Kinetics of dehydration of carbonaceous chondrites for evaluating heating processes of their parent asteroids

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The CI, CM, and CR carbonaceous chondrites contain hydrous minerals, indicating that these parent bodies experienced aqueous alteration processes at low temperature. It has been reported that some of these chondrites, such as heated CM and CY chondrites, suffered thermal dehydration by impacts or solar radiation after aqueous alteration [1, 2]. The dehydration is attributed to the loss of the OH groups from the dominated hydrous mineral, phyllosilicates, at 400℃ to 770℃ [3]. Although heating experiments on carbonaceous chondrites have been conducted to constrain the heating temperature and the thermal process [4, 5], the kinetic studies including heating duration were limited. In this study, in order to constrain the thermal history of parent asteroids of heated CM, CI, and CY chondrites by determining the degree of dehydration of the hydrous minerals, we conducted thermal dehydration experiments on carbonaceous chondrites and applied kinetics to evaluate the dehydration rates.

Unheated carbonaceous chondrites Murchison (CM subtype 2.5) and Ivuna (CI) were used as starting samples, and the -OH peak at 2.72 μm was observed under in-situ infrared spectroscopy (FTIR) with heating stage. The changes in the peak area of -OH with isothermal heating at 350℃ to 525℃ were investigated. To determine the rate constants, the decrease of the -OH was fitted by models such as first-order reaction, two-dimensional diffusion, and three-dimensional diffusion [6]. Arrhenius plots were drawn from the average of the reaction rate constants, and apparent activation energy E_a and frequency factor *A* were determined by the Arrhenius equation. Then, a Temperature-Time-Transformation (TTT) diagrams were drawn to represent the decrease in the -OH as a function of temperature and heating duration.

The three-dimensional diffusion models provided better fitting results on both Murchison and Ivuna. Apparent activation energy E_a using Jander's three-dimensional diffusion model and Ginstling-Brounshtein's three-dimensional diffusion model are estimated as 45.3 kJ mol^{-1} (Murchison), 70.4 kJ mol^{-1} (Ivuna) and 42.5 kJ mol^{-1} (Murchison), 66.2 kJ mol^{-1} (Ivuna), respectively. The frequency factor *A* using Jander's three-dimensional diffusion model and Ginstling-Brounshtein's three-dimensional diffusion model are estimated as 11.9 h^{-1} (Murchison), 785 h^{-1} (Ivuna) and 6.56 h^{-1} (Murchison), 339 h^{-1} (Ivuna), respectively.

In addition, the TTT diagrams, which represents the relationship of dehydration degrees with temperature and time, were obtained from these kinetic parameters. For example, starting from the composition of Murchison, it would take ~10 days for 50% dehydration at 200℃, ~5 days at 250℃ and ~20 days at 300℃ calculated from the TTT diagram of three-dimensional diffusion models. On the other hand, starting from the composition of Ivuna, it was estimated as ~100 days for 50% dehydration at 200℃, ~30 days at 250℃ and ~5 days at 300℃.

As described above, we expect to constrain the thermal processes of parent asteroids of heated carbonaceous chondrites from kinetics of thermal dehydration of hydrous minerals.

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