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MINERALOGY OF EXPERIMENTALLY HEATED TAGISH LAKE.

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Introduction: Since the 1980s, more than 20 thermally metamorphosed carbonaceous chondrites (TMCCs) have been found in Antarctica [e. g., 1, 2] and in hot deserts [3]. The petrology of TMCCs suggests that some C-type asteroids were heated and dehydrated after aqueous alteration [e. g., 1]. Besides, previous studies indicate that the conditions of thermal metamorphism experienced by these meteorites may have been quite variable. It reflects that metamorphism of the TMCCs was complex [e.g., 4, 5].

The Belgica group represents strongly heated TMCCs consisting of secondary silicates formed by decomposition of hydrous minerals during heating [3]. The estimated heating conditions for this group are 10 to 10^3 days at 700 °C to 1 to 100 hours at 890 °C [6]. These relatively short heating durations of thermal metamorphism are inconsistent with internal heating by the decay of the short-lived radionuclide, ^{26}Al and ^{60}Fe, and suggest that the heat source might be impact-induced heating and/or solar radiation heating. Although the petrography of the Belgica group is apparently similar to typical CM2 chondrites, they are also similar to the Tagish Lake carbonate-poor lithology with respect to their bulk oxygen isotopic compositions and the chemical composition of the matrix. The oxygen isotopic compositions of the Belgica group lie on or close to the TF line and have lower δ^{16}O values than CMs [7], and the matrix shows an enrichment in Si compared to CM chondrites [6] because of saponite enrichment in the matrix. To understand the formation process of the Belgica group TMCCs, we have performed heating experiments on fragments of the Tagish Lake meteorite and observed the mineralogical changes as a function of temperature and duration of heating.

Experimental procedures: X-ray computed tomography was obtained at the University of Texas to identify the Tagish Lake carbonate-poor lithology. The carbonate-poor lithology sample was then divided into eight fragments each weights approximately 100 mg. The heating experiments were performed at four different conditions: 600 °C for 1 hour (hereafter 600 °C/1 h), 600 °C/96 h, 900 °C/1 h, and 900 °C/96 h. Two Tagish Lake sample fragments were used for each experiment. During the heating period, the oxygen fugacity was kept at the IW buffer in order to reproduce the secondary iron-bearing minerals in the Belgica group meteorites that contain both Fe and Fe^{2+}.

The Tagish Lake samples were weighed before and after the heating experiments. In addition, the mineralogical, structural, and chemical characteristics of the matrix were determined using synchrotron X-ray diffraction (XRD) analysis at KEK BL-3A and SEM/EDS installed in JAXA/ISA. Organic materials of the heating experiment products were studied using the STXM technique and XANES analysis at KEK BL-13A.

Results: _Tagish Lake heated at 600 °C/1 h:_ The products show weight loss of about 11 % of the unheated Tagish Lake despite the heating duration. The constituent minerals of 600 °C/1 h matrix obtained by XRD are magnetite, pentlandite, pyrrhotite, and olivine with high crystallinity. The absence of saponite suggests that the matrix phyllosilicate has been already decomposed. Based on SEM observations, no significant petrographic changes have occurred during the heating. The matrix consists of the Tagish Lake original materials, which are the heterogeneous mixture of submicron and micron-sized mineral fragments, and framboidal magnetite that is common in the carbonate-poor lithology can be observed throughout the matrix. We could observe tiny compacted framboidal magnetite, which consists of less than 150 nm in diameter particles.

Tagish Lake heated at 600 °C/96 h: The XRD patterns of magnetite and saponite in the 600 °C/96 h sample are wider and smaller than unheated and 600 °C/1 h samples, suggesting its low crystallinity. SEM observation shows a similar texture and petrography for the unheated and 600 °C/1 h samples. Framboidal magnetite can be observed throughout the entire matrix, and the fine-grained framboidal magnetite consisting of less than 150 nm particles still survives.

Tagish Lake heated at 900 °C/1 h: The sample lost about 17 % of its original weight during heating. The constituent minerals determined by XRD is quite different from that in the samples heated at 600 °C. Pentlandite, which decomposes at 610 °C, magnetite, and phyllosilicates were not detected. Instead of these common phases, Fe-Ni metal, troilite, and low crystallized secondary silicates, olivine and pyroxene, dominate in the matrix. Based on the SEM observation, troilite and metal were found as assemblage and also isolated grains. Although framboidal magnetite is rarely observed, aggregate of Mg, Si-bearing iron oxide with partially-melted framboidal texture distributes throughout the matrix (Fig. a). Chemical composition of the iron oxide aggregate varies from the grain texture. Smooth and massive grains are iron oxide with several wt % of Mg. On the other hand, porous grains contain several wt % of Si in addition to the composition of smooth grains. Fine-grained, anhydrous silicate minerals, such as olivine or pyroxene, as a result of the heating experiment were not found in the sample matrix at the SEM scale even the minerals were detected by XRD.

