Li and B in Gently Separated Pre-Solar SiC grains, evidence of material from interstellar clouds. I. Lyon[1] J. Tizard[1] and T Henkel[1], [1]School of Earth, Atmospheric and Environmental Sciences, The University of Manchester, Manchester, M13 9PL, UK. Ian.Lyon@manchester.ac.uk, Torsten.Henkel@manchester.ac.uk

Introduction: It has recently become clear that the harsh acid separation treatments used to separate presolar grains from meteorites can alter the chemical and even isotopic abundances of the surfaces of the grains [1,2]. Further, any non-refractory coating formed in the interstellar medium would be lost during the extraction process. To overcome this problem we developed a new method of gently separating SiC grains [3] and here present measurements of the Li and B elemental and isotopic abundances found within coatings on the grains and within the grains. We infer that analyses of these coatings may be used to deduce the composition and conditions in the interstellar medium.

Samples: 9 SiC grains gently separated (GS) from the Murchison meteorite were analysed with 11 KJG SiC grains separated by the acid residue technique (AR) also from the Murchison meteorite [4]. A comparison was made between the grains extracted by these two different methods.

Analytical Technique: The grains were analysed using a Time-of-Flight Secondary Ion Mass Spectrometer (TOFSIMS) [5] developed to obtain high spatial resolution (~200nm), high mass resolution (~2500MRP) analyses of presolar grains. The large advantage of TOFSIMS instruments over other forms of SIMS instruments is the ability to acquire analyses of all isotopes of all elements simultaneously. The analyses reported here concentrated upon Li and B isotopes which could be acquired with relatively low mass resolution (~600) due to the absence of significant isobaric interferences.

The primary ion beam was finely focused and rastered over the sample surface to acquire a complete mass spectrum in every pixel of the image. From this raw data, secondary ion distribution images and mass spectra for the region of interest were reconstructed.

Atoms are sputted from the sample so rastering the beam across the sample and acquiring several measurements therefore leads to a depth profile enabling a quasi 3-dimensional study.

Results: Measured values of Si isotope ratios, Li/Si, B/Si, $^{11}B/^{10}B$ and $^{7}Li/^{6}Li$ values are given in table 1.

	Grain size (μm)	δ29Si	δ30Si	δ26Mg	7Li/6Li	11B/10B
AR grains						
AR1-M2-1	2 x 1.4	60 ± 40	90 ± 40	90 ± 220	11.5 ± 1.2	4.0 ± 0.4
AR1-M2-2	0.9	20 ± 50	11 ± 17	220 ± 160	13.3 ± 4.3	NQ
AR1-M2-3	0.8	10 ± 120	30 ± 90	NQ	11.0 ± 2.1	NQ
AR1-R-1	2	50 ± 120	-20 ± 50	-370 ± 260	13.4 ± 2.5	3.6 ± 0.3
AR2-S0-1	1.9	NQ	160 ± 70	-20 ± 60	13.3 ± 1.2	NQ
AR2-S0-2	1.2	130 ± 70	140 ± 60	-70 ± 40	11.6 ± 1.0	3.0 ± 0.8
AR2-S0-3	1.3	240 ± 100	60 ± 50	-8 ± 23	12.2 ± 0.5	3.2 ± 0.9
AR2-S0-4	2	NQ	120 ± 80	120 ± 50	11.9 ± 1.0	5.0 ± 2.4
AR2-S3-1	~ 2.1	NQ	50 ± 60	-100 ± 140	12.7 ± 1.0	NQ
AR2-S3-3	~ 1.4	70 ± 80	40 ± 70	-80 ± 70	12.3 ± 0.7	2.7 ± 0.6
AR2-30-1	4 x 1.4	NQ	200 ± 60	NQ	15.8 ± 2.1	NQ
GS grains						
C4-K2-1	~ 2	100 ± 60	122 ± 17	0 ± 4	12.0 ± 0.4	3.7 ± 0.4
C4-K2-2	~ 2.6	0 ± 100	100 ± 40	28 ± 12	11.1 ± 0.6	3.4 ± 0.8
C4-R-1	5 x 6.5	20 ± 90	9 ± 26	-22 ± 8	14.5 ± 2.5	4.8 ± 0.9
D4-Y1-2	5.1 x 3.5	40 ± 110	60 ± 80	90 ± 30	9.9 ± 2.5	1.3 ± 1.0
D4-E-1	~ 1	70 ± 180	40 ± 140	10 ± 50	10.6 ± 1.9	2.2 ± 1.3
D4-G2-1	4.9 x 2.7	190 ± 210	150 ± 70	-50 ± 60	13.7 ± 0.9	3.8 ± 0.9
D4-K1-1	3.3 x 2.6	40 ± 110	60 ± 50	-10 ± 40	11.7 ± 0.6	3.6 ± 0.3
D4-Y1-1	~ 1	230 ± 230	30 ± 60	360 ± 50	10.4 ± 0.8	4.4 ± 0.8
D4-Y1-3	2.4 x 2	200 ± 100	50 ± 60	20 ± 80	10.8 ±	4.0 ± 0.7

Table 1. Measured values from this study. AR grains are from the KJG acid residue from the Murchison meteorite [4] and GS grains separated from the Murchison meteorite by the technique of [3]. The $^{7}Li/^{6}Li$ and $^{11}B/^{10}B$ given are the averages for each grain.

In addition to the totals for each grain given in table 1, a strong correlation was found between the measured Li/Si and B/Si values for each grain as the grains were depth profiled, both for AR and GS grains shown in figure 1.

