REASSESSMENT OF THE HETEROGENEITY OF ALUMINUM-26 IN THE SOLAR NEBULA. E. T. Dunham[1], S. J. Desch[1], M. Wadhwa[1], and D. L. Schrader[1], [1]Arizona State University, School of Earth and Space Exploration, Tempe AZ 85287.

Introduction: Aluminum-26 is a short-lived radionuclide that existed in the early Solar System, but which has since decayed away (to ^{26}Mg with $t_{1/2}$=0.7 Ma [1]). A vital, open question is whether ^{26}Al was homogeneous or heterogeneous in the early Solar System. The answer has implications for the origin of the Solar System, chronometry of Solar System events, and the melting of planetesimals and planetary embryos in the early Solar System.

The first evidence of excess ^{26}Mg due to the in situ decay of ^{26}Al was found in the first-formed Solar System solids, the calcium-rich, aluminum-rich inclusions (CAIs) [2]. Since then, a preponderance of CAIs, including most CV CAIs, have been shown to contain excess ^{26}Mg with uniform inferred initial ^{26}Al/^{27}Al ~ 5×10^{-5}, the "canonical" ratio [3]. One prevailing hypothesis is that ^{26}Al was homogeneously distributed in the early Solar System. This would suggest that ^{26}Al in the early Solar System was inherited from the molecular cloud (with an origin from stellar source(s)), can be applied as a robust chronometer, and was the primary heat source for the melting and differentiation of early-formed rocky bodies. However, some authors have argued that ^{26}Al was distributed heterogeneously [4,5]. Many refractory inclusions apparently have initial ^{26}Al/^{27}Al ratios significantly lower than the canonical value. If ^{26}Al was distributed homogeneously, such low values would require formation or isotopic resetting of the inclusions after parent body accretion. This is not possible in most unequilibrated chondrites and is therefore taken as evidence for heterogeneous ^{26}Al (e.g., [5]). Specifically, this has been taken to imply that the solar nebula initially had a low ^{26}Al abundance, that ^{26}Al was subsequently introduced via a late injection event, and that ^{26}Al cannot easily be used for chronometry.

In this study, we adopt and test the hypothesis of homogeneous ^{26}Al. We assume that low initial ^{26}Al/^{27}Al ratios are due to late formation or resetting. We re-evaluate ^{26}Al–^{26}Mg isotope systematics for corundum (Al_2O_3) grains, corundum-bearing inclusions, and FUN (Fractionation and Unidentified Nuclear effects) CAIs. These refractory inclusions often appear to record non-canonical abundances of ^{26}Al. The hypothesis of homogeneity would be invalidated if we find any inclusion with ^{26}Al/^{27}Al so low that it must have been formed or altered after parent body accretion, but which is in a body that was not substantially heated. Rather than accept previously reported ^{26}Al/^{27}Al values, we have recalculated all isochrons based on data from the literature because: 1) many are model isochrons that are forced through an assumed initial or bulk Solar System composition, an assumption incompatible with late resetting; 2) many are based on just one or two data points, which precludes calculation of the mean square weighted deviation (MSWD); and/or 3) several previously reported isochrons with multiple data points do not report MSWD values, which must be below a certain threshold for the fits to be valid). In re-evaluating and recalculating ^{26}Al–^{26}Mg isochrons based on previously reported data, our goal was to create a self-consistent dataset with uniform selection criteria.

Methods: Our goal is to re-evaluate all the ^{26}Al–^{26}Mg isotope data reported in the previous literature [6-23]. We regressed all the data consistently, using the York method in IsoplotR [24]. Outputs include initial ^{26}Al/^{27}Al, initial δ^{26}Mg*, associated uncertainties, and MSWD. The isochron is valid if MSWD is $< 1 + 2(2/(N-2))^{1/2}$, where the number of data points N must be ≥ 3 [25]. In cases where data appear to be reset, it is desirable to have high enough precision to resolve the y-intercept from the chondritic ^{26}Mg/^{24}Mg ratio. Assuming a valid isochron, we then calculate the time the CAIs were formed or reset based on the inferred initial ^{26}Al/^{27}Al and assuming a canonical value at the time of Solar System formation [26]. We assume that the ^{26}Al–^{26}Mg system would not be reset in inclusions on most unequilibrated (type 3 or lower) chondrite parent bodies, as ^{26}Al–^{26}Mg disturbance generally requires temperatures much higher than those experienced by unequilibrated chondrites [26]. The hypothesis of homogeneous ^{26}Al can be rejected if the upper limit to the initial ^{26}Al/^{27}Al ratio (inferred + 2σ) still implies a formation or resetting age after accretion of their host chondrite parent bodies. The approximate chondrite parent body accretion times (expressed relative to the time of Solar System formation, when ^{26}Al/^{27}Al was its canonical value) are taken from [27]: CV (2.4–3.0 Ma), CM (3.0–4.2 Ma), CO (2.5–2.9 Ma), CR (3.7–4.0 Ma), CI (3.1–4.1 Ma), and OC (2.0–2.2 Ma).

