THERMAL METAMORPHISM OF CM CARBONACEOUS CHONDRITES: EFFECTS ON PHYLLOSILICATE MINERALOGY AND PRESOLAR GRAIN ABUNDANCES. T. Nakamura[1], R. Okazaki[1] and G. R. Huss[2], [1]Department of Earth and Planetary Science, Kyushu University, Hakozaki, Fukuoka 81-8581, Japan (tomoki@geo.kyushu-u.ac.jp), [2]Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Manoa, Honolulu, HI 96822, USA.

Introduction: CM carbonaceous chondrites have been constituent materials of hydrated planetesimals in the early solar system. They consist mainly of hydrous minerals as a result of extensive aqueous alteration. At a certain period after the aqueous alteration, many CM chondrites have been heated to higher temperature [e.g., 1], which caused evaporation loss of highly volatile elements [2] and dehydration of hydrous minerals [e.g., 3-5]. However, it remains unknown when the heating took place and what induced the heating. To address this issue, a combined study on mineralogy and noble gas isotopes was carried out on CM chondrites, which were heated to various extents based on the results of previous mineralogical and bulk chemical studies [2-5]. Our noble gas study includes analysis of acid-residues, diamond separates, and SiC+spinel separates prepared by chemical processing of two thermally metamorphosed CM chondrites.

Results and discussion: CM matrix is an aggregate of very fine particles of mostly hydrous minerals; thus it is a sensitive indicator to heating. Synchrotron X-ray diffraction (SR-XRD) analysis indicates that CM matrix can be classified into four heating stages based on the degree of thermal decomposition of hydrous minerals [6]: Stage I is unheated or very weakly heated samples (< 300°C) that consists of hydrous phases such as serpentine and tochilinite, stage II is weakly heated samples (< 500°C) that consist mostly of amorphous silicates formed from decomposed phyllosilicates, stage III is moderately heated samples (<700°C) that consist of poorly crystallized olivine, and stage IV is strongly heated samples (>700°C) that consist of crystalline olivine and low-Ca pyroxene. Samples investigated by SR-XRD in the present study are: Stage I samples are Murray, Murchison, Y-791198, A-881458, and Y-793495, stage II samples are A-881334, Y-86695, and Y-793321, no stage III sample, and stage IV samples are B-7904 and Y-86789. Matrix particles of each CM chondrite were exposed to synchrotron X-rays with a wave length of 2.161Å in the Gandolfi camera to produce X-ray diffraction patterns. The analysis was performed at beam line 4A of the Photon Factory, High Energy Accelerator Research Organization, Japan.

Matrices of CM chondrites contain large amounts of trapped noble gases. The abundance of noble gases is expected to reflect the degree of heating. Noble gas analyses were performed on meteorite chips of Murray (stage I), A-881458 (stage I), Y-86695 (stage II), Y-793321 (stage II), A-881334 (stage II), B-7904 (stage IV), and Y-86789 (stage IV), using a MM5400 mass spectrometer at Kyushu University equipped with a Ta furnace and a stainless steel purification line "Jack and the beanstalk". Noble gases were characterized by stepwise pyrolysis at seven temperature steps; 260, 500, 680, 910, 1140, 1400, and 1700 °C. Light noble gases in a stage-I sample A-881458 and those in a stage-II sample Y-793321 were dominated by solar-wind noble gases. In Y-793321, parts of solar noble gases, which are extracted in low temperature fractions (< 500°C) during stepwise heating analysis, were depleted due to heating in a parent asteroid, and the temperature is consistent with that estimated based on stage-II matrix mineralogy. Details of mineralogy and noble gas signatures of Y-793321 and A-881458 were summarized recently in Nakamura (2006) [7].

Concentrations of trapped heavy noble gases, Ar, Kr, and Xe, decrease in stage-II and especially in stage-IV samples relative to stage-I samples. In the stage-IV samples B-7904 and Y-86789, $^{36}Ar_{trap}$ concentrations are approximately 1/3 of those of stage-I samples, indicating significant loss of Q-type noble gases from phase Q as well as P3 noble gases from pre-solar diamonds. The depletion is observed in temperature steps from 250 to 910°C, and thus suggests that the two meteorites were heated in space at least to 910°C. Stepped heating analyses of bulk meteorites therefore indicate that noble gas depletion in stage-IV samples is much greater than that in stage-II samples and that the temperature of heating estimated from noble gas loss is in agreement with that estimated from matrix mineralogy. The good correlation demonstrates that both the dehydration of phyllosilicates and the loss of trapped noble gases occurred simultaneously by the same heating events.

