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The Inventory of Presolar Grains in Primitive Meteorites: A NanoSIMS Study of C-, N-, and O-isotopes in NWA 852

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Meteorites as well as interplanetary and cometary dust contain small amounts of mineral grains that formed in the winds of evolved stars or in the ejecta of stellar explosions and survived incorporation into solid bodies of our own solar system. Investigation of the abundance and distribution of these "presolar grains" in primitive solar system matter can shed light on parent body processes as well as possible heterogeneities in the early solar nebula. We investigated presolar silicate and oxide grains in the CR chondrite NWA 852 with a NanoSIMS 50. Abundances of 77 ppm for silicates, 39 ppm for oxides, and 160 ppm for silicon carbide, as well as evidence for ^{15}N-enriched organic molecular cloud material were observed. Although NWA 852 has the lowest presolar silicate/oxide-ratio observed so far for presolar-grain-rich material, indicating extensive aqueous alteration, a significant fraction of O-anomalous grains (silicates and oxides) remained intact. Thus, this meteorite may be a link between presolar-grain-rich, pristine CR chondrites and CRs with lower presolar grain abundances.

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1. Introduction

Primitive solar system materials contain varying amounts of refractory dust grains that formed in the outflows of evolved stars or in the ejecta of stellar explosions [1; see also the contribution by P. Hoppe in this issue]. These grains are dubbed "presolar", since they survived processing in the interstellar medium and were incorporated into the protosolar dust and gas cloud prior to the formation of our solar system. They can be found as trace components (ppb to ppm) in primitive meteorites, interplanetary dust particles (IDPs), and cometary dust. Silicates and oxides are among the most abundant types of presolar grains [2–6].

Carbonaceous chondrites of the CR type are among the most primitive meteorites. Surprisingly, first studies of CR chondrites indicated only small concentrations of presolar material [7,8]. Recent investigations, however, revealed much higher abundances of presolar dust in individual meteorites of this group [9–11]. Investigating the variations in the abundance of presolar material in CR chondrites can give new insights on parent body processes as well as possible heterogeneities in the protosolar nebula. Here, we report results of our investigation of the CR2 chondrite NWA 852.

2. Experimental and techniques

Promising matrix areas, i.e., areas with only little or no visible alteration were identified in a thin section of the CR chondrite NWA 852 by optical microscopy. We performed ion imaging of 5×5 µm²- to 10×10 µm²-sized matrix areas with a NanoSIMS 50 ion probe. All analyses were performed with a 100 nm-sized Cs^+ ion beam at high mass resolution. $^{16}O^-$, $^{17}O^-$, $^{18}O^-$, $^{28}Si^-$, and $^{27}Al^{16}O^-$ were measured in multi-collection. Presolar silicate and oxide grains are identified in situ by their large O-isotopic anomalies. Detection of ^{28}Si and $^{27}Al^{16}O$ allows us to distinguish between silicates and Al-rich oxides. $^{12}C^-$, $^{13}C^-$, $^{12}C^{14}N^-$, $^{12}C^{15}N^-$, and $^{28}Si^-$ were also measured, but on a smaller area of matrix material, partly overlapping with the area studied for O-isotopic compositions, to search for C- and N-isotopic anomalous phases.

Measured O-isotopic compositions of presolar grains are normalized to O-rich material in the surrounding matrix, which has solar isotopic ratios within error limits. C- and N-isotopic ratios are normalized to an N-doped SiC-standard.

One of the O-anomalous grains was subsequently prepared by the focused ion beam technique (FIB) for studies by transmission electron microscopy (TEM). For FIB-sectioning, a protective Pt-strap was deposited on top of the grain. After that, "trenches" were cut out parallel to the grain, and it could be lifted out by using a nanomanipulator. After thinning the section to ~100 nm, it was welded to a half cut standard TEM Cu grid.

3. Results

20,000 µm² of fine-grained matrix material were analyzed for O-isotopic compositions. 22 presolar silicates and 9 oxides were identified (Fig. 1). 26 of the grains are enriched in ^{17}O and, according to the definition of [12], belong to Group 1, most likely originating from 1.2–2.2 $M_\odot$

AGB-stars. Four grains display higher than solar $^{18}O/^{16}O$ ratios and fall into Group 4. Their most probable sources are the ejecta of Type II supernovae. The last grain is depleted in ^{17}O and is a candidate for Group 3 grains, which may have originated from a low-mass AGB star of sub-solar metallicity or a Type II supernova. These 31 O-anomalous grains give abundances of 77 ppm for silicates and 39 ppm for oxides, respectively (Fig. 2). One large group 1 presolar Al-rich oxide grain (1.75 µm × 0.3 µm) was prepared and extracted by FIB. Subsequent TEM investigations revealed that it consists of a single crystal of hibonite with a distinct titanium enrichment of ~7 at% in the central part.

