THE EFFECT OF TARGET'S POROSITY ON THE FATE OF THE IMPACTOR IN HYPERVELOCITY COLLISIONS

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Introduction: The investigation of the projectile, and projectile debris, during hypervelocity impacts is crucial to explain the observations of mixed mineralogies on the surface of asteroids. Such phenomena, which have been observed only relatively recently, are the source of the olivine and dark material deposits observed on Vesta [1,2] and probably of the "Black Boulder" on (25143) Itokawa [3]. Mixing of asteroid material with different lithology through impacts might be also necessary to explain the nature of the Near-Earth asteroid 2008 TC3, a multi-lithology body whose formation mechanism is still not completely understood [4,5]. Over the last four decades, a plethora of laboratory experiments and computer simulations have provided insights into collisional processes that constitute the foundation of our current understanding of large-scale asteroid collisions [6]. However the majority of these studies focused on the fate of the target after an impact and not on the projectile. In this work we try to investigate the fragmentation, implantation and final state of the impactor after hypervelocity collisions using targets with different porosity. This experimental campaign was performed over 13 months in total including more than 40 shots.

Methods: The main goal of this work is to go one step further than previous experiments and make use of materials that are more representative of the mineralogy that one can detect on small bodies. During this campaign, which consists of three runs, a standard procedure for each individual target type was developed and carefully followed in order to secure to a maximum level the reproducibility of each shot. The gun used to perform the experiments was the horizontal two- stage Light Gas Gun (LGG) of the University of Kent [7]. The impact angle was always 0° with respect to the impactor's trajectory prior to impact event. In order to unambiguously separate projectile fragments from those of the targets and gun contamination, we used a high purity, Mg-rich olivine (in the form of a gem quality peridot) and synthetic basalt spheres as projectiles. As target we used for the first run (Run#1) of experiments, a high purity water-ice target of low porosity (<10%), comparable to the microporosities of the examined meteorites. For the second run (Run#2) of experiments was also used high purity water-ice target but with higher porosity (~40%), comparable to the bulk porosities of C-type asteroids. In the third run (Run#3) the projectiles were fired on to very fine $CaCO_3$ powder with very high porosity (~70%) and therefore examining an extreme range of porosities. These targets were also chosen because one of the main aims of this study was to attempt to recover projectile fragments within the target. By using a water-ice, the targets of Run#1 and Run#2 only had to melt and the resulting water filtered to recover the projectile fragments. The target material of Run#3 was dissolved in nitric acid leaving behind the projectiles fragments that were unaffected by acid.

The general methodology consists of seven steps: i) Initially a physical characterisation of the projectiles pre-shot was carried out; namely measurement of their sizes, masses and perform Raman spectroscopy. Raman spectroscopy was used to identify possible line shifts due to deformation of the projectile's crystal structure induced by the impact shock. ii) The projectiles are fired onto the targets. The formation of impact craters is observed, although due to the ephemeral nature of the target they were not measured. The projectile and target material, along with contaminating residues from the gun, collected by our ejecta collecting setup. iii) All projectile fragments were collected and we visually identified the largest of them. The ratio between the mass of the largest fragment to the initial mass of the projectile ($M_{l,f}/M_{im}$) in relation with the energy density during the impact (Q), gives information about the degree of fragmentation of the latter. iv) The projectile material from the target container and the ejecta collector is removed, after melting or solution in acid, and thus projectile fragments, plus contaminating gun debris, is filtered. v) The filters were analysed using a Scanning Electron Microscope (SEM). Energy-dispersive X-ray spectroscopy (EDX) maps of the same fields were taken simultaneously in order to distinguish projectile fragments from any contaminating material. We thus recorded information about the elemental composition of the sample. Considering that the peridot projectiles have a very strong signal in Mg and there is no Mg contamination from gun debris, we used the EDX maps of Mg to discriminate the projectile fragments. vi) The final phase consists in analysing the data from the SEM, discriminating projectile fragments from gun detritus and allowing us to build the size frequency distributions (SFDs) of the fragments and quantify the amount of projectile embedded in the target. Another novelty of this work was the development of an automated way to identify and measure projectile's fragments among gun debris. An astronomical photometry technique was applied to each frame using the Source Extractor ('SExtractor') open source software for astronomical photometry [8]. SExtractor has the ability to discern objects even in highly dense fields, giving good statistics by automatically counting thousands of fragments. vii) Raman spectra provides indications of structural alteration of the recovered fragments.

