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Remnants of pristine water of the early solar system: Discovery of extreme O-17 O-18 rich materials from Acfer 094

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Oxygen isotopes of meteorites are a key tracer to solve issues for origin and early evolution of the solar system. Oxygen in meteorites changes their isotopes not only by mass-dependent isotope fractionation law, but also by mass-independent isotope fractionation (MIF) keeping nearly constant O-17/O-18 ratio. The observed MIF for oxygen is as large as a range from -80 permil to 0 permil relative to the standard mean ocean water (SMOW). In this study, we report isotopically and chemically unique material from Acfer 094 chondrite, that have extremely large MIF enriched in O-17 and O-18 than ever reported (+180 permil relative to SMOW).

Polished thin sections of Acfer 094 C3-ungrouped chondrite and Murchison CM2 chondrite were prepared. The chemical compositions have been determined by electron probe microanalysis using an energy dispersive X-ray spectrometer (EDS, Oxford INCAEnergy) attached on a field-emission type scanning electron microscope (FE-SEM, JEOL JSM-7000F). A Hokudai isotope microscope system (Cameca ims-1270 + SCAPS; originally installed in Tokyo Institute of Technology and now in Hokkaido Univ. (Hokudai)) has been used to image precise oxygen isotope distribution (isotopography) in the meteorite matrix. A point analysis of secondary ion mass spectrometry (SIMS) has been also applied to determine oxygen isotopic compositions using the Cameca ims-1270. An analytical transmission electron microscope (ATEM, JEOL JEM-2010) equipped with EDS (Thermo Electron Noran system SIX) has been used to analyze crystal structure, crystal size, texture and compositions. A sample for ATEM study was directly cut out from the thin section by focused ion beam (FIB) method using SII NanoTechnology SMI3050TB instrument.

The typical composition (in wt%) of the chemically unique material may be represented as Fe, 61.6; Ni, 5.4; O, 19.3; S, 9.6; Mg, 0.1; and Si, 0.2. ATEM suggests that this material is composed of aggregate of nanocrystals over the range between 10nm and 200nm. The electron diffraction patterns from ˜100 nm sized crystals reveal that the main spots of this material are similar to those of magnetite (space group Fd3m) and corresponding cell parameter is a =˜0.83 nm. But there are weak extra spots between them, indicating a 3-fold superstructure. The ATEM study has been detected the same elements detected by the FE-SEM-EDS study from individual crystals. The materials are often surrounded by fractured FeS similar to comet FeS grains of STARDUST mission. Therefore, the crystals seem to be a sulfur-bearing magnetite-like structure and to be likely a new mineral although more detail characterization is necessary to identify the phase. We label these materials as new poorly characterized phase (new-PCP) because conventional PCPs or tochilinite observed in aqueously altered carbonaceous chondrites consist of those elements. We found 22 new-PCP grains in totally 11 square millimeters area of the Acfer 094. The abundance of new-PCP in the matrix is calculated to be 94 ppm by volume and 3.3 per square millimeters for grain density. Six new-PCP grains from Acfer 094 were analyzed by isotopography and oxygen isotopic compositions of a grain among them were determined by conventional point analysis by SIMS. One PCP grain from Murchison was measured by isotopography. The new-PCP is significantly enriched in O-17 and O-18 of +180 permil relative to the Earth, while the PCP has oxygen isotopic composition similar to the Earth. This extreme MIF shows that the MIF of oxygen in our solar system have extended more than triple ever believed. Recent theoretical studies suggest that oxygen isotopic composition of water ice in the solar nebula was extremely enriched in O-17 and O-18. The enrichment factor of the water estimated is comparable to that of the new-PCP. Therefore, new-PCP would be formed in the water ice enriched environment in the early solar system. The oxygen isotopic composition of new-PCP would be a proxy of nebular water ice.