^{26}Al-^{26}Mg SYSTEMATICS OF PLAGIOCLASE IN H4 CHONDRITES: IMPLICATIONS FOR THE H-CHONDRITE PARENT BODY. M. Telus[1], G. R. Huss[1], R. C. Ogliore[1], K. Nagashima[1], [1]HIGP, University of Hawai'i at Mānoa, USA. Email: telus@higp.hawaii.edu.

Introduction: Zinner and Göpel [1] found clear evidence for the former presence of ^{26}Al in H4 chondrites Ste. Marguerite and Forest Vale that gives dates of 5 and 6 Myr after CAIs, respectively. They inferred that the ^{26}Al-^{26}Mg systematics likely date the time when the parent body cooled down to the closure temperature of the Al-Mg system. Plagioclase in H4 meteorites can have low counts of Mg, making them potentially susceptible to positive ratio bias. Also, Zinner and Göpel [1] used the mean of the ratios to reduce their Al-Mg data, a method that enhances ratio bias [2-3]. We reanalyzed the Al and Mg isotopic composition of plagioclase in H4 chondrites to evaluate the possible influence of ratio bias on the initial ^{26}Al/^{27}Al ratios and to evaluate how ^{26}Al-^{26}Mg systematics of H4 chondrites fit into the overall picture of the structure and thermal history of the H-chondrite parent body.

Methods: To get an overview of the composition of plagioclase from each chondrite, we analyzed ~20 plagioclase grains from H4 chondrites, Ste. Marguerite, Forest Vale, Beaver Creek and Sena, using the electron probe at the University of Hawai'i. Aluminum-Mg isotope analyses of plagioclase were collected in mono-collection mode using the Cameca ims 1280 ion microprobe at UH. The mass resolving power was set to ~3900, which resolves molecular interferences. Data were collected over 150 to 275 cycles through the masses to permit time interpolation of the data. Olivine, pyroxene and Cr-spinel were measured to constrain the intercept of the isochrons. Standards were measured to monitor drift in the detectors and to determine the Al-Mg relative sensitivity factors.

The data were corrected for background and deadtime in the EM, and also for instrumental mass fractionation. The isotope ratios reported here were calculated from the total counts acquired for each isotope during each measurement, a less-biased method for determining isotope ratios [2]. Ratios were also calculated using the mean of the ratios to compare the magnitude of the ratio bias on the results. Biased ratios combined with an internal mass fractionation correction using ^{25}Mg/^{24}Mg, result in lower ^{26}Mg/^{24}Mg ratios and a lower inferred initial ^{26}Al/^{27}Al ratio [3]. Uncertainties on the measured ratios were determined using the standard error of the ratios calculated from individual cycles, which allows us to account for non-statistical cycle-to-cycle variations during the measurement. Uncertainties on the isochron slopes are 2σ.

Results: Stoichiometry determined from electron probe measurements shows that the grains we analyzed are feldspar and not glass. Plagioclase in Ste. Marguerite and Forest Vale are mainly found within chondrules. They are bimodal in composition. Most grains are between An_{10-15}, but some are $>An_{50}$. Plagioclase from Beaver Creek and Sena are commonly associated with isolated aggregates of olivine, metal and sulfide. They have a uniform composition of An_{12}.

Our isotope analyses are consistent with those previously reported by [1], indicating that ratio bias is not significant in these Al-Mg datasets. ^{24}Mg counts per cycle in our plagioclase measurements range from 5000 to 20,000. The magnitude of the ratio bias from averaging the ratios (the inverse of the counts per cycle of ^{24}Mg) is less than 0.2‰, insignificant compared to the uncertainties on ^{26}Mg/^{24}Mg (~4‰). Using total counts reduces the ratio bias to less than 1 ppm.

We inferred $(^{26}Al/^{27}Al)_0$ ratios of $(3.0\pm0.5)\times10^{-7}$, $(1.5\pm0.7)\times10^{-7}$, and $(0.9\pm0.7)\times10^{-7}$ for Ste. Marguerite, Forest Vale, and Beaver Creek, respectively. These initial ratios correspond to 5.2 (+0.16/-0.19), 5.9 (+0.6/-0.4), and 6.5 (+1.7/-0.6) Myr after formation of CAIs with the canonical ^{26}Al/^{27}Al ratio. Sena does not show evidence for the former presence of ^{26}Al. It has an $(^{26}Al/^{27}Al)_0$ ratio of $<0.3\times10^{-7}$ (2σ-upper limit), consistent with results for Quenggouk [1].

Discussion: The Na-rich plagioclase in H4 chondrites is of secondary origin [4]. The anorthitic plagioclase originally crystallized from the chondrule melt, but the high Al/Mg ratios (>1000) compared to anorthite in type 3 ordinary chondrites indicates that the Mg in these grains has been redistributed by metamorphism [e.g., 1]. The thermal conditions necessary to preserve radiogenic ^{26}Mg in anorthite are described by [5]. The well-behaved isochron of Ste. Marguerite indicates that this chondrite experienced sufficiently high temperatures (between 550 and 750 °C [5]) to equilibrate the Mg isotopes in plagioclase and that it cooled to below ~450 °C [5], the approximate closure temperature of Mg in anorthite grains, at ~5.2 Myr after CAIs. Isochrons for Forest Vale and Beaver Creek also indicate cooling to below the Al-Mg closure temperature while ^{26}Al was extant. Sena and Quenggouk cooled to below the closure temperature ≥8 Myr after CAIs, after ^{26}Al had decayed. The relative ^{26}Al-^{26}Mg ages of these chondrites are consistent with metallographic studies [e.g. 6], which indicate Ste. Marguerite, Forest Vale and Beaver Creek cooled to below 500 °C at rates of >5,000 to >10,000 °C/Myr, much higher than all other H4 chondrites (including Sena and Quenggouk), which cooled at 10-50 °C/Myr.