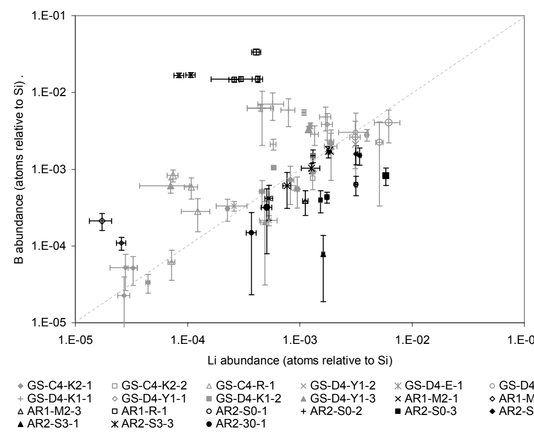

Figure 1. Measured B/Si against Li/Si ratios for AR (black symbols) and GS (grey symbols).

Sputtering removes material from the grains so early analyses sample the outer coatings of a grain whilst later analyses tend to largely sample the core of a grain. All of the grains analysed here showed the same trend with initial analyses tending to exhibit higher Li/Si and B/Si values than later analyses. Where intial analyses showed high B/Si ratios, these decreased in a way that brought the measurements to the line B/Si=Li/Si and then to lower values with [(B/Si)/(Li/Si)]=constant until B/Si~Li/Si~$1x10^{-5}$ which matches the values found by other authors in bulk measurements of SiC grains [6,7]. The Li and B countrates for the grains were low so isotope ratios for each grain were obtained by summing all of the counts acquired during analysis of that grain. These are, within error, equal to average solar system isotope ratios.

Li and B signals were strongly localized to the analysed grains with almost no contribution from the surrounding gold foil used to mount the grains. In addition, 6 silicate grains separated from the Murchison matrix in the gentle separation process with the SiC grains were also analysed for Li and B contents. None showed any measurable B and the analysed Li/Si ratios were $<10^{-5}$.

Interpretation and Discussion: An obvious interpretation of the high B/Si and Li/Si ratios with average solar system isotope ratios is that they result from contamination either in the laboratory extraction processes or by alteration in the meteorite during the early history of the solar system. The absence of Li and B from neighbouring grains extracted by the same processes argues strongly against this. In addition, the highest Li/Si and B/Si ratios are found not exactly at the surface but just below it. arguing that these elements have been implanted with high energies into the grains.

The solar system isotope ratios argues against spallation by cosmic rays in the interstellar medium as being the source of the Li and B which would have $^{7}Li/^{6}Li{\sim}2$ and $^{11}B/^{10}B{\sim}2$, very different from what is found. By contrast, spectroscopic measurements of $^{7}Li/^{6}Li$ and $^{11}B/^{10}B$ ratios in nearby molecular clouds [10] indicate that in the majority, these isotope ratios are approximately the same as solar system average. The abundances of Li and B in these clouds may also be high, seeded from nearby AGB stars.

There are Li-rich AGB stars which may have been able to supply the very high Li abundances seen here through the Cameron-Fowler mechanism in which α particles react with ^{3}He nuclei to produce ^{7}Be which decays to ^{7}Li [8]. However, this process does not produce ^{6}Li so implantation of ^{7}Li into the grain directly from the star would not give the solar Li ratio. K giants do however release circumstellar shells with high ^{7}Li, seeding the surrounding region [9]. Some of these regions are observed to have very high Li, B abundances and solar-like Li and B isotope ratios by mixing high abundances of spallation Li and B with high ^{7}Li and ^{11}B abundances [10]. The giant star that produced the high Li abundances need not necessarily have been the same star that formed the SiC grains but only seeded the region through which the grain was travelling. Supernovae can produce Li and B but we see no evidence that the grains contain any other supernova signature isotopes. The protosolar nebula is only likely to have had low Li/Si and B/Si ratios on average and so we do not see that as a viable source for the very high Li and B abundances. Models of the early solar nebula that invoke an 'X' wind producing the high Li and B abundances either by implantation or in-situ in the grain would have great difficulty in producing the solar-like isotope ratios found here [11].

Our model for these grains is therefore that the core SiC grain was condensed in the outflow from an AGB star and acquired the high Li and B abundances in the star-forming region in which that AGB star resided.

References: [1] Henkel, T. et al. (2002) M&PS **37**, A61; [2] Nittler, L. R. & Alexander, C. M. O. (2003) GCA **67**, 4961-4980, [3] Tizard, J., Henkel, T. & Lyon, I. C. (2005) M&PS 40, 335-342; [4] Amari, S., Lewis, R. S. & Anders, E. (1994) GCA 58, 459-470; [5] Henkel, T. et al., Submitted to Journal of Scientific Instuments; [6] Hoppe, P. et al., (2001) Ap. J. 551, 478-485; [7] Huss, G. R., Hutcheon, I. D. & Wasserburg, G. J. (1997) GCA 61, 5117-5148; [8] Sackmann, J. and Boothroyd, A. I. (1999) Ap. J. 510, 217-231; [9] de la Reza, R. (2000) Lithium in giant stars. In 'The light elements and their evolution' IAU Symposium, Vol 198, 310-319. da Silva L., Spite M. and Medeiros J. R. eds.; [10] Federman S.R et al., (1996), Nature 381, 764-766; [11] Gounelle, M. et al., (2001) Ap. L. 548, 1051-1070

Acknowledgements: We are grateful to PPARC for funding a studentship to JT and a post to TH. We thank JD Gilmour, M Grady and G Turner for helpful discussions, B Clementson and D Blagburn for technical assistance and S Amari and R Lewis for provision of Murchison KJG grains.