

THE THERMAL EVOLUTION OF THE PRIMITIVE HYDROUS ASTEROIDS RECORDED IN DEHYDRATED CARBONACEOUS CHONDRITES. A. Nakato¹, T. Nakamura¹, T. Noguchi², I. Ahn³, and J. I. Lee³, ¹Tohoku University, Miyagi, 980-8578, Japan. (aiko@s.tohoku.ac.jp), ²Ibaraki University, Ibaraki, 310-8512, Japan., ³Korean Polar Research Institute, Incheon, 406-840, Korea.

Introduction: Based on the evidence derived from spectroscopic observation and meteorite analysis, some C type asteroids were heated and dehydrated after aqueous alteration [e. g., 1]. On the other hand, more than 20 samples of hydrous carbonaceous chondrites, mainly CM and CI chondrites, show evidence of dehydration due to high temperature heating in their parent asteroids [e. g., 2, 3]. It is important to understand ranges of mineralogical and chemical variations in hydrous carbonaceous chondrites having been dehydrated by heating, because the variation reflects diversity of the asteroids that underwent thermal evolution. In this study, detailed mineralogical and compositional properties of dehydrated carbonaceous chondrites were characterized by various analytical methods in order to recognize the variations of dehydrated CM and CM-like chondrites.

Dehydrated CM samples and experimental procedures: To identify samples experienced thermal metamorphism, we are studying more than 40 samples of CM and CM-like carbonaceous chondrites. Fine-grained phyllosilicate-rich matrix is a sensitive indicator of heating. Prior to detailed mineralogical studies, synchrotron X-ray diffraction (XRD) analysis was performed for small pieces of matrices of all samples and the results indicate that matrix phyllosilicates in Belgica (B-) 7904, Dhofar 735, EET 87522, PCA 91084, Yamato86695, LAR 06318, ALH 84033, DOM 03183, and MIL 05152 are decomposed and two of them (B-7904 and Dhofar735) show evidence that they suffered strong heating enough to crystallize secondary olivine and pyroxene.

To understand variations of conditions of thermal metamorphism in these chondrites, transmitted electron microscope (TEM) and FE-SEM/EDS observation, and FE-EPMA/WDS analysis were carried out. The maturation grade of organics in matrix is estimated by micro-Raman spectroscopy. In addition, oxygen isotopic compositions of bulk chondrites were analyzed by oxygen isotope mass spectrometer equipped with a CO₂ laser and BrF₅ fluorination system at Korea Polar Research Institute [4].

Results and Discussion: Most of samples, excepting B-7904 and Dhofar735, show evidence that they experienced weak thermal metamorphism. The interpretation is confirmed by low maturation grade of organics measured by micro-Raman spectroscopy, low totals of FE-EPMA analysis of matrices, and detection

of relatively high Cr₂O₃ concentration (approximately 0.35 wt%) in large ferroan olivines in type-II chondrules. TEM observation of matrices of these samples shows that phyllosilicates were partially replaced by amorphous materials and the degree of crystalline-to-amorphous transformation varies between samples. This indicates that the temperature of heating differs between samples. On a three oxygen isotope plot, these chondrites distribute along a CM-CO-TagishLake line. It indicates that these chondrites formed from the same oxygen isotopic reservoir.

The mineralogy of B-7904 and Dhofar735 suggests that these samples suffered strong heating. It is consistent with previous studies [e. g., 5, 6]. They show high maturation grade of organics, high analytical totals of matrices and detection of ~0.27 wt% Cr₂O₃ in type-II chondrules. Primary olivine grains at outer edges of chondrules in B-7904 and Dhofar735 ubiquitously show narrow Fe-Mg zoning. Since Mg-Fe interdiffusion rates is faster than any cation diffusion rates in silicate crystals in CM chondrites, it implies that durations of heating is much shorter than those expected for internal heating that keeps maximum temperature over million years [3]. Therefore, it is unlikely that the short-lived radionuclide ²⁶Al is a heat source for dehydration of these two chondrites.

Besides, their chemical composition of matrix and bulk oxygen isotopic compositions differ from the other samples. Si enrichment of their matrices indicates the presence of not only serpentine and but also saponite prior to heating in their parent asteroids. The presence of saponite indicates that aqueous alteration of the two samples proceeded in the solution enriched in SiO₂. Oxygen isotopic compositions of these samples show smaller Δ¹⁷O than that of the other samples. Based on all results about B-7904 and Dhofar735, the conditions of aqueous alteration and thermal metamorphism in their parent asteroids might be completely different from the other dehydrated CM or CM-like carbonaceous chondrites.

LAR06318 and ALH84033 have unique oxygen isotopic compositions: they are plotted on or close to CCAM line and not on the CM-CO-TagishLake line (Fig.1). FE-SEM observation indicates that both meteorites show a low abundance of chondrules and thus the oxygen composition represents matrix oxygen isotope ratios. The two meteorite samples are expected to have characteristic matrix properties similar to an unique CM2 chondrite Al Quss Ab Said that has matrix oxygen composition plotted on the CCAM line [7].

