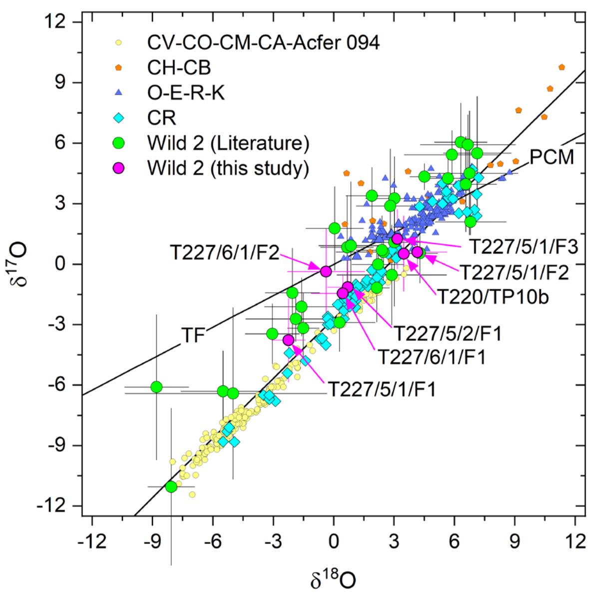
INTRA- AND INTER-TRACK OXYGEN ISOTOPE DIVERSITY OF CRYSTALLINE SILICATES FROM COMET 81P/WILD 2. M. Zhang[1], D. E. Brownlee[2], D. J. Joswiak[2], A. J. Westphal[3], Z. Gainsforth[3], and N. T. Kita[1], [1]WiscSIMS, Department of Geoscience, University of Wisconsin–Madison, Madison, WI 53706, USA (mzhang467@wisc.edu), [2]Department of Astronomy, University of Washington, Seattle, WA 98195, USA, [3]Space Sciences Laboratory, University of California, Berkeley, California 94720, USA

Introduction: It has been well recognized that a large fraction of materials returned from comet 81P/Wild 2 by NASA's *Stardust* mission is composed of high-temperature crystalline fragments [1]. Previous studies have revealed (i) a mixture of unequilibrated anhydrous minerals (mainly olivine and low-Ca pyroxene, showing wide compositional ranges) [2]; (ii) the existence of calcium-aluminum-rich inclusions (CAIs), chondrule-like fragments, and LIME olivine and enstatite that likely condensed from solar nebula gas [3-6]; (iii) oxygen isotope systematics closest to CR chondrite chondrules [5-6]; and (iv) an accretion age later than ~3 Ma after CAIs [7-8]. The findings have broad similarities to meteoritic components and suggest a large-scale transport of solids across the full dimension of the solar nebula [1].

However, the source of crystalline silicate remains controversial. Fe as well as Mn and other minor elements in olivine indicate a source of various carbonaceous and ordinary chondrite-forming regions [9]. In contrast, oxygen isotope systematics of crystalline silicates indicate the major source is CR chondrite chondrule-like materials [4-5]. In addition, the genetic relationship between particles within individual tracks or from different tracks needs further investigation [10]. The purpose is to understand the chemical and isotopic diversities of minerals within type B tracks (made by aggregates of unequilibrated coarse- and fine-grained materials), as compared to that in type A tracks (made by single mineral or a mineral assemblage) [2].

Samples and results: This study includes a terminal particle (TP10) from track 220 and six particles from the bulb region of track 227, with a size ranging from 4 × 2 μm^2 to 13 × 9 μm^2. T220 is a large type B track composed of more than six terminal particles, numerous small particles, and large areas of melt. TP10 is dominated by low-Ca pyroxene ($En_{95}Wo_3$) with an olivine (Fo_{87}) inclusion. T227, one the eight largest tracks within the cometary tray, is a type B track (~ 17 mm) composed of a large bulb, a major root, and three <1 mm-long roots. T227/5/1/F1-F2 are iron-rich olivine ($Fo_{78\text{-}80}$) fragments. T227/5/1/F3 and T227/6/1/F1-F2 are low-Ca pyroxene ($En_{96\text{-}99}Wo_{0.5\text{-}3}$) fragments. T227/5/2/F1 is a polymineralic fragment dominated by olivine ($Fo_{90\text{-}92}$) with inclusions of low-Ca pyroxene and nm-size roedderite-like materials.

