POSSIBLE INTERPRETATIONS OF VISIBLE/NEAR-INFRARED SPECTRA OF ASTEROID RYUGU OBTAINED BY THE HAYABUSA2 MISSION.

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Introduction: Visible and near infrared spectra of asteroid 162173 Ryugu were obtained recently by the Near-InfraRed Spectrometer (NIRS3) and Optical Navigation Camera (ONC) onboard the Hayabusa2 spacecraft [1, 2]. In addition to an average spectrum of the whole asteroid, close-up spectra are also obtained when the spacecraft descending to the surface, for instance, upon MASCOT deployment operations. The bright spots where reflectance is much brighter than average areas, were identified by both ONC and NIRS3. In this study, possible interpretations of Ryugu spectra are introduced based on the spectral comparison between Ryugu and various carbonaceous chondrites, including experimentally-heated carbonaceous chondrites with no effects of adsorbed and rehydrated atmospheric water [3, 4].

Samples and measurements: Many hydrated (CM/CR/Tagish Lake) and dehydrated (CM/CI) carbonaceous chondrites and experimentally-heated Murchison CM [3] and Tagish Lake [4] chondrites were measured at Tohoku University for visible/near-infrared/mid-infrared spectra in the wavelength from 0.38 to 15μm in vacuum and at a standard measurement condition (phase angle = 30°, incident angle = 30°, emission angle = 0°), using FT-IR (Bruker VERTEX 70v). Except for the laboratory-heated samples, measurements were done for various grain sizes: 3350, 512, 155, and 77μm to see the grain-size effects on the spectra. Visible and near-infrared spectra of asteroid Ryugu, obtained by ONC and NIRS3, are averaged and calibrated to the standard measurement condition for comparison to meteorite spectra. The Near-infrared spectra of NIRS3 are thermally corrected and calibrated [2].

Results and discussion: The visible and near-infrared spectra of Ryugu are relatively flat, with very low reflectivity, and no apparent absorption features except a sharp and small 2.7μm absorption probably due to phyllosilicates (Fig. 1). The average reflectance of the whole asteroid (except polar regions) is approximately 2% at both 0.55 and 2.0μm wavelengths [1, 2] (Fig. 1). On the other hand, the darkest extraterrestrial material recovered on earth are hydrated carbonaceous chondrites [e.g., 5] and interplanetary dust particles (IDPs: [6]).

Our laboratory measurements of hydrated carbonaceous chondrites with various grain sizes show variations of the reflectance at 2.0μm, depending on the type of carbonaceous chondrites and grain size: 2.5~7% for CM/CI, 5~11% for CR, and 3~4% for Tagish Lake. Samples with larger grain sizes show lower reflectance, but none of the hydrated carbonaceous chondrite samples show the very low reflectance comparable to average Ryugu (~2%). This suggests that Ryugu is darker than any hydrated carbonaceous chondrites and therefore some additional processes are required to reduce the reflectance of material, if Ryugu consists of primitive material similar to hydrated carbonaceous chondrites, as indicated by the presence of 2.7 μm absorption feature.

On the other hand, in general, material around Ryugu's equator is found to be brighter and bluer than material at other areas (Fig. 1). In addition, small bright spots were found in places in both equatorial and non-equatorial areas. The spectra of the equatorial areas and the bright spots are apparently brighter than the average (Fig. 1), but show similar overall features including the shape and depth of the 2.7 µm absorption feature, suggesting that they all originated from the same material.

We propose that Ryugu material is: (1) heated, partially-dehydrated carbonaceous chondrites, (2) partially-hydrated, carbon-enriched primitive material like IDPs, or (3) space-weathered hydrated/dehydrated carbonaceous chondrites. Other materials (anhydrous carbonaceous chondrites such as CV/CO/CK types and C-rich ureilites) seem to be too bright to be candidates for Ryugu material. We discuss below the pros and cons of interpretations (1), (2) and (3).

