MISSING "CARROTS" IN THE STARDUST AEROGEL.

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Introduction

Stardust apparently produced exciting results – as can be deduced from the scarce data available (e.g., NASA Stardust Web site). The conclusions drawn, however, seem to reflect a certain degree of confusion among investigators, who reach the grand conclusion that "*...the Stardust minerals may have crystallized from melts near other stars...*" and "*...at least some comets may have included materials ejected by the early sun to the far reaches of the solar system*". Durda [1] even commented recently, about the Stardust minerals: *"Or may be these mineral grains did not come from comet Wild 2…and represent some sort of "contamination" of something other than comet dust*". There is no grand surprise with the mineralogical findings on Wild 2 particles (W2s) as they can be expected from what we know from meteorites, Antarctic micrometeorites (AMMs) and stratospheric IDPs [e.g., 2]. We discuss here our earlier prediction of a possible link between cometary matter and AMMs [3].

Bulbs against carrots

The W2s recovered at the terminus of about 20 well visible tracks in the aerogel (with length of up to 3 cm) are made of refractory minerals (forsterite, enstatite, diopside, spinel, anorthite). These tracks have a "bulb" shape (**Fig. 1**) very different from the "carrot" shape observed for all projectiles fired into aerogels at speeds similar to that of the W2s (~6 km/s), as to assess their survival during aerogel capture (**Fig. 2**). These spectacular "bulbs" are sprayed with tiny shell-splinters tracks. This bulb shape probably is the result of a powerful microscopic explosion ignited along the upper part of the track of the W2s.

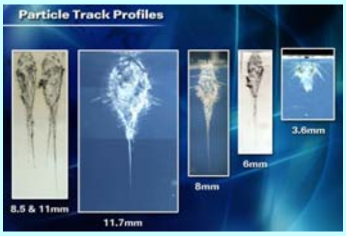

Figure 1

Figure 2

A dominance of dry projectiles in the dust guns experiments.

There was an astonishingly disparate choice of artificial projectiles fired with dust guns on aerogel targets at speeds of about 6 km/s. They were intended to simulate the encounter of the Wild 2 dust with the aerogel of Stardust. Burchell *et al.* [4] probably reported one of the most extensive and coherent choice of targets (see **Table 1**).

Mineral projectiles	Idealized formula	Important extraterrestrial occurrence	Aerogel density (kg m^{-3})	Impact speed (km s^{-1})
Olivine	$(Mg,Fe)_2SiO_4$	**IDP, Ch, Pal, Mes, Ach, eCH**	96	5.1
Pyroxene (enstatite)	$MgSiO_3$	**IDP, Ach, oCh, cCh, Mes, eCH**	96	4.80
Pyroxene (diopside)	$(CaMg)SiO_3$	**oCh, cCh, Pal, Mes, Ach, eCH**	96	5.1
Serpentine (lizardite)	$Mg_3Si_2O_5(OH)_4$	**IDP, cCh**	60	5.1
Serpentine (sensu latu)	$Mg_3Si_2O_5(OH)_4$	**IDP, cCh**	110	No impacts
Feldspar (albite)	$NaAlSi_3O_8$	**oCh, cCh, Ach**	110	4.5
Nepheline	$NaAlSiO_4$	**eCh**	110	5.7
Rhodonite	$MnSiO_3$	–	60	5.1
Calcite	$CaCO_3$	**cCh**	110	4.2
Silicon carbide	SiC	**oCH, cCH, eCH, IDP, AMM**	60	6.12
Corundum	Al_2O_3	**eCh**	96	4.95
Synthetic alumina	Al_2O_3	–	110	6.2
Spinel	$MgAl_2O_4$	**IDP, oCh, cCh, Ach, eCH**	96	4.95

Table 1 (From Burchell *et al.* [4])

Additional projectiles were used in other experiments for the same purpose. They included: — fragments of Allende, which is a "dry" carbonaceous chondrite; — fragments of the Orgueil and Murchison hydrous-carbonaceous chondrites, where the dominant hydrous silicate is serpentine; — cronstedtite, which is chemically related to the chlorites and texturally related to serpentine; — soda lime glass; — metallic beads; — pyrrhotite; — ill-defined projectiles quoted as "materials imbedded in epoxy"; etc. With the exception of serpentine, lizardite and cronstedtite, which belong to the general group of the hydrous sheet silicates (it includes 10 subgroups), and which contain two forms of water, all the other projectiles used in the simulation experiments were "dry".

