MAGNESIUM ISOTOPES IN HIBONITE-BEARING INCLUSIONS FROM CM METEORITES. D. Phinney, Lockheed Electronics Co., Inc., Houston, TX 77058, J.D. Macdougall, Scripps Institution of Oceanography, La Jolla, CA 92093, and B. Whitehead, Dept. of Space Science and Astronomy, Rice Univ., Houston, TX 77001.

Hibonite-bearing refractory element enriched inclusions seem to be characteristic of CM meteorites. They are typically small ($\leq$ 1 mm diam.) and consist predominantly of spinel with variable amounts of blue hibonite (1,2). Most of those which we have examined in detail are rimmed by a thin (few μm) band of diopside. In some cases we have observed discontinuous forsterite zones, also a few μm thick, outside the diopside rims. We have identified generally similar inclusions in the CM meteorites Murchison, Murray, Nogoya, Cold Bokkeveld and Mighei.

A number of features of these inclusions suggest an origin by condensation. Their central regions often consist of delicately intergrown small crystals with considerable void space. Hibonite and spinel, the most abundant components, are expected to be among the earliest phases to condense from a cooling gas of solar composition (3). Subsequent rimming of spinel-hibonite clusters with diopside followed by forsterite is also consistent with a condensation origin. The inclusions are chemically very refractory, with total $Al_2O_3 \geq 60\%$.

In spite of their refractory nature, the CM inclusions are not closely similar to the Allende refractory-rich inclusions which are larger and have been examined in more detail. Two particularly important differences are the paucity of silicates (neither melilite nor anorthite, both important constituents of many Allende inclusions, occur in the inclusions we have examined) and the lack of refractory metal particles. Although all of the phases we have identified in the CM inclusions also occur in Allende inclusions, they are present in very different proportions. These differences suggest differing chemical and/or physical conditions during formation. It is significant that the CM inclusions are considerably different from those in Allende in spite of the continuum of oxygen isotopic compositions observed in CM olivine and pyroxene separates and Allende inclusions.

The possibility that the CM inclusions are early condensates, coupled with the presence of the early-forming, high-Al phase hibonite, led us to consider Mg isotopic analyses in a search for ^{26}Al effects. The small sizes of these inclusions and their constituent grains dictated an isotope-measuring technique with high spatial resolution, and therefore we chose the ion microprobe. Although the Mg content of CM hibonite is relatively high, electron microprobe analyses had indicated considerable variability, with some grains or regions of grains having $^{27}Al/^{24}Mg$ up to $\sim$100. For initial $^{26}Al/^{27}Al$ in the range reported by (4) for an Allende chondrule, such grains would have ^{26}Mg excesses easily observable by ion microprobe techniques. Additionally, (5) had reported large ^{26}Mg excesses for some Allende hibonites with considerably lower $^{27}Al/^{24}Mg$.

In an earlier study of Mg measurements in Murchison inclusions, we reported three experimental findings: (1) Mass Fractionated Mg. One inclusion showed mass-fractionated Mg of up to 10% per mass unit favoring the heavier isotopes. (2) Anomalous $^{26}Mg/^{24}Mg$ ratios. Another inclusion showed larger-than-normal $^{26}Mg/^{24}Mg$ ratios in some samples along with normal $^{25}Mg/^{24}Mg$ ratios. However, this effect did not vary uniformly with $^{27}Al/^{24}Mg$ ratios, thus preventing an unambiguous assignment of the effect to extinct ^{26}Al. (3) Normal Mg. Several inclusions, including one with $^{27}Al/^{24}Mg \simeq 90$, have normal Mg to within ±2%. Normal Mg in inclusions with high $^{27}Al/^{24}Mg$ ratios implies that they were formed either from material with different $^{26}Al/^{24}Mg$ or at a later time relative to those inclusions from Allende with ^{26}Mg excesses corresponding to

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initial $^{26}Al/^{27}Al = 6X10^{-5}$ (4).

Our new results are set out in Table 1. The experimental and data-reduction procedures are given in (6). The results in Table 1 have been corrected for detection-system deadtime and baselines. In addition, the ^{24}Mg peak height was corrected for a $^{48}Ca^{+2}$ interference, based on the mass-22 ($\equiv {}^{44}Ca^{+2}$) peak height, which in all cases amounted to $\leq 0.07\%$ of the mass-24 peak height. Interferences from Ti^{+2} ions and hydrocarbons have been searched for and are below our detection limits. All analyses show a broad peak in the vicinity of mass 24. This peak is a reflection of the $^{27}Al^{+}$ beam from a set of plates ahead of the collector slit in the mass spectrometer, and its effect is satisfactorily removed in the base-line subtraction for mass 24.

