

MG ISOTOPIC SYSTEMATICS IN EURITES: IMPLICATIONS FOR THE ^{26}Al - ^{26}Mg CHRONOMETER. M. Wadhwa¹, C. N. Foley¹, P. E., Janney¹, and L. Spivak-Birndorf², ¹Isotope Geochemistry Laboratory, Department of Geology, The Field Museum, 1400 S. Lake Shore Dr., Chicago, IL 60605, ²Department of Geophysical Sciences, The University of Chicago, Chicago, IL 60637.

Introduction: The applicability of the ^{26}Al - ^{26}Mg system (half-life ~ 0.74 Ma) towards obtaining a high-resolution chronology of early solar system events has been debated for over two decades (e.g., [1] and references therein). Additionally, ^{26}Al has long been suggested as a potential heat source for melting and differentiation of planetesimals in the early solar system [2]. However, it was only recently that definitive evidence for its presence was found in a differentiated meteorite, the Piplia Kalan eucrite, in which the $^{26}\text{Al}/^{27}\text{Al}$ ratio was inferred to be $(1.6 \pm 0.6) \times 10^{-6}$ [3]. Subsequently, evidence for live ^{26}Al has been reported in only two other eucrites ($^{26}\text{Al}/^{27}\text{Al} \sim 1.2 \times 10^{-6}$) [4,5] and two angrites ($^{26}\text{Al}/^{27}\text{Al} \sim 2 \times 10^{-7}$) [6]. While some recent studies provide support for the viability of the ^{26}Al - ^{26}Mg chronometer for age dating early solar system events (e.g., [7,8]), others cast doubt on the significance of ^{26}Al as a heat source for planetesimal differentiation as well on its applicability as a chronometer (e.g., [9]).

We are investigating Mg isotopic systematics in differentiated meteorites with the goals of (1) constraining the initial ^{26}Al distribution in these meteorites towards better understanding the role of this short-lived radionuclide in the differentiation of planetesimals, and (2) determining the applicability of the ^{26}Al - ^{26}Mg system as a high resolution chronometer for early solar system events. Towards addressing these goals, last year we reported preliminary results of high precision Mg isotopic measurements of pyroxene and plagioclase separates from the Juvinas eucrite [10,11]. Here we report results of additional analyses of mineral separates and whole-rocks of the eucrites Juvinas, Ibitira and Asuka 881394.

Analytical Techniques: A summary of our sample preparation, chemical separation and mass spectrometric techniques for high precision Mg isotopic analyses is given in [10]. To prepare the mineral separates, bulk samples (typically ~ 100 mg) were crushed in a boron carbide mortar. After sieving, pyroxene and plagioclase separates were obtained from different size fractions using a Frantz magnetic separator, followed by hand-picking. Mineral separates were washed in ultra-clean water, dried and weighed; subsequently, they were dissolved by treatment with an HF/HNO₃ mixture. The whole-rock samples comprised of interior chips (~ 50 - 100

mg), free of fusion crust, which were washed in ultra-clean water, dried and weighed. The chips were subsequently crushed in a boron carbide mortar and dissolved in HF/HNO₃.

A 5–10% aliquot of each mineral separate or whole-rock solution was taken for measurement of $^{27}\text{Al}/^{24}\text{Mg}$ ratios. Mg was separated from aliquots of the remaining solutions using cation exchange column chemistry. Only a single column treatment was necessary for whole-rocks and pyroxenes, but for the plagioclases two column treatments were required to obtain adequate removal of Al and Ca from the Mg. In all cases, $>98\%$ of the Mg was recovered. Total procedural blanks for Mg are ~ 1 ng and are insignificant.

The clean Mg obtained from each mineral separate and whole-rock sample was diluted in 3% nitric acid to a concentration of 1 ppm and analyzed with the GV Instruments IsoProbe multicollector ICPMS in the Isotope Geochemistry Laboratory at The Field Museum. Sample solution was introduced into the plasma through a CETAC Aridus desolvating MCN. The array of 9 Faraday collectors allows simultaneous collection of ^{24}Mg , ^{25}Mg , ^{26}Mg and ^{27}Al . Our analytical protocol consists of alternating between standard (NIST SRM 980) and sample solutions. Each reported data point (Figs. 1 and 2) typically comprises at least five sample-standard brackets. Our long-term reproducibility (2σ) for Mg isotopic analyses is $\sim 0.06\text{\textperthousand amu}^{-1}$; 2σ reproducibility for $\Delta^{26}\text{Mg}$ (defined as the deviations in permil in the $^{26}\text{Mg}/^{24}\text{Mg}$ ratio from the terrestrial mass-dependent fractionation line) is typically $\leq 0.06\text{\textperthousand}$.

