CORRELATED REE AND Mg ANOMALIES IN ALLENDE INCLUSIONS

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We report on Mg isotopes in selected Ca-Al-rich inclusions from Allende. The work was undertaken using a newly completed multi-cup mass spectrometer constructed in the Department of Nuclear Physics, Research School of Physical Sciences in collaboration with the Research School of Earth Sciences at the Australian National University. The instrument consists of a 61-cm radius 180° sector magnet incorporating a thermal ionization ion source and three Faraday cups for simultaneous data collection. Three Keithley model 642 electrometers are held in a temperature controlled environment. The ion source is based on the design developed at Caltech for the Lunatic I and III mass spectrometers. The reproducibility and gain stability of the instrument has been exhaustively tested. The gains of the electrometers have been stable to within the precision of the measurements for over a year. For δ^{26}Mg, for good runs, we obtain a precision of 0.05‰ ($2\sigma_{mean}$) within about 2 hours of starting a run. Repeat analyses on both chemically separated Mg standards and directly loaded crystals show identical δ^{26}Mg. There are no detectable Al interferences in the Mg mass region for samples with high Al content [1]. This significantly enhances the utility of the instrument for Mg measurements as precise and reliable data can be obtained without the need for chemical separation. All data reported in this paper were obtained by direct loading. Details of the instrument will be published elsewhere [2].

The present work was undertaken to search for FUN type inclusions. One of the easier ways of detecting FUN affiliations is to look for isotopic fractionation in Mg. For this purpose, we utilized left over powdered material from Allende inclusions previously used in spark source mass spectrometry for the measurement of trace-element concentrations [3]. From each inclusion a small amount of powder was directly loaded and the measured raw ^{25}Mg/^{24}Mg and ^{26}Mg/^{24}Mg ratios were compared with standards. In this rapid initial survey sufficient data were not obtained to determine δ^{26}Mg with good precision. In Table 1 we have grouped the samples according to their normalized REE abundance patterns as determined by Mason and Taylor [3]. As we demonstrate in a following paper [4], for Mg, we can clearly distinguish naturally fractionated samples from machine produced fractionation down to about 4‰ per amu. Data in Table 1 show that Group II inclusions, with one exception, contain fractionated Mg with values ranging from 4.5‰ to 10‰ per amu. In contrast, Group I, III, V and VI inclusions with the possible exceptions of 3529-46 and 3655A have unfractionated Mg. All of the Group II inclusions, except 4691 (coarse-grained type A), are fine-grained aggregates with relatively high alkali and FeO contents. Grain sizes are ≤ 40 μm; they resemble closely packed aggregation of dust particles and fragmented debris. Furthermore, Group II inclusions show highly fractionated RE distribution pattern characterized by the depletion of the most refractory REE (Er,Lu) as well as anomalies in Eu, Yb and Tm. Combining the isotopic data (Table 1) with REE and mineralogical characteristics we conclude the following: a) there appears to be a direct correlation between the highly fractionated REE patterns of Group II inclusions and Mg isotopic fractionation; b) the fine-grained Group II aggregates have negative values of $\Delta(^{25}\text{Mg}/^{24}\text{Mg})$ corresponding to an enrichment of the lighter Mg isotopes; in contrast, the only coarse-grained Group II inclusion 4691 shows positive fractionation corresponding to an excess in the heavier isotopes. The same complementary pattern exists between the fine-grained inclusions B29, EGG-5 and the coarse-grained inclusions C-1, EK-1-4-1 and EGG-3 [5]. Among these inclusions EK-1-4-1 is known to have a Group II REE pattern. On the basis of simple kinetic considerations, the coarse-grained inclusions could be distillation residues and the fine-grained aggregates the complementary volatile condensates. The regularities observed in the Mg isotopes clearly argue for a generic relationship between the two types. Indeed, Wark and Lovering [6] have demonstrated that the fine-grained aggregates are essentially composed of rim material enclosing the coarse-grained inclusions. In an attempt to explain the correlations between the trace-element data, mineralogy and isotopic data, we consider two plausible models previously proposed to explain some of the characteristics of these inclusions: a) distillation and condensation in the solar nebula [7], or b) as recently proposed by Meeker et al.[8], metamorphism in a small proto-planet. The first model accounts for the correlation between the coarse/fine textures and heavy/light enrichment in Mg isotopes. However, it is not clear whether the distillation process could result in similar REE patterns both in the coarse-grained evaporation residues as well as the complementary volatile condensates. In the second model the correlation between the coarse/fine textures and Mg isotope fractionation is coincidental (assuming the bulk planetoid to have terrestrial Mg isotopic composition). Furthermore, significant refractory element migration from the planetoid material into the inclusion has to preserve the REE patterns common to both the severely metamorphosed inclusions and those that have been altered to a lesser extent. Clearly both models appear to have difficulties in explaining the totality of the observed correlations. In an accompanying paper [4] we present further Mg isotopic data on the Group II Allende inclusions which may shed further light and impose additional constraints on the nature and possibly the origins of these inclusions.

Table 1. Survey for Mg Fractionation in Allende

Sample Group[a]: Name	Fractionation[b] $\Delta(^{25}Mg/^{24}Mg)$‰	$\Delta(^{26}Mg/^{24}Mg)$‰
I: Z	- 1.6	- 3.2
II: 3529-40	-10.1	-19.3
-43	- 4.6	- 9.2
5284	- 4.6	- 9.5
3655-B	- 2.7	- 5.5
4691	+ 4.9	+10.1
5242	- 6.9	-12.6
III: 3529-42	+ 0.5	+ 1.0
-41	- 0.3	- 0.3
-46	- 5.0	-10.2
-0	+ 1.0	+ 2.1
V: 3529-21	- 2.3	+ 1.3
-45[c]	- 5.8	- 2.2
3655A	- 4.1	- 7.2
3682	- 2.7	- 5.5
VI: 3529-44	+ 3.0	+ 7.5
-Y	- 2.3	- 4.7
-47[c]	- 4.0	- 2.0

[a] Classified according to distinct trace-element patterns.

[b] $\Delta(^{25,26}Mg/^{24}Mg)=[(^{25,26}Mg/^{24}Mg)_{meas}/(^{25,26}Mg/^{24}Mg)_{GM}-1]\times10^3$; where GM are the grand mean values $^{25}Mg/^{24}Mg=0.12378$ and $^{26}Mg/^{24}Mg=0.13474$ determined from repeat analyses of normals.

[c] These samples exhibit significant non-linear effects possibly due to ^{26}Al decay.

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