U-PB CHRONOLOGY OF CHONDRULES. J. N. Connelly[1], J. Bollard, and M. Bizzarro[1], [1]Centre for Star and Planet Formation, Natural History Museum of Denmark, University of Copenhagen, 1350 Copenhagen K, Denmark.

Chondrules form from primitive dust that has been heated above its melting temperature and rapidly cooled in hours to days, one or more times [1]. “Nebular chondrules” are taken here as chondrules that formed within the protoplanetary disk before the dust and gas cleared. A second group of chondrules apparently formed by planetary collisions [2].

The high temperatures and melting associated with chondrule formation effectively increases their U/Pb ratios making them amenable to dating by this decay system. Chondrule melting raises the $^{238}U/^{204}Pb$ ratio (μ value) from starting Solar values of approximately 0.2 to upwards to values of 20 to 100’s [3,4]. Using the stepwise dissolution method of [5], there is now 22 individual chondrules dated by the Pb-Pb method [3,4] with 6 chondrules of the 22 dated having measured $^{238}U/^{235}U$ ratios that overlap the Solar value of 137.786 [3]. In this chronometric framework, nebular chondrules started forming at the same time that calcium aluminum inclusions (CAIs) were formed (4567.30±0.16 Ma, [3]) and continued to form for ca. 3.6 Myr. This age range defines the minimum lifespan of the Solar System’s protoplanetary disk, with the age of chondrules formed by planetary collision defining the maximum lifespan of the protoplanetary disk at 4.8 Myr [6]. As importantly, approximately half the chondrules dated by this method were formed within the first million years of the Solar System’s formation.

The extrapoloation to the y-axis in an inverse Pb-Pb diagram ($^{204}Pb/^{206}Pb$ vs $^{207}Pb/^{206}Pb$) provides chronometric information, whereas a projection in the opposite direction to higher $^{204}Pb/^{206}Pb$ ratios provides information about the Pb isotopic composition at the time of chondrule formation. The projected compositions of the oldest chondrules are consistent with them having acquired an isotopic composition that had not radiogenically evolved significantly from the Solar System initial composition. Conversely, the younger chondrules inherited Pb isotopic compositions with evolved compositions relative to the Solar System intial values. This trend indicates that the younger chondrules acquired an elevated μ value earlier in their history, an observation most consistent with them having first experienced heating and melting (i.e. chondrule formation) early in the protoplanetary disk and later reworked. Collectively, our data set of ages and estimates of the intial Pb isotopic composition suggests that there are two distinct phases of nebular chondrules formation: 1) a primary chondrule formation episode within the first million years of the Solar System and 2) a more prolonged period lasting up to 3.6 Myr in which the primary chondrules continued to be reworked.

Our results are in direct contrast to the age range of chondrule formation inferred from the ^{26}Al-^{26}Mg decay system [7 for review] and recent estimates based on the ^{182}Hf-^{182}W decay system [8,9]. In the case of the ^{26}Al-^{26}Mg ages, we conclude that an offset to younger ages relative to the Pb-Pb age range and the so-called “chondrule gap” reflects heterogeneous distribution of the $^{26}Al/^{27}Al$ ratio in the protoplanetary disk. In contrast, the younger age range for chondrule formation based on $^{182}Hf/^{182}W$ ages most likely reflects an average age for chondrules formation derived by bulk analyses of large numbers of chondrules. The $^{182}Hf/^{182}W$ age estimates for chondrules are also compromised if the author’s assumption that bulk chondrules and their host matix were in isotopic equilibrium at the time of chondrules formation is incorrect.

Recent models of planetesimal formation by streaming instabilities leading to efficient chondrule accretion predict that planetesimals will only effectively begin forming contemporaneously with the first appearance of chondrules [10]. As such, the earliest chondrules forming contemporaneously with CAIs is consistent with the existence of a crust on the angrite parent body already by 4564.39±0.24 Ma [11]. The reduced abundance of ^{26}Al in the protoplanetary disk defined by recent models [12] also predicts the onset of planetesimal accretion to have started within a few 100 kyr after CAI formation else there will be insufficient thermal energy to drive differentiation.

Finally, the assembly of chondrules with diverse ages and isotopic signatures [13,14] in a single chondrite requires that chondrules formed in different regions of the protoplanetary disk before they were transported to their respective accretion regions. This precludes a genetic link between the chondrules or between chondrules and matrix as predicted by models of chemical complimentarity in chondrites [15].

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