

PROBLEMS IN THE NUCLEOSYNTHESIS OF O, Mg, AND Ti IN AN Al_2O_3 GRAIN FROM AN AGB STAR. Gary R. Huss, Albert J. Fahey, and G. J. Wasserburg. Lunatic Asylum, Div. of Geol. and Planet. Sci., California Institute of Technology, Pasadena, CA 91125 USA

Presolar Al_2O_3 grains have now been identified from primitive meteorites from four chondrite groups (CI, CM2, LL3, H3) [1-4]. The majority of these grains are interpreted to have come from red giant or AGB stars due to large enrichments in ^{17}O and depletions in ^{18}O relative to solar oxygen and high initial $^{26}\text{Al}/^{27}\text{Al}$ ratios [3, 4]. For many grains, partial hydrogen burning during normal main sequence evolution followed by homogenization of the stellar envelope during first, second, and/or third "dredge-up" adequately explains the observed oxygen systematics. However, some grains require more complicated explanations. For example, the oxygen compositions of three Al_2O_3 grains (Orgueil B, Murchison 83-5, Bishunpur B39) cannot all be explained by main-sequence nucleosynthesis in stars of solar composition. Different initial oxygen compositions in the parent stars are also apparently required [3, 5]. Extreme ^{18}O depletions observed in some grains [4] cannot be explained unless one invokes hot bottom burning in the convective envelope during the AGB phase [6]. Other grains have $^{17}\text{O}/^{16}\text{O}$ ratios indicative of low-mass stars which do not experience hot-bottom burning, but exhibit depletions of ^{18}O too large to explain by standard main-sequence processing [4, 6]. A possible explanation for such grains (and low-mass stars with very low $^{12}\text{C}/^{13}\text{C}$ ratios) might be slow turbulent diffusion below the base of the convective zone due to differential rotation in the radiative envelope [7]. The availability of isotopic data for several elements from a single grain that must come from one star places further constraints on possible nucleosynthetic processes. In particular, Al_2O_3 grain Orgueil B has a $^{17}\text{O}/^{16}\text{O}$ ratio ~ 2.5 x solar, a solar $^{18}\text{O}/^{16}\text{O}$ ratio, and an initial $^{26}\text{Al}/^{27}\text{Al}$ ratio of $\sim 9 \times 10^{-4}$ [1]. It also exhibits excesses of ^{25}Mg and ^{46}Ti , ^{47}Ti , ^{49}Ti , and ^{50}Ti relative to solar compositions [8]. We find no way to explain these characteristics solely in terms of stellar nucleosynthesis in a low-mass star of solar composition.

The oxygen composition of Orgueil B and two other presolar Al_2O_3 grains are discussed in detail in [3 and 5]. The excess ^{17}O implies a parent star for Orgueil B of about $1.5 M_{\odot}$. The observed "solar" $^{18}\text{O}/^{16}\text{O}$ ratio implies that the parent star originally had a higher-than-solar $^{18}\text{O}/^{16}\text{O}$ ratio [3, 5]. The high initial $^{26}\text{Al}/^{27}\text{Al}$ ratio apparently requires that Orgueil B formed after the onset of third dredge-up so that H-shell material could be mixed into the envelope. The fact that the grain is an oxide requires that it formed before the thermal pulses of the third dredge-up could increase the C/O ratio of the envelope above unity [3, 5].

The ^{25}Mg and Ti data for Orgueil B are shown in the Figure. Orgueil B exhibits a $\sim 25\%$ enrichment in ^{25}Mg and large enrichments in all of the minor Ti isotopes relative to the solar compositions. In [8], we interpreted these enrichments to be due to s-process nucleosynthesis and incorporation of He-shell material into the envelope of the parent star before the grain was formed. However, this suggestion is inconsistent with s-process nucleosynthesis acting on material of solar composition. For example, while enrichments of all four minor Ti isotopes are expected from s-process nucleosynthesis, the largest enrichments should be in ^{49}Ti and ^{50}Ti [e.g., 9], not ^{46}Ti and ^{47}Ti (Fig.). This is because the neutron capture cross sections for ^{45}Sc and $^{46-49}\text{Ti}$ are comparable [10], while the abundance of ^{48}Ti is ~ 10 x as high as the other Ti isotopes and ~ 50 x as high as ^{45}Sc . Thus, ^{49}Ti and ^{50}Ti will be produced via neutron capture on ^{48}Ti in larger amounts than will ^{46}Ti and ^{47}Ti via ^{45}Sc . In addition, the cross section for ^{50}Ti is ~ 0.2 x that of the other Ti isotopes [10], which allows ^{50}Ti to build up. Thus s-process, as currently understood, cannot produce the observed ratios from Ti of solar composition. Possible explanations of the Orgueil B composition might be: 1) the neutron-capture cross sections are badly in error and s-process does work; 2) the initial seed composition for the s-process was not solar; 3) the Ti in Orgueil B did not result from s-process synthesis.