The isotopic results in Table 1 have been corrected for instrumental mass discrimination. This correction was obtained from the mean Mg isotopic composition of our working isotopic standard, Madagascar hibonite (MAD HIB). Forty-one analyses (interspersed in time throughout this experiment) of MAD HIB gave the following mean values: $\Delta_{25} = (-0.71\pm0.25)\%$ and $\Delta_{26} = (-1.43\pm0.25)\%$ (normalized to the isotopic composition of (7); uncertainties are $\pm2\sigma_{mean}$). During this experiment the total spread in observed MAD HIB Mg isotopic compositions is $\pm2.01\%$ about these mean values. This range of $\pm2\%$ in Δ_{25} and Δ_{26} from MAD HIB provides a conservative measure of our ability to distinguish between normal and anomalous Mg isotopic compositions, i.e., meteoritic hibonite Δ-values falling outside of this range can be reasonably considered anomalous.

The uncertainties in Table 1 are $\pm2\sigma_{mean}$, based on multiple measurements of each sample. The tabulated $^{27}Al/^{24}Mg$ ratios have not been corrected for the ion-probe Al/Mg relative sensitivity. Preliminary electron-microprobe results for these samples indicate that this relative sensitivity is essentially unity and that the $^{27}Al/^{24}Mg$ ratios in Table 1 are accurate to $\pm20\%$.

Table 1 lists results for hibonite grains from three CM inclusions. We comment on these results as follows.

1) MY6-2. This sample is from Murray. The Mg composition is inside the range observed in the MAD HIB analyses, and the $^{27}Al/^{24}Mg$ ratio is high ($\sim$100). Thus, this is another instance of a sample with large $^{27}Al/^{24}Mg$ and normal (to within 2%) Mg isotopic composition such as we found in our earlier experiment (6).

2) MH96. Some grains from Murchison inclusion MH96 showed significant enhancements of Δ_{26} in our earlier experiment (6). Our purpose for the measurements in Table 1 was to investigate further the relationship between Δ_{26} and $^{27}Al/^{24}Mg$ ratios in other grains from this inclusion. Although the mean Δ_{26} for each of these samples is positive, none lies outside of the range observed in the MAD HIB sample; and there is no significant correlation between Δ_{26} and $^{27}Al/^{24}Mg$ ratios.

3) MH115, 3-2. The three data-sets in Table 1 were obtained on a single spot ($\sim$10 μm in diameter) at the center of this Murchison sample ($\sim$40 μm in diameter). The measurements began with eight consecutive analyses (data-sets 1 and 2). The first five analyses (data-set 1) yielded reasonably stable values for Δ_{25}, Δ_{26}, and $^{27}Al/^{24}Mg$; the corresponding mean values are listed in Table 1. The next three analyses (data-set 2) gave results which were highly variable and did not lie in the ranges defined by data-set 1. These data are listed in Table 1 as ranges, since the average values for this data-set have little meaning. When we discovered these effects during data reduction, we reanalyzed this spot on the grain and obtained the results listed for data-set 3. A simple interpretation of these results is that grain 3-2 of MH115 contains two components, both of which have ^{26}Mg excesses but whose excesses

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differ significantly (~5.5% relative to ^{24}Mg). The large variability in $^{27}Al/^{24}Mg$ ratio is primarily due to changes in Mg concentration. Qualitative SEM-EDX analyses of this grain show large Ti variations on a similar scale. These chemical and isotopic variations strengthen the case made in (6) that Mg isotopic heterogeneity on a micron scale is preserved in some hibonite-bearing inclusions.

Table 1. Mean Mg isotopic compositions and $^{27}Al/^{24}Mg$ ratios for grains from hibonite-bearing inclusions.

Sample	N*	Δ_{25}, ‰†	Δ_{26}, ‰†	$^{27}Al/^{24}Mg$
MY6-2	2	-0.49±.47	-0.61±.25	103±11
MH96:				
Grain 5	8	-0.29±.37	-0.30±.43	31.2±2.9
Grain 6	2	-0.48±.99	1.48±.25	31.5±1.6
Grain 7	2	0.17±1.12	1.91±.86	36.9±5.0
Grain 8	7	-0.17±.43	1.26±.48	49.4±1.2
Grain 9	3	-0.19±.31	0.70±1.38	31.1±0.9
MH115, 3-2				
Data-set 1	5	0.55±.53	7.96±1.29	196.8±8.4
Data-set 2	3	(1.3 to 2.6)	(2.9 to 5.8)	(123 to 158)
Data-set 3	4	0.49±.30	2.37±.65	84.1±3.2

*Number of measurements

†$\Delta_N = 100\left[\frac{N_{Mg/^{24}Mg}}{(N_{Mg/^{24}Mg})_{REF}} - 1\right]$ ‰ where $(N_{Mg/^{24}Mg})_{REF}$ are given in (7).

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