THE STARDUST INVENTORY OF THE CR CHONDRITES GRAVES NUNATAKS 95229 AND 06100 ASSESSED BY NANOSIMS.
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Introduction: Primitive solar system materials contain varying amounts of presolar dust grains that formed in the winds of evolved stars or in the ejecta of stellar explosions [1]. Refractory silicates and oxides are among the most abundant types of presolar grains. These grains can be distinguished from Solar System material by their highly anomalous isotopic compositions. The abundances of presolar grains vary among different materials and even among individual meteorites of the same class. Carbonaceous chondrites of the CR type are among the most primitive meteorites, while showing evidence for extensive aqueous alteration [2]. First studies of CR chondrites indicated only small amounts of presolar material [3,4]. Recent investigations, however, revealed much higher abundances of presolar dust in individual meteorites of this group [5–7]. Investigating these 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.

Samples and Experimental: Promising matrix areas, i.e., areas with only little or no visible alteration were identified in thin sections of the CR2 chondrites Graves Nunataks (GRA) 95229 and 06100 by optical microscopy. Additionally, element distribution maps of Mg, Si, S, Ca and Fe were acquired with a JEOL Superprobe 8200 Electron Microprobe, to facilitate a more reliable identification of fine-grained matrix material. For the oxygen isotope measurements a ~100 nm primary Cs^+ beam was rastered over 10×10 µm²-sized sample areas (256×256 px) in the NanoSIMS 50 at the MPI for Chemistry in Mainz. $^{16,17,18}O^-$, $^{28}Si^-$, and $^{27}Al^{16}O^-$ ion images were acquired in multi-collection mode. Each measurement consisted of 5 planes, with integration times of ~11 minutes per plane. O-anomalous grains were identified in situ by their O-isotopic composition. They are considered as presolar if the anomaly is more than 4σ away from the average value of the surrounding matrix and visible in at least two subsequent image planes. Detection of $^{28}Si^-$ and $^{27}Al^{16}O^-$ allows distinguishing between silicates and aluminum-rich oxides, the most common type of presolar oxides. $^{12}C^-$, $^{13}C^-$, and $^{28,29,30}Si^-$ were measured on a subset of matrix from GRA 06100 containing Si hotspots to identify presolar silicon carbide (SiC) grains. During these measurements, 10 planes of 4 minutes integration time each were acquired over 5×5 µm²-areas (128×128 px).

Results and Discussion: *GRA 95229.* 10,000 µm² of fine-grained material have been analyzed so far.

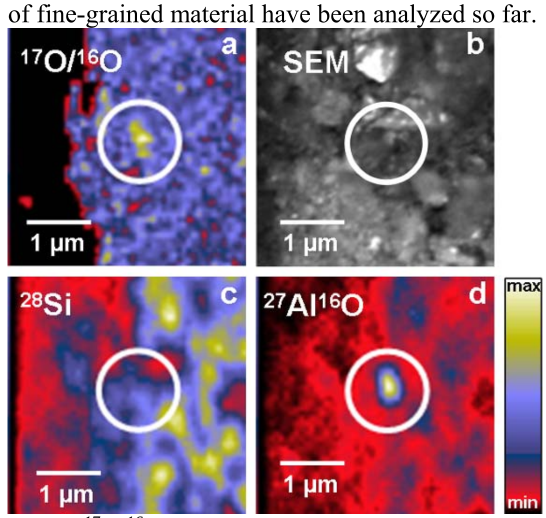

Fig.1. *$^{17}O/^{16}O$-ratio (a), SEM image (b), and secondary ion images of $^{28}Si^-$ (c) and $^{27}Al^{16}O^-$ (d) for the O-anomalous grain 8_07 from GRA 95229.*

Two O-anomalous grains were identified by their oxygen isotopic compositions and afterwards relocated by FE-SEM. Both grains are enriched in ^{17}O and have subsolar to solar $^{18}O/^{16}O$ ratios (Table 1). They belong to group 1, originating from 1.2–2.2 $M_\odot$ AGB stars [8,9]. These two grains represent a presolar O-anomalous grain abundance of 19 ppm. While grain 04_16 clearly is a silicate grain, unambiguous distinction between silicate and oxide was not yet feasible for grain 08_07. From Fig. 1 can be seen that the anomaly extends over an area associated with a strong $^{27}Al^{16}O$-signal (Fig. 1d), while silicon is also present (Fig. 1c). The SEM image (Fig. 1b) shows that the grain hosting the anomaly may consist of different components, perhaps being a “complex” grain as has been previously reported by [10] . Due to the small size of the grain, analysis by SEM/EDX was not feasible. Future investigations by FIB-TEM or Auger spectroscopy may provide more detailed information.

