High-precision ^{26}Al-^{26}Mg dating solid and planetesimal formation in the young Solar System

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The short-lived ^{26}Al-to-^{26}Mg isotopic system ($t_{1/2}$ = 0.73 Myr) is potentially the most powerful chronometer to study early Solar System timescales. This reflects the short half-life of ^{26}Al and large Al/Mg fractionations induced by nebula and planetary processes, which coupled with the precisely determined initial ^{26}Al abundance of CAIs, makes it the only isotopic system that allows relative age determinations on meteorites to be made with a resolution of ±0.1 Myr. However, full utilization of the ^{26}Al-^{26}Mg dating system requires the measurement of $\delta^{26}Mg^*$ excesses or deficits with an accuracy and precision of ±0.003 to 0.004‰ (2 se). We have developed new methods for measuring the Mg isotope ratios of meteorite material by pseudo-high resolution MC-ICP-MS. Tests have been conducted to ensure that $\delta^{26}Mg^*$ can be determined with an accuracy and precision of ≤ ±0.004‰. Improved chemical separation techniques have been developed to minimise the contaminant elements (e.g. Mn, Ni) in purified Mg, which are not separated by conventional nitric-acid-based cation exchange techniques.

Data obtained thus far shows: (1) Unaltered bulk CAIs from CV chondrites have resolvable differences in initial $^{26}Al/^{27}Al$ from 4.7 to 5.2 x 10^{-5} (corresponding to a time interval of 89±30 kyr) with no CAIs showing evidence for "supercanonical" ^{26}Al. (2) Most basaltic meteorites from the eucrite (3.1 Myr), mesosiderite (2.8 Myr) and angrite (4.8 Myr) parent bodies have elevated $\delta^{26}Mg^*$ that dates planetary melting to 2.8 to 4.8 Myr after CAI formation. Some angrites (ADOR, LEW86010) contain no evidence for the former presence of live ^{26}Al, consistent, with their young Pb-Pb ages. NWA2976 is also characterised by elevated $\delta^{26}Mg^*$ which, given its anomalous O-Cr isotope ratios compared to all other basaltic meteorites, suggests these small excesses of $\delta^{26}Mg^*$ in basaltic meteorites reflect decay of ^{26}Al and are not nucleosynthetic anomalies. (3) Olivines from four main group pallasites yield deficits in $\delta^{26}Mg^*$ = -0.0157±0.0015‰, which dates olivine crystallization and isolation from high Al/Mg parts of the pallasite parent body at its core-mantle boundary to 0.97±0.10 Myr after CAI formation. Work is ongoing to examine if other meteoritic material (aubrites, ureilites) with sub-chondritic Al/Mg has $\delta^{26}Mg^*$ deficits that may enable precise dating of differentiation on their parent bodies.

Predicting solidus temperatures and modes of mantle peridotites

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The peridotite solidus (T_s) is an important control on the initiation and extent of adiabatic mantle melting. While the pressure (P) - T_s relationship of fertile peridotite is fairly well constrained [1, 2], the relationship between composition (X) and T_s is less well quantified. We have developed an algorithm based on mineral-mineral exchange and distribution coefficients (K_ds) and stoichiometric and mass balance constraints for calculating the mode and compositions of phases (oliv, opx, cpx, sp, gt) for subsolidus peridotite as a function of T, P, and X. This in turn allows us to estimate the MgO, Na_2O, and K_2O (wt %) of near-solidus melt (F = 0.005) using T-, P-, and X-dependent crystal-liquid K_ds and the assumption that the solidus mode and the mode at F = 0.005 are equal. Using 4-phase saturated liquids in CMAS+Fe [3] and CMAS+Na [4], and experimentally determined solidii on natural peridotites [1, 2, references therein, and unpublished data], we parameterized the peridotite solidus as a function of P, and liquid MgO and K_2O contents. The data set consists of 32 model system experiments and 33 T_s values from fertile to depleted peridotites; the 65 data points cover a P, T, and Mg# range of 1 to 4.2 GPa, 1210 to 1594°C, and 1 to 0.75, respectively. The mean T deviation of the fit is ~7°C, i.e., less than the uncertainty on any one determination (estimated to be at least ±10-15°C); the largest mismatch is -26°C ($T_{exp} - T_{calc}$).

The calculated T_s of a primitive mantle (PM) composition [5] varies from 1239°C at 1 GPa to 1506°C at 3.5 GPa, in good agreement with [1] (mean T deviation is ~13°C); over this pressure range the modal opx/cpx ratio at the solidus decreases from 1.24 to 0.04. The calculated solidus for a partially depleted peridotite [6] (MgO = 41.6 wt %), is 45-60°C higher than that calculated for the PM over this P range; the modal opx/cpx ratio at the solidus decreases from 2.88 to 0.97. For a given bulk composition, our calculations show that small changes in silica content have a relatively large effect on opx abundance at the solidus, which in turn affects the P of opx-out along the solidus.

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