FRAGMENTATION OF BASALT PROJECTILES IN HYPERVELOCITY IMPACTS IN THE LABORATORY.

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Introduction: Hypervelocity impacts have long been studied as a major process in the evolution of bodies and surfaces in the Solar System. However, whilst craters themselves, and increasingly the ejecta from craters, have been studied in detail in laboratory experiments, computer simulations and fieldwork, the fate of the projectile is relatively neglected.

There have been studies of the projectile post-impact dating back to the 1960s, but these are less frequent than other impact studies. Nevertheless, projectile survival after impact is of importance for a variety of reasons: Projectile fragments have been recovered from 13 impact sites on Earth (e.g. see Table 15.1 in [1]). It has been suggested that projectile fragments can be present in central peaks in lunar impact craters [2]. The dark material on the surface of Vesta is likely to come from impactors [3]. Non-indigenous materials have been found on the Moon e.g. [4], inside meteorites e.g. [5] and so on. Indeed the sub-surface regions at man-made impact sites should also contain impactor material (e.g. the crater on comet 9P/Tempel-1 arising from the Deep Impact mission [6]).

Laboratory studies of impactor survival do exist. There are examples such as those of [7-9]. As well as size distributions of fragments, there are reports of analyses of recovered fragments to see if the impact processed their organic content, with particular relevance to astrobiology, e.g. [10-11]. Indeed, there is even a recent study of whether fossils inside projectiles can survive impacts intact [12]. It is no surprise therefore that more studies are now appearing on projectile fragment survival, including [13-14].

Accordingly, we report on the survival of basalt projectiles fired into water at speeds up to 5.3 km s^{-1}. Water was used as the target for ease of extraction of the projectile fragments. In this present work we focus on the fragment size distribution and its evolution vs. impact speed and peak shock pressure.

Method: We use the Univ. of Kent two stage light gas gun [15] to fire 1 mm cubes of basalt into bags of water. The impacts studied so far were at 0.64, 0.70, 2.02, 3.04, 4.51 and 5.31 km s^{-1}. The water was filtered after the impact to extract the projectile fragments. After extraction, the samples were imaged in a SEM (Hitachi S3400N); see Fig. 1 for an example fragment. Automated software was used to find and size the individual fragments. We can extract and measure fragments down to around 5 μm in size and can find over 100,000 fragments in the higher speed shots. As a check, one sample was measured directly on the SEM by the user to confirm the accuracy of the software method.

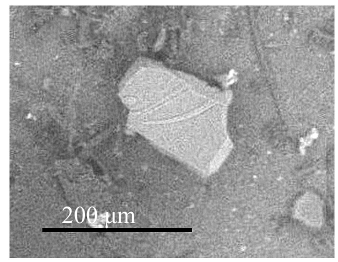

Fig. 1 Example fragment after impact.

We use the Planar Impact Approximation [16] to find peak shock pressures in each impact. This requires a linear shock wave speed relation of the form U = C + Su, with values for C and S for both projectile and target materials. From [16] we take for basalt: C = 2.60 km s^{-1}, S = 1.62 and density 2860 kg m^{-3}. And for water, the equivalent values were 1.48 km s^{-1}, 1.60 and 1000 kg m^{-3}. We find that for the impact speeds here, the peak pressures range from 1.1 to 26 GPa.

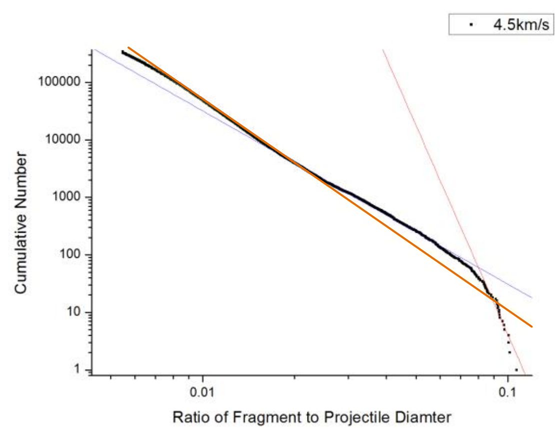

Fig. 2 Cumulative (normalised) size distribution for the impact at 4.51 km s^{-1}. The data are in black, the three coloured straight lines are fits (see main text).

Results: In Fig. 2, we show an example fragment size distribution (normalised to the original projectile diameter) for the impact at 4.51 km s^{-1}. We have fitted the cumulative size distributions with power laws of the form $N(>S) = aS^b$, where N is the number of fragments greater than a given size S. A single power b

does not usually fit the entire size range of fragments recovered from a single shot and so we make 3 fits to each distribution at small, medium and large (normalised) fragment sizes. There is usually a steeper (larger *b* value) at larger fragment sizes, with a smaller slope (lower *b* value) at smaller sizes. *b* ranges from: Small sizes -2.5 to -3.5, Intermediate Sizes -3 to -4.5 and at the Largest Sizes is <-4.5.

The behavior of the fragment size at the very largest sizes depends sharply on impact speed. At the lower speeds the first few largest fragments form a concave shape on the cumulative size distribution in log-log space. This flattens out at an intermediate speed (3 km s^{-1}, 10.5 GPa) and then becomes convex at higher speeds. This is suggestive of the behavior of the similar cumulative size distributions for fragmented *targets* as they pass from the just disrupted to the heavily disrupted regimes (e.g. see [17-18].

We have looked at the ratio of the largest axis (a) and an orthogonal axis (b) to characterise each fragment shape. We find that the mean value of b/a is ~0.55.

We have also estimated the total surviving mass fraction we extract after each impact. This is shown in Fig. 3 vs. peak shock pressure as found by the PIA. We see an initially rapid drop in the mass fraction retained in the target but this then flattens off at higher speeds and pressures. Given that, due to the small size of the grains, there is not much mass in the very fine size fraction below 5 µm where our sensitivity falls off, the missing mass must be lost by being carried away from the target (by water lost during the impact back in the impact direction where our target holder was not sealed to allow entrance of the projectile). That target ejecta can carry projectile material away from the impact is shown for example in [19].

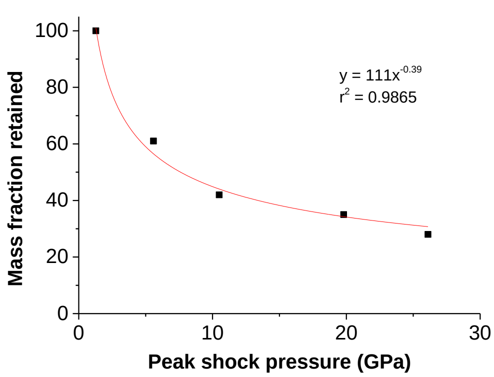

Fig. 3 Surviving mass fraction vs. peak shock pressure

Conclusions: We have conducted a detailed set of measurements of the fragment size distribution for impacts of basalt on to water in the speed range 0.6 to 5.3 km s^{-1}, which corresponds to peak shock pressures of 8 to 84 GPa. The fragment size distribution changes with increasing impact speed, with more fragments overall and fewer large fragments in the higher speed shots. However, even at the higher speeds there is significant retention of the projectile material in the target.

As part of on-going analysis we are comparing our results to those of [19] who studied basalt projectiles impacting sand targets at speeds up to 0.9 km s^{-1} and peak pressures up to 0.9 GPa. We are also looking further at the fragment shape and at possible processing of the projectile material during the impact.

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