Results: *Projectile fragmentation* Our experiments have demonstrated a difference in the fragmentation of the forsterite olivine and synthetic basalt projectiles, that were fired onto low porosity water-ice targets, giving catastrophic disruption energy densities of $Q^*_p = 7.07\times10^5$ J/Kg and $Q^*_b = 2.31\times10^6$ J/Kg respectively. The impactor's fragmentation is related to the porosity and strength of the target (see Fig. 1). The SFDs of the projectile fragments have a definite turn-over at a point well above the detection limit of our method. The positions of the modes and slopes of the size distributions are velocity invariant, although there is a difference in the SFDs by altering the target's porosity. This is counter to the observations made for ductile (i.e. metal) projectiles [10,11]. This suggests that the fracturing mechanism between lithological projectiles and metallic (ductile) projectiles is different.

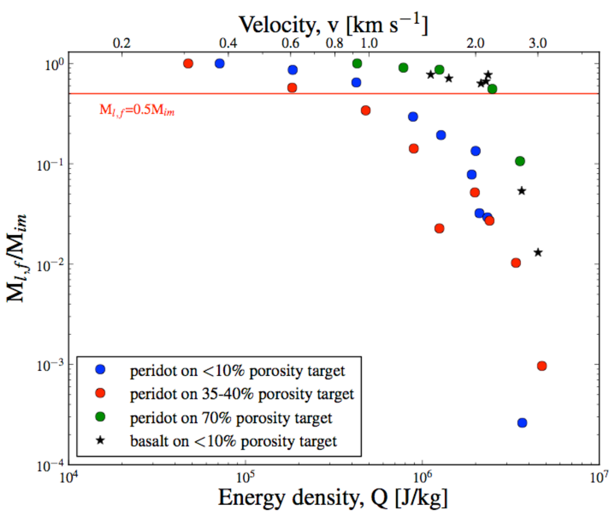

Figure 1: Mass ratio of the largest fragment of the impactor ($M_{l,f}/M_{im}$) vs. the energy density, Q_{im}, for speed ranges 0.3 – 3.0 km/s for olivine and basalt projectiles. The red horizontal line indicates the catastrophic disruption limit [9, Avdellidou et al. in prep.].

Implantation on the target Impactor's material is still implanted up to 3 km/s. This amount significantly increases with increasing porosity.

Final State of the projectile At impact speeds up to 3 km/s, which occur at the lower part of the velocity distribution in the Main Belt [12,13], we observe no detectable melting of the projectile for all three runs, as determined by visual observation and Raman spectroscopy (melting of olivine results in a degradation of the Raman spectra due to loss of olivine crystal structure). This observation is backed up by hydrocode modelling for Run#1 which demonstrates that the temeratures at maximum pressures experienced by the olivine and basaltic impactors do not reach their melting point, which is 2100 K and 2500 K at pressures of 10 GPa and 4.6 GPa respectively. This is an important observation when we consider the mineralogical signature of implanted impactors on asteroids i.e. the projectile's mineralogy (including crystallinity) will be preserved. By examining the Raman spectra of the survived fragments, and calculating the difference $\omega - \omega_{ref}$, we found that there is no alteration in the Fe abundance of the fragments as all the calculated differences lie inside the resolution limit of the instrument.

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Acknowledgments: C.A. thanks T.M.K. and P.I. for their advice and Royal Astronomical Society for financial support. M.D. acknowledges support from the French Agence National de la Recherche (ANR) SHOCKS. M.C.P. and M.J.C. would like to thank STFC, UK for funding this work.