MICROANALYTICAL INVESTIGATIONS OF PRESOLAR SIC OF TYPE AB. K. M. Hynes, S. Amari, T. J. Bernatowicz, and E. Lebsack. Laboratory for Space Sciences and Department of Physics, Washington University, St. Louis, MO 63130, USA, kmhynes@wustl.edu.

Introduction: More than 90% of presolar SiC grains are thought to originate in the circumstellar outflows of low-mass asymptotic giant branch (AGB) stars. However, the isotopic compositions of a subpopulation of SiC, known as type AB grains, do not agree with theoretical models of nucleosynthesis in AGB stars [1]. AB grains, which constitute ~4 – 5% of the presolar SiC population, are defined as having $^{12}C/^{13}C < 10$ [2]. Their Si isotopic compositions are similar to those of mainstream grains, with excesses in both ^{29}Si and ^{30}Si. While, like mainstream grains, many AB grains have $^{14}N/^{15}N$ ratios greater than solar, AB grains span a much larger range of N isotopic compositions, with a significant fraction (~33%) of AB grains having subsolar $^{14}N/^{15}N$ ratios, compared to only ~3% of mainstream grains [3]. These AB grains also tend to have lower $^{12}C/^{13}C$ ratios. Trace element analysis indicates that roughly two-thirds of AB grains have s-process enrichments of 3 – 5 times solar abundances, while the rest of the grains have solar s-process elemental abundances [4].

The disparate compositions of type AB grains make identifying a single astrophysical source difficult. Type J stars have been suggested as likely candidates due to their low $^{12}C/^{13}C$ ratios and solar s-process abundances [2]. Unfortunately, J stars are poorly understood with an unclear evolutionary history, as well as a lack of reliable $^{14}N/^{15}N$ ratio measurements. Furthermore, J stars cannot be the source of AB grains with s-process enrichments. To explain these grains, a second stellar source for AB grains has been invoked. Born-again AGB stars (like Sakurai's object), which are thought to be experiencing a very late thermal pulse during their decent along the white-dwarf path, are the best match for AB grains with s-process enrichments. Observations of Sakurai's object indicate that it is C-rich and has $^{12}C/^{13}C \leq 5$, large enrichments in the light s-process elements, and high $^{14}N/^{15}N$ ratios [2].

While there have been isotopic studies on hundreds of AB grains, detailed structural and chemical microanalytical studies, which can provide valuable insights into grain formation conditions, are limited. Over 500 small SiC grains (~0.5 µm) were analyzed in the transmission electron microscope (TEM), but most of these grains are mainstream and have limited or no available isotopic data [5]. Correlated isotopic and microstructural information has been reported for only a few AB grains, but no elemental data or evidence of internal grains have been reported for these grains [6, 7]. Here we present preliminary isotopic, structural, chemical, and subgrain data on four SiC AB grains.

Experimental: AB grains from the KJG fraction (~3 µm average diameter [8]) of the Murchison meteorite were first identified by their low $^{12}C/^{13}C$ ratios during ion imaging with the IMS-3f. The C, Si, and N isotopes of the grains were later measured in the NanoSIMS. No additional isotopic measurements were made in order to preserve material for subsequent TEM analysis. Four AB grains were randomly selected, removed from the Au NanoSIMS mount, and embedded in resin to prepare them for TEM study. The grains were then sliced into ~70 nm-thick slices with a diamond ultramicrotome (Figure 1), placed on TEM grids, and analyzed in a JEOL 2000FX TEM equipped with an Energy Dispersive X-ray Spectrometer (EDXS).

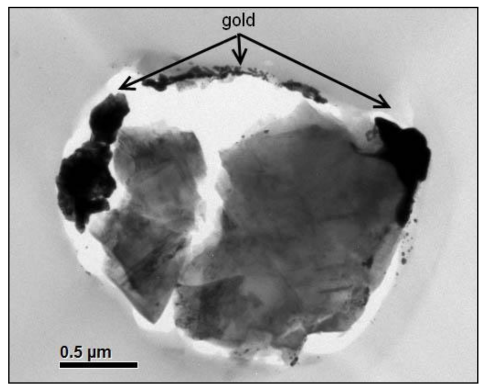

Figure 1. Bright-field (BF) TEM image of a slice of a KJG SiC of type AB showing the general condition of the grain after ultramicrotomy. Although some fracturing of the grain occurs, individual crystal domains are still visible in the grain slice. The black areas around the perimeter of the grain are Au deposited during NanoSIMS analysis.

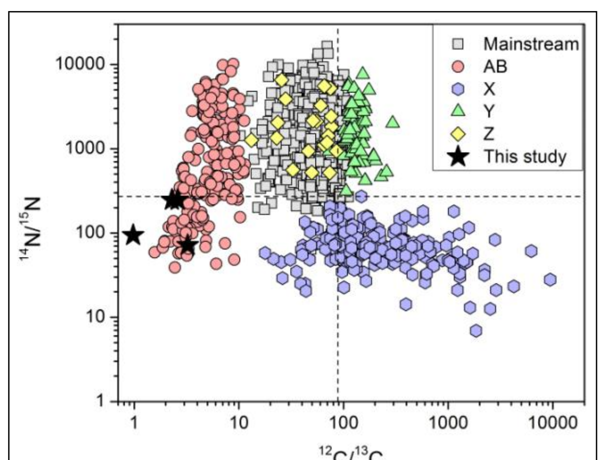

Figure 2. Carbon and N isotopic ratios of type AB SiC grains in this study (black stars) compared to presolar SiC grains previously measured by references in [3].

