

**STARDUST TRACK 130 TERMINAL PARTICLE: POSSIBLE Al-RICH CHONDRULE FRAGMENT OR ALTERED AMOEBOID OLIVINE AGGREGATE.** D. J. Joswiak<sup>1</sup>, D. E. Brownlee<sup>1</sup>, G. Matrajt<sup>1</sup>, S. M. Messenger<sup>2</sup> and M. Ito<sup>2</sup>, <sup>1</sup>University of Washington, Dept. of Astronomy, 351580, Seattle WA 98195, <sup>2</sup>Johnson Space Center 2101 NASA Parkway, Houston TX 77058. Correspondence e-mail: joswiak@astro.washington.edu.

**Introduction:** CAI's and chondrules or chondrule-like objects are among the high temperature materials present in comet Wild 2 [1,2,3]. We studied the terminal particle (TP) from Stardust track 130 which has not been previously examined. Our data show that it is dominantly composed of a refractory mineral assemblage composed of Mg-rich olivine, Al and Ti-bearing clinopyroxene (augite) and anorthite. Similar phase assemblages (+/- spinel) are observed in both Al-rich chondrules and amoeboid olivine aggregates (AOAs), refractory objects that are rare but present in most chondritic meteorite classes. Al-rich chondrules are igneous objects believed to have origins similar to but distinct from ferromagnesian chondrules while AOAs likely formed by high temperature condensation in the solar nebula [4].

Here we present the mineralogy, petrography, oxygen isotope measurements and bulk chemical composition data of the TP (Bidi) from Track 130. Much of the data suggest that Bidi may be related to either Al-rich chondrules or altered AOAs (nebular). However, its bulk composition, high Al<sub>2</sub>O<sub>3</sub> content and moderate abundance of olivine supports the conclusion that Bidi is more closely akin to Al-rich chondrules than AOAs.

**Techniques:** Track 130 is a 1.3 mm-long, debris-free carrot-shaped track containing a single 8 μm terminal particle. Following extraction at the Johnson Space Center (JSC), the track was flattened and embedded at the University of Washington with acrylic resin and cut into segments for microtoming [5]. Approximately 80 nm-thick microtome sections containing the TP were placed onto Cu or Au 200 mesh TEM grids with 10 nm carbon support films and studied with a Tecnai F20 200 kV STEM using standard techniques. Quantitative EDX analyses by K-factor reduction were done using a light element EDAX X-ray detector and Genesis analyzer. To minimize beam damage, the compositional analyses were performed at reduced beam currents in conventional TEM mode with spot sizes of ~ 100 nm or larger. Using average mineral compositions, we estimated the bulk composition of Bidi from modal analyses of three nearly complete microtome sections.

Oxygen isotopic measurements were obtained with the NanoSIMS 50L ion microprobe at JSC. Images of <sup>16</sup>O<sup>-</sup>, <sup>17</sup>O<sup>-</sup> and <sup>18</sup>O<sup>-</sup> were acquired simultaneously with multiple electron collectors by rastering a 1 pA 16keV primary Cs<sup>+</sup> ion beam focussed to 100 nm. Isotopic compositions were determined with custom-written

image processing software in which corrections were made for electron multiplier deadtime, QSA and instrumental mass fractionation.

**Petrography/mineralogy:** TEM investigations show that Bidi is dominantly composed of three major phases, equilibrated Fo<sub>97</sub>, Al- and Ti-rich augite and anorthitic plagioclase, which appear to be aligned in a manner similar to barred or radial structures in some chondrules (Figure 1). Spinel was not observed. Measured Al<sub>2</sub>O<sub>3</sub> and TiO<sub>2</sub> contents of augite range from 1.7 – 8.0 wt% and 0.72 – 2.0 wt%, respectively. Relatively high Cr<sub>2</sub>O<sub>3</sub> (1.3 – 2.1 wt%) was also measured in the augite. Plagioclase contents varied from 94 – 100% anorthite component. Electron diffraction patterns confirmed the anorthite phase. Ni-free, Fe inclusions, 10 – 20 nm in diameter, were also observed in the anorthite. SiO<sub>2</sub> glass was nearly always present with anorthite and usually interleaved on scales ranging from 10 - 100 nm. The nature of this glass is uncertain but it has been reported in anorthite in some Al-rich chondrules [6]. We are reasonably certain that the glass is not related to silica aerogel from capture.

