NANOSIMS D/H IMAGING OF ISOTOPICALLY PRIMITIVE INTERPLANETARY DUST PARTICLES.

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Introduction: The presence of large and variable H and N isotopic anomalies in interplanetary dust particles (IDPs) is well-established and is generally attributed to the preservation of interstellar materials within these particles [e.g., 1]; recent studies have shown that IDPs also contain organic matter with anomalous C isotopic compositions [2, 3] and grains with highly anomalous O and/or C isotopic compositions that are indicative of a circumstellar origin [3-5]. We have been carrying out a comprehensive isotopic (C, N, O) imaging survey of IDPs in order to better understand the origin and distribution of isotopic anomalies in these particles. Here we report the results of a survey of the H isotopic compositions of the same particles. We also report the results of S and B isotopic measurements.

Experimental: We used the NanoSIMS to measure the H, B and S isotopic compositions of a subset of the IDPs in which we previously measured the C, N, and O isotopes. The measurements were made in raster imaging mode, in which a Cs^+ primary beam is rastered over the sample surface and secondary ions are collected in parallel at high mass resolution. The procedures are similar to those outlined in our earlier work on other isotopic systems [6, 7], and consist of one set of measurements for S isotopes ($^{12}C^-$, $^{28}Si^-$, $^{32}S^-$, $^{33}S^-$, $^{34}S^-$) and another for H and B ($^{1}H^-$, $^{2}H^-$, $^{10}B^-$, $^{11}B^-$). However, because of the low abundances expected for D, experimental conditions for the H and B measurements were optimized to provide the maximum secondary signal. The higher primary beam current resulted in a degradation of the spatial resolution, with a primary beam diameter of ~250 nm.

Results: Sulfur isotopic compositions were measured in 13 IDPs. All of the particles analyzed have normal S isotopic compositions; the average uncorrected S isotopic compositions for all of the IDPs measured are $^{32}S/^{33}S = 127.1 \pm 2.6$ and $^{32}S/^{34}S = 21.5 \pm 0.4$, close to the solar values of 127 and 22.6, respectively. These results are consistent with previous studies of S isotopes in IDPs [8, 9], which also show no anomalous S isotopic compositions.

Hydrogen and boron isotopic compositions were measured in 17 IDPs. Boron abundances were generally quite low in the IDPs, leading to relatively large statistical variations. However, within the errors (~10%), B isotopic compositions are normal in all of the IDPs measured.

As expected, H isotopic compositions show considerable variability. Six of the 17 IDPs measured have normal H isotopic compositions, but the remaining particles exhibit D anomalies of varying magnitude. Some of the IDPs contain regions up to several microns in size that may be either enriched or depleted in D, by several hundred permil, as well as localized hotspots that are strongly enriched in D (Fig. 1a). Other IDPs contain only D-enriched hotspots in an otherwise isotopically normal matrix (Fig. 1b). The hotspots have δD_{SMOW} values that range from about +500 to +4300 ‰ (Table 1). The apparent sizes of the hotspots range from 350 – 700 nm; their true sizes, taking into account the size of the primary beam, are significantly smaller. The sizes of these D-rich hotspots are similar to those of other presolar phases found in IDPs, including ^{15}N-rich hotspots of probable interstellar origin [10] and circumstellar silicates, SiC and corundum [3, 5]. In some instances D-depleted 'coldspots' also appear to be present, but because of the large errors associated with the low D abundances, we cannot be certain these are statistically significant.

Discussion: Last year we reported the existence of a discrete sub-group of IDPs with primitive isotopic characteristics [3]. Of the 29 particles we have analyzed for C and N, fourteen belong to this sub-group. They are characterized by anomalous bulk N isotopic compositions, generally have large ^{15}N-rich hotspots (up to +1300 ‰), occasional C isotopic anomalies and abundant presolar silicate grains (~400 ppm) [3, 10]. In contrast, the remaining 15 IDPs in our survey have normal bulk N isotopic compositions and, although a few contain ^{15}N-enriched hotspots, none exhibit C isotopic anomalies and none contain any presolar silicate or oxide grains.

Of the 17 IDPs measured here for H, nine are isotopically primitive, with anomalous bulk N isotopic compositions (Table 1), while the remaining eight IDPs have normal bulk N. However, there is no clear correlation of the presence of D anomalies with bulk N composition: of the six IDPs that have normal D/H ratios, three belong to the isotopically primitive sub-group and three do not (Table 1). Moreover, with one possible exception, D and N hotspots in the same IDPs are not spatially associated. In the exception, Sillanpää, the N hotspot listed in Table 1 occurs in the same general region as the second D hotspot listed; however, we cannot be sure the same material is being sampled in both measurements, since S isotopes were analyzed between the C,N and H,B measurements and the N-anomalous material may have sputtered away. The lack of a correlation between H and N isotopic anomalies is consistent with previous studies [1, 11, 12] and may be due to

different carrier phases and/or different processes for the generation of the isotopic anomalies [e.g., 13].

