HIGH RESOLUTION ^{26}Al CHRONOLOGY: RESOLVED TIME INTERVAL BETWEEN RIM AND INTERIOR OF A HIGHLY FRACTIONATED COMPACT TYPE A CAI FROM EFREMOVKA.

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Introduction: The Al-Mg chronometer (decay of ^{26}Al to ^{26}Mg with a half-life of ~0.73 Ma) has proven to be extremely useful in establishing the relative ages of the earliest-forming solar system objects [1], if one can safely assume that ^{26}Al was homogeneously distributed throughout the early solar system. Given the proper set of conditions, this short-lived radionuclide can also be used to establish an internal relative chronology of a single object by investigating the initial ^{26}Al/^{27}Al in different petrographic components within that object. CAIs that formed early enough to contain live ^{26}Al and then later experienced high-temperature event(s) leading to Wark-Lovering rim formation before the complete decay of ^{26}Al may meet this requirement. As reported previously in [2], we have identified an unusual compact type A CAI from Efremovka that contains highly fractionated Mg in the interior, in the same range as FUN inclusions, and unfractionated Mg in the rim. Two separate well-correlated internal Al-Mg evolution isochrons have been obtained for the interior and the rim, yielding a high-resolution chronology for the formation of the interior followed by the later formation of the Wark-Lovering rim.

Sample description: Efremovka E44L is a ~2 mm × 1 mm compact type A CAI composed of melilite, spinel, hibonite and minor perovskite. The melilite has an igneous texture and ranges from ~$Åk_{31}$ in the interior to $Åk_5$ near the rim. Spinel occurs as subhedral to euhedral grains 10-50 µm in size, heterogeneously enclosed in melilite. Small (~2-5 µm) anhedral grains of hibonite are scattered throughout the inclusion, with the largest concentration of hibonite found near and within the Wark-Lovering rim. The rim ranges from 50–150 µm across and consists (1) an innermost layer of intergrown clumps of hibonite and spinel with minor perovskite, 50-80 µm thick, (2) a thin (~10 µm) layer of highly gehlinitic melilite, followed by (3) a thick outermost layer of diopside which varies in thickness from 10 to 70 µm.

Analytical methods: Mg and O isotope compositions were measured on the UCLA Cameca ims 1270 ion microprobe. Mg data were obtained using a multi-collector method that allows determination of Δ^{26}Mg* with a high precision (better than 0.1‰) in mineral phases with low Al/Mg ratios. Spot size was approx. 20 µm. All Mg isotope data have been normalized to the DSM3 standard [2] by correcting for instrumental mass fractionation using terrestrial standards (Burma spinel, Madagascar hibonite and pyroxene glass). Oxygen isotope data were collected with the Cameca ims 1270 operated in monocollection mode with a spot size less than 15 µm.

Mg Isotopes: E44L was analyzed in two separate sessions, two months apart, with the data in good agreement between the two sessions. A total of 22 spots were measured, 11 in the interior of the inclusion and 11 in the rim. The interior spots included 6 of the largest spinel grains, 3 melilite points, and 2 fassaite points. Four spots located in the rim area are situated in the outer diopside layer, with 2 spots not containing overlap with any other phases (Fig.1). One rim point is located in a region consisting entirely of hibonite and yielded a relatively high Al/Mg ratio of 14.5.

Mineral phases in the interior of E44L contain fractionated Mg favoring the heavy isotopes, on the order of 14-16‰ per amu, consistent with Mg fractionation seen in most FUN inclusions. Rim phases do not contain isotopically heavy Mg, with δ^{25}Mg ranging only from -2 to 0.2‰ per amu.

