CONSTRAINING THE AGE OF PARTIAL MELTING ON THE BRACHINITE PARENT BODY BY INVESTIGATING Al-Mg SYSTEMATICS IN BRACHINA AND PAIRED ACHONDRITES GRA06128/9

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Introduction: The very short half-life of the extinct ^{26}Al-^{26}Mg system ($t_{0.5}$ = 0.72Myr) allows us to constrain the chronology of events in our early solar system to very high precision when tied to absolute chronometers such as Pb-Pb. Accordingly, the Al-Mg system has been applied to a range of meteorites and meteoritic components in recent times, including investigations into the relative formation ages of chondrules and CAI's (e.g. [1, 2]), as well as achondritic meteorites such as eucrites [3] and angrites [4, 5].

Unlike the most common achondrites (eucrites), which have a basalt composition, the paired achondritic meteorites Graves Nunatuk (GRA) 06128/9 have a bulk andesitic chemistry. Their unique mineralogy is dominated by Na-rich plagioclase (~81% vol), with the remaining mineralogy is dominated by pyroxenes and olivine [6]. They are inferred to have formed from early, high temperature partial melting (~10%) of a chondritic planetesimal that is probably related to the brachinite parent body [7]. Brachinites are olivine rich achondrites with a chondritic bulk element composition [8, 9]. Brachina was the first reported brachinite [8] and contains ~80% olivine in a fine grained equigranular texture, with the remaining mnineralogy dominated by plagioclase (10%) and clinopyroxene (5.5%). Despite the fact that GRA meteorites are mineralogically distinct from the brachinites, they share common bulk oxygen isotope compositions of around Δ^{17}O=-0.18‰ [6]. In addition, they have similar Fe/Mn ratios and Ni contents and were formed in similar fO_2 conditions, all of which is strong evidence to suggest that they shared a common chondritic precursor [7].

The aim of this study is to investigate the Al-Mg systematics in whole rock samples of GRA06128/9 and Brachina in order to estimate when the GRA/Brachinite parent body differentiated, and to compare this timescale with those gained from other achondritic meteorites.

Methods: Fragments of Brachina and GRA06128/9 (~100mg) were carefully crushed and fine fragments were ultrasonically cleaned in MQ water and acetone to remove any altered surface material. Approximately 0.5-2mg of this cleaned material was then dissolved using the standard HF:HNO_3 dissolution technique. After dissolution, ~10% of this material was saved for Al/Mg analyses. The remainder was processed through cation chromatography; separating Mg from any interferences in order to accurately measure the Mg isotope ratio. Both Mg isotopes and Al/Mg ratios were measured on a Thermo *Neptune Plus* MC-ICP-MS in the Geology Department at UC Davis.

Al/Mg ratios were normalized to the USGS basalt standard BCR-2, with Al/Mg ratios of another basalt standard (BHVO-2) reproducing to within 2% of certified values. Magnesium isotopes were bracketed against the DSM-3 standard, with each sample measured a minimum of five times. Typical reproducibility of radiogenic Mg (δ^{26}Mg*) is better than 0.02‰ (2s.e.)

Results: *Brachina:* Magnesium isotope analyses show no resolvable excess in ^{26}Mg [δ^{26}Mg* 0.00‰ ±0.018 (2s.e.)] and low ^{27}Al/^{24}Mg ratios (0.067) similar to the results of previous analyses on Brachina [6,10], and similar to previous estimates of the chondritic source reservoir (δ^{26}Mg* -0.001±0.002‰, ^{27}Al/^{24}Mg = 0.101±0.004 [11]).

GRA 06128/9: Both GRA meteorites contain resolvable excesses in ^{26}Mg with δ^{26}Mg* values of 0.058 and 0.064‰ (± 0.012, 2s.e.) respectively. These are slightly smaller than the 0.08‰ excess in ^{26}Mg published for GRA06129 [7, 10].

Discussion: The resolvable excess of ^{26}Mg in both GRA meteorites requires that ^{26}Al was active during Al/Mg differentiation in the parent body of Brachina. Previous work on individual plagioclase crystals from GRA06129 shows that the excess of ^{26}Mg is uniform, irrespective of major differences in ^{27}Al/^{24}Mg (ranges from 5 in whole rock to >250 in plagioclase [6, 10]), and requires the equilibration of Mg isotopes to have occurred after the complete decay of ^{26}Al. These two observations place stringent time constraints on two separate event: (1) The resolvable excess of ^{26}Mg* in GRA suggests that the precursor reservoir that formed the andesitic composition of GRA became isolated from the bulk solar composition when ^{26}Al was still extent. (2) On the other hand, the time of crystalisation, i.e. the final stages of accumulation of high-Na plagioclase by partial melting or metamorphic reequilibration must have occurred when ^{26}Al was extinct [7]. If we assume that GRA crystalised from the brachinite parent body (as suggested by their common Δ^{17}O values), then we can use the measured Al-Mg composition of Brachina to constrain this timescale. In fact, Brachina shares the same Mg isotopic composition as the bulk composition of chondrites [11]. For this reason (^{26}Al/^{27}Al)$_0$ model ages for GRA are identical whether Al-Mg data for Brachina or average chondrites are used. Using the composition of Brachina as our chondritic source, together with the measured values for GRA, generate a $(^{26}Al/^{27}Al)_0$ model age of $(3.9 \pm 0.65) \times 10^{-6}$ (Figure 1). If we anchor this model age to Allende CAI's ($^{26}Al/^{27}Al=4.96\times10^{-5}$, Pb-Pb age =4567.6Ma [1]) we obtain a final age of 4564.9 (±0.2) Ma, or (relative to CAI formation) ΔT_{CAI} = 2.65Ma, which is 0.5Ma older than the previous ΔT_{CAI} calculated for GRA 06129 [6, 10]. This age is within error of the estimated age of crystalisation of Brachina from Mn-Cr isotopes (4564.5 ± 0.9Ma, [9]), which supports the idea of a common origin between GRA and Brachina (Figure 2). The inferred crysalisation age of GRA is also comparable to the range of ΔT_{CAI} obtained for the eucrite and mesosiderite parent bodies (3.1-4.04 and 2.56-3.59Myr respectively [5]). Thus our results are consistent with the consensus that magmatism on the brachinite parent body occurred between 2-3Myr after the formation of CAI's [7]. This magmatism is not only one of the earliest generations of planetary differentiation in our solar system [9], but also represents the earliest known felsic asteroidal crust formation in the Solar System.

