ALUMINUM-26: A NON-UNIFORM HEAT SOURCE IN THE EARLY SOLAR SYSTEM

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Some refractory inclusions in primitive meteorites show enrichments in Mg²⁶, which correlate with Al and thus imply the former presence of the radionuclide Al²⁶ (mean life 1.02 Ma). This Al²⁶ apparently came from interstellar grains that were reprocessed and diluted in the early solar system.

A major question has been the variability of the initial Al²⁶/Al²⁷ ratio (≡ Ro) among inclusions in a single meteorite, ranging from a "canonical" maximum of 5 × 10⁻⁵ to 5.2 × 10⁻⁶ (1,2). If attributed to a difference in crystallization times, the lower value implies an extended interval of 7.2 × 10⁶ a for the lifetime of the solar nebula, for melting events (≥ 1800 K) within it, and for accretion of asteroids. Such an interval is much longer than theoretical estimates or even observational limits for accretion disks of T-Tauri stars (< 3 × 10⁶ to 10⁷ a; 3), causing some authors to favor heterogeneous distribution of Al²⁶ (4). Either way, since Al²⁶ is a potential heat source for melting of asteroids (5) and planets, its distribution in the early solar system is of interest.

To study this problem, we have analyzed 26 corundum (Al₂O₃) grains from the Murchison C2 chondrite by ion microprobe mass spectrometry (6). Corundum is the most refractory major phase in solar matter but has only a ~25° stability range in a solar gas before being converted to other minerals by reaction with Ca or Mg vapor. Thus any surviving corundum must have been isolated soon after formation, preserving a record of early high-T events.

The data show ≥3 discrete groups and thus favor heterogeneous distribution of Al²⁶. The Al₂O₃ grains divide into 3 groups on the basis of Ro and Ti or V content, with identical membership in both plots (Fig. 1a,b). These groups also differ in O-isotopic composition (Fig. 2). All but one of the Group 1 grains fall in the main cluster at δ¹⁸O = -50 ‰, whereas 4 out of 5 Group 2 grains fall at δ¹⁸O = -20 ‰. Only Group 3 scatters widely. (The lines in this 3-isotope diagram show paths for mass-dependent fractionation and for mixing or exchange).

Very likely, each group is derived from an isotopically distinct parcel of gas and dust that entered the solar nebula, was vaporized, and then recondensed after some mixing with local material. All fossil radiogenic Mg²⁶ must have been lost from the Al-bearing phases at that time, else some corundum grains would show Ro greater than the canonical limit of 5 × 10⁻⁵. During recondensation, the corundum continually equilibrated with the gas, taking up Ti, V, and other compatible refractories in solid solution, in amounts that increased with falling temperature. The lower Ti, V concentrations in Group 2 may reflect lower nebular pressures, because the condensation curves of these elements diverge increasingly from the Al curve at lower P, leading to lower concentrations in corundum (7).

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The $\delta^{18}$O values should reflect those of the accompanying gas, as modified by admixtures of other gas-dust parcels and solid-gas exchange. Group 1 shows an interesting trend: $R_0$ correlates with $\delta^{17,18}$O, i.e. with $O^{16}$ (Fig. 3). No such correlation of $Al^{26}$ with $O^{16}$ had ever been observed before, probably because the minerals studied were not as primitive as corundum. This correlation can hardly be due to decay of $Al^{26}$, as it requires 1.1 Ma and leaves the oxygen trend unexplained. More likely, it represents mixing of $Al^{26}$-rich material of $\delta^{17,18}$O $\approx$ -44, -45‰ with $Al^{26}$-poor material of lighter $\delta^{17,18}$O (-60, -67‰). Grain 6, with $R_0 \leq 0.025 \times 10^{-5}$ and $\delta^{18}$O $\approx$ -94.1‰, is a somewhat more extreme version of such a light endmember.

Group 3 probably is not a discrete group at all, as its key characteristic—low $R_0$—will be shared by all grains older than $\sim$20 Ma, regardless of source and accompanying oxygen. We can estimate the mass fraction of such dead Al on the assumption that the $Al^{26}$-rich endmembers of Groups 1 and 2 had $R_0 = 5 \times 10^{-5}$ and $5 \times 10^{-6}$, and that all lower ratios in these groups represent dilution by old, $Al^{26}$-free grains. In terms of this model, live $Al^{26}$ in corundum came from two main sources, which had decayed to ratios of $5 \times 10^{-5}$ (44%) and $5 \times 10^{-6}$ (13%) prior to arrival in the solar system. The remaining 43% was dead Al (of mixed pedigree). Put differently, the mean $R_0$ was 2.3 $\times$ 10^{-5}, nearly 5 times the present-day ratio of $5 \times 10^{-6}$ from $\gamma$-ray astronomy (8). However, given the very special conditions required for survival of corundum, we cannot be sure that this value is representative of the entire early solar system, particularly as it neglects $Al^{26}$ contributions from SiC and graphite (9).

Nonetheless, it seems clear that the variability of $R_0$ is mainly due not to decay but to mixing of several kinds of dust with variable $Al^{26}$ and $\delta^{16}$O contents. Consequently, heating by $Al^{26}$ must have varied greatly among planets, asteroids, and comets, depending on $R_0$ of the local dust. This is consistent with observations, which show little correlation of thermal history with size. For planets, the effects of $Al^{26}$ would be greatly attenuated by the long accretion time, but not for asteroids or comets, whose accretion time could have lasted only as long as the solar nebula itself, i.e. $<10^6$ a.

References