CHEMICAL, MINERALOGICAL, AND ISOTOPIC CHARACTERIZATION OF TERMINAL PARTICLES FROM STARDUST TRACKS. C. E. Jilly-Rehak[1], G. R. Huss[2], A. L. Butterworth[1], A. J. Westphal[1], Z. Gainsforth[1], D. R. Frank[2] and R. C. Ogliore[3]. [1]Space Sciences Laboratory, University of California at Berkeley, Berkeley CA 94720, USA; [2]Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Mānoa, Honolulu HI 96822, USA; [3]Physics Department, Washington University, St. Louis, MO 63130.

Introduction: We report on the past year of our consortium study of Stardust cometary tracks, with the goal of exploring the chemical, mineralogical and isotopic diversity of materials returned from comet 81P/Wild 2.

Samples and Methods: We studied six tracks extracted from aerogel tile C2031.

We used the *keystone extraction* technique [1] to extract tracks from the tile, isolate terminal particles, and dissect track bulbs. We separated the terminal particles from each other and from the track bulbs using keystone microsurgery, in which we laid the keystone containing the track on its side, secured it using an 4-μm-thick ultralene "surgical tent" with an access slit, then sliced it into $\sim 100-300\,\mu$m-thick wafers using the keystoning system. We isolate terminal particles separated in the aerogel by $\geq 50\mu$m using this technique.

In preparation for measurements of oxygen isotopes in fine-grained material captured in the track bulb [2], we used a newly developed *high-pressure sapphire press*, which uses a C-coated sapphire window for high transfer efficiency, to press dissected bulb halves into indium in the center of a polished Al round. The round incorporates polished standards surrounding the In, in a configuration identical to the standard "buckler" mount [2,3].

We used *synchrotron x-ray microprobe* beamline 10.3.2 at the Advanced Light Source at Lawrence Berkeley National Lab (LBNL) to analyze particles while still in the aerogel keystones, and to identify silicates for subsequent oxygen isotopic analysis. Using fluorescence mapping at 10 keV and a 6μm $\times$ 6μm beamspot, we measured the elemental composition of particles for the rock-forming elements $20 \leq Z \leq 30$ (Ca-Zn). We also used spot X-ray Absorption Near-Edge Structure (XANES) analyses [4] and chemical mapping [5] at the Fe edge to identify silicates, sulfides, and metals.

After wafering, terminal particles identified as silicates were impregnated with epoxy on the end of epoxy bullet. After curing, we used the *ultramicrotome* at the National Center for Electron Microscopy (NCEM) at LBNL to remove $\sim$100-nm thick slices and place them on TEM grids. The remaining potted butts were mounted in our specially designed "buckler" mounts for ion probe analysis [2,3].

We conducted *TEM analyses* at NCEM, using the Philips CM200/FEG TEM equipped with an Oxford EDS detector. The beam voltage was set to 200 keV for imaging and chemical analyses. Quantitative EDS analyses were made for individual phases in track 202 TP5, with a dwell time of 30 min per phase.

Oxygen isotopes were measured using the University of Hawai'i Cameca *ims 1280 ion microprobe* in multi-collector mode. A $\sim$2 μm, $\sim$20 pA Cs^+ primary ion beam was used to measure individual phases within the terminal particles [e.g., 2].

Results: *Track 200* (C2031,1,200) was a type "A" carrot-shaped track 390 μm long. Optical microscopy and X-ray microprobe analyses indicated a $\sim 2 \times 3\mu$m terminal particle consisting of mixed silicate and sulfide. TEM examination of microtomed sections showed that the particle consists of two silicate phases, one Mg-rich (likely olivine), and one Ca-rich (likely pyroxene), surrounded by a rim of Fe-sulfide. EDS analyses were not quantitative as they were enriched in SiO_2 from aerogel contamination, and small grain sizes led to mixed analyses. Unfortunately, the potted butt contained only a quenched melted mixture of aerogel and particle.

Track 201 (C2031,2,201) was a 1800-μm long type "A" track. The deepest terminal particle was $\sim$2x4 μm. SXRF and XANES analysis showed Fe-bearing material dominated by sulfide. The TEM sections were mostly plucked out, and the residual material consisted of SiO_2 with some tiny embedded sulfides. Ion probe analysis confirmed that the SiO_2 was melted and quenched aerogel.

Using the keystoning technique, we dissected the bulb of track 201 into two halves, and pressed into In. Oxygen isotopic analyses are pending.

We also identified a second terminal particle in track 201 in optical imagery that was not visible in synchrotron x-ray microprobe maps. This particle is likely to be a cap of melted aerogel that separated from the terminal particle shortly before it stopped.

Track 202 (C2031,3,202) was a 5mm-long type "B" track, with a $\sim$500-μm diameter bulb and 14 terminal particles. Synchrotron analysis indicated that the terminal particles consist of 5 silicates, 3 sulfides, 2 metals, and 4 particles of mixed composition.

In Fig. 1, we show the scatterplot of Fe chemical-map data indicating the presence of discrete metal particles in the bulb of track 202. These particles are not identifiable visually, so cannot be targeted for extraction using the wafering technique. These might be isolated in the future using new fluorination techniques [6-8].

Terminal particle 5 (TP5) in track 202 was identified by Fe XANES as a silicate. TEM analysis (Fig. 2) showed that the terminal particle consists of two silicate phases. The first is olivine with composition (in elemental wt. %): 42.2% O, 26.2% Mg, 18.6% Si, 12.9% Fe. The second is pyroxene with composition: 46.0% O, 14.3% Mg, 2.8% Al, 27.1% Si, 1.7% Ca, 0.2% Ti, 0.7% Cr, and 7.2% Fe. The pyroxene composition is slightly non-stoichiometric, possibly due to the presence of multiple-valence cations. The oxygen isotopic composition of TP5 (Fig. 3) is consistent with that of the majority of other Wild 2 silicates.

