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Compositional evolution at late stage of protoplanetary accretion disk and the origin of primitive meteorites

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Recent progress in theoretical and observational studies have revealed dynamical evolution (temporal variations of mass accretion rate and surface density/temperature profiles, etc.) of protoplanetary disk, from which planetary systems are formed. Meanwhile, compositional evolution of the disk has not yet fully understood because of its complicated nature. To consider about this issue, chondrite, which is one of the most primitive objects in the solar system, has played an important role.

Coexistence of 16O-rich CAIs and 16O-poor chondrules in a chondrite implies that oxygen isotopic composition of the protoplanetary disk was heterogeneous. Considering that most chondrules formed after 2, 3 Myr of CAI formation, oxygen isotopic composition of the disk seems to have largely changed during this period. In addition, some CAIs have oxygen isotopic heterogeneities among their constituents, implying more complicated fluctuation of oxygen isotopic composition of the disk. Heterogeneous C/O ratio of the disk is also indicated from chondrite. For example, oldhamite (CaS) in the enstatite chondrite could be formed only in reduced environment (whose C/O ratio is larger than 0.95), while the solar proportion is ~0.5.

In this study, we present a theoretical model which illustrates compositional evolution of the protoplanetary disk. First, we formulate processes which would have changed the disk composition at evaporation area of each dust constituents (H2O ice, organics and silicate). This shows that the protoplanetary disk compositionally evolves with its dynamical evolution. Next, we simulate the compositional evolution of the disk by calculating enrichment due to above processes and transportation by advection-diffusion.

For the oxygen isotopic heterogeneity, numerical results have fluctuation range similar to those of Yurimoto and Kuramoto (2004) and analytical estimate. The time scale of the evolution is consistent with the interval between CAIs and chondrules formation. In addition, intermittent fluctuation of accretion rate, which is common phenomena at CTTS stage, possibly formed O-isotopically heterogeneous CAIs. For the C/O ratio heterogeneity, Nakano et al. (2003) suggested that evaporation of organics would form reduced environment but they did not take into account the effect of advection-diffusion. Our results shows that, even taking into account this effect, reduced environment would be formed at the evaporation area of organics. Estimated Duration of the reduced environment are 0.5-2 Myr. Moreover, reduced environment would also be formed in high-temperature region under several disk conditions. If this is the case, reduced refractory minerals such as SiC might be formed in the solar system. Addition of this solar SiC possibly explain the correlation between reduced nature and Si excess of the enstatite chondrite.