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Ice World Oceans, Salt Grains and Hypervelocity Impacts

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Abstract

We report on studies of residues from salt projectiles fired into aluminium foil at speeds up to 7 km s^{-1}. The results show that we can find identifiable residue in craters after impact, with shock pressures up to 77 GPa. This has implications for analysis of samples obtained by flying through the plumes of sub-surface oceans on icy satellites e.g. [1-3], i.e. substantial amounts of residue are captured at speeds likely for impacts on a passing spacecraft.

1. Introduction

The presence of sub-surface oceans on various icy satellites of Jupiter and Saturn holds great interest for those interested in the development of minerals and organic chemistry on such bodies [4-7]. They are also of great interest to astrobiology. The water in the oceans is not however totally inaccessible – in some cases (e.g. Europa and Enceladus) it vents naturally from the satellites as plumes. The Cassini mission showed that a spacecraft can successfully traverse such plumes, and sample material from them. In the case of the Cosmic Dust Analyser on Cassini, small grains of salt were reported associated with the plumes [8]. Here we investigate in the laboratory what happens to salt grains when impacting a target at speeds from 2 to 7 km s^{-1}. Such speeds exceed those of a craft orbiting the body, but are typical of those for one in orbit around the parent planet and which makes a flyby of the body of interest.

2. Method

In this work we use four types of salt: sodium chloride (NaCl), sodium bicarbonate ($NaHCO_3$), and magnesium sulfate ($MgSO_4$), the latter in both hydrous (kieserite, $MgSO_4•H_2O$) and anhydrous forms. Grain size was from 10 µm up to 100s of µm. Small amounts (µg) of each salt were fired at aluminium targets using the University of Kent two stage light gas gun [9]. After a shot, the foil were examined using a combination of SEM-EDX and Raman spectroscopy. There have been 17 shots so far. The impact speed was measured in each shot and ranged from 2 to 7 km s^{-1}.

3. Results

A typical impact crater is shown in Fig. 1. The rubble like debris in the lower part of the crater image shows strong Na and Cl EDX signals.

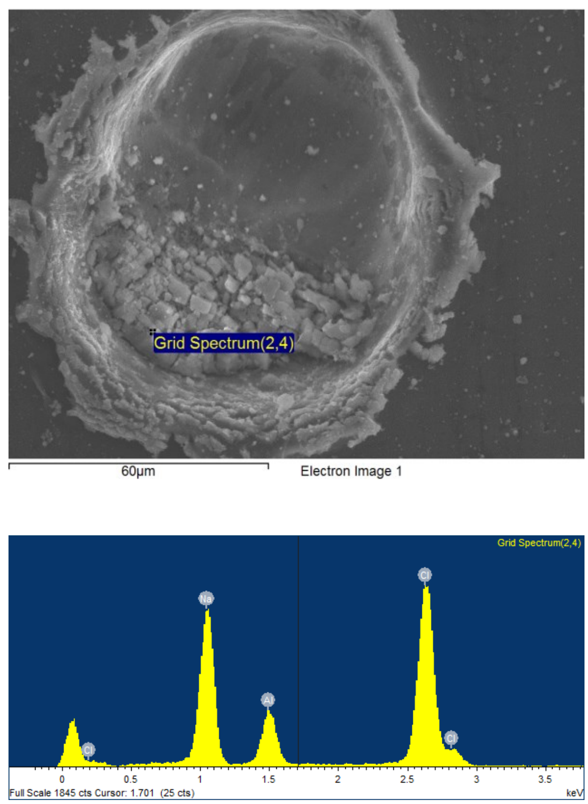

Figure 1: Impact of a NaCl grain at 1.94 km s^{-1}. (Top) The resulting impact crater. (Bottom) SEM-EDX spectrum showing peaks for Na and Cl, which are coincident with the rubble like residue visible in the lower region of the image of the crater.

The individual foil targets show a range of crater sizes due to the polydispersive size distribution of the raw samples. Therefore, when examined under the SEM, a range of crater sizes down to 10 µm diam. has been studied. Projectile residue is found in all four types of salt, at all crater sizes and at all speeds used.

Peak pressures were calculated using the Planar Impact Approximation [10] and linear wave speed coefficients derived from the LANL database for single crystal NaCl salt. At the impact speeds here, peak shock pressures range from 14 to 77 GPa.

Using the EDX analysis it is possible to distinguish NaCl from the other salt types. Sodium bicarbonate is flagged by the presence of C and O peaks, and magnesium sulfate by Mg, S and O peaks. However, based on EDX alone we cannot currently distinguish hydrous from anhydrous.

The texture of the residue on the craters does vary with impact speed and salt type. In some cases we found what appeared to be salt crystals in the residues, but these may have recrystalised after impact when exposed to the damp atmosphere. Accordingly, we are testing recovery after impact and storage under inert N_2 atmospheres to investigate this further.

4. Summary and Conclusions

The results so far are supportive that, despite capture via a high speed impact, a significant amount of identifiable residue is present in the resultant impact craters. We are currently doing the Raman spectrometry and testing to see if it has retained its original crystal structure as well as composition. To a degree this is not a surprise. The NASA Stardust mission to comet 81P/Wild-2 captured significant amounts of small particle residues after high speed impacts on foils [11-12], some of which retained significant crystallinity after capture [13]. Here we are demonstrating that this also applies to salt crystals, such as may be found in the plumes of Europa and Enceladus.

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