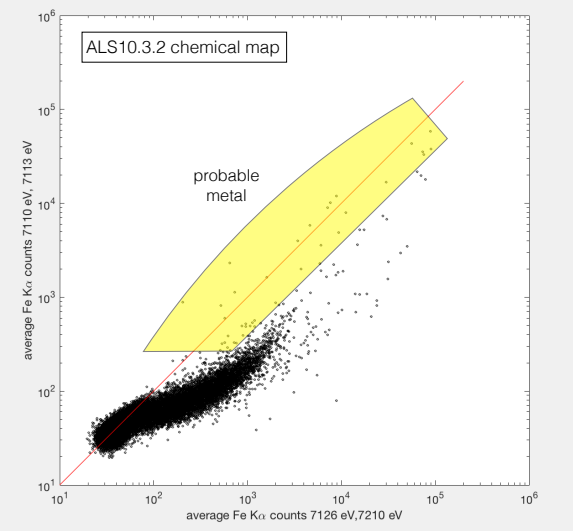

Figure 1: Scatterplot of Fe chemical map data on the bulb of track 202. We acquired data on ALS beamline 10.3.2. Pixels containing probable metals in the bulb are shown in yellow.

Track 203 (C2031,4,203) is a 5.2 mm-long type "B" track. Synchrotron X-ray microprobe analysis of the two large terminal particles indicates that they are sulfides. A chemical map of the bulb, similar to the chemical map done on the track 202 bulb, also indicates the presence of small metal particles. Sulfur-isotope measurements of the terminal particles are pending.

Track 204 (C2031,5,204) is a bulbous type "C" track, with a very small terminal particle, identified as a sulfide by synchrotron X-ray analysis. We dissected the bulb of track 204 and pressed both sides into In in preparation for SIMS O-isotopic analysis. Analyses are pending.

Track 205 (C2031,6,205) is a small bulbous type "C" track with no identifiable terminal particle. Chemical mapping at Fe showed that the bulb is dominated by Fe^{2+}-bearing material.

Acknowledgments: The Advanced Light Source and the Molecular Foundry are supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

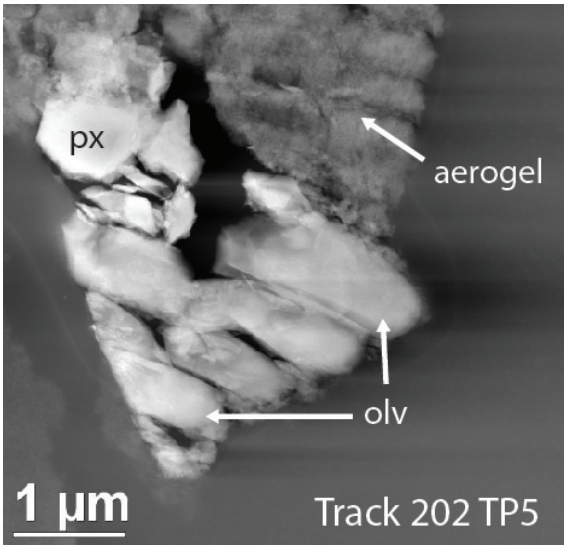

Figure 2: TEM image of microtomed section from Track 202 TP5. olv = olivine, px = pyroxene.

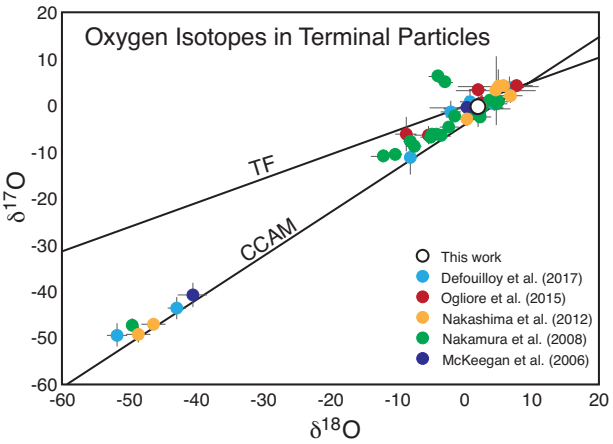

Figure 3: Oxygen isotopic composition of track 202 TP5 (C2031,3,202,1,0) compared to other terminal particles. Data from [2, 9-12].

References: [1] Westphal A. J. et al. (2004) *Meteorit. Planet. Sci.* 39, 1375-1386. [2] Ogliore R. C. et al. (2015) *Geochim. Cosmochim. Acta* 166, 74-91. [3] Westphal A. J. et al. (2011) *Meteorit. Planet. Sci.* A 74, 5274. [4] Westphal A. J. et al. (2009) *Ap. J.* 694, 18-28. [5] Ogliore R. C. et al. (2008) *Proc. 39th LPSC*, 2363 [6] Westphal A. J. et al. (2004) *Proc. 35 LPSC*, 1860. [7] Martin A. A. et al. (2016) *Meteorit. Planet. Sci.* 51, 1223. [8] Haas, B. et al. (2018) these proceedings. [9] Defouilloy C. E. et al. (2017) *Earth Planet. Sci. Lett.* 465, 145-154. [10] Nakashima D. et al. (2012) *Earth Planet. Sci. Lett.* 357-358, 355-365. [11] Nakamura T. et al. (2008) *Science* 321, 1664-1667. [12] McKeegan K. D. et al. (2006) *Science* 314, 1724-1728.