An exponential mass fractionation law was assumed when calculating excess ^{26}Mg*. In the preliminary Mg isotopic data for E44L reported in [2], we did not distinguish between mass fractionation due to equilibrium or kinetically controlled processes, but used a fractionation law (β= 0.515) obtained from ionprobe analyses of terrestrial standards. This method assumes that the processes causing the mass fractionation in the CAI were the same as in the terrestrial standards, and resulted in a fairly high initial ^{26}Al/^{27}Al ratio of over 7×10^{-5}. In order to obtain a lower bound on initial ^{26}Al/^{27}Al, excess ^{26}Mg* has been recalculated using kinetic fractionation (β= 0.511).

The excess ^{26}Mg* is very well correlated with ^{27}Al/^{24}Mg ratios for all phases (except melilite) in both the interior and the rim of E44L, as long as these two distinct petrographic regions are considered as separate isotopic systems. Spinel and fassaite data from the interior, measured on both analysis days, define an isochron with a slope corresponding to an initial ^{26}Al/^{27}Al ratio of 6.41×10^{-5}, intercept = 0.029‰, which is within error of 0. If the fit is forced through the origin, the initial ^{26}Al/^{27}Al changes slightly to $(6.56 \pm 0.14) \times 10^{-5}$ (2σ) with a reduced χ^2 for this fit of 1.7. A best-fit to the rim phases yields an isochron with an initial ^{26}Al/^{27}Al of $(4.9 \pm 0.2) \times 10^{-5}$, intercept of 0.04, also very close to zero (reduced χ^2 = 2.3) (Fig. 2).

Oxygen Isotopes: O isotopes were measured in the interior (spinel and melilite) and the rim (diopside and spinel) of E44L. The interior melilite and spinel, as well as diopside from the rim, are slightly displaced to the right of CCAM line by ~5‰ (Fig. 3). However, all O isotopes from the spinels found in the rim (except for one) lie on the CCAM line. Data from two spinel grains from E44, a non-FUN inclusion located in the same thin section as E44-L, were also obtained, and plot on the CCAM line.

Implications: The difference in initial $^{26}Al/^{27}Al$ ratios inferred from the two separate isochrons implies a relative time interval of ~300,000 years between the last heating event affecting the interior of E44L and the high-temperature (possibly flash heating) event [4] resulting in the creation of the Wark-Lovering rim. The high initial $^{26}Al/^{27}Al$ for the interior of E44L is somewhat above the classical canonical ratio of 5.0×10^{-5}, in agreement with suggestions [5-7] for a new solar system initial ^{26}Al based on ICPMS analyses. The oxygen isotopes indicate that E44L has some affinity for a FUN inclusion, but we have not measured nuclear effects in this CAI to make this more definitive.

References: [1] Lee T. and Papanastassiou D.A. (1974) *GRL, 3,* 225-228. [2] Taylor et al., (2004) *Chondrites and the Protoplanetary Disk,* p.197. [3] Galy et al. (2003) *J Anal. At. Spectrom., 18,* 1352-1356. [4] Wark D. and Boynton W. (2001) *MAPS, 36,* 1135-1166. [5] Galy et al. (2004) *LPS XXXV,* #1790 [5] Simon J. et al., (2004) *LPSC* XXXV, #1668. [6] Liu M.-C. et al., (2004) *Workshop on Chondrites and Protoplanetary Disk,* Abstract #9099.

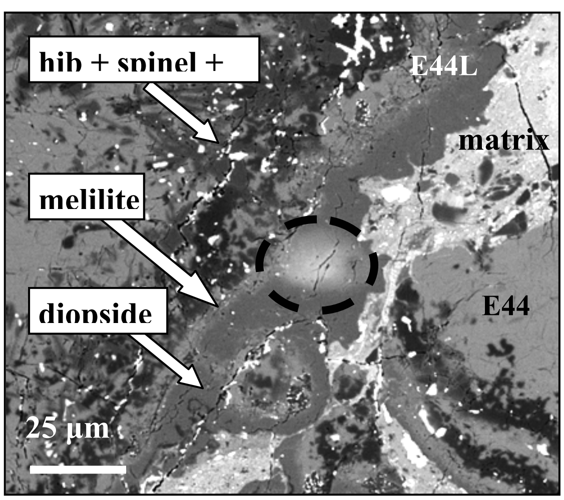

Fig. 1. Rim layer sequence (hibonite + spinel, melilite and diopside). Ionprobe spot lies completely within the rim diopside.