Oxygen isotope ratios of the seven particles were determined using the CAMECA IMS-1280 at WiscSIMS, following the analytical procedures described in [5-6, 11]. The primary Cs$^+$ beam was ~2 × 1.5 μm^2 in size with an intensity of 2.5-3.0 pA. Precise aiming of target locations (±0.2 μm) was achieved by shifting the primary ion beam by ≥0.1 μm steps with the "Nanodeflector," according to the ion image of a region with FIB marks. Typical analytical uncertainty (2SD) for $\delta^{18}O$, $\delta^{17}O$, and $\Delta^{17}O$ on running standard San Carlos olivine are 1‰, 2‰, and 2‰, respectively.



Of 20 measurements made on the seven particles, nineteen have similar pit shapes with a flat bottom and no signs of overlapping aerogel. Mean oxygen isotope ratios of individual particles have a narrow range (magenta circles in Fig. 1), with $\delta^{18}O$, $\delta^{17}O$, and $\Delta^{17}O$ varying from –2.3 ± 0.8‰ to 4.2 ± 1.5‰, from –3.8 ± 2.1‰ to 1.3 ± 1.5‰, and –2.6 ± 1.9‰ to –0.2 ± 1.4‰, respectively. All particles plot close to the primitive chondrule mineral (PCM) line and below the terrestrial fractionation (TF) line, falling in the range defined by literature results of Wild 2 particles [4-7, 10-13].

Discussion: In terms of oxygen three-isotope ratios (Fig. 1) and Mg#–$\Delta^{17}O$ relationship (Fig. 2), the data from new seven Wild 2 particles are similar to those of other Wild 2 particles in the literature and overall are consistent with an origin similar to CR chondrite chondrules [5-6]. However, as compared to chondrules in primitive chondrites, six out of 43 (14%) Wild 2 particles (Cecil, T22/F7, F8, and F12, T77/F7, and T191/B1/F6, Fig. 1) have positive oxygen isotope ratios that plot above the TF line and overlap with chondrules in ordinary (O), enstatite (E), R, K, and CH-CB chondrites [14]. This is similar to what was observed in crystalline silicates of a giant cluster IDP of likely cometary origin, where four out of 20 (20%) particles were likely derived from the inner solar system or CH-CB-forming region [11].

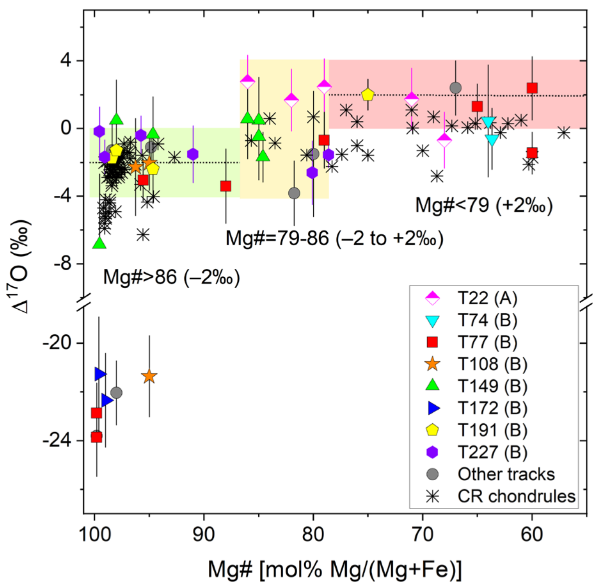


Fig. 2. Mg#–Δ17O relationship in Wild 2 particles [4-7, 10-13, this study] and CR chondrite chondrules [14]. "A" and "B" in parentheses represent the type of track.