TEM and FE-SEM observation indicates that matrix of LAR06318 have high abundance of primary Mg-rich anhydrous silicates. The anhydrous silicates such as olivine and low-Ca pyroxene occupy approximately several tens areal percents in one thin slice of matrix prepared by the ultramicrotomy. Low-grade of aqueous alteration is responsible for the high abundance of primary silicates in the matrix of LAR06318. The high primary silicate abundance is consistent with the oxygen composition falling on the CCAM line.

However, major parts of matrix of LAR06318 consists of phyllosilicates and decomposed phyllosilicates. The presence of prism reflection in XRD patterns and the low totals of FE-EPMA analysis confirm the presence of hydrous phases. Therefore, in a bulk sample of LAR06318, phyllosilicates and decomposed phyllosilicates are most dominant phases and oxygen composition of the bulk samples should reflect that of these phases. Our mineralogical and bulk oxygen isotope analysis suggest that hydrous phases in the matrix of LAR06318 has oxygen composition that falls on the CCAM line.

Phyllosilicate-dominant matrix of typical CM2 chondrite such as Murchison has oxygen composition on the CM-CO-TagishLake line and not on the CCAM line, because prevailed aqueous alteration changes oxygen composition from CCAM toward CM-CO-TagishLake line due mainly to low-temperature equilibration between water and phyllosilicates [8]. On the contrary, matrix of LAR06318 shows mineralogical evidence indicating that aqueous alteration is far from final equilibration and has oxygen composition on the CCAM line. These facts can be explained as follows: The solution in the parent body prior to aqueous alteration had oxygen composition somewhere upper-right part on CCAM line relative to matrix composition. The presence of water with such composition was predicted in [8, 9]. Incomplete reactions between the solution and pre-existing anhydrous silicates took place, but oxygen composition of matrix did not change so much because the alteration did not reach equilibration. The alteration might have occurred at low water/rock ratio, because, in this condition, the newly formed hydrous phases would have oxygen composition close to primary anhydrous silicates. SIMS analysis of matrix of LAR06318 is required in order to testify this hypothesis.

TEM observation revealed some indigenous features of primary anhydrous silicates in LAR06318 matrix. Most of submicron size primary olivine and pyroxene show Mg-rich chemical composition, however some of them having relatively high Mn concentration can be LIME olivine and pyroxene. In additions, we discovered some unique enstatites, which are similar to enstatite platelets observed in IDPs, in the matrix. Based on its morphology, the enstatite might have formed by

primary vapor phase condensation in the early solar nebula [10].

All results taken together, it is concluded that the degree of heating and the original mineralogy prior to heating vary among nine hydrous carbonaceous chondrites, which results in a wide variation of dehydrated primitive asteroids in mineralogy and organic chemistry. In addition, with respect to oxygen isotope ratios, the carbonaceous chondrite samples analyzed make three different groups: B-7904 and Dhofar735, LAR06318 and ALH84033, and the others. It suggests that aqueous alteration, in addition to post-alteration heating, has taken place at variable degrees and conditions.

Acknowledgement: Meteorites samples were allocated to us from NASA/JSC (USA) and NIPR (Japan). This work was supported by Japan Society for the Promotion of Science

References: [1] Hiroi T. et al. (1993) *Science*, 261, 1016-1018. [2] Kimura, M. and Ikeda Y. (1992) *Proc. NIPR Symp. on Antarctic Meteorites*, 5, 74-119. [3] Nakato A. et al. (2008) *Earth, Planets and Space*, 60, 855-854. [4] Ahn I. et al. (2009) *72nd Annual Meeting of the Meteoritical Society*, Abstract #5219. [5] Tomooka K. (1990) *Proc. NIPR Symp. Antarct. Meteorites*, 3, 40-54. [6] Ivanova M. A. et al. (2004) *67th Annual Meeting of the Meteoritical Society*, Abstract #5013. [7] Nakamura T. et al. (2008) *71st Annual Meeting of the Meteoritical Society*, Abstract #5124. [8] Clayton R. N. and Mayeda. T. K. (1984) *Earth and Planetary Science Letters*, 67, 151-161. [9] Sakamoto N. et al. (2006) *Science*, 317, 231-233. [10] Bradley J. P. et al. (1983) *Nature*, 301, 473-475.

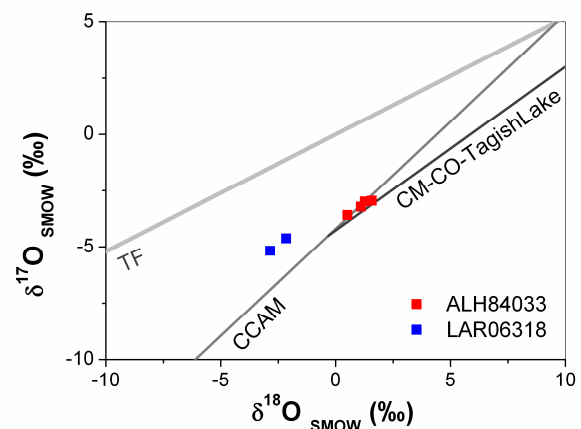


Fig.1. Three oxygen isotope plot of ALH84033 and LAR06318. They are plotted on or close to CCAM line.