MAGNESIUM ISOTOPE IMAGING OF ANORTHITE FROM ALLENDE CAI WITH THE NANOSIMS 50L ION MICROPROBE. Motoo Ito and Scott Messenger, Robert M. Walker Laboratory for Space Science, ARES, NASA JSC, 2101 NASA parkway, Houston TX 77058, USA. (motoo.ito-1@nasa.gov, scott.r.messenger@nasa.gov).

Introduction: Heterogeneous ^{26}Mg isotopic distributions among coexisting mineral phases in refractory inclusions, such as Ca, Al-rich Inclusions (CAIs), and chondrules, have been reported [1]. Isotopic imaging techniques now enable investigation of isotopic distributions within individual mineral grains [e.g, 2, 3]. Two leading instruments: IMS-1270 with SCAPS [2] and NanoSIMS [3], are capable of approximately 5 ‰ precision and 0.5 μm spatial resolution O isotopic imaging. Isotope imaging within a crystal or of a boundary between different crystals is useful for constraining the thermal histories of these objects.

Here we report the results of a Mg isotopic imaging study of anorthite from an Allende CAI, HN3-1c, utilizing the JSC NanoSIMS 50L ion microprobe. We evaluate the measurement conditions, the instrumental mass fractionation factor, and the precision and accuracy of the isotopic image through the analysis of a Madagascar hibonite standard with known Mg isotopic ratios. To understand the initial ^{26}Al distributions when CAI formed and later re-dstribution of ^{26}Mg during metamorphism, it is desirable to acquire high precision Mg isotope images with sub-micrometer spatial resolution within and among the coexisting mineral phases.

Sample: HN3-1 is a typical coarse-grained Type-B1 CAI from Allende CV3 chondrite. HN3-1c is large (~1cm) and consists of melilite mantle (Åk$_{30-60}$), small spinel grains, anorthite and fassaite [4]. The O isotopic characteristics in those minerals of the CAI show typical O isotope ratios of $\delta^{17,18}$O ~ 0 ‰ for anorthite and melilite, and $\delta^{17,18}$O ~ -40 ‰ for fassaite and spinel [5, 6]. The initial ^{26}Al/^{27}Al ratio for the CAI has been reported to be (3-5)×10^{-5} [7].

Experimental: Al-Mg isotopic measurements were performed with the JSC NanoSIMS 50L ion microprobe. Each of the samples and standards were measured both by spot analysis (5 x 5 μm raster) and by isotopic imaging. In spot analyses, the Mg isotopes were measured in a multi-detection with three different electron multipliers (EMs) while ^{27}Al signal was detected with the adjacent Faraday cup. The sample was coated with a 30 nm Au film to mitigate electrostatic charge on the sample surface. Other measurement conditions were same as our previous work [8].

Terrestrial madagascar hibonite standard with known Mg isotopic ratios (δ^{25}Mg = -5.82 ‰, δ^{26}Mg = -11.36 ‰) was used to correct for instrumental mass fractionation, including the differing sensitivities of EMs. We also determined the $^{27}Al^{+}/^{27}Al^{++}$ sensitivity factors using hibonite (^{27}Al/^{24}Mg = 45.34) and labradorite (^{27}Al/^{24}Mg = 254.67).

We acquired Mg isotopic images of 5 separate areas within the anorthite crystal in the HN3-1c CAI. The images were acquired by rastering a 130-200 pA, 400 nm O- primary ion beam over an area of 15 x 15 μm. Secondary ions of $^{27}Al^{++}$, $^{23}Na^{+}$, $^{24}Mg^{+}$, $^{25}Mg^{+}$, $^{26}Mg^{+}$, and $^{54}Fe^{+}$ were counted with electron multipliers in multidection. Analyses were performed at a mass resolving power of > 8,000, sufficient to resolve Mg hydride interferences from ^{25}Mg and ^{26}Mg. Each imaging run consisted of 30-50 repeated scans acquired over a ~2 hour period. Isotopic images were processed using custom-written software developed in the Interactive Data Language (IDL). Data were corrected for EM dead time (44 ns) and QSA effect following standard procedures.

