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The chronology of formation of solids and meteorite parent bodies in the early solar system

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Abstract

Meteorites are fragments from small bodies (mostly asteroids) in the early solar system. These planetesimals formed within a few Ma, before the solar nebula was dissipated. Radioisotope dating allows to infer a detailed insight into the chronology of formation of the first solids, meteorite parent body formation and their thermal evolution. While differentiation was completed within a few Ma, cooling of both undifferentiated chondrites and differentiated parent bodies took place over tens of Ma.

1. Introduction

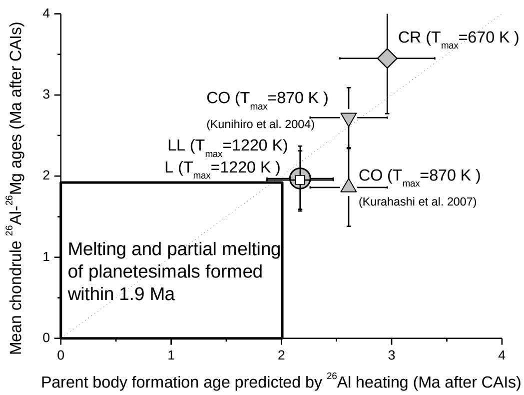
Meteorites contain both decay products of long-lived nuclides (^{238,235}U-^{206,207}Pb, ^{40}K-^{40}Ar [1,2]) and also short-lived radionuclides (^{129}Xe from ^{129}I; $T_{1/2}$=16 Myr [3], excess ^{26}Mg from ^{26}Al; $T_{1/2}$=0.73 Myr [4], ^{53}Cr from ^{53}Mn; $T_{1/2}$=3.7 Myr [5], ^{182}Hf from ^{182}W; $T_{1/2}$=9 Myr [6,7]). Radioisotope dating based on these nuclides provide a framework for the formation of solids in the early solar system. Particular short-lived nuclides can provide a high resolution early solar system chronology, if short-lived isotope chronometries are calibrated against each other using several tie points (e.g., CAIs, some H chondrites, Acapulco). Moreover, it is possible to derive planetesimal formation timescales by constraints derived from ^{26}Al heating of meteorite parent bodies [2,8]. Conditions of formation of the first solids in the solar nebula varied - most probably due to p,T differences imposed by the early sun - with radial distance and/or time, and caused the compositional variety of planetesimals concerning refractory and volatile elements, metals, and Mg-rich silicates [8,9].

2. Chronology of formation of solids and planetesimals

The oldest solids in the early solar system (c. 4567 Ma old) are cm-sized refractory Ca,Al rich inclusions (CAIs) in meteorites. Abundant spherical chondrules are about 2-4 Ma younger. Radiometric dating of chondrules from different meteorite classes and formation time scales inferred by ^{26}Al heating (Figure 1) define a sequence of formation of ordinary chondrites (L and LL type), and carbonaceous CO and CR chondrites about 2-4 Ma after CAIs. These data and chemical composition - particular chondrule-matrix complementarity – suggest that individual planetesimals grew rapidly in the asteroid belt (within < 1 Ma), but different planetesimals formed over a time interval of 4 million years [2,7,8], well within the lifetime of protoplanetary dust disks inferred from extrasolar systems [10,11]. Planetesimals forming earlier than undifferentiated chondrites were even more strongly heated by decay heat of short-lived nuclides, primarily ^{26}Al [2]. This caused melting and differentiation in planetesimals that formed within < 2 Ma after CAIs and led to the formation of iron cores and basaltic rocks, while chondritic planetesimals that accreted later remained undifferentiated [2,7,8]. As most chondrules were immediately consumed in accreting planetesimals, they were only preserved in unmelted chondritic parent bodies and their age distribution is biased to the formation time interval of chondrites 2-4 Ma after CAIs [8].

3. Conclusions and open questions

The formation of solids in the early solar system (CAIs, chondrules, planetesimals and terrestrial planets) are still insufficiently linked to astrophysically constrained processes like early protostellar activity, disk dissipation, formation and migration of gas planets interacting with young disks [10,11]. Models of Earth and Mars formation based on ^{182}Hf –^{182}W core formation ages infer the presence of planetary embryos of 60% the size of Mars after 2-4 Ma. This indicates the early presence of Jupiter to effectively prevent the formation of a proto-planet in the asteroid belt. Planetesimal formation in the asteroid belt and the terrestrial planet formation zone at <3 Ma after CAIs was likely accompanied by inner disk clearing accompanied by solar wind irradiation and likely volatile element depletion of terrestrial – and partly asteroidal - precursor planetesimals [12].



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