EXPERIMENTAL IMPACT CRATERS IN ALUMINUM FOILS: INSIGHTS FOR COMETARY SAMPLE RETURN. G. A. Graham¹, A. T. Kearsley², R. J. Chater³, N. Teslich¹, W. Moberlychan¹, Z. R. Dai¹, M. J. Burchell², M. J. Cole², D. S. McPhail³, P. G. Grant¹, J. P. Bradley¹ and F. Hörz⁵. ¹Lawrence Livermore National Laboratory, USA (graham42@llnl.gov), ²Natural History Museum, UK, ³Imperial College, UK, ⁴University of Kent, UK, ⁵NASA Johnson Space Center, USA.

Introduction: The aluminum foils wrapped around the sample tray assembly (STA) of the Stardust spacecraft will contain a record of both cometary and interstellar dust hypervelocity collisions in the form of craters [1-2]. While the primary goal of the cratering preliminary examination (PE) is to define the cometary particle flux [2], previous studies of exposed metallic foils in space have shown that substantial information on projectile composition can be obtained from the preserved residues [e.g. 3]. Coupled with recent advances in sample preparation and microanalysis techniques [4-6], detailed analysis of the impact residue preserved in the STA foils may contribute significantly to the overall understanding of the compositional properties of comet Wild-2. Here we summarize sample recovery methods and the analysis of experimental impact residues to support Stardust studies.

Methods: A range of projectiles including soda-lime glass, crushed meteoritic material and single composition mineral grains were used in laboratory simulations. The projectiles were accelerated into Stardust flight-grade aluminum foil (1100 series) targets by light gas guns using a buckshot technique [4-5,7] (Fig. 1). Impact velocities were within the range of the Stardust encounter with Comet Wild-2 of ~6 km/s. [4-5,7].

Initial electron microscopy of the foils was carried out using a JEOL 5900LV SEM fitted with an Oxford Inca Energy Dispersive Spectrometer (EDS). Focused ion beam microscopy was performed using both an FEI FIB200 TEM workstation and a FEI Nova 600 DualBeam FIB-FESEM microscope. The FIB prepared TEM sections were recovered from the bulk material using both in-situ and ex-situ methods [8]. Analytical electron microscopy was performed using a 200 kV FEI Tecnai G2 F20 XT (S)TEM fitted with an EDAX EDS and FEI TIA spectral processing software.

Ion Imaging: The distribution of residues within impact craters is not uniform therefore the critical first order task is to locate the material. Due to complex topography of the craters, the compositional contrast between the residue material and the aluminum substrate is often masked when using back-scattered electron imaging. This problem can be overcome by acquiring ion-induced secondary electron images that are surface sensitive and show an increase in material contrast (Fig. 2). At low magnifications and/or with low ion currents, there is negligible sample damage during ion image acquisition. However prolonged use may increase implantation of Ga generating additional unwanted peaks in the subsequent EDS analysis.
**Sample Recovery:** Micrometeoroids captured on metallic foils exposed on the Long Duration Exposure Facility (LDEF) showed extensive evidence of alteration with glass residues lining the walls of the craters, rather than intact particles [3, 9]. For analytical electron microscopy, residues were extracted from impact craters using collision or micro-needle manipulation, followed by ultramicrotomy to produce electron transparent sections approximately 90 nm thick [10]. In addition to utilizing these techniques for the cratering PE, recent studies have applied focused ion beam (FIB) techniques to image, manipulate and extract residue preserved in experimental craters [4-5]. FIB enables sub-micron scale manipulation of regions of interest within the sample using the focused Ga+ ion beam to ablate material, and can be used to prepare site-specific electron transparent selections. Previous support studies for Stardust have used FIB-TEM techniques to prepare sections of entire craters and extract individual residue material from a crater [4-5]. FIB-TEM has now been applied to recover material from the crater lips (Fig. 3). This recovery method enables multiple sectioning of residues therefore allowing comment on the heterogeneity of the preserved impact material within an individual crater.

![Fig. 3. Ion-induced secondary electron image of basalt glass residue prior to ex-situ recovery.](image-url)

**Discussion:** The primary particle capture substrate for Stardust was silica aerogel [1] for which a variety of analysis techniques exist [12]. Recent studies have suggested that particles impacting aerogel at ~6 km/s can undergo alteration (shock and thermal) and extensive fragmentation leading to material loss [11]. The sub-micron fragmentation of an “aggregate” cometary grain along an impact track would require specialized recovery and therefore hinder the mineralogical and chemical studies of the Stardust PE. The cometary residues preserved within the impact craters may offer an opportunity to rapidly define the basic composition of Comet Wild-2 material. Previous studies of micrometeoroids recovered from LDEF identified a wide range of material from metallic glass to unmelted grains containing solar flare tracks [3]. The recovery methods already discussed herein would permit detailed electron microscopy and other micro-characterization of Stardust foil craters [3-6]. In addition to the ability to recover material from the craters, it is also important to understand the structural and chemical alteration that the cometary grains might have experienced. This is particularly significant if the compositional data acquired is to be compared with that of interplanetary dust particles and meteorites. A current on-going consortium study is characterizing impact residue material generated by the acceleration of well-defined basalt glass projectiles at 6.06 km/s onto aluminum foil targets. The aim of the study is to give an insight into degree of volatile elemental loss experienced during hypervelocity capture.

**Summary:** The sample recovery methods developed for LDEF and in preparation of Stardust will enable detailed characterization of impact craters and residues using a wide range of analytical tools. Analysis of the experimental residues will assist in the interpretation of the elemental and mineralogical properties of the captured Stardust cometary and interstellar material. It is therefore anticipated that analysis of foil residues will supplement the data acquired from the material captured in the low-density silica aerogel cells.


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