POROUS AGGREGATES IN COMET 81P/WILD 2? STARDUST Al FOIL CRATERS COMPARED TO EXPERIMENTAL IMPACTS FROM ARTIFICIAL AGGREGATES AND METEORITE POWDERS.

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Introduction: Does comet 81P/Wild 2 contain much very fine-grained, low-density, highly-porous cometary dust? Such material has been seen in stratospheric collections of interplanetary dust particles (IDPs), for example from comet 26P/Grigg-Skjellerup [1] in which abundant 'glass with embedded metal and sulfides' (GEMS) and grains with exotic 'presolar' isotopic signatures [2] indicate survival of primitive composition and structure as might be expected within dust gathered into a cometary nucleus. However, after return of Stardust [3], it seems that not all comets are dominated by fine, porous dust made of sub-micrometer amorphous silicate grain aggregates [4], and that coarser, crystalline material (with a hot, inner solar system origin) may be present in substantial quantity [5,6]. There are now considerable doubts even as to the abundance of significant quantities of interstellar and presolar materials in Wild 2 [7,8].

Abrasion and sub-grain disaggregation probably disrupted fragile components in Stardust grains that impacted onto aerogel, making it difficult to interpret original particle structure [9,10]. Interpretation of size and shape of Al foil craters is more straightforward. We can now quantify their three dimensional shape and interpret the properties of dust grains responsible, by comparison to impact features created by light gas gun (LGG) shots [11]. Complex, fine-grained, porous, and relatively low density artificial aggregate projectiles [12] allow more realistic simulation of impact by particles with highly heterogeneous internal density, including solid silicate and sulfide sub-grains, with partially filled pore space.

Materials and Methods of study: Flight spare Stardust Al1100 foils from NASA were used as LGG targets in powder shots [13] at the University of Kent, with impact speeds of ~ 6 kms^{-1}. Fine grain-size aggregate projectiles were made from olivine, powdered and column sedimented to remove grains > 8 µm, yielding grain size mode < 3 µm, cemented by acrylic spray droplet impregnation. Scanning electron microscope (SEM) images of polished sections of aggregates (Fig. 1) show that infilled porosity varies from 30% to 66%, with an average of 49%, implying a bulk grain density of ~ 2.2 g cm^{-3}. Other projectile powders were prepared from the carbonaceous chondrites Allende (CV3) and Orgueil (CI). Alicona MeX 4.2 software [12,14] was used to generate digital elevation models from SEM stereo pair images of craters, from which diameter (Di) and depth (De) were measured..

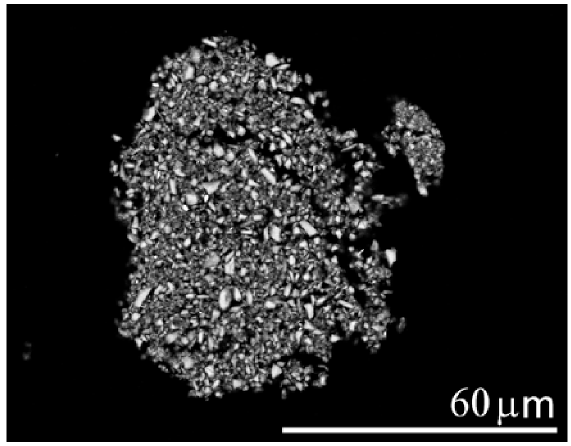

Figure 1. Backscattered electron image of a cross section through an artificial olivine aggregate projectile.

Results from Stardust: Four (possibly five) of the seven large (> 20 µm diameter) craters examined during Preliminary Examination show relatively simple plan view outlines (close to circular) and 'bowl-shaped' depth profiles of Di:De ratio ~ 0.56 - 0.76 [14]. Of two larger Stardust craters showing complex, shallower depth profiles (interpreted as impacts by lower density aggregates [14]), one gave diverse residue analyses, implying different sub-grain compositions within the impactor. Smaller Stardust impact structures exhibit a great variety of plan-view outline and three dimensional complexity in stereo-pair images, most show overlapping and mutually interfering depressions. Where energy dispersive X-ray microanalysis has been performed on small craters [14,15], residues of several different compositions are often found together, again implying complex impactors, often with crystalline remnants of a substantial proportion of the impactor, without clear evidence of non-stoichiometric amorphous materials.