Results: While we plan to re-evaluate previously reported data for all inclusions [6–23] to test the ^{26}Al homogeneity hypothesis, we began with the re-evaluation of data for corundum grains [9,18,27], corundum-bearing CAIs [10,16,19,20,28], and FUN CAIs [6,8,11–15,17,20,23] because many of these refractory inclusions are reported to have lower-than-canonical initial ^{26}Al and have been assumed to be diagnostic of ^{26}Al heterogeneity.

Corundum Grains. Few studies have measured the ^{26}Al–^{26}Mg systematics of these grains [9,18] and only one reported sufficient data to reproduce the isochrons [18]. In the study by [18], 15 of the corundum grains have at least 3 data points each, allowing the regression of ^{26}Al–^{26}Mg isochrons; all 15 grains have robust isochrons and ^{26}Al–^{26}Mg ages (maximum of 2.6 Ma after Solar System formation) less than the CM parent body accretion age (3.0–4.2 Ma [27]).

Corundum-Bearing CAIs. ^{26}Al–^{26}Mg systematics have been reported for 9 corundum-bearing CAIs with 3 or more data points each. It was not possible to access data for Murray CAI F5 [28] but it is reported to have $^{26}Al/^{27}Al=(4.1\pm0.2)\times10^{-5}$ [10], equivalent to a formation time of ~0.2 Ma after the Solar System formed (significantly older than the accretion time for the CM parent body). Seven CAIs (M98-8 [19], Kz1-2 [20], 1344-50, 1769-9-1, UH68-1, 3-9-1, 7-9-1 [10]) have robust regressions and ^{26}Al–^{26}Mg ages less than the accretion ages of their parent bodies. CAI BB-5 [16] is the only questionable sample, as its ^{26}Al–^{26}Mg age is ≥8.7 Ma after Solar System formation while its parent body (CM) accreted before 4.2 Ma.

FUN CAIs. This unique population of CAIs is distinct because of their isotopic anomalies, but they are mineralogically similar to other CAIs. ^{26}Al–^{26}Mg isotope systematics have been previously reported for 23 FUN CAIs [6,8,11–15,17,20,23]. For 7 of these (CG14, B7H10, B7F6, BG82HB1, AL1B-F, 1623-5, 7-792), data could not be accessed to reproduce isochron regressions. Four FUN CAIs (HAL, Kz1-2, C1, and BG82HB8 [11,17,20]) have regressions with unacceptably high MSWD. Ten FUN CAIs (GG#3, DH-H1, 7-404, SP15, STP-1, CMS-1, TE, EK1-4-1, AX2771, and CG-14 [6,8,11–13,15]) have robust isochrons with ^{26}Al–^{26}Mg ages younger than the accretion ages of their parent bodies. There are only 2 CAIs with the potential to invalidate the homogeneity hypothesis: KT-1 from CV NWA 779 [14], and H030 from R chondrite Hughes 030 [23].

Discussion: To invalidate the hypothesis of ^{26}Al homogeneity, we need to find a clear case of a CAI with a robust ^{26}Al–^{26}Mg regression with an age that suggests a formation time later than the accretion age of its parent body. In this study, we have thus far found only three CAIs which could potentially invalidate the hypothesis. Corundum-bearing CAI BB-5 has an ^{26}Al–^{26}Mg age of ≥8.7 Ma. The regression consists of 1 hibonite data point, which is an average of 3 hibonite analyses, and 2 corundum analyses. For this CAI, we find $^{26}Al/^{27}Al=(-1.3\pm2.5)\times10^{-8}$, initial $\delta^{26}Mg^*=6.9\pm1.6$ (2SE, MSWD=0.7). The very high intercept appears to indicate disturbance after ^{26}Al decay. The FUN CAI KT-1 [14] has a ^{26}Al–^{26}Mg isochron corresponding to $^{26}Al/^{27}Al=(-2.2\pm2.2)\times10^{-7}$ and initial $\delta^{26}Mg^*=0.08\pm0.54$ (2SE, MSWD=0.7). Based on the disturbance it apparently experienced [14], KT-1 also does not clearly support ^{26}Al heterogeneity. The FUN CAI H030 [23] is from an R3–6 chondrite, whose parent body is estimated to have an accretion time of ~2.2 Ma after Solar System formation, based only on thermal modeling [27]. H030 has $^{26}Al/^{27}Al=(7\pm1)\times10^{-7}$ and initial $\delta^{26}Mg^*=5.8\pm16.6$ (2SE, MSWD =0.2) which translates to an ^{26}Al–^{26}Mg age of 4.4±0.2 Ma. Conceivably the R chondrite parent body could have accreted this late, although this seems unlikely. However, the chondrite Hughes 030 is a breccia containing distinct lithologies. CAI H030 was found in the type 4 lithology of this meteorite [23], so was very plausibly heated and reset on the R chondrite parent body; therefore, this FUN CAI does not provide clear evidence for heterogeneity or late ^{26}Al injection.

No data for corundum grains, corundum-bearing CAIs, or FUN CAIs re-evaluated here provide strong evidence against the ^{26}Al homogeneity hypothesis. Out of dozens of analyses, only 3 inclusions provide weak evidence. We will continue to examine other inclusions and will report our findings, but so far, we have not found compelling evidence of heterogeneous ^{26}Al in the early Solar System based on the currently available refractory inclusion data.

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