

## Reflectance spectra, mineralogy, and chemistry of experimentally heated Tagish Lake carbonaceous chondrite

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C-, P-, and D-type asteroids, orbiting at the outer asteroid belt, are important objects for understanding of the evolution of outer solar nebula. A subset of these asteroids shows evidence of thermal evolution such as dehydration (Jones et al., 1990), though the thermal effects on reflectance spectra, mineralogy, and chemistry are not fully understood. The purpose of this study is to reproduce the spectral, mineralogical, and chemical changes of D-type asteroids caused by heating events, using the experimentally heated samples from Tagish Lake meteorite which is believed to have derived from a D-type asteroid (e.g., Hiroi et al., 2001). Besides, this study was performed to identify constituent minerals of Martian moons, Phobos and Deimos. The spectra of Phobos and Deimos are similar to that of D- and T-type asteroids (e.g., Rivkin et al., 2002). However the 3.0- $\mu\text{m}$  absorption band is shallower than these asteroids, suggesting that they are heated D-type objects.

The Tagish Lake carbonaceous chondrite fragments were experimentally heated in a vacuum at temperatures of 400, 600, and 900°C for 50 hours. Unheated and heated samples were analyzed using the powder and synchrotron X-ray diffraction (XRD) methods for bulk mineralogy, field-emission scanning electron microscope (FE-SEM) for texture, elemental analyzer for C, N, S contents, mass spectrometer for carbon isotope ratios, and FT-IR for reflectance spectra.

XRD patterns and FE-SEM observation showed that the unheated Tagish Lake sample consists of saponite, Mg-Fe carbonate, pyrrhotite, olivine and magnetite. Saponite was replaced by olivine, and recrystallization of secondary olivine was proceeded from 600°C to 900°C. Similarly, by heating at 600°C, Mg-Fe carbonate was decomposed into magnesiowüstite, which was reduced into taenite by heating at 900°C.

Carbon content and isotope ratio ( $\delta^{13}\text{C}$  values) start decreasing from the temperature of 600°C. Decomposition of carbonate, which has  $\delta^{13}\text{C}$  value of  $\sim +67\%$  (Grady et al., 2002), is responsible for the decrease of carbon content and  $\delta^{13}\text{C}$  value up to 600°C. Meanwhile, from 600 to 900°C, carbon content and  $\delta^{13}\text{C}$  value decreased due to gasification of organic carbons ( $\delta^{13}\text{C}$  of  $\sim -9\%$ ; Grady et al., 2002) by thermal cracking and oxidation taken place during heating at 900°C.

The 3.0- $\mu\text{m}$  absorption band in a reflectance spectrum is responsible for interlayer and structural water of saponite and absorbed water. The 3.0- $\mu\text{m}$  band of the unheated sample was deep and broad, which becomes shallower and shaper with increasing heating temperatures. Interlayer water was dehydrated up to 600°C, and structural water was dehydrated up to 900°C. In contrast, structural water of serpentine in the Murchison carbonaceous chondrite, which is derived from a C-type asteroid, was dehydrated at lower temperature of 600°C (Yamashita et al., 2015). Therefore, it may be possible that C- and D-type asteroids have different water content when they are heated at the same temperature.

Mineralogical, chemical, and spectral changes of Tagish Lake proceed with increasing heating temperatures; (1) saponite is dehydrated and recrystallized into olivine, (2) interlayer and structural water of saponite are dehydrated step by step, (3) Mg-Fe carbonate is replaced by magnesiowüstite and finally reduced into taenite, and (4) volatile elements including carbon, nitrogen, and sulfur are gasified and C isotope ratios are changed accordingly.

Comparison to Phobos and Deimos spectra suggests that 400°C and 600°C heated samples of Tagish Lake matches better. But 0.65- $\mu\text{m}$  absorption band that is characteristic absorption of the Phobos red areas was not reproduced. Therefore, the reproduction of 0.65- $\mu\text{m}$  absorption requires additional conditions, if Phobos was originally D-type asteroids.

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