^{26}Al-^{26}Mg SYSTEMATICS IN BRACHINA AND THE UNIQUE ACHONDRITE GRA 06129.

L. J. Spivak-Birndorf[1] and M. Wadhwa[1], [1]Center for Meteorite Studies, School of Earth and Space Exploration,, Arizona State University, Tempe, AZ 85287. Lev.Spivak-Birndorf@asu.edu

Introduction: The ^{26}Al-^{26}Mg extinct radionuclide chronometer ($t_{1/2}$ = 0.72 Myr) has proven to be useful for precisely constraing the timescales of planetesimal differentiation in the early Solar System. The ^{26}Al-^{26}Mg system has been investigated to some extent in basaltic achondrites (i.e., angrites and eucrites) [1-3] providing high-resolution chronological information as well as implicating ^{26}Al as a heat source for melting planetesimals. However, the ^{26}Al-^{26}Mg systematics of many other types of achondrites remain largely unstudied. Here we report an investigation of the ^{26}Al-^{26}Mg isotope systematics in Brachina and the unique achondrite GRA 06129, with the goal of constraining the chronology of these two meteorites.

Brachina is an olivine rich meteorite that has been suggested to represent a chondritic partial melt residue [4] or an igneous cumulate [5]. It was also determined to have an ancient formation age [6] making it a suitable sample to search for evidence of live ^{26}Al.

GRA 06128/9 (hereafter, GRA) are a pair of recently recovered achondrites with unusual sodic plagioclase-rich mineralogies [7]. They most likely formed by partial melting of a chondritic source followed by accumulation of plagioclase [7]. Furthermore, GRA and Brachina might be related meteorites. Oxygen isotopic compositions and Mn/Cr ratios for GRA and the brachinites suggest that they may have originated on a common parent body [7].

Analytical Methods: Interior fragments of Brachina and GRA 06129, each initially weighing ~200-300 mg, were processed for this study. The GRA sample was lightly crushed and leached in room temperature 1M HCl for ~1 hour, followed by rinsing in ultrapure water. A ~30 mg fraction of the washed whole rock (WR) sample was removed, followed by hand picking of two ~2 mg plagioclase fractions.

The Brachina sample was also lightly crushed and a ~25 mg chip was removed for WR measurements. Additionally, three small (<1 mg) plagioclase-enriched mineral separates were obtained from the crushed sample by density separation with heavy liquids (bromoform), followed by hand picking. An olivine separate was also obtained from the crushed sample by hand picking.

After digestion in acid, 5-10% aliquots of mineral separates and the whole rock samples were reserved for Al/Mg ratio mesurments. The remainder of the mineral separate solutions and aliquots of the whole rock solutions equivalent to ~3-4 mg were processed through cation exchange columns to separate Mg for isotopic analysis. All Mg isotope and Al/Mg ratio measurments were made on the Neptune multicollector inductively coupled plasma mass specterometer (MC-ICPMS) in the Isotope Cosmochemistry and Geochronology Laboratory at Arizona State University using established procedures similar to those described previously [3].

Results: *GRA 06129*. The whole rock sample and plagioclase separates from GRA all have resolvable excesses in ^{26}Mg*. Though the samples span a range of ^{27}Al/^{24}Mg ratios (up to ~250), they all have identical ^{26}Mg* enrichments, within the analytical errors, of ~0.08‰. The slope of the best-fit line through these data is indistinguishable from zero and corresponds to a ^{26}Al/^{27}Al ≤ 2.08×10^{-8} (Fig. 1.) at the time of the last equilibration of Mg isotopes in this meteorite.

Brachina. The WR and plagioclase-enriched mineral separates for Brachina all had normal (i.e., δ^{26}Mg* ≈ 0) Mg isotope compositions within errors. The ^{26}Al-^{26}Mg data for Brachina define an isochron slope that is not resolved from zero, corresponding to an upper limit on ^{26}Al/^{27}Al of 4.11×10^{-7} when Mg isotopes last equilibrated (Fig. 2.).

Discussion: *GRA 06129*. The ^{26}Mg excesses measured in GRA provide evidence for the former presence of extant ^{26}Al in this meteorite. However, the uniformity of these excesses in all of the fractions (regardless of ^{27}Al/^{24}Mg ratios; Fig. 1.), indicates that Mg isotopes equilibrated in GRA subsequent to the complete decay of ^{26}Al. Consequently, the internal ^{26}Al-^{26}Mg isochron for this meteorite can provide only an upper limit on the timing of the last Mg isotope equilibration, which corresponds to an age of ≤4559.1 Ma anchored to the Efremovka E60 CAI (^{26}Al/^{27}Al = ~5×10^{-5} [8] at an absolute Pb-Pb age of 4567.1 ± 0.2 Ma [9]). GRA shows textural and mineralogical evidence for extensive post-crystallization metamorphism and equilibration [7], which likely resulted in the homogenized Mg isotopic composition in this sample.

Despite the equilibrated Mg isotopic composition of its minerals, the preservation of a resolvable ^{26}Mg excess in the GRA WR sample allows some chronological information to be obtained. Assuming that GRA (GRA WR: δ^{26}Mg* = 0.080 ± 0.009‰ and ^{27}Al/^{24}Mg = 5.25 ± 0.11) formed from a chondritic reservoir (chondrites: δ^{26}Mg* = -0.001 ± 0.002‰ and ^{27}Al/^{24}Mg = 0.101 ± 0.004 [10]), a model initial ^{26}Al/^{27}Al ratio of $(2.19 \pm 0.25) \times 10^{-6}$ can be estimated. This corresponds to a model ^{26}Al-^{26}Mg age of 4563.9

± 0.2 Ma (relative to E60 CAI [8,9]), which corresponds to the timing of the Al/Mg fractionation event (most likely crystallization) that established the Al/Mg ratio of the GRA WR.