Somewhat more surprising, given the large number of IDPs measured, is the rather limited magnitude of the D anomalies that we observe. Although most of the hotspots we see have δD values higher than 1000 ‰, we have found no D enrichments approaching the extreme values found in several IDPs by [14]. One possibility may be that there is a contribution of isotopically normal H from the NanoSIMS; this would have the effect of diluting all the observed H anomalies.

Conclusions: Hydrogen isotopic imaging of these IDPs shows that D anomalies occur both as small discrete hotspots and as larger regions up to several microns in size. This is analogous to the N isotopic systematics of IDPs, which contain ^{15}N-rich hotspots as well as larger 'bulk' ^{15}N enrichments. Different carriers [e.g., 15] could be responsible for the D anomalies in the two areas.

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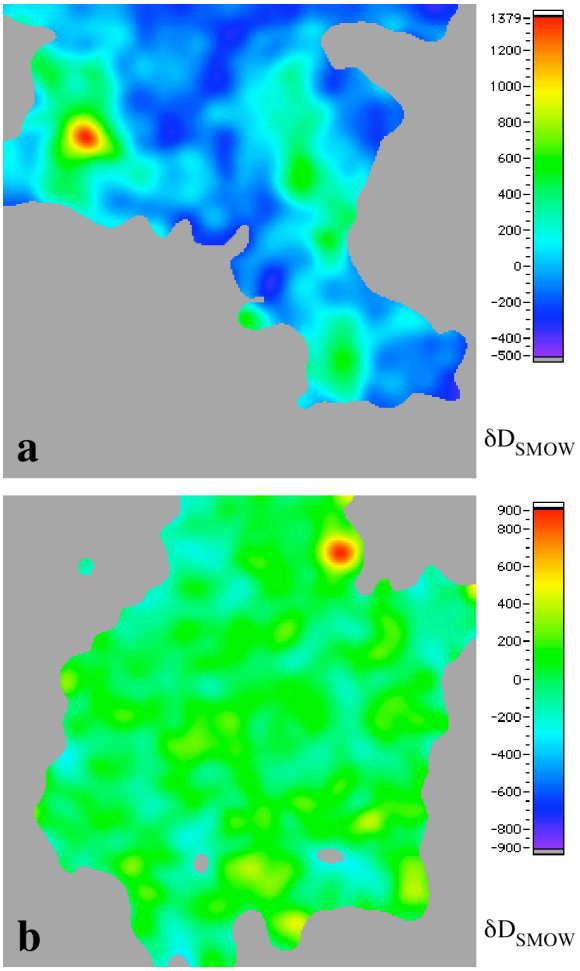

Figure 1. H isotopic images (δD$_{SMOW}$) of (a) Bunin and (b) Reymont. Imags are 20 x 20 μm^2 and are smoothed, resulting in larger apparent hotspot sizes.

Table 1. H and N Isotopic Compositions

	Regional D variations* range in δD (‰)	**D hotspots δD (‰)**	**Bulk N δ^{15}N (‰)**	**N hotspots δ^{15}N (‰)**
Hamsun (L2009-N11)	---	+965	normal	+865
Bergson (L2009-c5-H2)	---	+2500	normal	---
Anatole (L2009-c5-H3)	-100 to +400	+2255	normal	---
O'Neill (L2009-c13-I2)	---	---	+85	+1060; +815
du Gard (L2009-c13-I4)	–200 to +600	+1950	+87	+1020; +855
Sillanpää (L2011-c11-D3)	–200 to +500	+4360; +3805; +1730	+110	+1120
Yeats (L2036-I19)	–150 to+400	+2750	normal	+985
Reymont (L2036-c9-D2)	---	+1810	normal	+645
Jensen (L2036-c17-E3)	---	---	normal	---
Shaw (L2036-c17-E4)	---	---	normal	---
Galsworthy (L2036-c18-F2)	–200 to +600	+3160	+220	+1015; +1010
Mistral G. (L2036-c18-F3)	---	---	+65	+755; +685
Hesse (L2036-c18-F4)	---	+2140	+350	+1170; +970; +900
Gide (L2036-c21-H2)	---	---	+80	---
Deledda (L2036-c21-H3)	---	+545	+230	+625
Bunin (L2036-c21-H4)	–250 to +600	+2585	+110	+605
Pirandello (L2036-c24-I4)	---	---	normal	+850; +590

*range of δD values in micron-sized (and larger) regions of the IDPs.