(1) Heating of hydrated carbonaceous chondrites reduces the reflectance. Therefore heating is a probable mechanism to reproduce Ryugu spectra. Experimental heating of Murchison CM [3] and Tagish Lake [4] carbonaceous chondrites show darkening at 400 and 600°C but brightening at 900°C. X-ray diffraction analysis indicates that, at 400°C, Fe-rich phyllosilicates decompose to amorphous phases but Mg-rich phyllosilicates remain and only at 600°C is most of the phyllosilicates decomposed [3,4]. Partial decomposition of phyllosilicates and preferential survival of Mg-rich phyllosilicates is consistent with the Ryugu spectra that have a small 2.7µm band centered at 2.72µm, indicative of the presence of small to moderate amounts of Mg-rich phyllosilicates.

When we compare the 2.7µm phyllosilicate feature between Ryugu and meteorite samples, the effects of adsorption and rehydration by atmospheric water for the meteorite samples are severe and must be corrected. For this purpose, we have carried out experimental heating of Murchison and Tagish lake with no contribution by adsorbed and rehydrated atmospheric water [3,4]. The 2.7µm band of unheated Murchison is broad and large, but it becomes sharp and small with increasing temperature. The shape, depth, and band center of the 2.7µm band of the 400°C-heated Murchison and the 400°C -heated Tagish lake samples are strikingly similar to those of Ryugu (Fig. 1), which strongly suggests that Ryugu is hydrated carbonaceous chondrite-like material that experienced heating and partial dehydration. The spectral slope of the heated meteorite samples is higher (redder) than that of Ryugu, which could be explained by a difference of grain size (<155µm for the meteorite samples) and/or degree of space weathering.

(2) The very low reflectance of Ryugu may indicate a carbon-rich nature like partially-hydrated, carbon-enriched primitive material. Such primitive material with a limited degree of hydration cannot generally survive atmospheric entry as meteorites- rather they are recovered as IDPs [e. g., 7]. Reflectance spectra data of IDPs are scarce, but Bradley et al. [6] measured reflectance spectra of many chondritic IDPs in the wavelength range 0.38-1.1µm and showed that IDPs exhibit relatively flat spectra with 2~10% reflectance at 0.55µm. Thus the lowest reported IDP reflectance is compatible to Ryugu. Near-infrared spectra of IDPs have not been reported. More reflectance spectra of IDPs are required for further comparison.

The presence of Mg-rich phyllosilicates seems to be inconsistent with the idea that Ryugu experienced the limited degree of aqueous alteration, because in the early aqueous alteration in the primitive asteroids Fe-rich phyllosilicates form first due to high susceptibility to hydration. The explanation of this discrepancy could be that the 2.7µm-band strength is weakened (masked) by abundant carbonaceous material.

(3) The ubiquitous presence of the bright spots on the Ryugu surface may indicate that original Ryugu materials are brighter, hydrated/dehydrated carbonaceous chondrites and the whole surface was heavily space-weathered, as suggested by [8]. Higher-resolution spectra of NIRS3 or SCI bombardment will permit testing of this interpretation.

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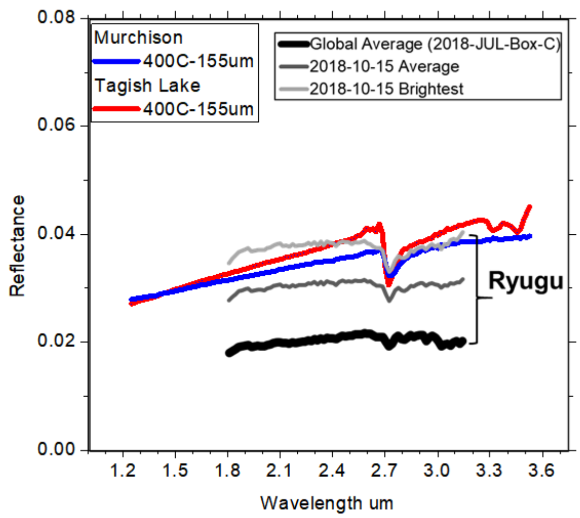

Fig. 1. Comparison between Ryugu and experimentally-heated Murchison and Tagish Lake. Ryugu data are global average, equatorial average (2018-10-15 average), and bright spot (2018-10-15 brightest).