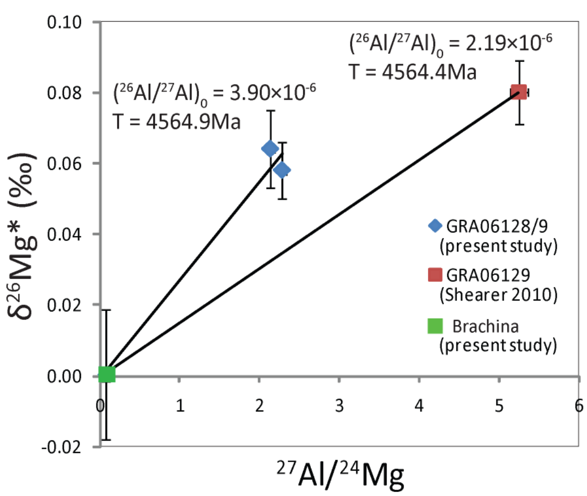

Figure 1 – Al-Mg systematics of the paired achondrites GRA06128/9 and Brachina measured in the current study. Initial $^{26}Al/^{27}Al$ ratios correspond to an age of crystalisation of 4564.9Ma, anchored to the Pb-Pb age of Allende CAI's [1]. This is ~0.5Myr older than a previous estimate for the crystalisation age of GRA [7]. Errors on Al/Mg ratios are <2%, errors on $\delta^{26}Mg^*$ are 2s.e.

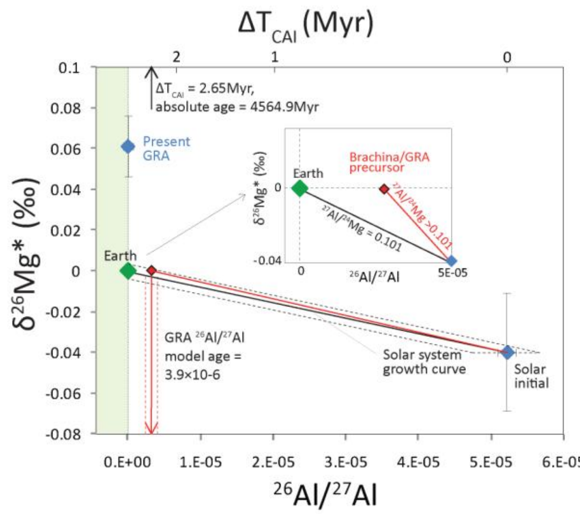

Figure 2 – Al-Mg evolution diagram (adapted from [12]). Solar system growth curve is based on a chondritic $^{27}Al/^{24}Mg$ value of 0.101[12], and an initial solar composition taken from bulk CAI's [1]. To account for the Al-Mg systematics in Brachina and GRA 06128/9 requires crystalisation to have occurred 2.65Myr after the formation of CAI's. In order to also account for the Earth-like composition of Brachina, the $^{27}Al/^{24}Mg$ composition of the precursor source must have been greater than 0.101.

References: [1] Jacobsen B. et al. (2008) *EPSL, 272, 353-364.* [2] Amelin Y. et al. (2002) *Science, 297, 1678-1693.* [3] Srinivasan G. et al. (1999) *Science, 284, 1348-1350.* [4] Baker J. et al. (2005) *Nature, 436, 1127-1131.* [5] Bizzarro M. et al. (2006) Astrophys. J., 632, L41-L44. [6] Shearer C. K. et al. (2008) *Am. Min., 93, 1937-1940.* [7] Shearer C. K. et al. (2010) *GCA, 74, 1172-1199.* [8] Nehru et al. (1983), *PLPSC 14th, JGR, 88,* Suppl., B237-B244. [9] Wadhwa M. et al. (2008) *LPS XXIX, Abstract #1480.* [10] Spivak-Birndorf L. J. & Wadhwa M. (2009) *LPS XL, Abstract #2132.* [11] Thrane K. et al. (2006) *Astrophys. J. 646, L159-L162.* [12] Villeneuve J. (2009) *Science, 325, 985-988.*