Recently, we documented variations in the isotopic composition of the NIST SRM 980 of up to $\sim 4\text{\textperthousand amu}^{-1}$ [12]. Therefore, our $\delta^{25}\text{Mg}$ and $\delta^{26}\text{Mg}$ values are relative to a single batch of the NIST Mg standard solution prepared in our laboratory (SRM 980_CH#1 [12]). Since the observed heterogeneity in SRM 980 is strictly mass-dependent, the reported $\Delta^{26}\text{Mg}$ values are unaffected by such variability.

Results and Discussion: On average, the mass-dependent fractionation in the Mg isotopic compositions of whole-rocks and mineral separates of the three eucrites investigated is $\sim 2.4\text{\textperthousand amu}^{-1}$ relative to SRM 980_CH#1 (with a total variability of $\leq 0.3\text{\textperthousand amu}^{-1}$).

Figures 1 and 2 show $\Delta^{26}\text{Mg}$ vs. $^{27}\text{Al}/^{24}\text{Mg}$ in the pyroxene (PX) and plagioclase (PL) minerals separates and whole-rocks (WR) of Juvinas, Ibitira and Asuka 881394.

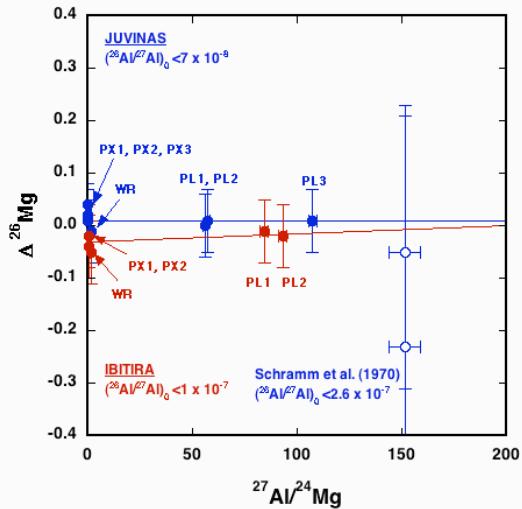


Figure 1. Al-Mg systematics in Juvinas and Ibitira. The upper limit on the $^{26}\text{Al}/^{27}\text{Al}$ ratio obtained by us for Juvinas is lower than that defined by [17] (open blue circles) by a factor of ~ 4 .

As can be seen in Fig. 1, there is no detectable evidence for live ^{26}Al in either Juvinas or Ibitira, and only upper limits on the $^{26}\text{Al}/^{27}\text{Al}$ ratios for these samples ($< 7 \times 10^{-8}$ and $< 1 \times 10^{-7}$, respectively) can be inferred. Using these upper limits, and assuming an initial $^{26}\text{Al}/^{27}\text{Al}$ ratio of $\sim 5 \times 10^{-5}$ at the time of CAI formation $\sim 4567.2 \pm 0.6$ Ma ago [8], we calculate an Al-Mg age of < 4561.0 Ma for Juvinas, and < 4561.4 Ma for Ibitira. Previously, Mn-Cr ages of 4562.5 ± 1.0 Ma and $4557(+2/-4)$ Ma have been determined for Juvinas and Ibitira, respectively [13]. Our results indicate that although the Al-Mg and Mn-Cr ages may well be consistent for Ibitira, they do not appear to be so for Juvinas, and this may be suggestive of resetting of the Al-Mg systematics in Juvinas at a later time. In this context, it is interesting that although the Pb-Pb age of Ibitira [14] is also consistent with its Al-Mg and Mn-Cr ages, Pb-Pb systematics in Juvinas appear to be reset at a later time [15].

