ALUMINUM-26 CHRONOLOGY OF DUST COAGULATION AND EARLY SOLAR SYSTEM EVOLUTION.

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Introduction: The formation timescale of the first solids in the Sun's protoplanetary disk has been of major interest because it is the first step towards the formation of terrestrial planets. Our current understanding of the chronology of the formation of the first solids in the Solar System is largely based on the short-lived ^{26}Al–^{26}Mg systematics ($t_{1/2}$ = 0.72 Myr) in Ca-Al-rich Inclusions (CAIs) found in chondritic meteorites. It has been established by numerous high precision in-situ and bulk-inclusion studies that pristine, large (>5 mm) CAIs in CV3 chondrite are characterized by ^{26}Al/^{27}Al of 5.2 (±0.1)×10^{-5}, and the initial (pre-^{26}Al-decay) ^{26}Mg/^{24}Mg ratio (≡Δ^{26}Mg$_0^*$) ranging from −0.13‰ to −0.014‰ relative to the chondritic value [REFs], implying a <30,000-year timescale for the formation of large CAIs in a reservoir with uniformly distributed ^{26}Al, but slightly heterogeneous initial ^{26}Mg/^{24}Mg [e.g., 1−5]. However, these cm-sized CAIs in CV3 chondrites are thought to have formed by melting and agglomeration of smaller particles (<10 μm) that condensed directly from the nebular gas. This fact calls into question how representative ^{26}Al/^{27}Al = 5.2 (±0.1)×10^{-5} recorded by these large CAIs is of the true initial ^{26}Al abundance and distribution in the protoplanetary disk. Here we focus on the ^{26}Al–^{26}Mg isotopes of small refractory inclusions (mostly 30-50 μm in size) in the ALHA77307 CO3.0 chondrite, which are best understood as products of initial coagulation of high-temperature dust condensates, in the hopes of evaluating the ^{26}Al/^{27}Al distribution during the condensation period and then inferring the chronologies of these small inclusions relative to those of the large CAIs in CV3 chondrites that have been the focus of many studies.

Experimental: The 22 CAIs studied here were discovered in situ on a polished thin section of ALHA77307 (CO3.0) by using a FEI field-emission scanning electron microscope. In-situ ^{26}Al–^{26}Mg isotope analyses were performed on the CAMECA ims-1290 ion microprobe at UCLA by following a method described in [6]. The target inclusions on the polished meteorite thin section were bombarded with a 1−8 nA ^{16}O$^-$ primary ion beam (ϕ ~ 1.5−4 μm) generated by a Hyperion-II oxygen ion source, yielding Mg and Al secondary ion signals intense enough to be simultaneously measured with multiple Faraday cups (FCs).

Results and discussion: Of 22 CAIs studied, 18 were found to have fossil records of ^{26}Al decay. The inferred ^{26}Al/^{27}Al ratios span a range from 8 (±16.5)×10^{-6} to 5.73 (±1.20)×10^{-5} (2σ errors). Five CAIs are characterized by ^{26}Al/^{27}Al = 5.2×10^{-5} within errors (reduced χ^2 < 2), and together yield a multi-CAI isochron with a slope corresponding to ^{26}Al/^{27}Al = 5.40(±0.13)×10^{-5} and an intercept of (−0.14±0.03)‰ as the initial Δ^{26}Mg$_0^*$ (reduced χ^2 = 1.1). Another 6 samples also form a well-defined multi-CAI isochron (reduced χ^2 = 4.3), from which ^{26}Al/^{27}Al = 4.89(±0.10)×10^{-5} and Δ^{26}Mg$_0^*$ = (−0.04±0.03)‰ can be inferred. The rest of the ^{26}Al-bearing inclusions are found to have lower, yet nonzero, ^{26}Al/^{27}Al ratios and more positive Δ^{26}Mg$_0^*$ compared to those in the aforementioned two main populations. Such an ^{26}Al/^{27}Al–Δ^{26}Mg$_0^*$ relationship can be best understood in the context of post-formation thermal processing, similar to that suggested to account for the ^{26}Al/^{27}Al differences between pristine (unmelted) and thermally reprocessed (igneous) CV3 CAIs [e.g., 5]. In this context, inclusions having ^{26}Al/^{27}Al = 5.4×10^{-5} and Δ^{26}Mg$_0^*$ = −0.14‰ could be considered the most pristine among those analyzed here and should most faithfully record the isotopic signatures of their formation region. A major thermal event appears to have occurred to reset the majority of inclusions when ^{26}Al/^{27}Al = 4.9×10^{-5}, i.e., ~10^5 years after initial formation. It is worth noting that ^{26}Al/^{27}Al = 4.9×10^{-5} has been registered not only by the CO3 inclusions, but also by many CM2 and CV3 CAIs [2,5,7–8], implying that such thermal processing was widespread in the regions where refractory inclusions resided or formed.

The ^{26}Al/^{27}Al = 5.40 (±0.13)×10^{-5} ratio inferred from multiple small CAIs also suggests <50,000 years (deduced from the error of ^{26}Al/^{27}Al, which corresponds to ±25,000 years) for the formation of refractory inclusions several tens of μm in size by accretion of μm-sized dust. Centimeter-sized CAIs would have started to emerge during the late period of this coagulation stage and formed in abundance ~40,000 years after the majority of 30−100 μm-sized inclusions appeared in the nebula. This timescale is consistent with that predicted by a recent astrophysical model, which couples CAI formation to the physics of material infall and disk building [9].

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