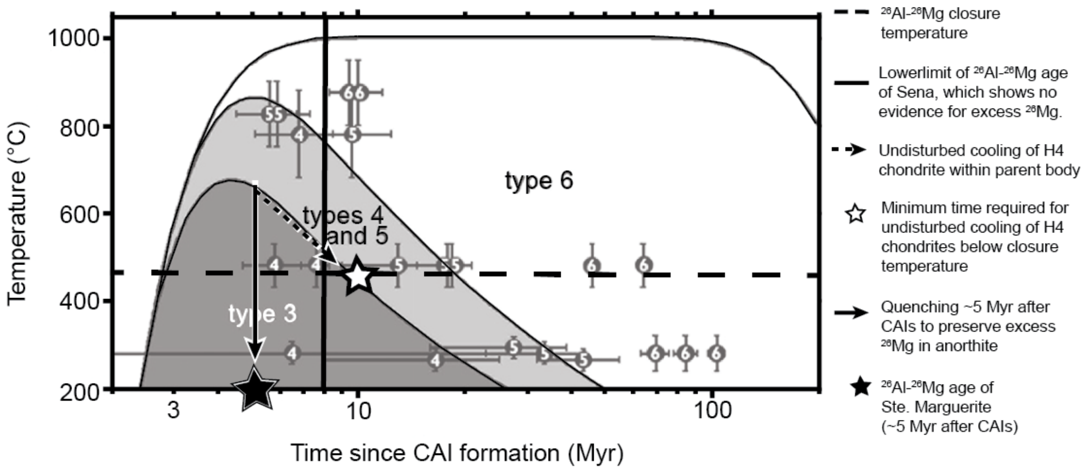

Figure 1. Modified version of Figure 2 from [8], which compared radiometric cooling ages of H-chondrites to calculated time-temperature cooling curves for a ~100 km radius onion-shell structured parent body that accreted 2.2 Myr after CAIs. Cooling of H4 chondrites within the onion-shell parent body requires a minimum of ~10 Myr after CAIs to reach the ^{26}Al-^{26}Mg closure temperature (dashed arrow; white star). The ^{26}Al-^{26}Mg systematics of Sena (solid vertical line) and Quenggouk can be explained by undisturbed cooling within an onion-shell parent body, while Ste. Marguerite (solid arrow; black star), Forest Vale, and Beaver Creek cannot.

The onion-shell model proposes that the H-chondrite parent asteroid cooled, undisturbed by major impacts, forming concentric layers with the most metamorphosed type 6 chondrites at the center of the asteroid and the least metamorphosed type 3 chondrites near the surface [e.g. 7]. Figure 1 shows time-temperature profiles of H chondrites within an onion-shell parent body [8]. In this model, H chondrites accreted 2 Myr after CAIs and H4 chondrites reached a peak temperature of ~700 °C ~5 Myr after CAIs. The slow heat loss that allowed the H4 chondrites to reach ~700 °C means that they would not have cooled below the closure temperature for Mg isotopes in plagioclase until ~10 Myr after CAIs (white star in Fig. 1).

The upper limits on the $(^{26}Al/^{27}Al)_0$ ratios of Sena and Quenggouk indicate that they cooled to below the closure temperature more than 8 Myr after CAIs (solid vertical line in Fig. 1), consistent with undisturbed cooling within an onion-shell body. However, the ^{26}Al-^{26}Mg age of Ste. Marguerite requires cooling to below the closure temperature ~5.2 after CAIs (black star), much shorter than the time required for undisturbed cooling within the parent body. The same is true for Forest Vale and Beaver Creek.

Within the context of the onion-shell model, the ^{26}Al-^{26}Mg systematics of Ste. Marguerite and its rapid metallographic cooling rate of >10,000 °C/Myr suggest that it formed at depth within the parent body, permitting homogenization of Mg in anorthite, but was excavated ~5.2 Myr after CAIs, allowing it to quench (solid vertical arrow) and freeze in the Mg isotopes in anorthite. Forest Vale and Beaver Creek had similar thermal histories. Sena and Quenggouk do not require an early impact excavation because they remained at high temperature until ^{26}Al had decayed.

Conclusions: Ste. Marguerite and Forest Vale are widely used to estimate the cooling history of all H4 chondrites within the H-chondrite parent body [e.g., 7]. However, any rock that cooled undisturbed at the depths and at the cooling rates indicated by the onion-shell model would cool to below the closure temperature of Mg isotopes in plagioclase too slowly to preserve evidence for the former presence of ^{26}Al (Fig. 1). Preservation of ^{26}Mg excess in anorthite and the rapid metallographic cooling rates for Ste. Marguerite, Forest Vale and Beaver Creek indicate that they did not cool within an onion-shell asteroid. Instead ^{26}Al-^{26}Mg systematics of these chondrite date rapid cooling near the surface of the parent-body, likely due to impact excavation of these chondrites.

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