

AN EXTREME ^{16}O -RICH CHONDRULE FROM ACFER 214 CH CHONDRITE. S. Kobayashi¹, H. Imai¹, and H. Yurimoto¹, ¹Department of Earth and Planetary Sciences, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro, Tokyo 152-8551, Japan (yuri@geo.titech.ac.jp)

Introduction: Oxygen isotope systematics between ^{16}O -rich and ^{16}O -poor reservoirs is well known in the solar system [1]. Since O is account for over 50 atomic % of terrestrial planets and also dominant in the solar nebular gas next to H and He [2], range and distribution of the systematics is an important tracer recording origin and global evolution of early solar system. The ^{16}O -rich endmember, about 5% enrichment relative to the terrestrial mean value, has been observed only in refractory inclusions that are <5 volume % constituents of chondrites [1,3]. Other 95 volume % of chondrite is relatively depleted in ^{16}O close to the terrestrial value. Therefore, it has been believed that ^{16}O -rich reservoirs existed at refractory inclusion forming event corresponding to the oldest dating in the solar system [4]. Here we report a chondrule consisting of about 8% enrichment of ^{16}O relative to the terrestrial value. This value corresponds to the lightest atomic weight of O in the solar materials ever found. The lightest oxygen found in abundant constituents of chondrites strongly suggests that ^{16}O -rich reservoir contained gaseous species with isotopically almost pure in ^{16}O or were universally distributed as dusts in the early solar system. In either case, O isotopic heterogeneities in the early solar system were at least two times greater than conventional thought.

Analytical Methods: The chondrule was found in a polished thin section of Acfer 214 CH chondrite. Back scattered electron images collected using a JEOL JSM-5310LV scanning electron microscope equipped with an Oxford LINK-ISIS energy dispersive detector. Quantitative elemental analyses of minerals were collected using JEOL JXA-8800 electron microprobe. *In situ* oxygen isotope analyses were collected with a TiTech Cameca 1270 SIMS instrument under analytical conditions previously described [5].

Mineralogy and Textures: An extreme ^{16}O -rich chondrule of $\delta^{17,18}\text{O}_{\text{SMOW}} \approx -75\%$, which we have designated a006, was found in a thin section of the Acfer 214 CH chondrite (Fig. 1).

The a006 chondrule has spherical core-shell structure with $\sim 130 \mu\text{m}$ across. The core is $\sim 100 \mu\text{m}$ across and shows multiple extinction under polarized optical microscope, indicating a nonporphyritic cryptocrystalline chondrule. The core is composed of submicrometer-size crystalline minerals (probably olivine and enstatite) and Ca-Al-containing glass enclosing small vesicles. Chromian spinel of $< 0.3 \mu\text{m}$ across appears on the surface as a minor phase. Unusual point from typical

cryptocrystalline chondrules is that the core is surrounded by olivine shell (Fo99) of $\sim 10 \mu\text{m}$ thick. Ca-rich pyroxene grains of $< \sim 1 \mu\text{m}$ across are mainly arranged at the boundary between the glassy core and olivine shell.

The bulk compositions are depleted in moderate volatile elements such as Mn and Na and metallic iron. These characteristics are similar to other nonporphyritic chondrules in CH chondrites [6]. On the other hand, refractory and normal lithophile elements in the chondrule show close to solar abundance ratios. Major compositions of this chondrule are similar to CR or O chondrite and included in compositional range of FeO-poor magnesian chondrules that are commonly observed in chondrites.

The cryptocrystalline texture with surrounding olivine shell indicates that the a006 chondrule crystallized from totally molten liquid droplet. The bulk chemical composition indicates that olivine is the first liquidus mineral. This crystallization sequence is consistent to the texture. Depletions of moderate volatile elements would have occurred by evaporation during the melting.

Oxygen Isotopic Results: Oxygen isotopic compositions of cryptocrystalline chondrules in Acfer 214 are commonly in ^{16}O -poor (Fig. 2) and are distributed within the range of chondrules of other carbonaceous chondrites [1]. In contrast, the chondrule, a006, is extremely enriched in ^{16}O with $\delta^{17,18}\text{O}_{\text{SMOW}} \approx -75\%$ (Fig. 2) and plotted on carbonaceous chondrite anhydrous minerals (CCAM) line [1] or slope-1 line [7] extrapolated towards pure ^{16}O composition (Fig. 1). The lightest O composition is homogeneously distributed in the whole chondrule.

The homogeneous distribution of O isotopic composition is consistent to complete melting origin of the chondrule, and indicates O isotopic composition of the liquid droplet was $\delta^{17,18}\text{O}_{\text{SMOW}} \approx -75\%$. Although large ^{16}O -enrichments had been only observed in refractory inclusions, oxygen isotopic compositions of refractory inclusions [1,8] including Acfer 214 and other CH chondrites [9] are distributed in $\delta^{17,18}\text{O}_{\text{SMOW}} > -50\%$ (Fig. 2). Therefore, refractory inclusions or refractory inclusion bearing chondrules [10,11] are not appropriate candidates as a006 precursor.

Discussion: Discovery of this chondrule demonstrates that ^{16}O -rich reservoir in the solar system must have the O isotopic composition of $\delta^{17,18}\text{O}_{\text{SMOW}} \leq -75\%$ which is clearly ^{16}O -rich side exceeding the conventional ^{16}O -rich limit. The O isotopic heterogeneity ob-

served in solar system is apparently explained by O isotope mixing between ^{16}O -rich and ^{16}O -poor cryptocrystalline chondrules (Fig. 2). These results indicate that the extreme ^{16}O -rich signature may have been widely distributed in nebular dust components and CH chondrite collected and has preserved pristine solar nebular materials formed in various nebular environments that we have not observed yet. Moreover, we emphasize that the maximum ^{16}O -enrichment is observed in a chondrule but not in refractory inclusions. Thus, any refractory inclusions previously reported have not recorded pristine signature of ^{16}O -rich reservoir in the early solar system. Refractory inclusions have experienced alterations to change not only chemical composition but also O isotopic composition through the formation.

