A GLOBAL VIEW OF THE NEAR-INFRARED REFLECTANCE PROPERTIES OF RYUGU AS SEEN BY THE NIR3 SPECTROMETER ON HAYABUSA2.


Introduction: The Japanese Aerospace Exploration Agency (JAXA) Hayabusa2 spacecraft encountered the asteroid Ryugu in June 2018 and collected a wealth of data until its departure in late 2019. Prior to arrival, Ryugu was classified as a C-type asteroid and was anticipated to contain primitive materials similar to what is observed in carbonaceous chondrite meteorites, possibly including hydrous phases and/or organic compounds [1-3]. The Hayabusa2 spacecraft includes NIR3, a point spectrometer with a 0.1° field of view that is observed in the “3 µm” region. This is similar to approaches that have been successfully applied to remote observations of the Moon [6]. The thermal contribution is then subtracted from the total radiance, and the residual (solar reflected) radiance is then converted to I/F or reflectance by accounting for the solar flux, viewing geometry, and Sun-Ryugu distance. The initial RCC was based on pre-flight calibration measurements [4], but observations acquired after launch indicated an update to the RCC was necessary, and observations of the onboard calibration lamps were used for this purpose [5].

Results: Based on data from the ‘global’ mapping campaign, Ryugu appears to be quite spectrally homogenous at the ~20–40 m spatial scale. The entire surface of the asteroid is extremely dark, exhibiting an average albedo of ~0.017 ± 0.002 [5]. This is darker than other primitive objects recently visited by spacecraft, including the nucleus of comet 67P/Churyumov-Gerasimenko measured by Rosetta. There are some albedo variations across the surface that may not be linked to photometric/viewing geometry effects (e.g., the equatorial region of Ryugu exhibits an increase in albedo relative to adjacent terrains, Figure 1), but absolute values of these variations are generally quite small [5].

The near-IR reflectance spectra of Ryugu are commonly linear with a slightly red (positive) spectral slope with increasing wavelength. The exact strength of this slope for wavelengths >2 µm is dependent on the accuracy of the thermal correction, and local geometry and physical properties can have strong links to surface temperature. Because of these complications and dependencies, weak variations in spectral slope that appear to be correlated with physical/morphologic properties of Ryugu are still under investigation.

There is currently no clear spectral evidence for the presence of pyroxene at the surface of Ryugu (i.e., no
absorptions at ~2 µm due to Fe$^{2+}$ in an M2 coordination site) [7]. Though not diagnostic, the lack of a 2 µm feature is common in certain types of C chondrites, particularly those in which primary silicates have been aqueously altered to form clay minerals (type C1/C2 meteorites). However, NIRS3 spectra of Ryugu also do not exhibit strong absorption features in the 3 µm region that indicate the object is rich in OH/H$_2$O. Rather, all spectra of Ryugu exhibit a weak and narrow feature with a reflectance minimum at 2.72 µm that is interpreted to indicate the presence of OH, likely attached to Mg [5]. This absorption feature is consistent with the presence of Mg-serpentine.

Figure 1. Top: Albedo map of Ryugu, showing minor variations with average albedo of ~0.017 and increase in albedo near equatorial ridge. Bottom: Temperature map derived from NIRS3 data, warmer colors indicate higher temperatures approaching ~375K. Data from July 11 & 19, 2018.

The OH feature is observed in all spectra of Ryugu, but it is very weak when compared with lab spectra of typical aqueously altered C chondrites [8] and weaker than the hydration feature observed for Bennu by OSIRIS-REx [9]. The closest meteorite match to Ryugu, based on existing spectral libraries, is to several samples of thermally metamorphosed C chondrites and spectra of heated samples of Ivuna (Figure 2). As such, Ryugu may represent a primitive object that was aqueously altered and then thermally metamorphosed prior to (or as a result of) disruption and reformation as a rubble pile. Alternatively, space weathering processes may be operating at Ryugu’s optical surface to degrade hydrous materials and weaken the OH feature. In this scenario, material beneath the uppermost surface may be more hydrated. Indeed, preliminary analysis of NIRS3 spectra (<1 m per spot) acquired at the impact crater experiment location indicate material excavated from depth may exhibit a deeper OH band that is shifted to slightly shorter wavelengths [10]. A third option is that Ryugu did not experience enough aqueous alteration to give rise to abundant hydrous phases, in which case the weak OH feature indicates low phyllosilicate abundance and/or OH formed by solar wind implantation.

Figure 2. Modified Fig. 3 from [5] showing comparison between typical Ryugu spectrum as acquired by NIRS3 and laboratory spectra of various C chondrites including thermally metamorphosed sample Meteorite Hills 01072. Within existing spectral libraries of meteorite samples, C chondrites that have experienced thermal metamorphism or alteration provide the closest spectral match in the near-IR.

Conclusions: At near-IR wavelengths, the surface of Ryugu is rather homogenous at the 20–40 m spatial scale. Major characteristics of Ryugu are that it is (1) extremely dark, (2) spectrally ‘flat’ with only a weak red slope, (3) exhibits a weak OH feature at all locations, (4) lacks clear evidence for pyroxene at a global scale, and (5) is most spectrally similar to lab data of thermally metamorphosed C chondrites [5].

Multiple samples were successfully acquired from the surface of Ryugu, including at the impact experiment site where weak variations in the OH band are observed. These samples are expected to be returned to Earth in late 2020, and detailed laboratory studies will allow testing of whether or not thermal metamorphism, space weathering, limited aqueous alteration or a combination of these processes best explains the spectral properties observed by NIRS3. It is clear that Ryugu is spectrally quite different from Bennu, and as such it provides a unique and distinct data point for improving our understanding of how to use reflectance data of C-type objects to infer their mineralogy, chemistry, and geological history.