

SUPRA-CANONICAL $^{26}\text{Al}/^{27}\text{Al}$ RATIOS IN AN UNALTERED ALLENDE CAI. M.-C. Liu¹, Y. Iizuka², K. D. McKeegan¹, E. Tonui¹ and E. D. Young^{1,3} ¹Dept. of Earth and Space Sciences, UCLA (mcliu@ess.ucla.edu) ²Inst. Earth Sciences, Academia Sinica, Taipei, Taiwan, ³Inst. Geophys. and Planetary Phys., UCLA.

Introduction: Mg isotope distributions contain clues for the formation environments and thermal histories of CAIs both in terms of mass-dependent fractionation and radiogenic $^{26}\text{Mg}^*$. Among the major constituents in CAIs, melilite and anorthite are especially susceptible to isotopic disturbance through interactions with surrounding minerals and mineral alteration during thermal processing. As a consequence, the original isotope signals and implied initial $^{26}\text{Al}/^{27}\text{Al}$ ratios are not necessarily preserved. Due to the rarity of unaltered melilite in most Allende inclusions, supra-canonical $^{26}\text{Al}/^{27}\text{Al}$ initial ratios (~ 6 to 7×10^{-5}) [1, 2, 3] may be difficult to find. Analyzing whole inclusions, Bizzarro et al. [4] suggested all CAIs have a single canonical ratio of 5.2×10^{-5} and formed contemporaneously within the first 50,000 years of the solar system, in contrast to previous studies [1, 2, 3]. Here we present data for two inclusions from Allende that exhibit contrasting levels of preservation of initial $^{26}\text{Al}/^{27}\text{Al}$ signals.

Allende MC-1: Mg isotope systematics for this type B CAI were previously investigated by both UV laser ablation MC-ICPMS (LA-ICPMS) and secondary ionization mass spectrometry (SIMS) at UCLA [5]. The Mg mass fractionation in MC-1, determined by LA-ICPMS which provides accurate analyses without complications of potential matrix effects, shows a marked decrease at the periphery of the CAI, indicating exchange of Mg isotopes with an external reservoir (Fig 1). The low Al/Mg of this sample makes the derived $(^{26}\text{Al}/^{27}\text{Al})_0$ sensitive to fractionation law. When the data are corrected using a kinetic (slope=0.511) mass fractionation law, radiogenic Mg ($\Delta^{26}\text{Mg}^*$) is found to be near canonical levels. The agreement between the methods is good (Fig. 2) with inferred $(^{26}\text{Al}/^{27}\text{Al})_0 \sim 5 \times 10^{-5}$. However, the melilites in the inclusion are clearly disturbed as evidenced by departures from a simple isochron.

Allende USNM-3712B: Allende USNM-3712B is a type B1 CAI with a melilite mantle and Ti-pyroxene, melilite and spinel interior (Fig. 3). Unlike usual melilite in Allende inclusions showing milky white color, most melilite crystals in this CAI are transparent, which may suggest that they could be less disturbed. Blocky melilite in the interior shows no signs of secondary alteration. Anorthite is absent in this CAI fragment. More detailed study of chemical composition has been shown in [6].

As with most Type B CAIs, Mg in USNM-3712B is mass fractionated with $\delta^{25}\text{Mg} \sim 7\text{‰}$ relative to the chondritic (DSM3) value. It's clear that the Mg mass fractionation is quite uniform throughout the CAI (Fig. 1, left). The relatively larger errors in $\delta^{25}\text{Mg}$ are due to the low Mg composition of 3712B-7 melilite (Geh 90). This flat mass fractionation profile contrasts with what we observed in MC-1 (Fig. 1, right). It suggests that, unlike MC-1, 3712B could have achieved closed system behavior with respect to Mg isotopes after evaporation and crystallization.

The melilite in 3712B displays well-resolved $\Delta^{26}\text{Mg}^*$ values that are correlated with Al/Mg (Fig. 2, left). A best fit through all melilite analyzed by LA-MC-ICPMS yields $(^{26}\text{Al}/^{27}\text{Al})_0 = (6.7 \pm 0.7) \times 10^{-5}$ with an intercept within error of zero ($0.09 \pm 0.14\text{‰}$ (All error 1 σ)). Because of the relatively large spread of Al/Mg in melilite, the slope of the apparent isochron is not very sensitive to assumptions regarding the form of the mass fractionation law. We have used a mass fractionation correction appropriate for kinetic processes, such as would dominate during evaporative processes. This approach provides a conservative estimate of $\Delta^{26}\text{Mg}^*$ (and hence $^{26}\text{Al}/^{27}\text{Al}$) since other mass fractionation laws result in steeper slopes on the 3 isotope diagram [2]. According to the comparison between ICPMS studies on two samples, we conclude that supra-canonical ratios can be preserved in melilite as long as the CAIs didn't experience further thermal events that led to open system Mg isotope behavior.

