Molecular Cloud Origin for the Oxygen Isotopic Composition of the Earth

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Although the dynamical aspects for the formation of the Earth have been fairly well understood for the past two decades, the origin of building blocks of the Earth still remains an open issue. In particular, the mass-independent differences in oxygen isotopic compositions of meteoritic matters and the Earth have cast several unresolved issues especially on the sources of this major rock-forming element. On the basis of recent observations of star-forming regions and models of accreting proto-planetary disk, here we suggest that sources with different oxygen isotopic compositions may be formed within a parent molecular cloud and their heterogeneous incorporation into silicates may occur during disk accretion.

Production of 16O-depleted water ice in molecular cloud cores are suggested from the observational data and numerical models which reveal selective ultra-violet dissociation of C17O and C18O isotopomers by the self-shielding effect of C16O, the dominant oxygen-bearing gas species in such star forming environment. In an accreting proto-planetary disk, preferential drift of dust grains toward the proto-Sun is expected to cause the heterogeneous enrichment of water-vapor and carbon-bearing reduced gas species in the inner disk through the vaporization of ice and organic matters from dust grains. In particular, the change in disk accretion rate possibly causes large variation of water vapor content and C/O ratio within the inner disk even if no dust enrichment occurs.

Diversity in oxygen isotope composition and redox state observed among the Earth and meteorites is possibly interpreted as a consequence of reprocessing in such variable environments within the inner disk. 16O-rich meteoritic materials such as CAIs are interpreted to be formed before the water vapor enrichment, whereas most of matters forming meteorites and inner planets, relatively 16O-depleted, to be formed later. This interpretation is supported by the 16O-rich oxygen isotope composition of implanted solar wind extracted from metal grains in lunar soil (Hashizume & Chaussion, 2005). Just before the water-enrichment occurs, innermost disk possibly has high C/O ratio allowing the formation of SiC, which might play an important role in the Si/Mg fractionation as well in the control of redox state inferred from the chemical systematics of chondrites.

A direct test of this scenario would be to measure the oxygen isotopic compositions of cometary ices. We predict the oxygen isotopic values as delta 17 and 18O relative to SMOW to be +50 to +200 permils and –100 to –450 permils for cometary H2O and CO, respectively. 16O-depleted oxygen isotopic compositions are predicted for the outer planets and their satellites because they are enriched in heavy elements originated in significant part from H2O ice. Exploration of these bodies would also provide in future a critical constraint for models attempting to explain the oxygen isotopic heterogeneity in the solar system.