Saponite, a powerful potential explosive in the W2s

The interlayer water of saponite could be the explosive that initiated the typical bulb shape of the Stardust tracks. Saponite is the dominant hydrous silicate of IDPs and AMMs. Suppose that it is also the dominant hydrous phase of the W2s before their impact into the aerogel. This mineral contains structural water that starts to be released at a low temperature of ~100 °C. In this case, the dominant bulb shape of the W2s tracks would reflect the explosive release of the constituent water of the W2s saponite at the lowest temperatures evolved during aerogel entry, in the upper part of the tracks, over a time scale (microsecond) typical of A-bomb explosions.

In contrast, all types of anhydrous particles, as well as particles mostly containing structural water like serpentine, would release this water at much higher temperatures of about 500-600°C, without triggering an explosion. They would thus leave carrot-shaped tracks, which might reflect a process of aerodynamical braking generating a shock wave that compresses the aerogel as it expends, thus leaving a typical carrot [6]. The explosion of saponite would markedly enhance the power of the shock wave.

The lack of such carrots in the Stardust aerogel would suggest a strong depletion of "dry" particles (such as chondrules and/or fragments of chondrules) in the Wild 2 dust flux before aerogel entry. Only the largest refractory phases of the W2 "shrapnel's" could continue and form a long track beyond the "bulb". Surprisingly, the missing raw carrots alone would reveal two major similarities between IDPs, AMMs and the W2s, i.e., the existence of saponite and a depletion of chondrules (we possibly observed one chondrule in a collection of about 2000 AMMs). In this case, the chemical and isotopic compositions of the AMMs and W2s olivines should be similar [7]. However, unmelted AMMs contain about 10% of crystalline grains made dominantly of a few "dry" crystals of pyroxenes and olivines. Therefore, about ~10% of the tracks observed in the Stardust aerogel should have a carrot shape, unless the abundance of crystalline AMMs is enhanced by their better survival upon atmospheric entry.

This discussion is very tentative. Indeed, it is based on sketchy results, exuding from the opaque secrecy of the Stardust studies conducted by about *"200 scientists on 3-4 continents"*. Furthermore, Kitazawa *et al.* [9] fired "dry" particles (aluminium oxides, olivine and soda lime glass) on aerogel. They report a surprising odd variety of track shapes for projectiles with rather similar masses and speeds, which range from pure carrots to shallow hemispherical craters! It could be argued that some of these tracks show a bulb rather similar to those formed by the Stardust particles (see the track reported in their Fig. 14b). But this is invalidated by the ratio of the mouth opening (entry diameter near the surface) to maximum diameter of the tracks, which is about 1 for these two specific tracks. This value is at least 10 times smaller than the high ratios (≥ 10) noted for the W2s bulbs on enlargements of their pictures available on the NASA website.

Expulsion of water from hydrous silicates.

Beside a small amount of adsorbed water, which is released at temperature ≤ 100 °C, sheet silicates contain two types of water: — structural water (OH) and; — interlayer water (H2O). These two types of water are also quoted as H2O+ and H2O-, resp., in Table 2. Clearly, saponite, which belongs to the smectite clan of the subgroup of the clay minerals, contains the largest amount of interlayer water. This is illustrated in **Table 2** for saponite and for the serpentine group of the sheet silicates (data extracted from the important book of Deer *et al.* [5]).