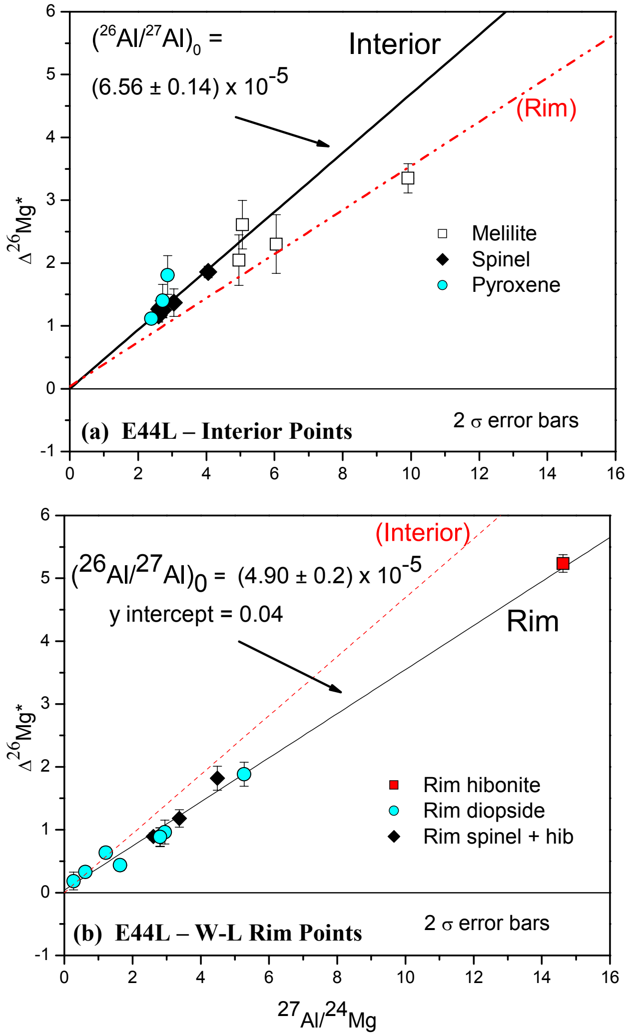

Fig 2(a,b). Al-Mg evolution diagrams for E44L **(a)** Data from the interior points. **(b)** Data from the W-L rim.

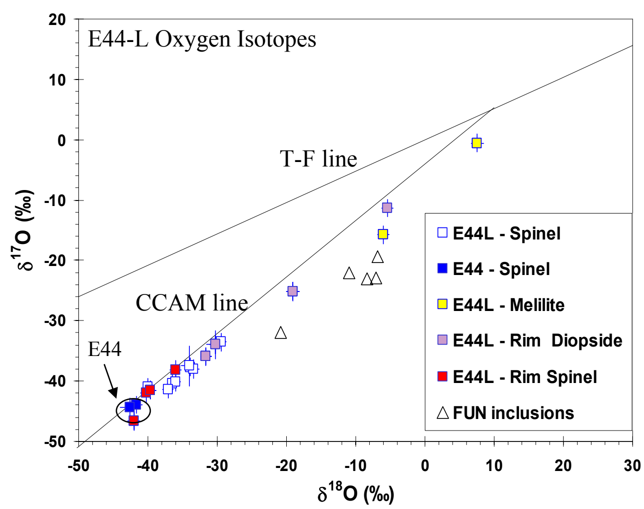

Fig. 3. Oxygen isotopes for spinel, melilite, rim diopside and rim spinel in E44L. Five typical FUN inclusions are shown for comparison. Two spinel spots from E44 are also plotted.