Results and Discussion: The C and N ratios of the four AB grains are plotted in Figure 2 and are characteristic of AB grains. All four grains have $^{12}C/^{13}C$ ratios lower than 3.5 (the equilibrium value of the CNO cycle) and corresponding $^{14}N/^{15}N$ ratios less than solar. These low N ratios are puzzling, as stellar models are unable to explain them [2]. The grains also have Si isotopic ratios typical of AB grains and fall on or near the mainstream correlation line of slope 1.37 on a Si three-isotope plot [9].

Although the ultramicrotomy process can fracture grains, it does not affect our ability to identify individual crystal domains within each SiC. Each AB grain is composed of several crystal domains, ranging in diameter from ~0.150 – 1.50 µm (Figure 3). However, this size range is not representative of the crystal domain size distribution because the grains have significantly different average crystal domain sizes. One grain is composed of three crystal domains: one large domain with an ~1.50 µm diameter and two smaller domains, each roughly 0.5 µm in diameter. Two other AB grains are each composed of approximately 20 crystal domains, which range in size from ~0.150 – 0.300 µm. A limited amount of material available in the fourth grain makes its crystal domain size difficult to estimate. These domain sizes must also be viewed as lower limits due to the possible effects of slicing. Crystal growth is extremely sensitive to formation conditions, suggesting that the considerable difference in domain size among the AB grains may be indicative of the different stellar environments from which AB grains are believed to originate (J stars and born-again AGB stars). Evidence for the effect of formation environment on crystal domain size exists in previous studies of SiC X and mainstream grains (also from the KJG size fraction), which originated in the outflows of Type II supernovae and AGB stars, respectively [10]. The mainstream grains were observed to contain only a few large crystal domains (0.50 – 1.7 µm), while the X grains are composed of many small crystal domains (0.024 – 0.46 µm). However, the effects, if any, of stellar origin on crystal domain size in AB grains requires further investigation.

Microdiffraction patterns from each of the AB grains were obtained and the polytypes of each of the grains were determined, mainly from <1 1 0> zones. All but one of the patterns is consistent with the 3C-SiC polytype (cubic; a = 4.35 Å). This is the most common polytype in presolar SiC, occurring in 79% of mainstream grains [5]. One large crystal was consistent with the 2H-SiC polytype (hexagonal; a = 3.08 Å, c = 5.03 Å), which occurred in 3% of mainstream grains, although an intergrowth between the 2H-SiC and 3C-SiC polytypes (observed in 17% of grains) cannot be conclusively ruled out.

EDXS analysis of three of the AB grains revealed several TiC subgrains. These have been previously observed with the TEM in 3 SiC grains [11, 12], although these grains were either mainstream or had no corresponding isotopic measurements. Furthermore, isotopic measurements of a large suite of over 200 randomly selected presolar SiC grains indicate that TiC subgrains are common in all types of presolar SiC (except X grains, which were not measured) [13]. One AB grain in our study also contained Zr and had an approximate composition of $Ti_{94}Zr_6$ (C is excluded due to background interference), which could be indicative of an s-process enrichment of over 10 times solar (relative to Ti). Such subgrains have been observed in high-density graphite grains from AGB stars [14], but none have been previously observed in SiC. Although trace element data on AB grains are limited, about two-thirds have s-process enrichments [4], indicating they could not have originated in J stars. While no other s-process enriched subgrains have been observed in the AB grains from this study, one grain has not yet been examined and additional ultramicrotome slices of the other three grains also remain to be studied. TEM analysis on additional AB grains is planned.

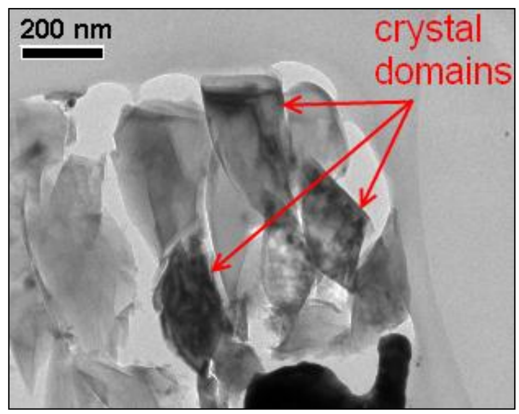

Figure 3. BF image of an area of a type AB SiC showing the multiple crystal domains (arrows) that are visible within the grain. Intensity variations between domains are due to orientation-dependent diffraction contrast. Note the difference in size between the crystal domains in this image (0.2 µm average diameter) and the much larger crystal domains in Figure 1 (up to 1.5 µm).

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References: [1] Meyer B.S. and Zinner E., in *MESS II,* Lauretta D. S., McSween H. Y., Jr., Eds. (Univ. of AZ, Tucson, 2006) pp. 69-108. [2] Amari S. et al. (2001) *ApJ, 559*, 463. [3] Hynes K.M. and Gyngard F. (2009) *LPS XL*, Abstract #1198. [4] Amari S. et al. (1995) *Meteoritics, 30*, 679. [5] Daulton T.L. et al. (2003) *GCA, 67*, 4743. [6] Daulton T.L. et al. (2006) *Met. Planet. Sci., 41*, A42. [7] Daulton T.L. et al. (2009) *Met.Planet. Sci. Suppl., 72*, 5381. [8] Amari S. et al. (1994) *GCA, 58*, 459. [9] Zinner E. et al. (2007) *GCA, 71*, 4786. [10] Hynes K.M. et al. (2009) *LPS XL*, Abstract #1398. [11] Bernatowicz T.J. et al. (1992) *LPS* XXIII, 91. [12] Stroud R.M. and Bernatowicz T.J. (2005) *LPS* XXXVI, Abstract #2010. [13] Gyngard F. et al. (2006) *Met.Planet. Sci., 41*, A71. [14] Croat T.K. et al. (2005) *ApJ, 631*, 976.