Nanometer-Scale Anatomy of Entire Stardust Tracks

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Analyses of samples returned from Comet 81P/Wild-2 by the Stardust spacecraft revealed a number of surprising findings that show the origins of comets are more complex than previously suspected. However, these samples pose new challenges for study because they are diverse and suffered fragmentation, thermal alteration, and fine scale mixing with aerogel. Consequently, fundamental questions remain about the nature of cometary materials, such as the abundances of organic matter, crystalline materials, and presolar grains. To overcome these challenges, Johnson Space Center (JSC) researchers developed new sample preparation and analytical techniques tailored for entire aerogel tracks of Wild2 sample analyses both on “carrot” and “bulbous” tracks. The team successfully sliced an entire track along its axis while preserving its original shape. The track was sliced into 510 thin sections with 70 nanometer (nm) thickness (figure 1). This innovation allowed examination of the distribution of fragments along the entire track from the entrance hole all the way to the terminal particle. Researchers used a scanning transmission electron microscope for elemental and detailed mineralogy characterization, a NanoSIMS for isotopic analyses, and an ultrafast two-step laser mass spectrometry (*ultra* L2MS) to investigate the nature and distribution of organic phases.

The JSC team’s most important findings from the analysis of these two Wild2 aerogel tracks and their terminal particles include the following:

- The terminal particles are dominated by magnesium-rich crystalline silicates (forsterite and enstatite) that formed at high temperatures.
- The crystalline silicates have oxygen (O) isotopic compositions within the range of meteoritic materials, implying that the crystalline silicates originated in the inner solar system.
- The forsterite grain shows a ^{16}O-enrichment of ~40‰, and likely formed in the inner solar system. This grain may have formed together with amoeboid olivine aggregates in meteorites.
- Sub-micrometer diamond grains were identified that likely formed in the solar system
- Complex aromatic hydrocarbons are distributed along aerogel tracks and in terminal particles. These organics are likely cometary but affected by shock heating.
- Some cometary grains contain nitrogen-rich organic matter in the form of aromatic nitriles (R-C≡N). Such materials have potential astrobiological importance because it is believed that comets significantly contributed to the prebiotic chemical inventory of both the Earth and Mars.
- The Stardust organic compounds share some similarities with those of carbonaceous chondrites but are more similar to interplanetary dust particles. These findings are consistent with the notion that a fraction of interplanetary dust is cometary.

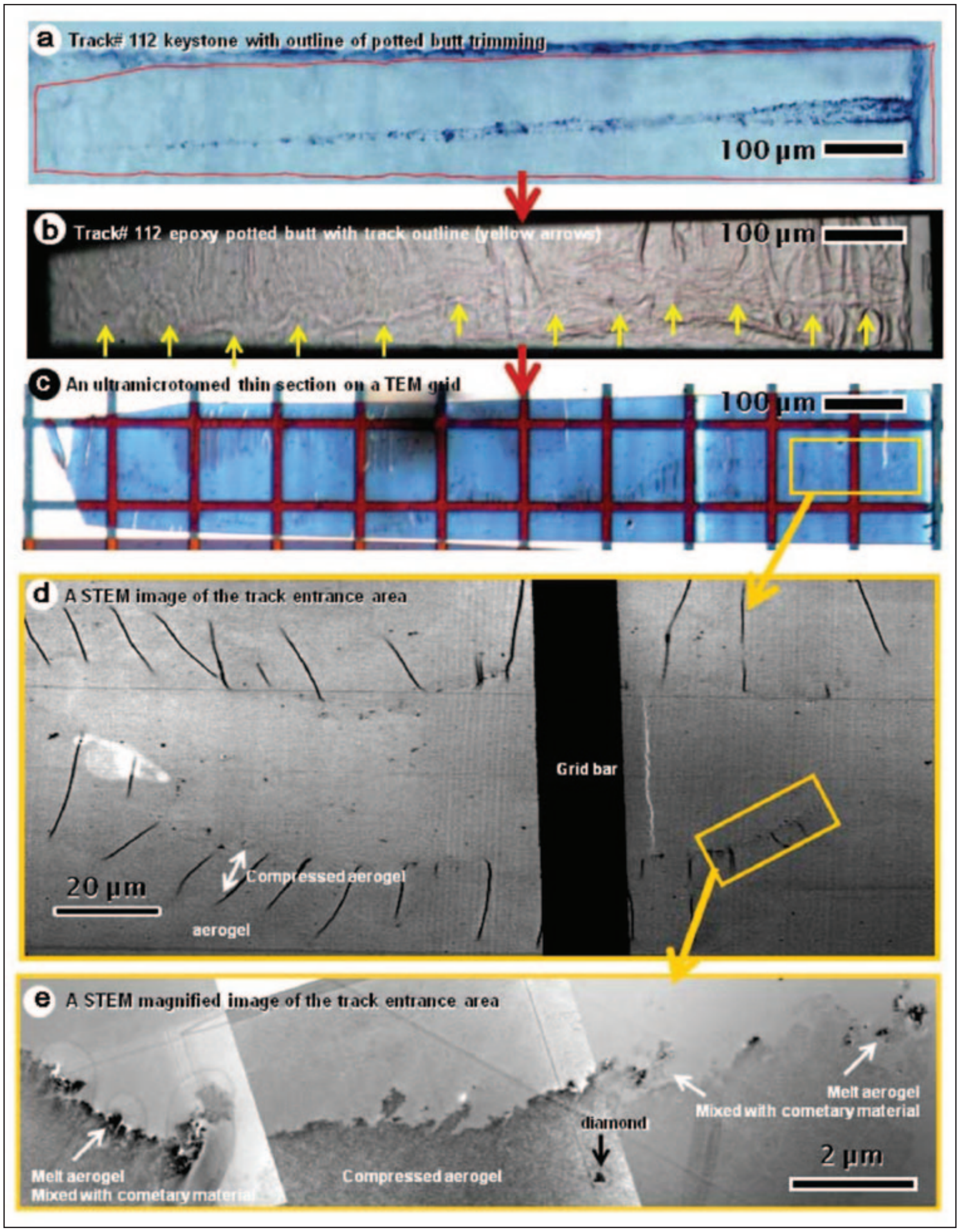

Fig. 1. *Processing flow chart for dissecting the whole track in aerogel.* ***(a)*** *Low magnification optical micrograph (under transmitted light) of the Track112 keystone after the terminal particle extraction. The red trapezoid indicates the outline of trimmed potted butt.* ***(b)*** *Top view of the epoxy potted butt of Track112 after trimming into trapezoid shape. Yellow allows indicate the track outline visible through the covering epoxy resin.* ***(c)*** *One out of 510 ultramicrotomed thin sections of Track112 mounted on amorphous carbon supported Cu transmission electron microscope grid.* ***(d)*** *A bright-field scanning transmission electron microscope micrograph of the boxed area in (c). The track morphology is well-preserved in an ultramicrotome thin section and material is intact. The aerogel within 20 µm of the track wall (darker contrast with wrinkles) was compressed by the impact.* ***(e)*** *Photo mosaic of bright-field scanning transmission electron microscope micrographs of boxed area in (d). Numerous sub-micrometer-sized grains are observed along the track wall. Many of these tiny grains consist of melt particles (cometary material intimately mixed with melted aerogel). One of the diamond grains is located in the compressed aerogel (arrowed).*