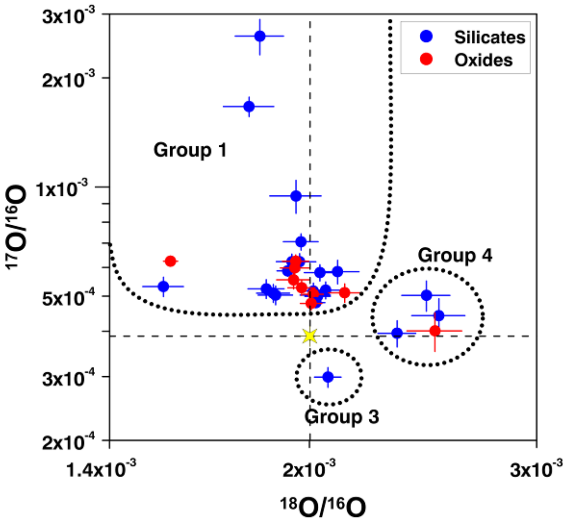

Figure 1: Three-isotope-plot for presolar silicate and oxide dust grains found in NWA 852. All errors are 1σ. Solar system isotopic composition is marked by the yellow symbol at the crossing point of the dashed lines.

Additionally, 1800 µm² of matrix were analyzed for C- and N-isotopic composition. A ^{15}N-rich organic phase, probably molecular cloud material, is present (average $\delta^{15}N$ = +115 ‰), with $\delta^{15}N$ > 1000 ‰ in individual spots. This is consistent with observations from other CR chondrites [13,14]. Together with the nitrogen isotopes, ^{12}C and ^{13}C were measured in the same matrix regions. Eight C-anomalous silicon carbide (SiC) grains were found, representing a matrix-normalized abundance of 160 ppm.

4. Discussion

High silicate/oxide ratios are considered to be a criterion for a low degree of alteration, since oxides are generally more resistant to parent body processes than silicates. Low silicate-to-oxide ratios are therefore expected for more processed material [9]. NWA 852 has the lowest presolar silicate/oxide-ratio observed so far for presolar-grain-rich material (sil./ox. = 2.0). A significant amount of O-anomalous grains remained intact, and the measured nitrogen isotopic compositions are comparable to those from more pristine CR chondrites, although in NWA 852 the molecular cloud material is very heterogeneously distributed. Thus, NWA 852 may be a link between presolar silicate-rich, nearly unaltered CR chondrites like MET 00426 and QUE 99177 [9] and CRs with lower presolar grain abundances.

NWA 852 was possibly subject to more severe parent body alteration than more "pristine" CR chondrites like MET 00426 and QUE 99177 and lost a significant fraction of its presolar silicates. Then, its initial presolar silicate abundance must have been significantly higher, and may have been well within the range observed for primitive IDPs [15]. This is even true if we consider the apparent heterogeneities in presolar grain abundances observed in individual meteorites (see below). This would point towards very heterogeneous parent body processes among individual meteorites of the same class, resulting in large variations of presolar grain abundances.

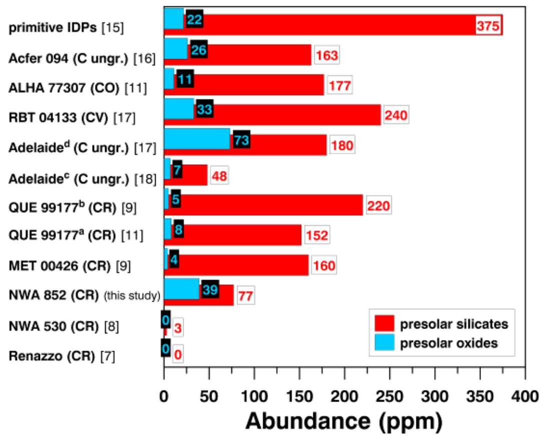

Figure 2: Abundances of O-rich presolar grains in IDPs and various primitive meteorites compared to the results for NWA 852.

Or, the variations are caused *ab initio* by small-scale heterogeneities in the region of parent body formation within the early solar nebula. These heterogeneities may be observable even in matrices of different meteorites of the same class and parent body (cf. QUE 99177 and Adelaide in Fig. 2). Statistics may also affect the observed presolar grain abundances. E. g., the matrix area in the Adelaide meteorite investigated by [18] is ~8 times larger than the area investigated by [17]. To minimize such effects, at least 10,000 µm² of matrix should be scanned per individual meteorite.

A final conclusion confirming one of the two possibilities presented above cannot be drawn yet. We are extending our investigations to samples from other CR chondrites to determine their inventory of presolar grains as well. Finding a connection between the state of alteration state and the abundance of presolar material in meteorites from the same class would definitely be evidence for the idea of variations in parent body alteration. If no such connection can be found, small-scale heterogeneities in the protosolar nebula itself are the most likely explanation for our observations. Also interesting in this context is the observed SiC abundance of 160 ppm in NWA 852, which is the highest found among primitive Solar System materials to date. We don't know whether this is connected to the high oxide/silicate ratio of NWA 852. Further studies of other meteorites are clearly needed to shed more light on this issue.

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