THE STARDUST INVENTORIES OF CR CHONDRITES QUE 99177 AND MET 00426, AND THE DISTRIBUTION OF PRESOLAR SILICATE AND OXIDE GRAINS IN THE EARLY SOLAR SYSTEM.

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Introduction: The CR chondrites are among the most primitive meteorites and have been compared with IDPs because both types of materials contain abundant H and N isotopic anomalies thought to be of interstellar origin [e.g., 1, 2]. Circumstellar grains are also abundant in IDPs [3, 4], but have only rarely been found in CR chondrites due to the extensive aqueous alteration they have experienced [5, 6]. However, QUE 99177 and MET 00426 appear to be significantly less altered than most members of this group [7] and, thus, are good candidates in which to search for presolar grains. Indeed, we recently showed that QUE 99177 has very high concentrations of presolar grains [8], with O-anomalous grain abundances that exceed those of the primitive chondrites Acfer 094 and ALHA77307 [9]. Our continued investigation of these two CR chondrites shows that MET 00426 also contains high concentrations of both O-anomalous and C-anomalous presolar grains. Here we report results for the O-bearing presolar grains in these two meteorites and discuss implications for the distribution of presolar materials in the early solar system.

Experimental: We used the NanoSIMS to carry out raster ion imaging of matrix material in thin sections of QUE 99177 and MET 00426 in order to locate isotopically anomalous grains. Individual areas of 10 x 10 μm^2 were mapped for C and O ($^{12}C^-$, $^{13}C^-$, $^{16}O^-$, $^{17}O^-$, $^{18}O^-$) for total analysis areas of 8500 μm^2 and 9200 μm^2 for QUE 99177 and MET 00426, respectively. In QUE 99177 we also carried out C and N ($^{12}C^-$, $^{13}C^-$, $^{12}C^{14}N^-$, $^{12}C^{15}N^-$, $^{28}Si^-$) imaging, with a total measured area of 5700 μm^2. C and O isotopic compositions were normalized to the average composition of matrix material from each meteorite, assuming solar isotopic compositions; N isotopic compositions were normalized to a Si_3N_4 standard.

Isotopically anomalous grains were analyzed for elemental compositions in the PHI 700 Auger Nanoprobe. Complete elemental spectra were obtained for individual grains and were quantified using sensitivity factors obtained from a variety of olivine and pyroxene standards. In addition, high resolution maps of selected elements (Fe, Mg, Si, O, Al, Ca, C, S) were acquired of the areas containing the grains.

O-anomalous Grains: We found 33 O-anomalous grains in QUE 99177 [8] and 28 in MET 00426 (Fig. 1). In QUE 99177, all but one of the grains are ^{17}O-enriched and belong to group 1; the remaining grain is ^{18}O-rich and belongs to group 4. In MET 00426, 23 grains belong to group 1 and two are group 4 grains; of the remaining 3 grains one is depleted in ^{18}O with normal $^{17}O/^{16}O$, one is depleted in ^{17}O with slightly sub-solar $^{18}O/^{16}O$, and the third is enriched in ^{18}O and depleted in ^{17}O.

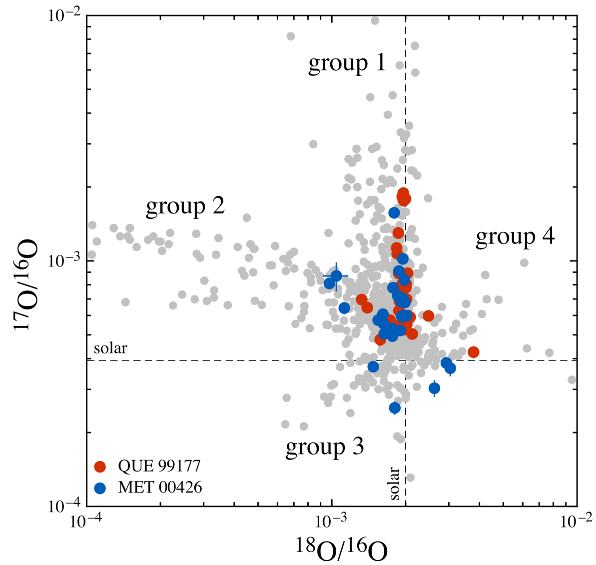

Figure 1. Oxygen three isotope plot showing O-anomalous grains from QUE 99177 and MET 00426. Comparison data (gray circles) from [10].