^{25}Mg should be produced at a rate comparable to that of ^{46}Ti by a standard s-process [e.g., 9], consistent with the data for these isotopes from Orgueil B (Fig.). But since a non-solar initial composition or grossly different cross sections are required for s-process to produce the observed Ti ratios, it is not evident why the ^{25}Mg and ^{46}Ti excesses with respect to solar should be similar at all. In addition, there is another source of ^{25}Mg in AGB stars. During the thermal pulses of the AGB phase, CNO products are transformed in ^{22}Ne , making it greatly over-abundant. At temperatures of $2.8\text{-}3 \times 10^8$ K, the reaction $^{22}\text{Ne}(\alpha, n)^{25}\text{Mg}$ is marginally activated. If about 1% of the ^{22}Ne is burned by this reaction, a ^{25}Mg excess of $>100\%$ could appear in the stellar envelope [11]. Thus, agreement between relative ^{25}Mg and ^{46}Ti excesses and s-process theory would seem to be coincidence.

The problem is clear. How can we understand the isotopic systematics of Orgueil B, a circumstellar condensate that carries the isotopic signatures of a single star? Stellar nucleosynthesis during the main sequence and AGB can explain the ^{17}O enrichment and the high $^{26}\text{Al}/^{27}\text{Al}$ ratio. However, the observed solar $^{18}\text{O}/^{16}\text{O}$ ratio requires that the initial oxygen composition of the parent star was non-solar. The ^{25}Mg and $^{46,47,49,50}\text{Ti}$ excesses are broadly consistent with s-process nucleosynthesis which is believed to be a normal feature of low-mass AGB stars. However, the detailed compositions cannot be explained by s-process nucleosynthesis on material of solar composition without relatively extreme modifications to the theory or to the starting composition. Even then there are problems. One can again appeal to a non-solar starting composition. Perhaps the ^{25}Mg and $^{46,47,49,50}\text{Ti}$ have not been significantly affected by stellar nucleosynthesis. If so, then we must establish how the initial composition arose. A parent star with a higher initial $^{18}\text{O}/^{16}\text{O}$ ratio than the solar system [3, 5] might be expected to have a higher abundance of "secondary" isotopes such as $^{17,18}\text{O}$, $^{25,26}\text{Mg}$, $^{46,47,49,50}\text{Ti}$, etc. relative to "primary" isotopes such as ^{16}O , ^{24}Mg , ^{48}Ti [12], perhaps implying a star of higher metallicity. It is not clear that metallicity should have a one-to-one relationship with the isotopic (or chemical) composition of the "metals". These considerations provide a broad outline for a model to explain Orgueil B, but substantial theoretical and observational work is still required.

[1] Hutcheon I. D. *et al.* (1994) *Ap. J.* **425**, L97. [2] Nittler L. R. *et al.* (1993) *LPSC* **24**, 1087. [3] Huss G. R. *et al.* (1994) *Ap. J.* **430**, L81. [4] Nittler L. R. *et al.* (1994) *Nature* **370**, 443. [5] Boothroyd A. I. *et al.* (1994) *Ap. J.* **430**, L77. [6] Boothroyd A. I. (1994) *Ap. J.*, in press. [7] Gilroy K. K. (1989) *Ap. J.* **347**, 835. [8] Huss G. R. *et al.* (1994) *Meteoritics* **29**, 475. [9] Gallino R. *et al.* (1990) *Nature* **348**, 298. [10] Beer H. *et al.* (1992) *Ap. J. Supp.* **80**, 403. [11] Wasserburg G. J. *et al.* (1994) *Ap. J.* **424**, 412. [12] Timmes F. X. *et al.* (1994) preprint. Supported by NASA NAGW 3040 and 3297. Division Contribution 5497 (891).