Conclusion and Implication: The result of this study strengthens the case for initial $^{26}\text{Al}/^{27}\text{Al}$ ratios higher than "canonical" values. Both in situ and whole rock analyses suggest that $^{26}\text{Al}/^{27}\text{Al} \sim 6$ to 7×10^{-5} is closer to the true initial value when CAIs were formed. In this case, canonical ratios $\sim 5 \times 10^{-5}$ reflect isotopic redistribution several thousands years after CAI formation. In this view, CAIs were not all formed at the same time and thermal processing of CAIs continued for substantial ($>10^5$ year) durations.

References: [1] Galy A. et al., (2000) *Sciences* 290: 1751-1753. [2] Young E. D. et al., (2001) *GCA* 66: 683-698. [3] Galy A. et al., (2004) *LPSC XXXV*: Abstract #1790. [4] Bizzarro M. et al., (2004) *Nature* 431: 275-278 [5] Liu, M.-C. et al., (2004) *Workshop on Chondrite and Protoplanetary disk*: Abstract #9099. [6] Liu, M.-C. et al., (2002) *MAPS* 35: A88

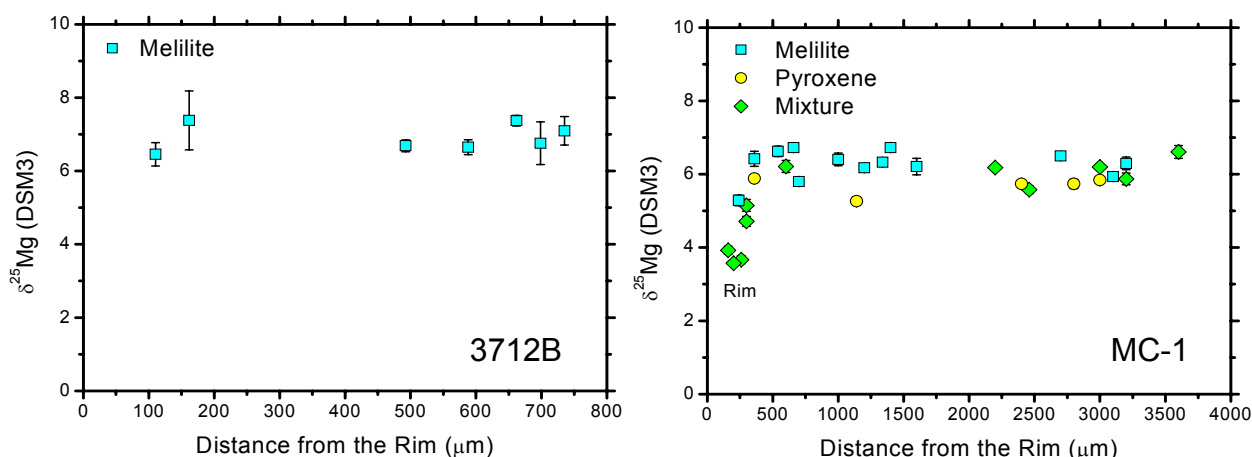


Fig. 1 Left: Mass fractionation vs. distance in 3712B CAI showing a very uniform profile that suggests this CAI could have comprised a closed system with respect to Mg isotopes. Right: Mg mass fractionation as a function of distance in MC-1 CAI along the A-B line shown in Fig. 1 of [5].

