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 26Al-24Mg system (t½ = 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 Nunatak (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 mneralogy 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 Δ17O = -0.18‰ [6]. In addition, they have similar Fe/Mn ratios and Ni contents and were formed in similar fO2 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:HNO3 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 (δ26Mg*) is better than 0.02‰ (2s.e.)

Results: Brachina: Magnesium isotope analyses show no resolvable excess in 26Mg [δ26Mg* = 0.00‰ ±0.018 (2s.e.)] and low 27Al/24Mg ratios (0.067) similar to the results of previous analyses on Brachina [6,10], and similar to previous estimates of the chondritic source reservoir (δ26Mg* = -0.001±0.002‰, 27Al/26Mg = 0.101±0.004 [11]).

GRA 06128/9: Both GRA meteorites contain resolvable excesses in 26Mg with δ26Mg* values of 0.058 and 0.064‰ (± 0.012, 2s.e.) respectively. These are slightly smaller than the 0.08‰ excess in 26Mg published for GRA06129 [7, 10].

Discussion: The resolvable excess of 26Mg in both GRA meteorites requires that 26Al 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 26Mg is uniform, irrespective of major differences in 24Al/27Mg (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 26Al. These two observations place stringent time constraints on two separate event: (1) The resolvable excess of 26Mg* in GRA suggests that the precursor reservoir that formed the andesitic composition of GRA became isolated from the bulk solar composition when 26Al was still extant. (2) On the other hand, the time of crystallisation, i.e. the final stages of accumulation of high-Na plagioclase by partial melting or metamorphic reequilibration must have occurred when 26Al was extinct [7]. If we assume that GRA crystallised from the brachinite parent body (as suggested by their common Δ17O 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 (26Al/27Al)0 model ages for GRA are iden-
tical 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 \( \left( ^{26}\text{Al}/^{27}\text{Al} \right)_{b} \) model age of \( (3.9 \pm 0.65) \times 10^{6} \) (Figure 1). If we anchor this model age to Allende CAI’s \( ^{26}\text{Al}/^{27}\text{Al} = 4.96 \times 10^{-5} \), Pb-Pb age = 4567.6 Ma [1]) we obtain a final age of 4564.9 (±0.2) Ma, or (relative to CAI formation) \( \Delta T_{\text{CAI}} = 2.65 \text{Ma} \), which is 0.5 Ma older than the previous \( \Delta T_{\text{CAI}} \) calculated for GRA 06129 [6, 10]. This age is within error of the estimated age of crystallisation of Brachina from Mn-Cr isotopes (4564.5 ± 0.9 Ma [9]), which supports the idea of a common origin between GRA and Brachina (Figure 2). The inferred crystallisation age of GRA is also comparable to the range of \( \Delta T_{\text{CAI}} \) obtained for the eucrite and mesosiderite parent bodies (3.1-4.04 and 2.56-3.59 Myr respectively [5]). Thus our results are consistent with the consensus that magmatism on the brachinite parent body occurred between 2-3 Myr 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.