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Timing of crust formation on differentiated asteroids inferred from Al-Mg chronometry

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Determining the timing of assembly and differentiation of planetary bodies in the young Solar System is essential for a complete understanding of planet-forming processes. This is best achieved though the study of extinct radionuclides with short half-lives, as they provide unsurpassed time-resolution compared with long-lived chronometers. Furthermore, evidence for the former presence of some extinct radionuclides in early Solar System bodies has bearing on whether heating by short-lived radionuclides triggered planetesimal melting. With a short half-life of ~730,000 years, the ^{26}Al-to-^{26}Mg decay scheme is ideally suited to study objects formed in the first 5 Myr of the Solar System. While the ^{53}Mn-^{53}Cr and ^{182}Hf-^{182}W chronometers are affected by core-forming processes, Al and Mg are lithophile elements and insensitive to metal-silicate fractionation events. As such, the ^{26}Al-^{26}Mg chronometer is perhaps the most useful tool to constrain the timing of silicate differentiation in early-formed planetesimals. Building on previous work (Bizzarro et al., 2004), we have developed analytical protocols to measure ^{26}Mg abundances in silicate rocks to $\pm$5 ppm. Given the typical ^{27}Al/^{24}Mg values (ca. 1.5-3.5) of basaltic achondrites, our technique allows detection of excess ^{26}Mg if magmatism occurred within 5 Myr of CAI formation. Moreover, if basaltic magmatism occurred within 3 Myr of CAI formation, the time-resolution inferred from our isotope measurements is $< \pm$150,000 years. High-precision Mg isotope data have thus been acquired for basaltic meteorites from the angrite (APB), eucrite (EPB) and mesosiderite (MPB) parent bodies. Because of the likelihood that the Al-Mg systematics in these meteorites have been affected by either slow cooling in the parent bodies and/or late impact-related heating events, we have focused our investigations on 'bulk' materials. Thirteen individual sample diges-

tions of materials from Earth, including modern basalts (n = 5), mantle olivines (n = 6) and standard Mg solutions (n = 2), yielded an average δ^{26}Mg* = 0.0007±0.0015 ‰ (2 sd). Excess ^{26}Mg was detected in all the studied basaltic meteorites. Angrites (NWA1296 and SAH99555) yielded δ^{26}Mg* = 0.0169±0.0063 to 0.0344±0.0075‰, while three basaltic eucrites (Camel Donga, Juvinas and Ibitira) have δ^{26}Mg* = 0.0291±0.0068‰ to 0.0388±0.0054‰. Three basaltic clasts from the Vaca Muerta mesosiderite yielded δ^{26}Mg* = 0.0335±0.0070‰ to 0.0417±0.0065 ‰. We interpret the presence of ^{26}Mg excess in these samples to be related to *in-situ* decay of the ^{26}Al nuclide. Model isochrons yield $(^{26}\mathrm{Al}/^{27}\mathrm{Al})_0$ = $1.3\pm0.5\times10^{-6}$ to $2.4\pm0.5\times10^{-6}$ for the APB, $2.2\pm0.5\times10^{-6}$ to $2.9\pm0.4\times10^{-6}$ for the EPB and $1.7\pm0.3\times10^{-6}$ to $2.7\pm0.4\times10^{-6}$ for the MPB, which are the highest $(^{26}\mathrm{Al}/^{27}\mathrm{Al})_0$ values reported for basaltic meteorites. These $(^{26}\mathrm{Al}/^{27}\mathrm{Al})_0$ values suggest that the APB, EPB and MPB accreted and differentiated while ^{26}Al was sufficiently abundant to drive asteroid melting. Assuming a homogeneous distribution of ^{26}Al in the young Solar System, these high-precision Mg isotope data constrain formation of a pervasive basaltic crust to $\leq$ 3 Myr after CAI formation. The model ages yield a maximum range of magmatic activity of 0.85 ± 0.41 Myr. Although preliminary, these results favor a relatively brief period of magmatism on these planetesimals. A simple thermal model assuming negligible heat loss and a peak temperature of 1500˚K, indicates that accretion of these bodies must have been largely completed <1.5 Myr after CAI formation, if heating only occurred by the decay of ^{26}Al. Thus, accretion of these asteroids is coeval with or pre-dates the youngest ^{26}Al-^{26}Mg dated Allende chondrules (Bizzarro et al., 2004), in agreement with recent Hf-W isotope data indicating that some chondrites accreted after differentiation of some iron meteorites (Kleine et al., 2004). Lastly, our new high-precision Mg isotope data can also provide time constraints for core formation on differentiated asteroids, providing that metal-silicate segregation pre-dates basaltic volcanism, as suggested by the depletion in moderately siderophile elements observed in basaltic eucrites. Our high-precision Mg isotope data thus require core formation on the APB, EPB and MPB to have occurred $\leq$ 3 Ma after CAI formation.

Bizzarro, M. et al. (2004) *Nature*, **431**, 275-278.

Kleine, T. et al. (2004), *AGU* **85(47)**.