We determined the reproducibility of δ^{25}Mg, δ^{26}Mg, ^{26}Mg excess and ^{27}Al/^{24}Mg ratios obtained by isotopic imaging by measurements of hibonite and labradorite standards. Images of standards were divided 8 by 8 bins (~2 x 2 μm in a 15 μm field of view) and Mg isotopic ratios, ^{26}Mg excess, and Al/Mg ratios of these 64 bins were calculated. The 1σ precision for ^{27}Al/^{24}Mg ratio was approximately 9.5 %, determined from statistical error of the $^{27}Al^{++}$ and ^{24}Mg intensities and the error of the $^{27}Al^{+}/^{27}Al^{++}$ sensitivity factor. The 1σ uncertainties for δ^{25}Mg, δ^{26}Mg and ^{26}Mg excess were 4.5, 6.0 and 7.5 ‰, respectively. The overall reproducibility of the ^{26}Mg excesses measured in 4 isotopic images of the terrestrial hibonite and labradorite standards were 1.5 and 2.0 ‰, respectively.

Results and Discussion: Isotopic measurements of HN3-1c anorthite performed by spot analysis indicate clear evidence for extinct ^{26}Al. The ^{26}Mg excess corresponds to (^{26}Al/^{27}Al)$_0$ = (3.4 ± 0.4) (2σ) x 10^{-5}, close to the canonical value and good agreement with previous work [8].

Figure 1 shows typical Mg isotopic images of anorthite in the HN3-1c CAI. As we acquired images of all Mg isotopes, Al^{++}, Na and Fe simultaneously, we can readily determine Mg isotopic ratios of micron-size region in the field of view by our image processing software. We observed relatively homogeneous distribution of $\delta^{25}Mg$. In contrast, $\delta^{26}Mg$ was heterogeneous, ranging from 20 to 340 ‰ (Figs 1b and c). Clear evidence of ^{26}Mg excess due to ^{26}Al decay was observed by Mg isotope imaging technique.

We calculated Al-Mg evolution diagram of 2 x 2 µm bins within the Mg isotope images (Fig 1). All bins show ^{26}Mg excesses corresponding to the $(^{26}Al/^{27}Al)_0$ = 3 to 5 x 10^{-5}. The excess ^{26}Mg of these bins is well correlated with the $^{27}Al/^{24}Mg$ ratios for the range of 100-1200 (Fig 2).

Several small Mg-rich grains appear in the Al/Mg ratio image of the anorthite crystal (Fig 1a). Small unresolved inclusions may commonly occur in spot analyses, potentially affecting both isotopic and elemental ratio measurements. We evaluated the effect of these small Mg-rich grains on the isotopic measurements by calculateing the $(^{26}Al/^{27}Al)_0$ values for (1) the entire image (2) the Mg-rich areas ($^{27}Al/^{24}Mg$ = 100-300) and (3) the Al-rich area ($^{27}Al/^{24}Mg$ ~300-1200); (Fig 2). These data fall on a slope of (3.4 ± 0.4) (2σ) x 10^{-5} which is the same value we obtained by spot analysis.

Thermal diffusion of Mg may cause a resetting of the initial distributions of ^{26}Mg excesses in anorthite [9]. Small (tens of µm) anorthite gains are especially susceptible to this effect, as has been observed in some CAIs having low initial $^{26}Al/^{27}Al$ values [e.g., 1, 8]. Yurimoto et al. [10] showed that the disturbed initial $^{26}Al/^{27}Al$ values could be explained by Mg diffusion during thermal metamorphism, assuming an initially canonical $^{26}Al/^{27}Al$ ratio, metamorphic temperature of 400°C and a duration of several Myr.

We evaluated whether the Mg isotopic composition of this CAI was affected by thermal metamorphism by comparing our results with the previously published model [10]. Our data fall within the expected range of values (Fig 2, gray area; 10) resulting from Mg diffusion in anorthite. The heterogeneous distributions of ^{26}Mg excesses we observed at 2 µm scale may be explained by thermal metamorphism.