Table 2

Saponite	
SiO_2	50.25
TiO_2	0.03
Al_2O_3	4.44
Fe_2O_3	0.50
FeO	—
MnO	0.02
MgO	23.81
CaO	1.70
Na_2O	0.76
K_2O	0.10
H_2O^+	7.25
H_2O^-	10.76
Total	99.69

Serpentine	Chrysotile	Lizardite	Antigorite
SiO_2	41.83	41.25	43.60
TiO_2	0.02	0.02	0.01
Al_2O_3	0.30	0.54	1.03
Fe_2O_3	1.29	1.32	0.90
Cr_2O_3	—	—	0.02
FeO	0.08	0.09	0.81
NiO	—	—	0.16
MnO	0.04	0.07	0.04
MgO	41.39	41.84	41.00
CaO	tr.	0.02	0.05
Na_2O	—	—	0.01
K_2O	—	—	0.03
H_2O^+	13.66	13.68	12.18
H_2O^-	1.57	0.97	0.08
Total	100.18	99.80	99.92

(From Deer *et al.* [5])

The expulsion of water (dehydration) from the structure of the sheet silicates has been investigated by differential thermal analysis (DTA) and dehydration experiments. We use below the dehydration temperatures, ***Tc***.

The following inferences can be made:

1- Serpentine, lizardite and cronstedtite contain structural water (OH) with a negligible component of interlayer water (**Table 2**). The values of ***Tc*** are about 500-600°C for cronstedtite, and 600-700°C for serpentine and lizardite;

2- Saponite belongs to the smectite family, which contains both structural water (OH) and interlayer water (H2O) (see **Table 2**). This water is expulsed at a much lower temperature with ***Tc*** values ranging from about 100 °C to 200 °C. In all smectites, the component of structural water, which is generally the dominant one, is released at higher temperatures around 500 - 600°C.

3- Saponite contains the largest proportion of interlayer water observed among the smectites (~60%). In the serpentine group and in cronstedtite this proportion is quoted as negligible (≤ 1%).

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STARDUST's goal is to capture dust from a comet's tail and return to planet Earth - the first sample return mission to a comet! This structure represents about 1,000 square centimeters of area for collecting dust trailing within 150 kilometers of the nucleus of P/Wild-2. Comet P/Wild-2 is new to the inner Solar System.Â Dust from P/Wild-2 should impact the aerogel at high speeds and come to rest leaving carrot-shaped tracks in this amazingly tough, transparent, ultra-low density material. Returning to Earth by parachute in 2006, the cometary dust sample will be analyzed for clues to the formation and primordial composition of our Solar System. Complex aromatic hydrocarbons are distributed along aerogel tracks and in TPs. These organics are likely cometary but were affected by shock heating. Three TPs of track #147 and two of track 168 have completely different mineralogy.Â TP4 contains pentlandite, Fe-olivine, albite and high Ca pyroxene with Na and Cr (kosmochlor component). TP1 of #168 contains Fe-olivine, albite and pentlandite, and the concentric TP2 has a core of olivine grains with co-existing indigenous amorphous SiO2 surrounded by a carbon mantle, which in turn is surrounded by a layer of compressed aerogel. The TP of the carrot track #112 is a 16O-rich forsteritic olivine grain that likely formed in the inner Solar System. The track also contains submicron-sized diamond grains of likely Solar System origin. Read more. Silica aerogels like the ones used on the Stardust probe are extremely brittle and machining it using normal techniques causes it to fracture unpredictably. I can corroborate thisâ€“at one point before Stardust returned, NASA reached out to me personally (as they did many aerogel researchers) to ask if I had any experience cutting aerogels! Allâ€™s well that ends wellâ€“the ingenious team at NASA developed a method using a high-frequency vibrating microscopic needle to extract the comet particles from the aerogel in time to make use of the samples that were returned, making Stardust one of the most