DIVERSE SOURCE REGIONS FOR FRAGMENTS FROM A SINGLE STARDUST TRACK: A MINERALOGICAL AND ISOTOPIC STUDY OF TRACK 77. D. J. Joswiak[1]*, D. E. Brownlee[1], G. Matrajt[1], D. Nakashima[2], T. Ushikubo[2], N. T. Kita[2], Z. Gainsforth[3] and A. Westphal[3]. [1]University of Washington, Dept. of Astronomy, Seattle, WA 98195, [2]University of Wisconsin-Madison, Dept. of Geoscience, Madison, WI 53706, [3]University of California at Berkeley, Space Sciences Laboratory, Berkeley, CA 94720. *joswiak@astro.washington.edu.

Introduction: The particles returned from comet Wild 2 are dominantly composed of high temperature minerals and rock fragments suggesting their derivation from the hot inner solar nebula [1,2]. A number of the Wild 2 fragments resemble materials observed in chondritic meteorites including chondrules [2] and CAIs [1]. Two important issues regarding the Wild 2 particles are the number of source regions of materials that were sampled and possible associations between the Wild 2 fragments and particular meteorite groups.

Here we report on our results obtained from detailed TEM examinations of 29 large fragments (typically several microns) from Stardust (SD) track 77. Additionally, six of the fragments were analyzed for oxygen isotopes by [3]. Combined mineralogical and isotopic studies of Wild 2 fragments are a powerful means toward gaining insight into their likely origins.

Analytical Techniques: Microtome sections of the large fragments were obtained after flattening the track and embedding with acrylic resin. The sections were studied with a FEI TF20 TEM equipped with bright- and dark-field, STEM and EDX detectors. Backscatter images of some of the fragments were obtained from the potted butts with a FEI Sirion FESEM.

Results: Optical examination indicated that track 77 was a type B (bulbous) track with >54 large fragments dispersed troughout the bulb and several large roots. TEM investigations of the microtome sections obtained from 29 coarse fragments showed that 24 were composed of single mineral grains. These include 16 olivines, 3 low-Ca pyroxenes, 2 high-Ca pyroxenes, 2 pyrrhotites and a single albite fragment. The olivines ranged from Fo_{52} to Fo_{100} with the largest proportions represented by the most FeO-rich and the most FeO-poor compositions.

Three enstatite fragments (En_{95}, En_{95}, $En_{99.8}$) and a Na- and Cr-rich augite (Na_2O = 3.5 wt%; Cr_2O_3 = 4.9 wt%) were present in a small region in the middle portion of the bulb. A Ca-bearing pyroxene (varying from pigeonite to augite), was present as a terminal particle at the end of a short side track and is unusually rich in Mn, Cr and Al (MnO = 7.9-12.3 wt%; Cr_2O_3 = 1.6-2.8 wt%, Al_2O_3 = 3.1-4.7 wt%).

Four rock fragments consisting of FeO-rich olivine ($Fo_{61\text{-}66,83}$)+Na,Cr-rich high-Ca pyroxene+/-albite were also found in the track. This unique assemblage, previously termed a Kool grain has been observed in at least 9 SD tracks [4]. Correlated Ca and Cr observed in images obtained from synchrotron studies further suggest that additional Kool grains are present. A fifth rock fragment consists of $Fo_{59\text{-}60}$ olivine+kamacite. The Fe,Ni metal phase occurs as a proportionately large inclusion in the interior of the grain.

Oxygen isotope ratios obtained from six individual fragments from the track are variable (Fig. 1; data from [3]). Two fragments (6 and 50) are LIME (low-Fe, Mn-enriched) forsterites and plot at the extremely ^{16}O-rich end of the CCAM line near many CAIs and pristine AOAs [5]. Fragment 1, a $Fo_{62\text{-}67}$ olivine grain, and fragment 5, a Kool grain, both plot above the TFL with $\Delta\delta^{18}O$ values of ~+1.3‰ (Fig. 1, inset). Fragment 4, a $Fo_{53\text{-}61}$ olivine grain plots slightly below the TFL with a $\Delta^{17}O$ of -1.5‰ and falls on the CCAM line. Fragment 9, the Mn,Cr,Al-rich calcic pyroxene, plots significantly below the TFL with a $\Delta^{17}O$ value of ~ -3‰.

Discussion. The diversity of fragments observed in track 77 indicates that the original Wild 2 particle that produced the track was an aggregate of mineral and rock fragments. Some of the fragments in the track are believed to be pieces of former larger coherent grains which physically broke apart during capture. Fragments included in this category are the LIME forsterites, the two En_{95} fragments, and at least three of the Kool grains which have similar mineralogy and mineral compositions to one another. The widely-ranging Mg numbers (0.52 – 1.0) observed in the ferromagnesian silicates in the track demonstrate its unequilibrated nature.