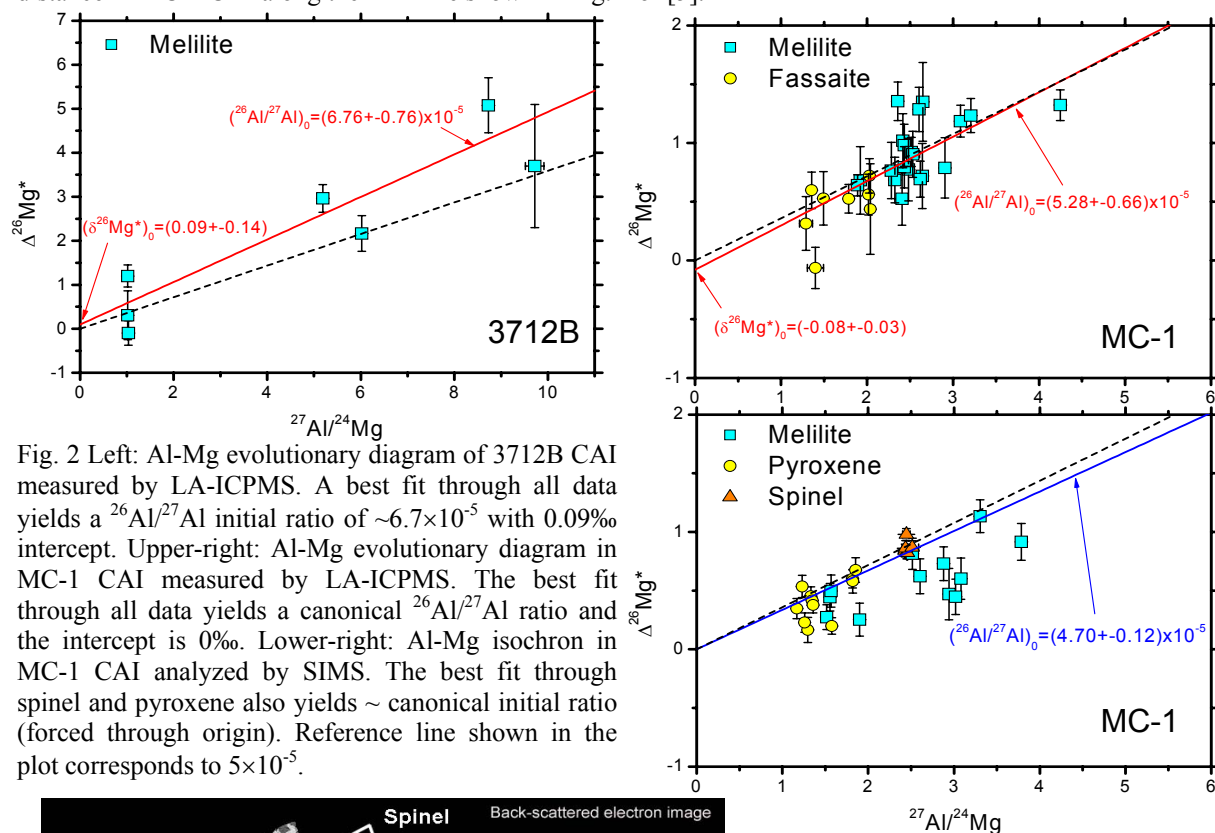


Fig. 2 Left: Al-Mg evolutionary diagram of 3712B CAI measured by LA-ICPMS. A best fit through all data yields a $^{26}\text{Al}/^{27}\text{Al}$ initial ratio of $\sim 6.7 \times 10^{-5}$ with 0.09‰ intercept. Upper-right: Al-Mg evolutionary diagram in MC-1 CAI measured by LA-ICPMS. The best fit through all data yields a canonical $^{26}\text{Al}/^{27}\text{Al}$ ratio and the intercept is 0‰. Lower-right: Al-Mg isochron in MC-1 CAI analyzed by SIMS. The best fit through spinel and pyroxene also yields \sim canonical initial ratio (forced through origin). Reference line shown in the plot corresponds to 5×10^{-5} .

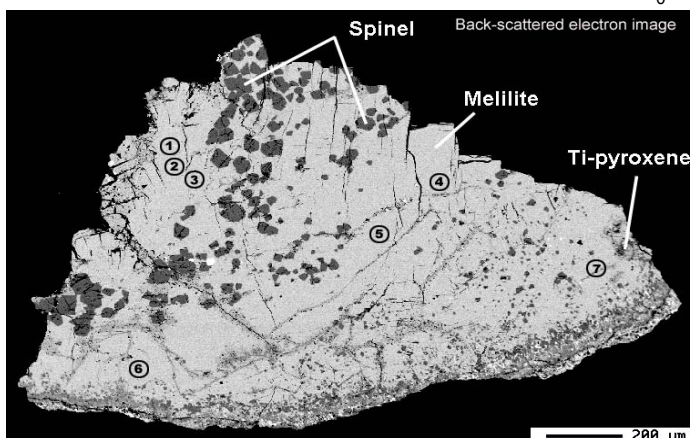


Fig. 3 Back-scattered electron image of Allende USNM-3712B CAI. The main constituents in this sample are melilite and spinel; tiny fassaite (Ti-pyroxene) is shown but anorthite is absent. Numbers indicate locations of LA-ICPMS analyses; spot size was ~ 40 - $55 \mu\text{m}$.