The bulk composition of Bidi is plotted in the ternary diagram in Figure 2 (solid red circle) along with Al-rich chondrules from unequilibrated ordinary chondrites [7]. The fields from AOAs and fine-grained CAI's are also shown [8]. The measured bulk Al<sub>2</sub>O<sub>3</sub> content of Bidi is 10.1 wt%.

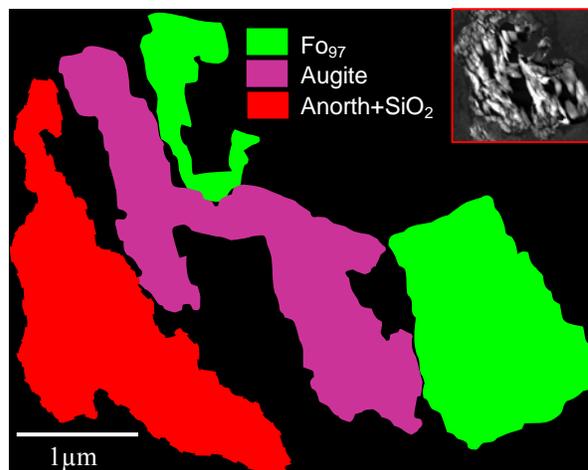


Figure 1: Color map of microtome slice from the interior of terminal particle from Track 130 (Bidi) composed of Fo<sub>97</sub>, Al- and Ti-rich augite and anorthite. Inset in upper right shows HAADF image of microtome slice.

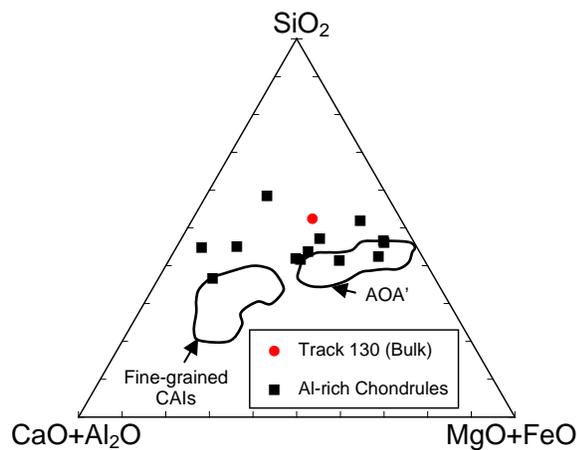


Figure 2: Ternary diagram (wt%) showing the estimated bulk composition of TP Bidi (red solid circle) compared to Al-rich chondrules (black squares), AOA's and fine-grained CAI's suggesting that Bidi is more closely related to Al-rich chondrules than AOA's.

**Oxygen Isotopes:** Oxygen isotopic measurements from Bidi (Track 130) olivine, Al- and Ti-rich augite and anorthite are plotted in Figure 3. Oxygen isotopic regions of the minerals olivine, fassaite and anorthite from AOA's [9] and from Al-rich chondrules [10] are plotted for comparison. Bidi olivine (green diamond) plots at  $\delta^{17}\text{O} = -10.9 \pm 9.0$  and  $\delta^{18}\text{O} = -5.7 \pm 3.6$  and overlaps with the  $^{16}\text{O}$ -rich edge of the Al-rich chondrule olivine field (green oval). Pristine AOA forsterites, however, plot at  $^{16}\text{O}$ -rich compositions indicating that Bidi olivine is not consistent with refractory AOA forsterite. Bidi olivine does, however, overlap FeO-rich olivines from altered AOA's as shown by the dotted oval in the figure [11]. Similarly, Bidi augite (purple square) overlaps the Al-rich chondrule field in  $\delta^{18}\text{O}$  but we cannot differentiate between pristine AOA's and Al-rich chondrules in  $\delta^{17}\text{O}$  because of large error bars.