Since the major compositions of the extreme ^{16}O -rich chondrule have similar trend of other cryptocrystalline chondrules in CH-chondrite [12], the chondrule would have directly condensed from hot nebular gas. If this origin is correct, the ^{16}O -rich reservoir is gaseous with $\delta^{17,18}\text{O}_{\text{SMOW}} \approx -75\text{‰}$. Another possibility is according to conventional chondrule forming model, i.e., chondrules were formed by flash melting of precursor dusts [13]. In this case the precursor of this chondrule has $\delta^{17,18}\text{O}_{\text{SMOW}} \approx -75\text{‰}$. In either case, existence of the ^{16}O -rich chondrule suggests that ^{16}O -rich reservoir was alive at chondrule formation and the degree of ^{16}O -enrichment was much larger than those at refractory inclusion formation, or the ^{16}O -rich chondrule formed at refractory inclusion formation but in more ^{16}O -rich reservoir. Dating of the ^{16}O -rich chondrule would be helpful to answer which scenario is plausible for the formation.

References: [1] R. N. Clayton (1993) *Ann. Rev. Earth Planet. Sci.* **21**, 115-149. [2] E. Anders, N. Grevasse (1989) *Geochim. Cosmochim. Acta* **53**, 197-214. [3] G. J. MacPherson et al. (1988) in *Meteorites and the Early Solar System* J. F. Kerridge, M. S. Matthews, Eds. (Univ. Arizona Press) pp. 746-807. [4] Y. Amelin et al. (2002) *Science* **297**, 1678-1683. [5] H. Yurimoto et al. (1998) *Science* **282**, 1874-1877. [6] A. N. Krot et al., (2001) *Science* **291**, 1776-1779. [7] E. D. Young, S. S. Russell, (1998) *Science* **282**, 452-455. [8] S. Itoh et al. (2000) *Lunar Planetary* **31**, 1323. [9] K. D. Mckeegan et al. *Earth Planet. Sci. Lett.*, (submitted) (2002). [10] A. N. Krot et al., (1999) *Lunar Planetary* **30**, 1511. [11] H. Yurimoto, J. T. Wasson (2002) *Geochim. Cosmochim. Acta* **66**, 4355-4363. [12] A. N. Krot et al. (2002) *Meteoritics & Planetary Science* **37**, 1451-1490. [13] J. N. Grossman et al. (1988) in *Meteorites and The Early Solar System* M. S. Matthews, Ed. (University of Arizona Press) pp. 619-659.

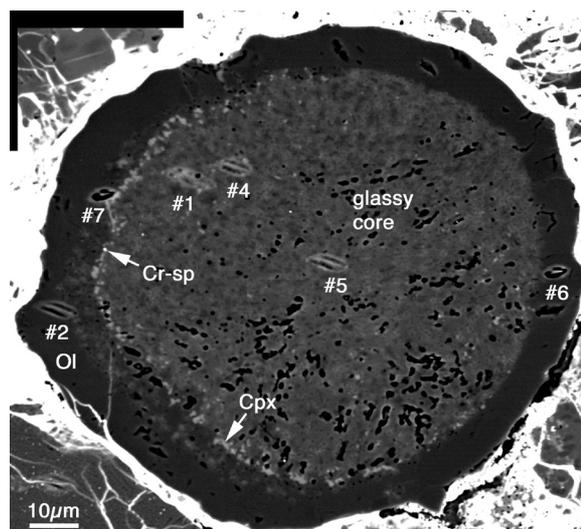


Fig 1. Back scattered electron image of an extreme ^{16}O -rich chondrule, a006. Analyzing points of O isotopic measurements are shown as sputtered craters of 5 to 7 μm across. Ol: olivine, Cpx: Ca-rich pyroxene.

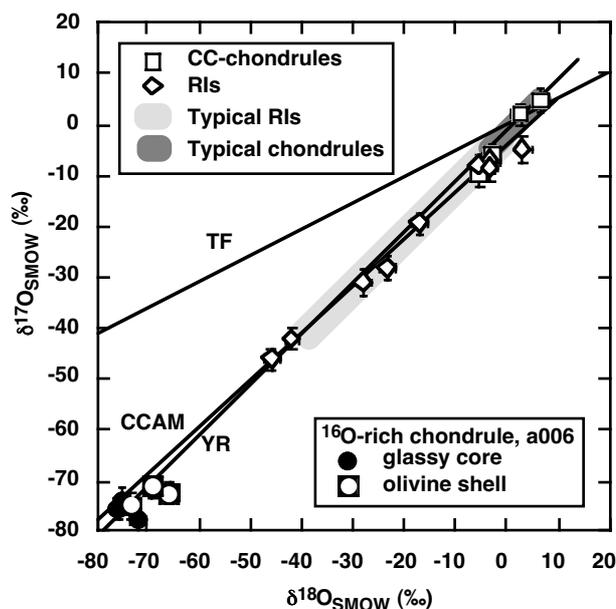


Fig. 2. Oxygen isotopic compositions of cryptocrystalline (CC-) chondrules and refractory inclusions (RIs) from Acfer 214 CH chondrite. All plots of refractory inclusions and chondrules can be explained by O isotope mixing between the ^{16}O -richest and ^{16}O -poorest chondrules.