By compiling oxygen isotope data from the literature and this study, we found the Mg#–Δ^{17}O relationship in ^{16}O-poor Wild 2 particles allows them to be divided into two groups, one is Mg# >86 particles with negative Δ^{17}O (~–2 ± 2‰), and the other is Mg# <79 particles with positive Δ^{17}O (~+2 ± 2‰) (Fig. 2). The two groups overlap at Mg# = 79-86. The positive Δ^{17}O values of iron-rich particles are rare in chondrules in carbonaceous chondrites except for CH-CB groups, while they are common in chondrules in O, E, R, and K chondrites that likely formed in the inner solar system [14]. This observation indicates that materials from the CH-CB-forming region or inner solar system contributed to comet Wild 2.

Within individual tracks, the studied particles typically have different chemical compositions and/or resolvable δ^{18}O and δ^{17}O values, supporting the idea that Stardust tracks were made by fragments or aggregates of unequilibrated materials [2]. Exceptions are LIME olivine fragments F6 and F50 in T77, olivine fragments F11a and F11b (Mg# = 80) in T149 and B1/F1 and B1/F2 (Mg# = 98) in T191, and two low-Ca pyroxene fragments (6/1/F1 and 6/1/F2, Mg# = 99) in T227. These fragments are typically close to each other and could be derived from a single particle that fragmented during impact onto the aerogel.

Among different tracks, the studied particles typically show different Mg#–Δ^{17}O relationships. The most studied track, T77 (type B), exhibits the largest ranges of Mg# (60 to 100) and Δ^{17}O (–24‰ to +2.4‰), indicating the impactor is an aggregate of silicate particles that formed in various environments [4]. In type B tracks 149, 191, and 227, most particles have similar Δ^{17}O values (Δ^{17}O = –1.7‰ to +0.6‰ in T149 and –2.4‰ to –1.3‰ in T191, –2.6‰ to –0.2‰ in T227), suggesting that they are dominated by materials of similar origins. The outliers are T149/F2 and T191/B1/F6, which is either more ^{16}O-enriched or more ^{16}O-depleted than others in the same track. Besides, this interpretation is tentative for T227 since more particles from this track will be analyzed soon. In contrast, the studied particles in type A track T22 have narrow Δ^{17}O ranges (Δ^{17}O= –0.7‰ to 2.8‰) that are almost independent of Mg# (71-86), suggesting that type A tracks were made by a single mineral or mineral assemblage formed in a similar environment.

Conclusion: The crystalline silicates in Wild 2 are composed of CR chondrule-like materials and materials derived from the inner solar system or the CH-CB-forming region. So far, except for track 77 which is composed of materials formed in various environments, the crystalline silicates in other type B tracks are dominated by unequilibrated materials of similar origin, just like that of type A tracks.

References: [1] Brownlee, D. E. (2014) Annu. Rev. *Earth Planet. Sci, 42*, 179-205. [2] Joswiak, D. J., et al. (2012) *MAPS, 47,* 471-524. [3] Joswiak, D. J., et al. (2017) *MAPS, 52,*1612-1648. [4] Nakamura, T., et al. (2008) *Science, 321*, 1664-1667. [5] Nakashima, D., et al. (2012) *EPSL*, *357-358*, 355-365. [6] Defouilloy, C., et al. (2017) *EPSL, 465,* 145-154. [7] Ogliore, R. C., et al. (2012) *APJ, 745*, L19. [8] Nakashima, D., et al. (2015) *EPSL, 410,* 54-61.[9] Frank, D. R., et al. (2014) *GCA, 142,* 240-259. [10] Chaumard, N., et al. (2018) *LPS XLIX,* Abstract #2163. [11] Zhang, M., et al. (2021) *EPSL, 564,* 116928. [12] Ogliore, R. C., et al. (2015) *GCA, 166,* 74-91. [13] Gainsforth, Z., et al. (2015) *MAPS, 50,* 976-1004. [14] Tenner, T., et al. (2018) *Chondrules: Records of Protoplanetary Disk Processes.* Cambridge University Press: 196-246.