We confirm the evidence for live ^{26}Al in the magnesian eucrite Asuka 881394. The $^{26}\text{Al}/^{27}\text{Al}$ ratio of $(1.39 \pm 0.07) \times 10^{-6}$ determined by us for this sample is more precisely defined (and slightly higher) than the value reported earlier by [5], but is nevertheless consistent with it within 2σ errors (Fig. 2). Compared with the Pb-Pb age for CAIs [12] (with $^{26}\text{Al}/^{27}\text{Al} \sim 5 \times 10^{-5}$), an Al-Mg age of 4563.8 ± 0.6 Ma is obtained for Asuka 881394. This is consistent with its Mn-Cr age of 4564 ± 2 Ma obtained by [5].

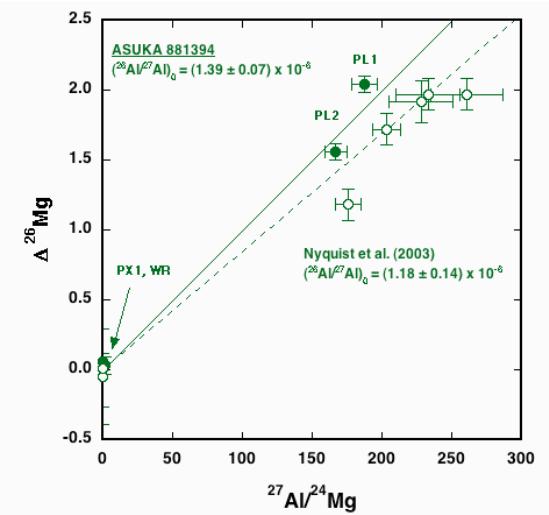


Figure 2. Al-Mg systematics in Asuka 881394. Within 2σ errors, our results are consistent with those of [5] (open symbols).

Overall, and with the noted exception of Juvinas, our results generally suggest concordance between the Al-Mg, Mn-Cr and Pb-Pb systematics. This supports a homogeneous distribution of ^{26}Al (at least in the meteorite forming region) and the viability of the $^{26}\text{Al}-^{26}\text{Mg}$ chronometer. The reason for the apparent discordance in Juvinas between the Mn-Cr systematics on the one hand, and the Al-Mg and Pb-Pb systematics on the other, is unclear at this time. It may be indicative of a greater susceptibility of the Al-Mg and Pb-Pb systematics to being reset by extensive thermal metamorphism.

Finally, it is interesting to note that $\Delta^{26}\text{Mg}$ values for all Ibitira data points are slightly negative (Fig. 1) and the initial $\Delta^{26}\text{Mg}$ for this eucrite (-0.03 ± 0.04) is systematically lower than the initial values for Juvinas (0.01 ± 0.03) and Asuka 881394 (-0.01 ± 0.04). As suggested by [16] based on oxygen isotope systematics, this may be indicative of a distinct source (or parent body) for the Ibitira eucrite compared to other HEDs.

- References:** [1] MacPherson G. et al. (1995) *Meteoritics*, 30, 365. [2] Urey H. C. (1955) *PNAS*, 41, 127. [3] Srinivasan G. et al. (1999) *Science*, 284, 1348. [4] Srinivasan G. (2002) *MAPS*, 37, A135. [5] Nyquist L. E. et al. (2003) *EPSL*, 214, 11. [6] Nyquist L. E. et al. (2003) *LPS XXXIV*, #1388. [7] Zinner E. and Göpel C. (2002) *MAPS*, 37, 1001. [8] Amelin Y. et al. (2002) *Science*, 297, 1678. [9] Kunihiro T. et al. (2004), *GCA*, in press. [10] Wadhwa M. et al. (2003) *LPS XXXIV*, #2075. [11] Wadhwa M. et al. (2003) *GCA*, 67, A517. [12] Galy A. et al. (2003) *JAAS*, 18, 1352. [13] Lugmair G. W. and Shukolyukov A. (1998) *GCA*, 62, 2863. [14] Chen J. H. and Wasserburg G. J. (1985) *LPS XVI*, 119. [15] Galer S. J. G. and Lugmair G. W. (1996) *Meteoritics*, 31, A47. [16] Wiechert U. et al. (2002) *GCA*, 66, A834. [17] Schramm D. N. et al. (1970) *EPSL*, 10, 44.