EVOLUTION OF OXYGEN ISOTOPE RESERVOIRS IN THE EARLY SOLAR SYSTEM. H. Yurimoto[1] and K. Nagashima[2], [1]Natural History Sciences, Hokkaido University, Sapporo 060-0810, Japan (yuri@ep.sci.hokudai.ac.jp), [2]Hawai‘i Institute of Geophysics and Planetology, University of Hawai‘i at Mānoa, USA (kazu@higp hawaii.edu).

Introduction: Oxygen is the third most abundant element in the universe and the most abundant element of the terrestrial planets. The presence of oxygen in both gaseous and solid phases makes oxygen isotopes (terrestrial relative abundances: ^{16}O = 99.757%, ^{17}O = 0.038%, and ^{18}O = 0.205%) important tracers of various fractionation processes in the solar nebula, which are essential for understanding the evolution of the early Solar System.

Since the discovery of oxygen-isotope anomaly in the solar system [1], the style of systematics of the anomaly has basically unchanged, but the range of their variations has been significantly enlarged [2-6]. The systematics is simply characterized by the variation along a slope-1 line on oxygen three-isotope diagram. Because materials having the oxygen isotope anomaly seem to be formed by usual chemical thermodynamic processes, the solpe-1 variations of oxygen isotopes can be understood by results of mixing of ^{16}O-rich and ^{16}O-poor reservoirs.

Numerous reservoirs having different oxygen-isotope compositions have been proposed from measurements of chondrite components, for example, a presolar dust component [7], nebular gas [7-9], nebular dusts [10, 11], ice [5], and organics [6]. Matrices of chondrites appear to contain all components originated from different oxygen-isotope reservoirs [2, 12]. However, relationships and evolution between proposed reservoirs remain controversial.

Recently, Solar oxygen isotopic composition was determined by solar wind and is enriched in ^{16}O compared to the terrestrial composition [13]. Self-shielding models have predicted the ^{16}O-rich composition [14-16]. The models suggest that oxygen isotopic composition of solar nebula started from the ^{16}O-rich composition and changed to ^{16}O-poor during the first ~million years of the early solar system [15]. The time scale of the oxygen-isotope evolution in the solar nebula is consistent with the time difference between Ca- and Al-rich inclusions (CAIs) and chondrule ages [17, 18].

In this paper, we discuss the evolution of oxygen isotope reservoirs in the early solar system according to the self-shielding model.

Evolution from Molecular Cloud age to Protostar age: By self-shielding of CO and proceeding ice formation, oxygen isotope anomaly along the slope-1 line is formed between gas and ice. The typical $\delta^{17,18}O_{SMOW}$ is ~+200‰ for H_2O ice inferred from the cosmic symplectite, COS found in matrix of Acfer 094 chondrite [5], and is ~−200‰ for CO molecules calculated by mass balance of solar nebular components. The heterogeneous oxygen isotopic distribution between phases exists in the outside of snowline of the solar nebula (outer solar nebula). Oxygen isotopic composition of outer solar nebular gas correspond to $\delta^{17,18}O_{SMOW}$ =~−200‰ because CO is the most dominant gas species containing oxygen.

On the other hand, in the inside of snowline (inner solar nebula), the mean oxygen isotopic composition of the nebular gas corresponds to the solar value, $\delta^{17,18}O_{SMOW}$ of ~−60‰ determined by the solar wind [13] because the ice evaporates and is mixed with the nebular gas. Isotopic equilibrium among gas species would proceed in the inner solar nebula because of higher temperature and higher pressure of this region.

Minerals formed in the inner solar nebula of this age would have ^{16}O-rich compositions close to $\delta^{17,18}O_{SMOW}$ = −60‰. Because CAIs are thought to be formed in the inner solar nebula, possibly near the proto-Sun [19], CAIs composed of uniformly ^{16}O-rich minerals might have formed in this age. Fine-grained CAIs and amoeboid olivine aggregates (AOAs) tend to have only ^{16}O-rich minerals [2], which may suggest that they formed by condensation from the ^{16}O-enriched nebular gas.

Minerals formed in the outer solar nebula would reflect the oxygen isotopic compositions of gas species reacted. The COSs in Acfer 094 chondrite [5] might have formed in the outer solar nebula of this age.

Evolution in T-Tauri Star age: In this age, oxygen isotopic composition of the gas in the inner solar nebula becomes depleted in ^{16}O because of enrichment of ^{16}O-depleted H_2O vapor, while the situation of the outer solar nebular remains unchanged [3, 15]. Isotopic equilibrium in the inner nebular gas would proceed because of higher temperature and higher pressure in the inner solar nebula. The typical $\delta^{17,18}O_{SMOW}$ of the inner nebular gas is ~0‰. Minerals formed in the inner solar nebula of this age would have ^{16}O-poor compositions close to $\delta^{17,18}O_{SMOW}$ =0‰. Most chondrules have this ^{16}O-poor signature [2].

The nebular gas is terminated at the inner edge of the nebular disk. The space between the inner disk-edge and the Sun is permeated with solar coronal flow with O-isotope composition of $\delta^{17,18}O_{SMOW}$ = ~−60‰. Therefore, there could be ^{16}O-rich and ^{16}O-poor reservoirs coexisting near the Sun as a dynamic steady state [2].

The coexistence of ^{16}O-rich and ^{16}O-poor reservoirs are supported by oxygen-isotope compositions recorded in CAIs. Many coarse-grained CAIs and some fine-grained CAIs have heterogeneous oxygen-isotope compositions composed of both ^{16}O-rich and ^{16}O-poor minerals [2]. This heterogeneity is likely due to oxygen isotope exchange between the initially ^{16}O-rich CAIs and ^{16}O-poor external reservoir and vice versa. Thermal processing of CAIs in ^{16}O-poor nebular gas may explain ^{16}O-poor minerals in CAIs [8, 9, 20]. Relict ^{16}O-poor ultra-refractory Zr, Sc, and Y-rich CAIs inside ^{16}O-rich less refractory inclusion also suggest coexistence of the two oxygen-isotope reservoirs [21].

The coexistence of ^{16}O-rich and ^{16}O-poor reservoirs during CAI formation is further constrained by combination studies of ^{26}Al-^{27}Mg and O-isotope systematics of CAIs [22, 23].

Present Solar System: The heritage of oxygen isotope reservoirs in the early solar system would be remained in the present solar system. Oxygen isotopic compositions of planets and satellites can be inferred from the evolution of the oxygen isotope reservoirs in the early solar system [24]. Nitrogen and hydrogen isotopic compositions of planets and satellites should be correlated if the evolution model is correct.

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