**Thermal metamorphic history of a CAI constrained by high spatial resolution Mg isotopic measurements.**
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**Introduction:** The $^{26}Al$-$^{26}Mg$ decay system offers great potential for unraveling the sequence of events in the early solar system [e.g., 1]. However, widespread application of this system is limited by uncertainty in whether $^{26}Al$ was initially uniformly distributed in the early solar system. Parent body alteration introduces additional complications in the interpretation of Al-Mg studies because of the potential for redistributing Mg by diffusion during thermal metamorphism.

Here we present the results of high spatial resolution Al-Mg isotopic measurements of minerals within a type A CAI (EK1-6-3) from Allende (described in 2, 3). This is an extension of earlier studies in which we presented preliminary Al-Mg measurements and sub-µm scale O isotopic distributions of this object [3]. Here we show that heterogeneous Mg isotopic distributions in an anorthite crystal reflect a history of thermal alteration that has disturbed the original $^{26}Al$-$^{26}Mg$ systematics.

**Experiments:** Mg isotope measurements of fassaite, melilite, and anorthite crystals in EK1-6-3 were performed with the JSC NanoSIMS 50L. A 16 keV $O^-$ primary beam was rastered over ~5µm regions and secondary $^{24}Mg^+$, $^{25}Mg^+$ and $^{26}Mg^+$ ions were measured in multicollection with electron multipliers, while $^{27}Al^+$ ions were detected with a Faraday cup by peak-switching. The measurements were performed with a mass resolving power of ~8000, sufficient to resolve Mg hydride interferences at mass 25 and 26. The integration time for each measurement was determined by the Mg and Al contents of each mineral. The data were corrected for EM dead time and QSA effect [4]. The instrumental mass fractionation and Al/Mg sensitivity factors were calibrated by terrestrial hibonite with known Mg isotope ratio, labradorite, augite and melilite (Åk50) glass standards.

**Results:** Al-Mg compositions of fassaite and melilite are shown in Fig 1a. The data for fassaite and melilite lie within errors on a straight line with an inferred initial $^{26}Al/^{27}Al$ ratio of $(5.8 \pm 2.4)$ $(2\sigma)$ x $10^{-5}$, equal to the canonical value. The analyses of anorthite are shown in Fig 1b. The $(^{26}Al/^{27}Al)_0$ for the anorthite scatters between 1.8 x $10^{-5}$ and 3.3 x $10^{-6}$.

We found that the $\delta^{26}Mg$ value of the anorthite grain varied with distance from its core. Figure 2 shows the $\delta^{26}Mg$ value measured at points spaced ~15µm apart from core to rim of the anorthite grain (80-100µm). These data suggest that the Mg isotopic composition of the anorthite grain has been affected by diffusion, as discussed below.

**Discussion:** The large difference in the inferred $(^{26}Al/^{27}Al)_0$ values determined for the fassaite/melilite and the anorthite appear to show a difference in their formation ages of at least 1 Ma. Further, the varying

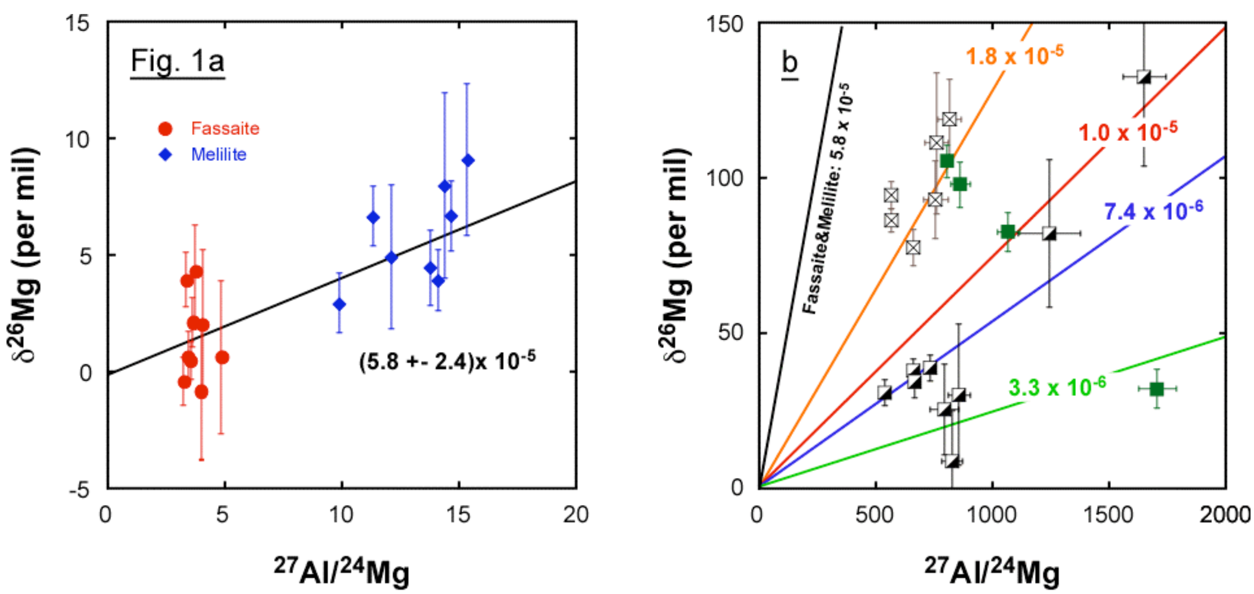


Fig 1. Al-Mg evolution diagram for EK1-6-3, a) melilite and fassaite and b) anorthite.

($^{26}Al/^{27}Al)_0$ values obtained within the anorthite imply an additional 2 Ma time interval for its formation after the fassaite and melilite were crystallized.

