Mg AND Ca ISOTOPIC ANOMALIES IN PRESOLAR OXIDES: LARGE ANOMALIES IN A GROUP 3 HIBONITE GRAIN.

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Introduction: Some 1400 presolar oxide and silicate grains have now been identified in primitive meteorites, both *in situ* and in acid residues. Most of these can be assigned to one of five groups [1, 2] (Fig. 1). The majority of grains (Groups 1 and 2) are well-understood as originating in low-mass asymptotic giant branch (AGB) stars with a range of metallicities. Group 4 grains most likely originated in supernovae (SNe) [3]. Group 3 grains show depletions in ^{17}O and ^{18}O and their origins are more enigmatic. Those with ^{17}O/^{18}O ratios greater than the solar value of 0.19 have been interpreted as originating in low-mass, low-metallicity AGB stars, whereas [3] argued that those with lower ratios might have originated in SNe like the Group 4 grains. However, assigning a definite origin to most Group 3 (and Group 4) grains has been hampered by a lack of isotopic data for elements other than O. Here we report Mg and Ca isotopic data for several Group 3 and 4 presolar oxide grains, including a Group 3 hibonite with unusually anomalous Ca isotopic ratios.

Methods and Results: We previously reported the identification of 107 new presolar oxides in an acid residue of the Murray (CM2) meteorite [4], of which some 50 are single grains with reliable O isotopic data (Fig. 1). A subset of these (colored symbols) was selected for further isotopic analysis with the NanoSIMS. Positive secondary ions of ^{24,25,26}Mg, ^{27}Al, ^{40,44}Ca, and ^{48}Ti were measured in multicollection with an ~10 pA, 0.5 – 1.0 µm O$^-$ primary beam. We note that the Mg-isotopic ratios of several Group 3 and 4 Al_2O_3 grains were compromised by re-deposition of Mg during removal of nearby spinel grains in the NanoSIMS or FIB. The Mg-Ca measurement of one Group 3 hibonite grain, 3-55-7, indicated that it had a large ^{44}Ca enrichment. We thus further measured this grain for its K and Ca isotopic ratios, measuring ^{27}Al$^+$, ^{39,41}K$^+$, and ^{40,42,43,44}Ca$^+$ in multicollection.

Data for highly ^{17}O-enriched nova grain candidates are discussed in a companion abstract [5]. Mg isotopic data for the analyzed Group 3 and 4 grains are shown in Figure 2 (Group 2 grains show similar compositions to previous Group 2 grains and are not discussed further here). Extreme ^{18,17}O-rich Al_2O_3 grain 5-2 shows a modest excess (76±13‰) in ^{26}Mg, most likely a lower limit due to Mg re-deposition. Two other Group 4 grains show ^{25}Mg depletions and ^{26}Mg excesses. All but one of the analyzed Group 3 grains show close-to-normal Mg isotopic and ^{44}Ca/^{40}Ca ratios. In contrast, grain 3-55-7 has a large Ca abundance, consistent with hibonite, a large ^{25}Mg depletion, normal ^{26}Mg and a large ^{44}Ca excess (460±10‰). Further analysis of this grain revealed a ~2-σ excess of ^{41}K (with inferred ^{41}Ca/^{40}Ca<1.7×10^{-5}) and significant anomalies in ^{42}Ca and ^{43}Ca (δ^{42}Ca=75±16 ‰, δ^{43}Ca=270±40 ‰).

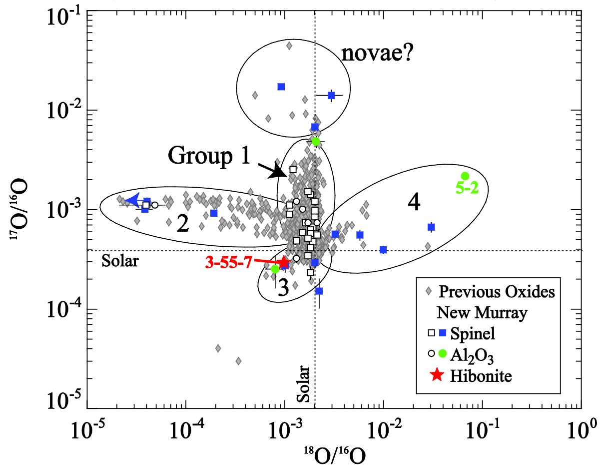

Figure 1: O 3-isotope plot for presolar oxide grains. Colored symbols indicate grains analyzed in this study.

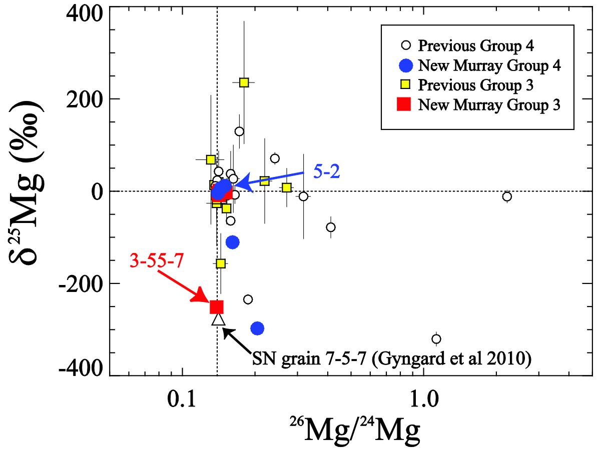

Figure 2: Mg 3-isotope plot for Group 3 and 4 presolar oxide grains. Dotted lines indicate solar ratios.

Discussion: *Group 3 Grains:* The normal Mg-isotopic ratios of most of the analyzed Group 3 grains likely reflect either partial isotopic equilibration with normal Mg either in space or on meteorite parent bodies [3] or, in the case of one Al_2O_3 grain, Mg re-deposition from nearby spinels. Most of the new data thus unfortunately do not provide useful constraints on the origins of Group 3 grains.