Results from laboratory experiments: The shot of fine olivine aggregates yielded many thousands of impacts, from sub-micrometre to sub-millimetre scale. Smaller craters (µm to 20 µm) vary greatly in shape, most being complex (Fig 2), showing irregular outline morphology similar to small Stardust craters. Our research on residue preservation in these smaller craters is continuing.

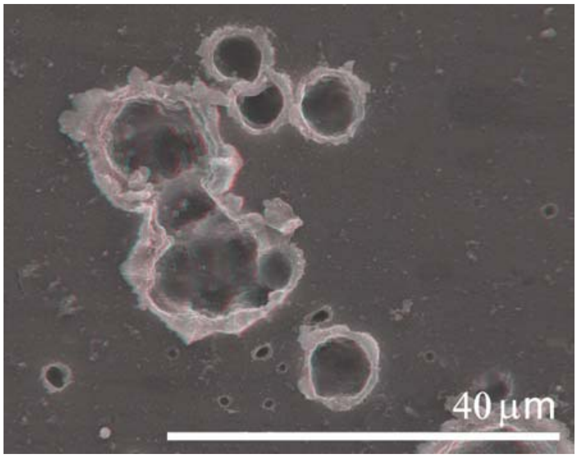

Figure 2. Secondary electron image (SEI) stereo anaglyph of complex crater made by fine olivine aggregate experimental impact on Stardust foil.

Most intermediate scale craters (20 > 50 µm) are sub-circular in plan, although with complex internal shape. The numerous larger impacts (> 50 µm diameter) have relatively circular outlines (Fig. 3) and simple bowl-shaped profiles, with average depth:diameter ratio of 0.54 ± 0.07, compared to 0.71 ± 0.08 for single-grain olivine impacts, determined previously[11].

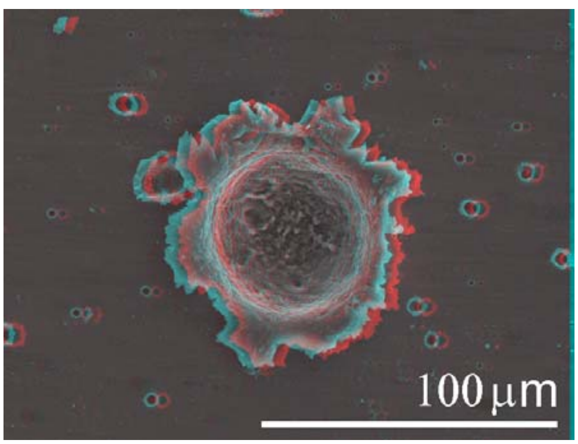

Figure 3. SEI stereo anaglyph of a large bowl-shaped crater, produced by a fine-grained olivine aggregate.

The craters produced by carbonaceous chondrite powder projectiles also show variation in shape, with larger craters being simple bowls, whilst features of < 20 µm diameter are often complex in internal form.

Discussion: The near-circular plan outline and depth:diameter ratios of deeper 'bowl-shaped' Stardust craters are similar to LGG craters made by single-crystal, low porosity silicate projectiles at ~6 kms^{-1} [11]. Although markedly inequant impactor shape can complicate matters, the average depth/diameter of experimental craters made by homogeneous, non-porous grains is linked to their density [12]. We have now shown that big shallow bowl-shaped craters, with De/Di similar to those of Stardust, can be made by large fine-grained aggregate particles of intermediate density (~ 2.2 g cm^{-3}), and by powders from meteorites with 20-35% bulk porosity [16].

Conclusions: Stardust crater morphology is consistent with interpretation of many Wild 2 dust grains being porous aggregates, albeit most of low porosity and therefore relatively high density. The majority of large Stardust grains (i.e. those carrying most of the cometary dust mass) had density of 2.4 g cm^{-3} (similar to soda-lime glass used in earlier calibration experiments [17]) or greater, and porosity of 25% or less, akin to consolidated carbonaceous chondrite meteorites, and much lower than the 80% suggested by [4] for fractal dust aggregates. If porosity of the Wild 2 nucleus is high, with similar density to other comets [18], much of the pore-space may be at a scale of tens of micrometers, between coarser, denser grains.

Successful demonstration of aggregate projectile impacts now opens the possibility of experiments to confirm conditions for creation of bulbous Type C tracks in aerogel [9,10], which we have observed in our most recent LGG shot. We are also using mixed mineral aggregates to document differential survival of pristine composition and crystalline structure in the diverse fine-grained components of aggregate cometary dust analogues, impacted onto both foil and aerogel under Stardust encounter conditions.

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