**Discussion/Conclusions:** Al-rich chondrules are defined as having  $> 10$  wt%  $\text{Al}_2\text{O}_3$  [12] and are composed of olivine +/- Ca-rich plagioclase +/- Al-rich high Ca pyroxene +/- spinel +/- Al-rich silicate glass. Based on its bulk chemical composition, measured 10.1 wt%  $\text{Al}_2\text{O}_3$ , subequal modal olivine, aligned mineral textures and relatively  $^{16}\text{O}$ -poor mineralogy (augite and olivine) we suggest that Bidi is more closely related to Al-rich chondrules than AOA's (pristine). Al-rich chondrules are refractory igneous objects intermediate to CAI's and ferromagnesian chondrules (FMC) and extend the range of  $^{17}\text{O}$  and  $^{18}\text{O}$  FMC compositions to approximately  $-15$  ‰ [13]. Al-rich chondrules, however, are not derived from either

CAI's or FMC but appear to have formed in an independent reservoir perhaps in a nebular environment similar to FMC [10].

Bidi does not appear to be directly related to pristine AOA's. Its olivine oxygen isotopic composition is nearly identical to altered FeO-rich olivines from AOA's in Allende [11]. However, Bidi olivine is much more equilibrated and Mg-rich ( $\text{Fo}_{97-98}$ ) than Allende olivines ( $\text{Fo}_{63-69}$ ). It is possible that Bidi formed from a pristine AOA that underwent alteration with  $^{16}\text{O}$ -poor nebular gas. This would assume that Bidi is modally heterogeneous and more olivine-rich than we estimated from the three single microtome sections.

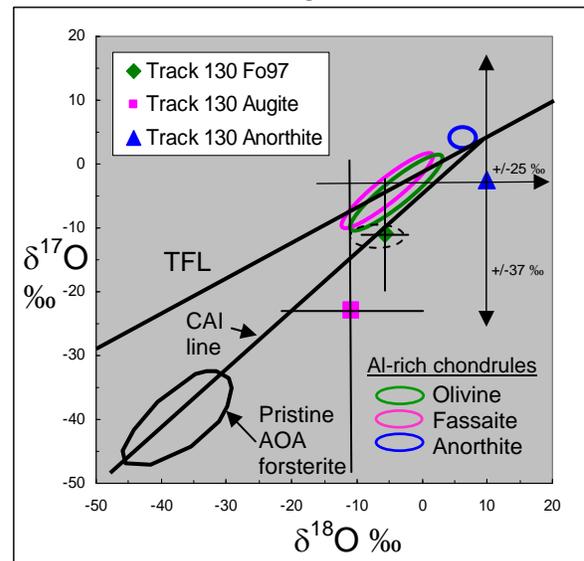


Figure 3: Oxygen 3-isotope plot ( $1\sigma$  error bars) of individual minerals (olivine, augite, anorthite) from Track 130 TP (Bidi) compared to pristine AOA olivine and Al-rich chondrules [11,13]. Dotted oval shows region for altered FeO-rich olivine from Allende AOA's [11]. Truncated error bars shown for anorthite.

**References:** [1] Simon S. B. et al. (2008) *MAPS* 43, 1861-1877. [2] Nakamura T. et al. (2008) *Science* 321: 1664-1667. [3] Zolensky M. E. et al. (2006) *Science* 314: 1735-1739. [4] Scott E. R. D. and Krot A. N. (2003) *Treatise on Geochem.*, Vol 1, 143-200. [5] Matrajt G. and Brownlee D. E. (2006) *MAPS* 41, 1715-1720. [6] Krot A. M. and Keil K. (2002) *MAPS* 37, 91-111. [7] MacPherson G. J. and Huss G. R. (2005) *GCA* 69, 3099-3127. [8] Komatsu M. et al. (2001) *MAPS* 36, 629-641. [9] Imai H. and Yurimoto, H. (2003) *GCA* 67, 765-772. [10] Russell S. S. et al. (2000) *EPSL*, 184, 57-74. [11] Yurimoto H. et al. (2008) *Reviews in Mineral. and Geochem*, Vol 68, 141-186. [12] Bischoff A. and Keil K. (1983) *Nature* 303, 588-592. [13] Franchi I. A. (2008) *Reviews in Mineral. and Geochem*, Vol 68, 345-397.