Relationship between visible reflectance at 550 nm and carbon contents in carbonaceous chondrites: Attempt to estimate the bulk carbon contents of asteroid Ryugu's surface.

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Introduction: Remote sensing observations of asteroid Ryugu by Hayabusa2 mission has revealed that Ryugu is one of the darkest bodies in the Solar System [1-3]. It is of great interest to identify the darkening agent of Ryugu's surface. In the preliminary investigation by Hiroi and Sugita, it was reported that there was a correlation between the reflectance at 550 nm of primitive carbonaceous chondrites and the insoluble organic matter (IOM) contents of the meteorites. Their result suggests that the bulk carbon contents of asteroid Ryugu are potentially estimated by the visible reflecntance acquired by optical navigation camera (ONC), an onboard scientific instrument of Hayabusa2 spacecraft. On the other hand, it is challenging to estimate IOM contents from meteorites, due to the mass loss during the purification process by the repetitive acid treatment and/or due to its static electricity. In this regard, total carbon contents can be estimated more accurately rather than IOM contents. Therefore, in this study, the reflectance spectra and total carbon contents (i.e., sum of IOM, SOM, and carbonates) of the same meteorite samples were measured in this study for increasing the accuracy of correlation.

Samples and Methods: As the samples, three primitive carbonaceous CM/CI chondrites (Murchison, Murray, and Yamato 980115), five thermally metamorphosed CM/CI chondrites (Jbilet Winselwan, Yamato 982086, Yamato 793321, Belgica 7904, and Yamato 86720), and three carbonaceous chondrites (Murchison, LAP 04721, and Tagish Lake) experimentally heated at different temperatures (300, 400, 500, 600 and 900°C) for 50 hours, and a simulant of Phobos were used. Their grain sizes and/or porosity were made constant. Reflectance spectra of the meteorites were analyzed by VERTEX 70v, Bruker (Tohoku Universty). Total carbon contents of the meteorites were analyzed by a CHN elemental analyzer (Flash EA1112, Thermo/Finnigan) (Kochi University).

Results and discussion: For the primitive CM/CI chondrites and thermally metamorphosed CM/CI chondrites, roughly linear correlations were observed between total carbon contents and reflectance at 550 nm (R(550)) and 390 nm (R(390)). Thus, the meteorites with higher carbon contents show lower reflectance. However, some meteorites (Murchison, Murray, Y-982086, Jbilet Winselwan, Y-793321) with similar carbon contents showed variations in reflectance. This is probably due to the difference in chemical compositions between primitive CM/CI chondrites and thermally metamorphosed CM/CI chondrites. The thermally metamorphosed CM/CI chondrites containing IOM with higher aromaticity [4] show lower reflectance compared to the primitive CM/CI chondrites. Based on the relationship, asteroid Ryugu, whose mean R(550) is 0.019, may contain higher than 3% of carbon.

In the correlation plots between total carbon contents and R(550) and R(390) for the experimentally heated carbonaceous chondrites, overall, meteorites with higher carbon contents show lower reflectance. However, individual meteorites showed different behaviors during heating. For instance, the reflectance values of Murchison were lowered while the total carbon contents of Murchison did not change during heating up to 400°C. During heating at 500 - 600°C, the reflectance values of Murchison were raised again while the total carbon contents of Murchison decreased only slightly. At 900°C, the total carbon contents of Murchison suddenly decreased with increasing reflectance. These variations in reflectance are related to not only total carbon contents but also chemical change of IOM with increasing temperature, such as aromatization, pyrolytic degradation, and gasification. LAP 04721 and Tagish Lake showed similar trends, but their variations in reflectance differed depending on their original carbon contents and compositions (including carbonates). Based on the relationship, R(550) of Ryugu is the most similar to those of the heated Tagish Lake at 400-600°C or heated Murchison at 400°C. The result appears to be consistent with the conclusion obtained by the near infrared spectral pattern of the surface of Ryugu [3]. However, further investigation will be necessary by consideration of other possible effects of grain sizes, porosity, space weathering degree, and inorganic compounds (e.g., magnetite, sulfide) on low reflectance of Ryugu's surface.

References: [1] Watanabe S. et al. (2019) *Science* 364: 268-272. [2] Sugita S. et al. (2019) *Science* 364: eaaw0422. [3] Kitazato K. et al. (2019) *Science* 364: 272-275. [4] Yabuta H. et al. (2005) *MAPS* 40: 779–787.