It is well known that trapped noble gases in carbonaceous chondrites are located in various carrier phases.

Concentrations of ^{22}Ne in specific carriers were determined by separating noble gases using isotopic ratios of the each end member. We adopted this separation to solar-gas poor samples. The results show that presolar diamonds have lost parts of noble gases during heating events, because the total concentrations of ^{22}Ne-A2 decrease with the increase of the degree of heating. On the other hand, presolar SiC grains seem to have retained noble gases during the heating, since the total concentrations of ^{22}Ne-E are nearly constant at 1~2 x 10^{-9} cc/g in all samples irrespective of heating degrees. ^{22}Ne-E was mainly extracted at relatively high temperatures in stepwise heating analysis and thus it is probably located mainly in SiC.

To obtain accurate changes of abundances of presolar grains during heating of CM chondrite parent bodies, chemical treatment was performed at ASU on a 0.7g chip of a stage-II sample Y-86695 and a 1.1g chip of a stage IV sample Y-86720 (pared with Y-86789), using a high-yield procedure developed by Huss and Lewis [8]. The treatment produced four fractions: HF/HCl residue, chromic-acid etched residue, diamond separate, and SiC+spinel separate. The results of step-heating noble gas analysis indicate that both $^{36}Ar_{trap}$ and ^{22}Ne-A2 concentrations are slightly lower in Y-86695 and significantly lower in Y-86720 compared with stage-I meteorites, Murray and Murchison [9]. On the other hand, ^{22}Ne-E concentration is nearly constant at ~2 x 10^{-9} cc/g in the two heated samples and in Murray and Murchison [9]. These results are essentially consistent with those of analysis of bulk meteorite chips.

SEM and FE-SEM observations indicate that, in spite of high temperatures during the heating, the thermally activated kinetic processes such as recrystallization and diffusion did not prevailed even in the stage-IV samples, which indicates short duration of heating. Matrix of the stage-IV samples mainly consists of fibrous materials. The texture strongly suggests pseudomorphic decomposition of hydrous phases into secondary recrystallized phases, mainly olivine. But the secondary olivine grains cannot be distinguished by FE-SEM, indicating that the diameter of the olivine particles is less than 100 nm, being consistent with [3]. The small grain size of the secondary olivine suggests short duration at high temperatures. In addition, Mg-rich olivines in chondrules in contact with Fe-rich matrix in stage-IV samples show very narrow Fe-Mg zoning less than 1μm width, which differs from the olivines in ordinary chondrites with petrologic type 3.4 to 3.8 that exhibit extensive Fe-Mg zoning due to prolonged heating. The zoning resulted from Fe-Mg inter-diffusion between chondrules and matrix during high temperature regime. The temperature of the heating is comparable between heated CM chondrites and the type 3.4-3.8 ordinary chondrites (around 400 to 700°C [e.g., 10]), thus the lack of extensive zoning suggests a short duration heating of CM chondrites.

Next question is when the heating occurred. The noble gas data gave crucial information on timing. In addition to the depletion of trapped noble gases, radiogenic noble gases, not only short-half-life decay products such as ^{129}Xe but also long-half-life decay products such as ^{40}Ar, are apparently depleted in heated samples relative to Murray. The degree of depletion is in accordance with increasing heating stage. This indicates that the heating events that caused both phyllosilicate decomposition and trapped-noble-gas depletion also induced the depletion of radiogenic noble gases. Potassium contents are relatively constant among the meteorites [11]: 370, 320, 320, and 400 ppm for Murray, A-881334, B-7904, and Y-86789, respectively, but ^{40}Ar is depleted in the heated samples by up to 70%. This suggests that the heating events, which caused the loss of ^{40}Ar, occurred relatively later in the meteorite history. The late timing and the short duration of heating suggests that the heat source for dehydration of CM chondrites was not the decay energy of short-lived radionuclides such as ^{26}Al, which is in clear contrast to the case of ordinary chondrites that suffered prolonged thermal metamorphism early in the meteorite history.

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