Comparison of the oxygen isotope ratios with their intrinsic mineralogies indicates that at least three populations of fragments are represented. First, the ^{16}O-rich LIME forsterites (fragments 6 and 50) are compositionally and isotopically distinct from the other olivines. These fragments which plot at $\delta^{18}O$, $\delta^{17}O$ = ~ -50‰ (Fig. 1) are isotopically similar to forsterites in AOAs from several groups of carbonaceous chondrites (CC) including the CR, CO and CV groups and overlap the most refractory minerals in CAIs [5]. LIME forsterites, first observed in IDPs and unequilibrated

ordinary chondrites (OC) were suggested to have formed at ~1100 K by reaction with Mn-bearing, Fe-depleted nebular gas [6].

A second population is composed of fragments with FeO-rich olivine grains (fragment 1 = Fo_{62-67}, fragment 4 = Fo_{53-61}, fragment 5 = Kool grain). The FeO-rich olivines in these fragments have Mg/(Mg+Fe) ratios that overlap R chondrite olivines (Fo_{60-69}) [7] and olivines in type II chondrules in CC. The Kool grain, which is composed of Fo_{66} olivine+Na,Cr-rich high-Ca pyroxene+albite, most closely resembles published olivine+high calcium pyroxene+albite lithologies in R chondrites [8]. The oxygen isotope ratios of the three fragments with FeO-rich olivines plot near the TFL, either slightly above or below, and overlap FeO-rich olivines from R chondrites [7] (Fig. 1, turquoise oval, inset) and CR chondrites (Fig. 1, yellow ovals, inset) [9]. They are also similar to bulk chondrules in OC [10] (Fig 1, orange oval, inset).

Fragment 9, representative of the third population, is a Mn,Cr,Al-rich calcic pyroxene which plots on the CCAM line (within analytical uncertainties) and overlaps bulk chondrules from CC [11] as well as SD fragments from previous studies [2]. It may be related to chondrules in CC meteorites.

Conclusions. The Wild 2 particle that produced track 77 was composed of a heterogeneous mixture of mineral and rock fragments whose Fe-Mg silicates have wide-ranging Mg numbers. Some of the fragments in the track were likely part of larger parent grains in the original particle but separated during capture. Oxygen isotopic compositions from six fragments in the track indicate that the fragments were derived from isotopically diverse sources. These likely included an ^{16}O-rich nebular source region similar to OC and R chondrites, or FeO-rich chondrules in CR and CH chondrites. Additionally, at least one fragment which falls on the CCAM line and is isotopically distinct may also be related to carbonaceous chondrites. The results from this single track study dramatically illustrate that comet Wild 2 is mineralogically and isotopically heterogeneous and unequilibrated at the μm scale and appears to have sampled spatially diverse regions in the solar nebula.

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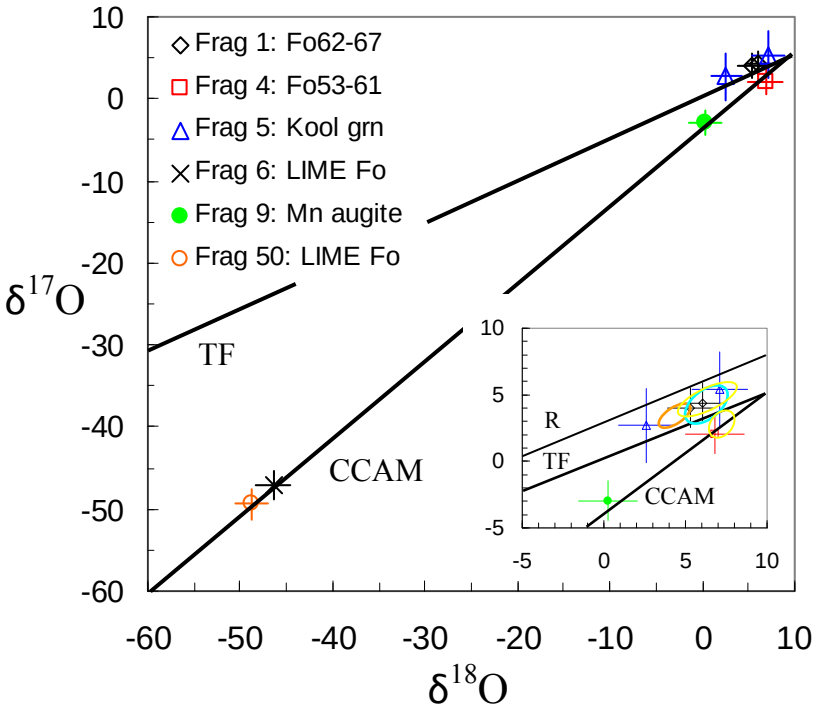

Figure 1: Oxygen 3-isotope diagram showing six analyzed fragments from track 77 (2σ error bars). Isotopic data from [3]. All fragments are composed of single minerals except fragment 5 which is a mixture of FeO-rich olivine (Fo_{66}), Na,Cr-rich augite and albite (Kool grain [4]). Turquoise and yellow ovals show that oxygen isotopic compositions of FeO-rich olivines (Fo_{60-69}) in R chondrites [7] and CR chondrites [9], respectively, overlap the FeO-rich olivine fragments in track 77. Orange oval field shows oxygen isotopic compositions of bulk chondrules from OCs [10]. Bulk R chondrite line from [7]. TF=terrestrial fractionation line, CCAM = carbonaceous chondrite anhydrous mineral line.