

Thermal evolution of Ryugu inferred from spectral characterization of experimentally-heated CI carbonaceous chondrite

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Spectral features of C-asteroid Ryugu, the target of the Hayabusa2 mission, are expected to be similar to experimentally-heated carbonaceous chondrites, however no published spectral data of carbonaceous chondrites completely match with that of Ryugu (Kitazato et al. 2019). There are two problems: (1) no meteorite samples show reflectance at visible wavelengths darker than Ryugu, (2) most of the reported spectra of experimentally-heated carbonaceous chondrite samples cannot be compared with asteroidal spectra, because they are severely affected by adsorbed and rehydrated water. Carbonaceous chondrites exhibit a significant absorption feature at around 2.7 μm owing to the presence of hydrated minerals, however, heated samples can easily be contaminated by atmospheric water, which causes an absorption feature at around 2.9 μm .

The present study shows the results of heating experiments of the Orgueil CI carbonaceous chondrite which has experienced extensive aqueous alteration. Orgueil contains Mg-rich phyllosilicates, which suggests that the parent body of Orgueil might have formed at the farther place from the Sun than other carbonaceous chondrites. We analyzed mineral compositions, water contents, and reflectance spectra of the heated samples to evaluate the systematic changes during heating. Reflectance spectra and water contents of the heated samples were measured without exposure to the air to minimize the effects of adsorbed and rehydrated water. An unheated powdered sample of Orgueil was prepared by preheating at $<150^\circ\text{C}$ with the purpose of removal of adsorbed water. Powdered Orgueil samples were then heated at 400, 500, 600, 700, and 900 $^\circ\text{C}$ under vacuum conditions, to demonstrate asteroidal heating processes.

S-XRD analysis provides precise mineralogical characterization of the fine-grained matrix of the samples. The results indicate that the unheated sample contains saponite, serpentine, and magnetite. The decomposition of serpentine occurs in the 500- $^\circ\text{C}$ heated sample, and saponite and secondary olivine coexist in the 600- $^\circ\text{C}$ sample. The 700- $^\circ\text{C}$ heated sample shows reflections from olivine and Fe-Ni metals, and they become well crystalline in the 900- $^\circ\text{C}$ heated sample.

The total water contents of the samples measured by the Karl Fischer titration are recorded as 7.7, 7.1, 3.9, 1.9, 0.9, and 0.5 wt.% for unheated, 400, 500, 600, 700, and 900 $^\circ\text{C}$, respectively. Water contents decrease by heating and retained water in the samples corresponds to the amounts and types of remnant hydrated minerals.

The spectroscopic results showed that (1) moderately-heated samples (400, 500, and 600 $^\circ\text{C}$) have darker reflectance in the visible region than unheated samples and the reflectance increases in the samples heated at high temperatures (700 and 900 $^\circ\text{C}$), (2) the depth of the 2.7- μm absorption band decreases with increasing heating temperature and it disappears at the temperature at which hydrated minerals in the samples completely dehydrate, (3) the peak position of the 2.7- μm band of the heated Orgueil samples is nearly constant, while that of the heated Murchison samples shifts towards shorter wavelengths with increasing heating temperature according to the decrease of the Fe/Mg ratio of the remnants of hydrated minerals in the heated samples (Mogi et al. 2017, METSOC), and (4) the depth of the 2.7- μm band and the water content of the heated Orgueil and other carbonaceous chondrites form a

positive correlation trend.

In this work, the Orgueil sample heated at 500 °C provides the best spectral match to Ryugu: it shows very low reflectance (~2%) at visible wavelengths and small absorption feature (~10%) around 2.72 μm . We suggest that Ryugu might have experienced heating and dehydration at a temperature around 500 °C, after aqueous alteration, and presently contains a small quantity of hydrated minerals equivalent to 1-2 wt.% of water at the surface.

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