GRA 06100. In this sample, 6,200 µm² of matrix material have been analyzed to date. No presolar silicates or oxides have been found. From our data, we can estimate an upper limit for the abundance of O-anomalous grains of ~11 ppm. Indicated by the presence of silicon hotspots not associated with oxygen, two silicon carbide grains could be identified in the investigated matrix material (Table 2). Both grains display C and Si isotopic ratios that are typical for "mainstream" (MS) grains, originating from 1.5–3 $M_\odot$ AGB stars of ~solar metallicity [e.g.,1]. They represent a matrix-normalized abundance of 56 ppm.

First investigations by [11] of the fine-grained material in GRA 95229 suggest an intermediate degree of aqueous alteration and place it between pristine CR chondrites like Meteorite Valley (MET) 00426 and extensively altered CRs like Renazzo and Al Rais. Due to these results, a higher presolar O-anomalous grain abundance might have been expected than the ~19 ppm from our data. This value lies between the abundances reported by [3] and [4] for Renazzo and North West Africa (NWA) 530 and recent findings for the CR3 chondrites MET 00426 and Queen Elizabeth Range (QUE) 99177 [5,7].

GRA 06100 shows evidence for a different alteration history than the other investigated CR2 chondrites. In addition to extensive aqueous alteration, it was subject to subsequent thermal metamorphism [12]. The absence of presolar silicates and oxides in the investigated matrix areas and matrix-like inclusions seems plausible when considering these previous observations, since silicates are more susceptible to thermal or aqueous alteration than, e.g., SiC grains. The average abundances of presolar SiCs in primitive meteorites are lower than those of presolar silicates. Thus, detection of two SiC grains while finding no silicate grains supports the idea of extensive alteration processes affecting the stardust inventory of GRA 06100.

Previous investigations of individual CRs revealed a wide range of presolar O-anomalous grain abundances. Renazzo and NWA 530, containing only low levels of presolar silicates and oxides, seem to constitute a "low-abundance-subset" within the CR group. It has to be taken into account that for Renazzo, only 4900 µm² have been investigated for presolar silicates [3]. NWA 530 was analyzed by [4] using a SCAPS-equipped Cameca IMS 1270 [13], while the other meteorites discussed here were investigated by NanoSIMS. Since the spatial resolution of SCAPS is lower than that of the NanoSIMS 50, a direct comparison of the two techniques may be complicated at best, since small O-anomalous grains that are still identifiable by NanoSIMS would be below the detection limit of the SCAPS system. Both GRA 95229 as well as GRA 06100 fall into the subset with low levels of O-anomalous grains, expanding the available data to four CRs of this subset in total. The "high-abundance-subset" consists of MET 00426 and QUE 99177 together with the CR2 NWA 852 with high O-anomalous grain abundances (116–225 ppm), but varying presolar silicate/oxide ratios. SiC abundances based on ion imaging data (27–160 ppm) do not correlate with the degree of alteration [3,5,6,14].

Conclusions: It has previously been suggested to apply the presolar silicate/oxide ratio as indicator for the degree of alteration of the host material [5], since oxide grains are more resistant to metamorphic parent body processes than silicates. Nevertheless, *ab initio* small-scale heterogeneities of presolar material abundances within the early solar nebula can add to the variations of silicate/oxide-ratios observed for individual primitive meteorites. The two GRA meteorites investigated in this study support the idea of a "low-level subset" among the CRs, now consisting of Renazzo, GRA 95229, GRA 06100, and (possibly) NWA 530. The fact that GRA 95229 contains significantly less presolar grains than NWA 852 needs further investigation. GRA 95229 was attributed a merely intermediate degree of aqueous metamorphism [11], while NWA 852 shows signs of extensive alteration in some areas. To explore possible systematics in detail, a larger data set for the CR chondrites is crucial.

Grain	$^{17}O/^{16}O$ ($\times10^{-4}$)	$^{18}O/^{16}O$ ($\times10^{-3}$)	Size (nm)	Group
04_16	5.21±0.29	1.95±0.06	490×310	1
08_07	8.01±0.77	1.80±0.11	370×240	1
solar	3.84	2.01		

Table 1. *O-anomalous grains identified in GRA 95229.*

Grain	$^{12}C/^{13}C$	$\delta^{29}Si$ (‰)	$\delta^{30}Si$ (‰)	Size (nm)	Type
C_01_06	91.4±1.5	4±9	24±11	510×680	MS
C_04_24	56.0±2.2	11±18	62±22	350×260	MS
solar	89.9				

Table 2. *Presolar SiC grains identified in GRA 06100.*

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