Tagish Lake heated at 900 °C/96 h: The weight loss of the matrix during heating is about 20 %, which is the largest sample loss observed among the other heating products. XRD result shows that the major components in the matrix are similar to that in the 900 °C/1h sample. Sharp and narrow diffraction patterns of secondary silicates suggest that these silicates are well developed and crystallized with increasing heating duration. No framboidal texture has been observed so far (Fig. b). Troilite and Fe-Ni metal aggregates dominate in the matrix. The Mg, Si-bearing iron oxide as observed in the 900 °C/1 h sample was rarely found in the aggregate. The microstructure of the matrix is more homogeneous and fine-grained than the other samples.

Discussion: The weight loss of the samples during heating reflects dehydration of volatile-rich materials, like phyllosilicate. Decomposition of phyllosilicate was also detected as decrystallization, as suggested by the broad peak of XRD pattern even in the 600 °C/1h sample. On the other hand, phyllosilicates have not been observed in the 900 °C samples. Instead of phyllosilicate, secondary olivine and pyroxene are dominant in the matrix. The crystallinity of secondary silicates increases with increasing heating duration. Framboidal magnetite that is common in the Tagish Lake carbonate-poor lithology still survives at 600 °C.

All results taken together, significant mineralogical changes are only evident after heating at 900 °C, and the main changes are reduction of magnetite to form Fe-Ni metal and the development of troilite. Consistent with previous experimental heating studies of hydrous minerals [8], our experiments demonstrate that the degree of mineralogical transformation in carbonaceous chondrites as a result of heating is more affected by temperature rather than the heating duration.

The relative degrees of transformation of the Tagish Lake meteorite can be estimated as following; 600 °C/1 h ≦ 600 °C/96 h < 900 °C/1 h < 900 °C/96 h. These degrees are estimated by observation of mineralogical changes of opaque minerals and crystallinity of secondary silicates as a heating parameter based on this study. A comparison of the mineralogy of our experimental results to the Belgica group meteorites shows that the sample heated at 900 °C reproduces the mineralogical and textural characteristics of the Belgica group meteorites. According to our previous study [9], these meteorites contain partially transformed phyllosilicates with a fibrous texture, no secondary grains of olivine and pyroxene more than 100 nm in size, and Fe-Ni metal and troilite assemblage instead of magnetite. We will present result of XANES analysis and STXM observation of these heating products. The information of organics will provide additional insights into how the organics in heated chondrites evolves as function of time and temperature.

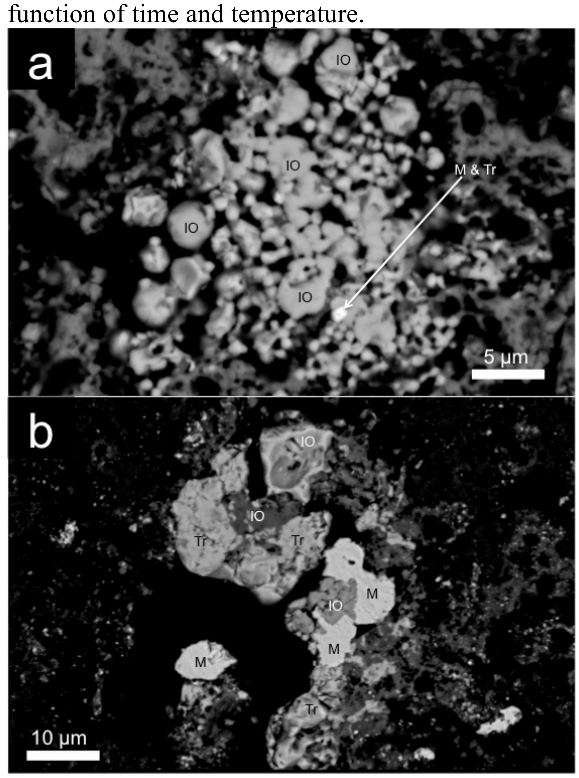

Figure. BSE images of heated Tagish Lake. Tr: Troilite, M: Fe-Ni metal, IO: Mg, Si-bearing iron oxide. (a) Aggregate of Mg, Si-bearing iron oxide with partially melted framboidal texture in the matrix of 900 ºC/1 h sample. (b) Troilite and Fe-Ni metal aggregate in 900 ºC/96 h sample.

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