In contrast, the rich data set for grain 3-55-7 allows an in-depth look at one grain with a fairly typical

Group 3 O-isotopic signature. The Mg isotopic composition of 3-55-7 is closely similar to that of ^{16}O-rich spinel grain 7-5-7 [2], believed to have originated from a Type II supernova (SN). In the SN picture, the coupled ^{16}O excess and ^{25}Mg depletion can be explained by mixing of ^{24}Mg- and ^{16}O-rich material from an inner SN zone with SN envelope material, whereas the ~normal ^{26}Mg/^{24}Mg ratio is explained by admixture of ^{26}Al to the ^{24}Mg-rich composition. At first glance, then, the similarity of the Mg isotopes of grain 3-55-7 to 7-5-7, as well as the ^{44}Ca excess of 3-55-7 point to a SN origin for this grain as well, if the latter anomaly is due to decay of short-lived ^{44}Ti. However, the other isotopic data for this grain argue against a SN origin. In the first place, the significant excesses in ^{42}Ca and ^{43}Ca preclude unambiguous interpretation of the ^{44}Ca excess as radiogenic. Moreover, mixtures of calculated 15$M_\odot$ SN zones [6] that reproduce the O- and Ca-isotopic ratios of the grain predict strong unobserved enrichments in ^{25}Mg and ^{26}Mg and a 10× higher than inferred ^{41}Ca/^{40}Ca ratio. Matching the grain's O isotopes, ^{25}Mg depletion and ^{44}Ca excess results in much higher than observed ^{26}Mg and ^{42}Ca excesses, a large unobserved ^{43}Ca depletion, and 60× too much ^{41}Ca. These problems reflect the fundamental nature of the nucleosynthesis occurring in different SN layers, and it appears highly unlikely that this grain's composition can be explained by an origin in a Type II SN. Similar comparisons with published yields for Type Ia SNe do not support a Type Ia origin for this grain either.

The common interpretation of typical Group 3 grains is that they likely formed in low-mass, low-metallicity AGB stars [1], and the O and Mg isotopic ratios of grain 3-55-7 are consistent with this as well. In this scenario, the lower-than-solar ^{17}O/^{16}O, ^{18}O/^{16}O and ^{25}Mg/^{24}Mg are all due to Galactic Chemical Evolution (GCE) effects. Assuming that the grain's parent star formed with a similar (25%) depletion in ^{26}Mg to that of ^{25}Mg, the inferred ^{26}Al/^{27}Al ratio required to bring the observed ^{26}Mg/^{24}Mg ratio to solar is ~10^{-3}, consistent with expectations for low-mass, low-metallicity AGB stars [7]. Similarly, the upper limit on the inferred ^{41}Ca/^{40}Ca ratio is consistent with predictions for AGB stars and measurements of presolar AGB-derived hibonite grains [3]. However, the excesses in ^{42,43,44}Ca are much larger than predicted for low-mass AGB star envelopes, especially since it is expected that GCE should also lead to lower-than-solar initial Ca-isotopic ratios for low-metallicity stars. Calcium-44 is likely produced in rare types of SNe and its high abundance in this grain thus might reflect heterogeneous GCE, as predicted by [8]. However, it is not clear that such an explanation is possible for the other stable Ca-isotopes. In any case, grain 3-55-7 illustrates the importance of obtaining multi-element isotope data on presolar grains and suggests that the stellar sources of Group 3 presolar oxide grains remain unsettled.

Group 4 Grains: The ^{25}Mg depletions and ^{26}Mg excesses observed in two of the analyzed Group 4 (^{18}O-rich) grains (Fig 2) are consistent with previous observations and with a SN origin as discussed above. Grain 5-2 has the largest ^{18}O excess of any presolar oxide grain measured to date and its composition is similar to those of some presolar graphite grains thought to originate in SNe [9]. In principle, large coupled excesses of ^{18}O and ^{17}O can be explained by mixing of the He/N and He/C SN zones. However, as shown by the solid black curve in Figure 3, mixing of these zones in a 15$M_\odot$ SN [10] cannot reach the composition of grain 5-2. The purple curves show that mixing of the most ^{18}O-rich layer of the He/C and most ^{17}O-rich layer of the He/N zone can reproduce the grain composition for a range of SN of masses ~15-22 $M_\odot$ [10], perhaps indicating preferential mixing at SN zone boundaries. Note that grain 5-2 plots near the transition from C-rich (dotted curves) to O-rich SN mixtures, perhaps helping to explain how both O-rich and C-rich grains form with similar O isotopic ratios. We intend to attempt a remeasurement of the Mg isotopes in 5-2 in the hope that the data will help constrain the origin of this interesting grain.

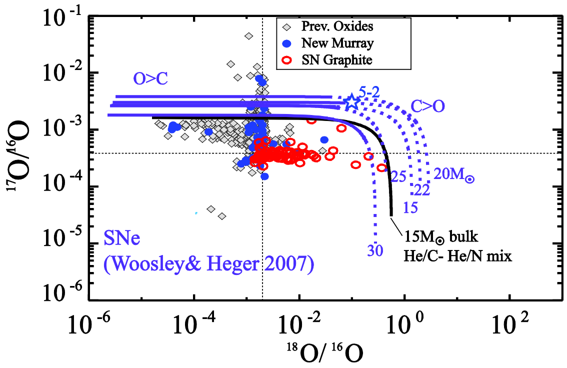

Figure 3: Mixing of predicted SN (^{17}O-rich He/N and ^{18}O-rich He/C) zone compositions compared to presolar oxide and graphite grains.

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