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Chondrule-bearing CAI from Y-81020 CO3.0 chondrite: Evidence of O isotope fluctuation in the early solar system

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Ca-Al-rich inclusions (CAIs) are the oldest preserved materials that formed during early evolution of the solar system (TATSUMOTO et al., 1976). Chondrules were also formed in the early solar system, but it is believed that they are ~2 Ma younger than the CAIs (RUSSELL et al., 1996; KITA et al., 2000; AMELIN et al., 2002). Because of the time gap and differences of chemical and isotopic compositions, it is believed that chondrules and CAIs formed independently (WOOD, 1996).

Here, we report the first observation of a O-16-poor chondrule fragment embedded in a O-16-rich CAI mesostasis, regarded as the chondrule-bearing CAI (named as A5) from Y-81020 CO3.0 chondrite. The chondrule-bearing A5 CAI is about 100 micron across and it consists of a O-16-poor large central polycrystalline melilite (ak10-13) clast with small O isotopic zoning and O-16-poor three-pyroxene assemblage included troilite and metal, as well as enstatite, augite and pigeonite, enclosed by a O-16-rich porous glassy mesostasis. These mesostasis consists of Al-rich clinopyroxene filaments embedded in Al-rich glass. These textures indicate that the mesostasis was quenched from a liquid. In addition, the chemical composition of mesostasis affected the nearby phases of melilite and pyroxene. The pyroxene assemblage has not previously been observed in CAIs (MACPHERSON et al., 1988) and the chemical compositions of the pyroxene phases are also not known from CAIs. However, such an assemblage is typical of chondrules (NOGUCHI, 1989). Thus, it is evident that the pyroxene assemblage is a fragment of a chondrule, which has mineralogical and textural properties similar to the most frequently observed Type-I (i.e. low FeO) porphyritic chondrules in the CO chondrites.

On the basis of these petrologic and isotopic results, we conclude that the A5 CAI contains a fragment of a chondrule. This chondrule fragment survived the last melting event in the formation of the CAI, probably because of the short duration of heating and cooling. The chondrule fragment must have formed before the CAI, which indicates that chondrule and CAI formation overlapped, at least partly, both in time and in space. Another important finding in the CAI is that a O-16-rich liquid encloses a relict CAI melilite fragment with a more O-16-poor composition. This indicates that O-isotopic variation in CAIs occurred in the solar nebula and did not monotonically changed from O-16-rich to O-16-poor. Therefore, the O-isotopic composition of solids in the solar nebula did not uniformly evolve from O-16-rich to O-16-poor. This occurrence, combined with the previously reported CAI-bearing chondrules (BISCHOFF and KEIL, 1984; SRINIVASAN and BISCHOFF, 1998; KROT et al., 1999; MARUYAMA et al., 1999), strongly suggest that the chondrule and CAI forming events overlapped, in both time and space.

Here we propose the model for indicating that CAI-forming and chondrule-forming events are not independent but overlapped during early solar system evolution. Both O-16-poor melilite with small O isotopic zoning and O-16-rich glassy mesostasis are present in the CAI whereas the chondrule fragment is O-16-poor, suggesting that CAIs and chondrules formed during oscillation in O isotopic composition in the solar nebula. These results can be explained by dynamic material mixing in the solar nebula around violent proto-sun. This model is consistent with fluctuating X-wind model that chondrules and CAIs were possibly formed by X-ray flare heating arisen as a result of the time-dependent interaction of a protoplanetary disk with the magnetosphere of the proto-sun (SHU et al., 1997).