References: [1] MacPherson G.J. et al. 1995. *Meteoritics* 30:365-377 [2] Nagashima K. et al. 2004. *Workshop on Chondrites and the Protoplanetary Disk* Abstract#9072. [3] Ito M. and Messenger S. 2007. *LPSC* 38:Abstract#1794. [4] Nagahara H. et al. 1987. *LPSC* 18:694-695. [5] Mayeda T.K. et al. 1986. *LPSC* 17:526-527. [6] Yurimoto H. et al. 1994. *EPSL* 128:47-53. [7] Koike O. et al. 1994. *LPSC* 25:725-726. [8] Ito M. and Messenger S. 2007. *MaPS* 42:A74. [9] LaTourrette T. and Wassrberg G.J. *EPSL*. 1998. 158:91-108. [10] Yurimoto H. el al. 2000. *LPSC* 31:Abstract#1593.

Fig 1

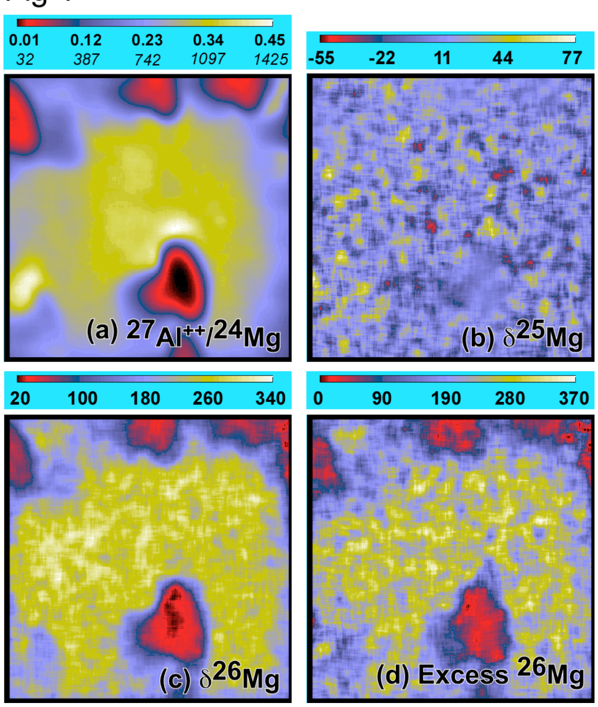

Figure 1.(a) $^{27}Al^{++}/^{24}Mg$ ratio image. *Italic* numbers indicate $^{27}Al/^{24}Mg$ ratio calculated from $^{27}Al^{+}/^{27}Al^{++}$ sensitivity factor (b) $\delta^{25}Mg$ image (c) $\delta^{26}Mg$ image (d) excess ^{26}Mg image calculated from images *b* and *c* using: ^{26}Mg excess = $\delta^{26}Mg - 2 \times \delta^{25}Mg$. Field of view of images are 15 x 15 µm. Image was smoothed by convolving each pixel with a 0.4 x 0.4 µm bin.

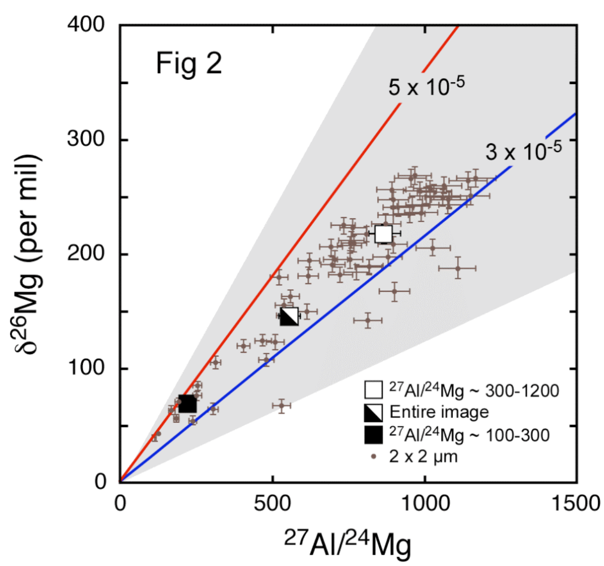

Figure 2. Al-Mg evolution diagram of anorthite in the HN3-1c. Two solid lines represent initial $^{26}Al/^{27}Al$ with 5 x 10^{-5} (upper one) and 3 x 10^{-5} (lower one). Gray area represents the simulated ^{26}Mg re-distributions by diffusion during metamorphism.