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

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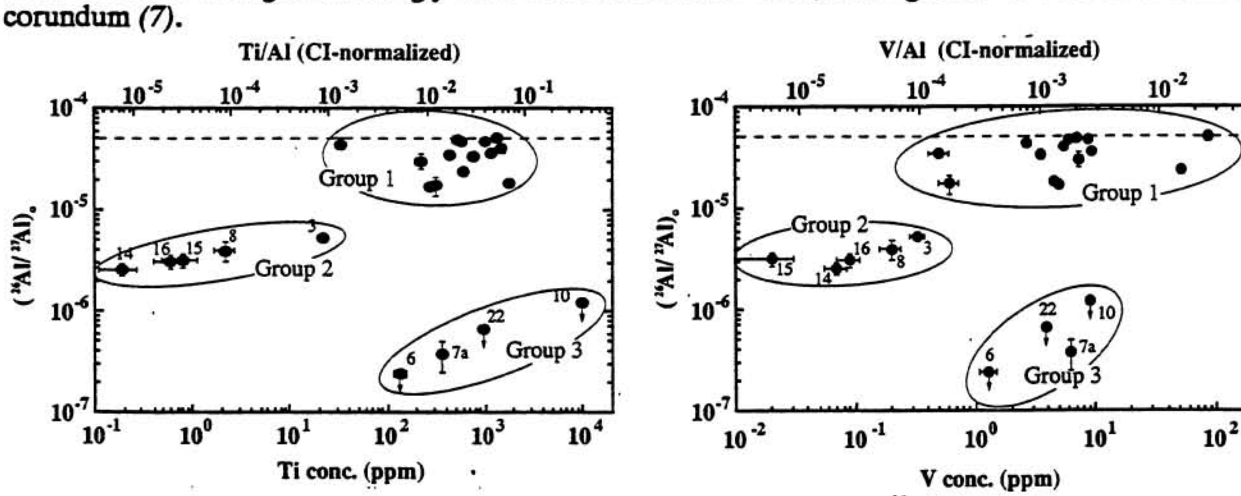
Some refractory inclusions in primitive meteorites show enrichments in Mg^{26}, which correlate with Al and thus imply the former presence of the radionuclide Al^{26} (mean life 1.02 Ma). This Al^{26} apparently came from interstellar grains that were reprocessed and diluted in the early solar system.

A major question has been the variability of the initial Al^{26}/Al^{27} ratio ($\equiv R_0$) among inclusions in a single meteorite, ranging from a "canonical" maximum of 5×10^{-5} to 5.2×10^{-8} *(1,2)*. If attributed to a difference in crystallization times, the lower value implies an extended interval of 7.2×10^6 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 [$<<3\times10^6$ to 10^7 a; *(3)*], causing some authors to favor heterogeneous distribution of Al^{26} *(4)*. Either way, since Al^{26} 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 (Al_2O_3) 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 Al^{26}. The Al_2O_3 grains divide into 3 groups on the basis of R_0 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 $\delta O^{18} \simeq -50$ ‰, whereas 4 out of 5 Group 2 grains fall at $\delta O^{18} \simeq -20$ ‰. 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 Mg^{26} must have been lost from the Al-bearing phases at that time, else some corundum grains would show R_0 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)*.



The δO^{18} 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 $\delta O^{17,18}$, 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 $\delta O^{17,18} \approx$ -44, -45 ‰ with Al^{26}-poor material of lighter $\delta O^{17,18}$ (-60, -67 ‰). Grain 6, with $R_0 \leq 0.025 \times 10^{-5}$ and $\delta O^{18} = -94.1$ ‰, 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 ~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 5×10^{-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 5×10^{-5} (44%) and 5×10^{-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 2.3×10^{-5}, nearly 5 times the present-day ratio of 5×10^{-6} from γ-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 δO^{16} 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

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