It is possible that the $^{26}Mg^*$ heterogeneity is not due to differing formation times, but rather resulted from Mg diffusion during parent body thermal metamorphism. We modeled the Mg isotopic evolution of the (80 μm) anorthite grain, assuming that it was initially homogeneously enriched in $\delta^{26}Mg$ = +200 per mil ($^{26}Al/^{27}Al = 5 \times 10^{-5}$ and $Al/^{24}Mg = 560$), and experienced a temperature of 600˚C in its parent body [5, 6]. We find that the $^{26}Mg^*$ in the anorthite would partially homogenize with the adjacent fassaite grain and decrease by a factor of ~2 in the anorthite grain after 0.6-0.8Ma (Fig. 2), in good agreement with the observed $^{26}Mg^*$ distribution. The time scale at 450˚C increases to ~ $10^3$Ma.

We calculated a numerical model of the evolution of the $^{26}Mg^*$ and Al/Mg ratio in anorthite affected by Mg diffusion kinetics in both directions (Fig. 3). Possible ranges of $^{26}Al/^{27}Al$ for certain time periods, 0.1, 0.5 and 1Ma, are shown in Fig. 3. The range for each bold-solid line represents the spatial heterogeneity toward to crystal boundary from 20μm depth to its core. If the anorthite was annealed at 600˚C for 1Ma, the $^{26}Al/^{27}Al$ slope will decrease to the observed values of ~$0.3\text{-}0.6 \times 10^{-5}$ from a canonical one. Thus Mg diffusion may be responsible for the apparent ($^{26}Al/^{27}Al)_0$ heterogeneity within the crystal, corresponding to 2-3Ma formation interval according to a chronological interpretation.

Thermal resetting is clearly important for interpreting the microscale distribution of $^{26}Mg^*$ in anorthite. This process may also affect other minerals, such as melilite, fassaite and spinel. The extent of Mg redistribution in refractory inclusions is expected to vary considerably with the grain size, geometry and composition of its mineral assemblages and the conditions of parent body alteration. Higher precision (sub per mil level) Mg isotopic measurements of low Al/Mg phases, melilite, fassaite and spinel may be required to fully resolve the formation and alteration histories of these objects.

**References:** [1] MacPherson G.J. et al. 1995. *Meteoritics* 30:365-377. [2] Ito M. and Messenger S. 2007. *Meteoritics & Planet. Sci.*, 42:A74. [3] Ito M. and Messenger S. 2007. 38th *LPS*, Abstract#1794. [4] Slodzian G. et al. 2004. *Applied Surface Science* 231-232:874-877. [5] LaTourrette T. and Wasserburg G.J. 1998. *EPSL* 158:19-108. [6] Ito M. and Ganguly J. *Meteoritics & Planet. Sci.* 39:1911-1919.

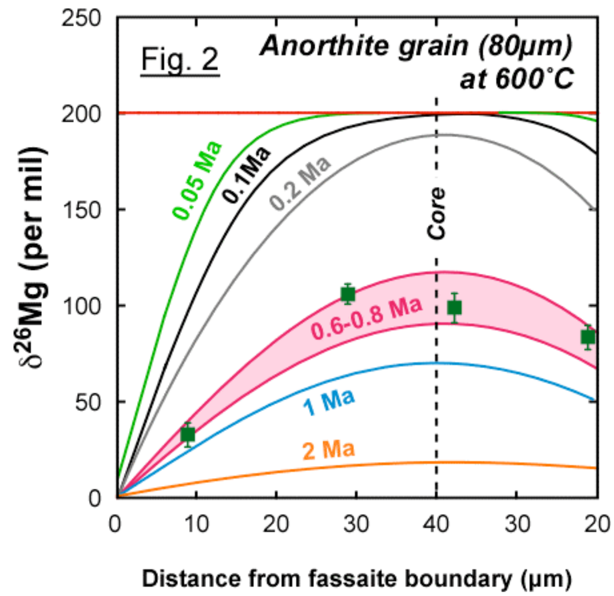


Fig 2. Numerical solutions to the initial $\delta^{26}Mg$ excess in anorthite using the Crank and Nicolson finite-difference technique. Curves indicate the $\delta^{26}Mg$ distributions as a function of distance at certain time intervals during metamorphic process.

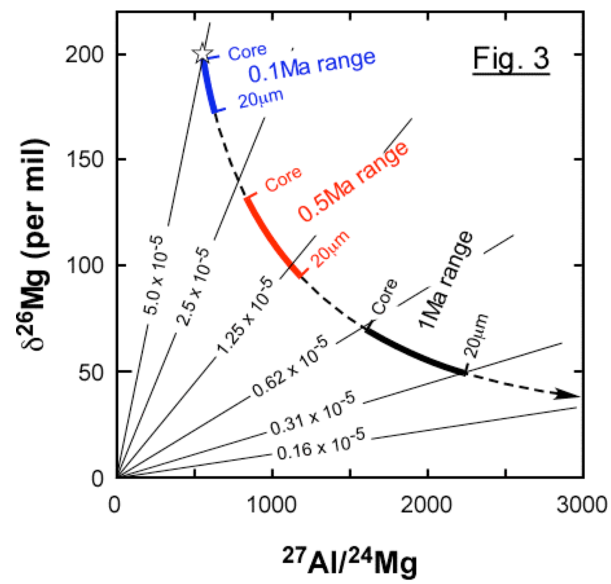


Fig 3. Al-Mg evolution diagram for 80μm anorthite grain calculated from Fig. 2. Dashed-line represents an Al/Mg evolution curve. Bold solid lines for 0.1, 0.5, and 1Ma represent a calculated range within a crystal during annealing. Thin solid lines represent different $^{26}Al/^{27}Al$ slopes at certain time periods corresponding to the half-life of $^{26}Al$ (0.72Ma).