EARLY DISK DYNAMICS INFERRED FROM ISOTOPE SYSTEMATICS OF INDIVIDUAL CHONDRULES

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The most abundant constituent of chondrites are chondrules, mm-sized spherules formed by transient heating events. High-resolution uranium-corrected Pb-Pb dates indicate that chondrule formation started contemporaneously with the solar system first solids, CAIs, and lasted ~3 Myr [1]. Further, numerical simulations show that the main growth of asteroids results from gas-drag-assisted accretion of chondrules, leading to the formation of planetary embryos <3 Myr [2]. Thus, chondrules represent the precursor material of most asteroids and, by extension, planets. We initiated a study aimed at providing U-corrected Pb-Pb ages for a reference set of individual inclusions from pristine enstatite, ordinary and various classes of carbonaceous chondrites (CV, CR and CK). These reference inclusions allow for comparison of the absolute Pb-Pb ages with that of the $^{26}$Al short-lived radionuclide as well as tracers of nucleosynthetic variability such as $^{54}$Cr.

Here, we report on the Pb-Pb ages (TIMS) and internal $^{26}$Al-$^{26}$Mg isochrons (SIMS) of eight chondrules from the Allende and NWA 5697 meteorites. Using the solar $^{235}$U/$^{238}$U ratio of 137.78±0.013 [1], the absolute ages range from 4567.88±0.58 Myr to 4565.8±1.0 Myr, in agreement with earlier work [1]. In particular, 4 chondrules yield absolute ages identical to Ca-Al-rich inclusions (CAIs), suggesting an abundance of chondrules with ancient absolute ages. Chondrules analyzed for Cr record depletions in $^{54}$Cr typical of inner solar system asteroids and planets. Internal Al-Mg isochron relationships define initial $^{26}$Al/$^{27}$Al ratios at the time of crystallization ranging from (4.04±2.79)$\times10^{-6}$ to (8.75±1.81)$\times10^{-6}$, i.e. comparable to earlier reports of $^{26}$Al/$^{27}$Al ratios in chondrules from primitive chondrites. However, these initials $^{26}$Al/$^{27}$Al are much lower than that expected from their Pb-Pb ages, corresponding to age differences ranging from 0.7 to 3.1 Myr confirming the observation of a reduced initial abundance of $^{26}$Al in the accretion region of differentiated asteroids [3]. Using the measured $^{26}$Al/$^{27}$Al and the corresponding Pb-Pb ages allows us to constrain the initial $^{26}$Al/$^{27}$Al in chondrule precursors at the time of CAI formation. We find two chondrule populations: a young population with a mean age of 4566.66±0.52 Ma and $^{26}$Al/$^{27}$Al of (1.79±0.08)$\times10^{-5}$, and an old population with a mean age of 4567.62±0.37 Ma and $^{26}$Al/$^{27}$Al of (4.01±0.23)$\times10^{-6}$. The latter $^{26}$Al/$^{27}$Al is similar to that observed in the STP-1 FUN CAI [4]. This establishes that the existence of early reservoirs with contrasting initial abundance of $^{26}$Al (i.e. canonical vs. FUN CAIs) is not limited to the CAI-forming region but extends to the inner protoplanetary disk where chondrules formed. We interpret the heterogeneity as reflecting progressive thermal processing of a young supernova-derived dust population during the earliest evolution of the disk [5, 6]. The higher $^{26}$Al/$^{27}$Al of (1.79±0.08)$\times10^{-5}$ observed for the young population may reflect their formation from less thermally processed material. This is consistent with their formation >1 Myr after CAIs, when the mass accretion rate to central star, and hence inner disk temperatures, were significantly lower.