Auger spectra of the 33 O-anomalous grains from QUE 99177 show that all but one are Fe- and/or Mg-bearing silicates. Thirteen grains have compositions consistent with pyroxene (Fe+Mg/Si ≈ 1); two of these contain significant amounts of Al, but none are Ca-bearing. Another eight grains are compositionally similar to olivine (Fe+Mg/Si ≈ 2); mg#s range from 27 to 93, but most grains are Mg-rich. The spectra of three grains (two pyroxene-like and one olivine-like) contain S that appears to be intimately associated with the grains; TEM studies are needed to evaluate whether these grains are similar to the GEMS found in IDPs [11]. Of the remaining 12 grains, 10 have (Fe+Mg)/Si ratios that are intermediate between olivine and pyroxene. The single group 4 grain is Mg-rich and depleted in Si relative to olivine and pyroxene (Fe+Mg/Si ≈ 3). Finally one grain consists essentially only of Si and O, with a stoichiometry consistent with SiO_2. Although we are still completing our analyses of the O-anomalous grains in MET 00426, we note that of the 21 grains for which were able to obtain Auger spectra, all appear to be silicates.

N Isotopic Compositions: CR chondrites typically exhibit abundant N isotopic anomalies, and QUE 99177 is no exception. Average N isotopic compositions of 10 x 10 μm^2 regions of matrix material are enriched in ^{15}N with $\delta^{15}N$ up to 500 ‰ and individual ^{15}N-rich hotspots have $\delta^{15}N$ up to 2475 ‰. The average bulk values are similar to those observed in isotopically primitive IDPs [4], but ^{15}N enrichments in the hotspots are higher than in IDPs and are similar to those reported for insoluble organic matter in primitive meteorites [2]. The ^{15}N enrichments in QUE 99177 are also higher than those observed in the CR chondrite Renazzo, which has hotspots with $\delta^{15}N$ up to ~800 ‰ and average bulk values of ~200 ‰ [6]. Aqueous alteration may be responsible for the lower values in Renazzo.

Discussion: Both QUE 99177 and MET 00426 contain high concentrations of O-anomalous presolar grains. Abundances (uncorrected for detection efficiencies), at 220 and 120 ppm, respectively, are similar to or exceed those observed in Acfer 094 and ALHA77307 (145 and 125 ppm, respectively, [9]), confirming the primitive nature of the CR chondrites. More interesting is the fact that none of the 54 O-anomalous grains for which we have compositional data appear to be oxide grains. Upper limits for the abundances of presolar oxides in QUE 99177 and MET 00426 are ~4–5 ppm, compared to abundances of ~30–55 ppm in Acfer 094 and ALHA77307 [9]. Silicate to oxide ratios in the latter two meteorites are on the order of 2-3, but are significantly higher in QUE 99177 and MET 00426 (Fig. 2). IDPs also seem to be depleted in presolar oxide grains relative to presolar silicates, with only one Al_2O_3 grain identified [12] versus 17 presolar silicate grains [3, 4, 13].