Brachina. The ^{26}Al-^{26}Mg systematics in Brachina indicate that ^{26}Al was essentially extinct at the last time of Mg isotope equilibration. The internal ^{26}Al-^{26}Mg isochron (Fig. 2) provides an an upper limit of 4562.2 Ma for this event. In contrast to GRA, the WR sample of Brachina has no excess ^{26}Mg and an Al/Mg ratio close to chondritic, precluding the determination of a meaningful model ^{26}Al-^{26}Mg age for this meteorite.

Evidence for the presence of live ^{53}Mn in Brachina at the time of its formation was previously reported by [6]. Relative to the initial ^{53}Mn/^{55}Mn ratio of LEW 86010 angrite [11] at an absolute Pb-Pb age of 4558.6 ± 0.2 Ma [12], Brachina has a ^{53}Mn-^{53}Cr age of 4564.5 ± 0.9 Ma. The ^{53}Mn-^{53}Cr and ^{26}Al-^{26}Mg chronometers are clearly discordant in Brachina, with the ^{26}Al-^{26}Mg system being reset at a later time. Alhough the spread of Al/Mg ratios in Brachina mineral separates obtained for this study is rather narrow, if the ^{26}Al-^{26}Mg and ^{53}Mn-^{53}Cr chronometers were concordant, the δ^{26}Mg* values expected in the mineral separate with the highest Al/Mg ratio would be easily resolvable given the analytical precision of this study (Fig. 2). Brachina shows evidence of subsolidus metamorphism and re-equilibration at high temperatures (~1000 °C; [4]). In order for this heating event to have reset the ^{26}Al-^{26}Mg system but not the ^{53}Mn-^{53}Cr system, the duration of this event must have been relatively short (<~10^3 yrs, assuming Mg and Cr diffusion parameters from [13, 14]).

Conclusion: Given the possible genetic link between Brachina and GRA [7], it is useful to compare the chronologies of these two meteorites. The ^{26}Al-^{26}Mg model age determined here for GRA is concordant with the ^{53}Mn-^{53}Cr age inferred for Brachina [6]. The homogenized Mg isotope compositions and zero-slope ^{26}Al-^{26}Mg internal isochrons of both GRA and Brachina are consistent with the re-equilibration of these meteorites above the closure temperature for Mg diffusion in these meteorites, after ^{26}Al was extinct. Overall, this is consistent with the origin of these two meteorites on a common parent body that differentiated within the first ~2-3 Myr of Solar System formation and then experienced later thermal metamorphism at temperatures of ~1000 ^{o}C.

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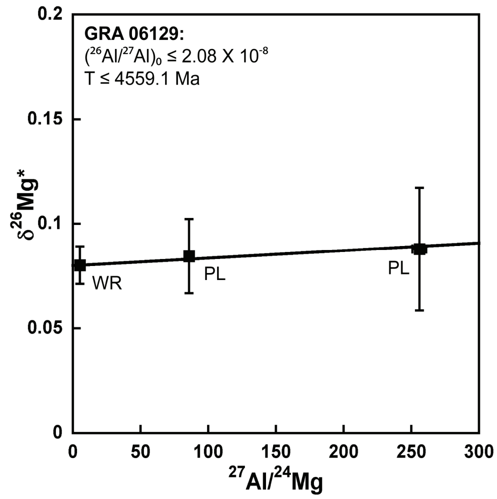

Fig. 1. ^{26}Al-^{26}Mg systematics of GRA 06129. The samples define a slope that is indistinguishable from zero, with an upper limit on the ^{26}Al/^{27}Al of ~2.1 × 10^{-8}. Errors are ±2SE on δ^{26}Mg* and ±2% on ^{27}Al/^{24}Mg ratios. PL = Plagioclase; WR = Whole Rock

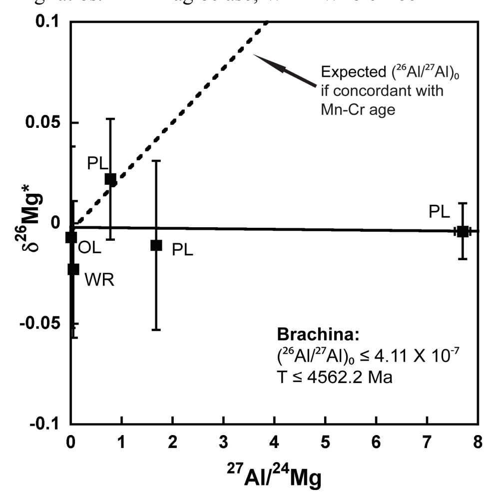

Fig. 2. ^{26}Al-^{26}Mg systematics of Brachina. The samples define a best-fit line with a slope that is indistinguishable from zero, with an upper limit on the ^{26}Al/^{27}Al of ~4.1 × 10^{-7} (solid line). Errors are ±2SE on δ^{26}Mg* and ±2% on ^{27}Al/^{24}Mg ratios. The dashed line corresponds to the expected isochron slope if the ^{26}Al-^{26}Mg chronometer was concordant with the ^{53}Mn-^{53}Cr chronometer for this meteorite [6]. PL = Plagioclase; OL = Olivine; WR = Whole Rock.