomes increasingly oblate (shape factor less than 1; Fig. 3). At an impact velocity of 20km/s, 5% of the spherical impactor survived the impact (remained solid). Impactor survivability decreased as ellipticity and oblateness increased with just 2% surviving at an ellipticity of 1.73, and nearly 0% at an ellipticity of 3.38 and 4.63. More importantly, the proportion of the impactor that remains solid after impact increases as the impactor shape becomes increasingly prolate (shape factor greater than 1; Figs. 2&3). In this case, at an ellipticity of 1.73 the proportion of the impactor surviving was 19% increasing further to 44% and 46% at ellipticities of 3.38 and 4.63 respectively.

At an impact velocity of 20 km/s, the proportion of the impactor surviving the impact was very similar for granite and 25% porosity quartzite targets (5% and 9%, respectively). However, in agreement with previous experimental and numerical modeling work [4], impact into water produces a dramatic increase in impactor survivability due to the large impedance contrast between water and rock.

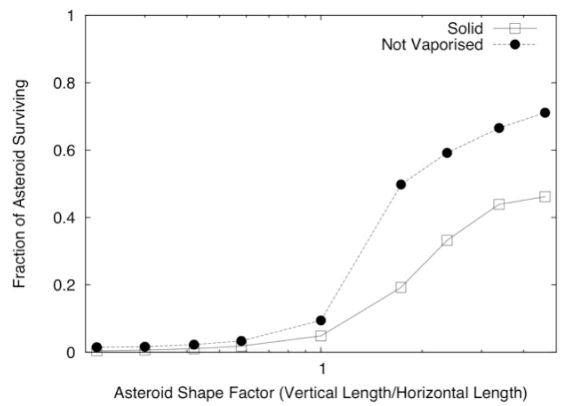

Figure 3: The effect of asteroid shape on the fraction of the asteroid that remains solid (squares), or does not vaporize (circles), during impact. Prolate impactors (in the vertical) have a shape factor greater than 1.

Summary: We have shown that for a significant fraction of an impacting asteroid to survive as solid fragments, the impact must occur either at a velocity near to escape velocity, into a deep water layer, or the impactor must be significantly prolate along the axis normal to the target surface.

Acknowledgements: We are grateful to Boris Ivanov and Jay Melosh for their work in the development of iSALE.

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