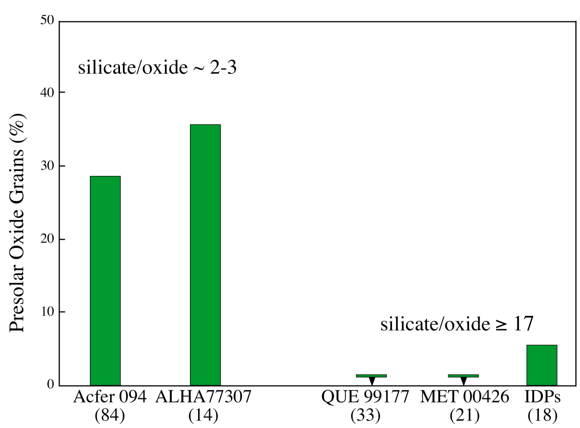

Figure 2. Fraction of presolar oxide grains in primitive meteorites and IDPs. Numbers below meteorite names indicate total number of O-anomalous grains included. Data from [3,4,9,12-16] and unpubl. data from our laboratory.

Presolar grain abundances in primitive meteorites are known to be affected by thermal metamorphism occurring on their parent bodies, with correlations between abundance patterns and metamorphic histories within meteorite classes [17]. Aqueous alteration also plays an important role in destroying labile presolar silicate grains, as is evident from the lack of such grains in more heavily altered CR chondrites [5, 6]. However, the four meteorites discussed here all seem to be largely unaltered, with abundant amorphous silicates and primitive carbonaceous matter [7, 18]. Thus, we do not expect parent body processing to have played a large role in determining their presolar grain inventories. Alternatively, pre-accretionary processing of nebular dust has been invoked to explain differences in the abundances of presolar grains among different meteorite classes [19], with preferential destruction of the more labile components.

A problem with both of these scenarios is that it is difficult to envision a process in which oxide grains would be preferentially destroyed over silicate grains. Indeed oxide grains are expected to be more resistant to secondary processing than silicate grains [e.g., 9]. If this is the case, one might expect lower silicate to oxide ratios in more processed meteorites. Although there is little evidence addressing this issue, we note that if the highest silicate to oxide ratios observed in primitive meteorites in fact reflect true nebular proportions, this would imply significant destruction of presolar silicate grains in Acfer 094 and ALHA77307, and silicate abundances in these meteorites that are an order of magnitude higher than current estimates. On the other hand, if secondary nebular or parent body processing cannot account for the variability in oxide grain abundances, an intrinsic heterogeneity in the early solar system must be considered. Finally, we note that the low abundance of oxide grains in IDPs provides another link to the CR chondrites and may have implications for the origins of both types of materials.

References: [1] Messenger et al. (2003) *Space Sci. Rev.* 106, 155. [2] Busemann et al. (2006) *Science* 312, 727. [3] Messenger et al. (2003) *Science* 300, 105. [4] Floss et al. (2006) *Geochim. Cosmochim. Acta* 70, 2371. [5] Nagashima et al. (2004) *Nature* 428, 921. [6] Floss and Stadermann (2005) *Lunar Planet. Sci. XXXVI*, #1390. [7] Abreu and Brearley (2006) *Lunar Planet. Sci. XXXVII*, #2395. [8] Floss and Stadermann (2007) *Meteorit. Planet. Sci.* 42, A48. [9] Nguyen et al. (2007) *Astrophys. J.* 656, 1223. [10] Presolar Grain Database (2007) http://presolar.wustl.edu/~pgd. [11] Bradley (1994) *Science* 265, 925. [12] Stadermann et al. (2006) *Geochim. Cosmochim. Acta* 70, 6168. [13] Messenger et al. (2005) *Science* 309, 737. [14] Bose et al. (2007) *Meteorit. Planet. Sci.* 42, A23. [15] Ngyuyen and Zinner (2004) *Science* 303, 1496. [16] Mostefaoui and Hoppe *Astrophys. J.* 613, L149. [17] Huss and Lewis (1995) *GCA* 59, 115. [18] Busemann et al. (2007) *Meteorit. Planet. Sci.* 42, 1387. [19] Huss (2004) *Antarct. Met. Res.* 17, 132.

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