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Asteroid 162173 Ryugu: Surface composition as observed by Hayabusa2/NIRS3

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Abstract

Near-infrared reflectance spectroscopy with the NIRS3 instrument on the Hayabusa2 spacecraft has revealed that the asteroid 162173 Ryugu possesses a very dark, hydroxyl (OH)-bearing surface. All Ryugu spectra obtained by NIRS3 exhibit a weak, narrow absorption feature centered at 2.72 µm, indicating that OH-bearing minerals are ubiquitous. The intensity of the OH feature and extremely low albedo are most spectrally similar to thermally- and/or shock-metamorphosed carbonaceous chondrites. A lack of significant variations in the OH-band position indicates that the surface composition is fairly uniform, consistent with Ryugu being a rubble-pile object generated from impact fragments of an undifferentiated aqueously altered parent body.

1. Introduction

In June 2018, the JAXA's Hayabusa2 sample return mission arrived at the target near-Earth C-type asteroid 162173 Ryugu and began a mapping campaign with the onboard remote sensing instruments for sample site selection [1]. The Hayabusa2 NIRS3 spectrometer acquired near-infrared reflectance spectra of Ryugu's surface in the wavelength range from 1.8 to 3.2 µm to provide direct measurements of the surface composition [2,3]. On 21 June 2018, NIRS3 made the first observations of Ryugu at a distance of 70 km and proceeded to acquire more than 69,000 spectra of Ryugu's surface through 17 August. On July 11 and 19, NIRS3 operated in a scanning mode, in which slews of the spacecraft were combined with the rotational motion of the asteroid, to acquire near-global coverage at a surface spatial resolution of 40 m and 20 m, respectively. During the descent operation for gravity measurements on August 6-7, NIRS3 continuously acquired spectra down to 1 km altitude, corresponding to a spatial resolution of 2 m. Together, these data provide an unprecedented view of a C-type asteroid at near-infrared wavelengths that can be used to constrain surface composition at sample sites and relate these properties to the surface composition of the asteroid as a whole.

2. Spectral features

The thermally and photometrically corrected NIRS3 spectra of Ryugu exhibit several common features. The first is a very low reflectance value across nearly the entire body. The globally-averaged reflectance value at 2.0 µm is 0.017 ± 0.002, which is consistent with values at visible wavelengths observed by the Hayabusa2 ONC-T camera [4]. Reflectance values vary within 15% across the entire observed surface, excluding regions in shadow. Brighter surfaces are primarily observed along the equatorial ridge, crater rims and for individual boulders, again similar to visible wavelength images. NIRS3 spectra of Ryugu also commonly exhibit a weak positive spectral slope (0.2 to 0.6 %/µm) between 2.0 and 2.5 µm. Finally, all spectra of Ryugu exhibit a weak, narrow absorption feature centered at 2.72 µm, with intensities ranging from 7 to 10%. The intensity of the 2.72 µm feature exhibits a positive correlation with estimated surface temperatures, which indicates that uncertainties in the radiometric calibration and/or thermal emission component could be responsible for the observed variations in the band depth of this feature. When normalized by the observed temperature trend, no significant variations correlated with topographic features are observed in the intensity of the 2.72 µm feature.

The detection of an absorption feature at 2.72 µm indicates the presence of OH attached to a cation, and the position of the reflectance minimum indicates is most likely Mg. The band position is similar to Mg-OH features observed in Mg-rich phyllosilicates, such as serpentine and saponite, which are known to be present in aqueously altered CI and CM chondrites [5,6]. Ryugu spectra indicate that the OH band position does not vary across the surface of Ryugu within the ~18 nm spectral sampling of the instrument, suggesting a relatively homogeneous phyllosilicate cation composition.

3. Comparison with meteorites

There are currently no meteorite samples whose reflectance spectra perfectly match that of Ryugu at visible to near-infrared wavelengths. However, spectra of thermally-metamorphosed CI chondrites and shocked CM chondrites are most similar to Ryugu at near-infrared wavelengths in terms of brightness and shape. Laboratory spectra of an Ivuna (CI1) sample heated to 500˚C and a MET 01072 (shocked CM2) sample are relatively dark and flat yet retain a weak 2.72 µm feature [3]. These meteorite data suggest that thermal alteration processes such as partial dehydration and decomposition of hydrated minerals induced by static or shock heating can act to darken hydrated carbonaceous chondrites. Such processes are consistent with current interpretations of Ryugu's formation history. The low bulk density (~1.2 g/cm^3) of Ryugu suggests that it is a rubble-pile asteroid formed by a collisional event with the parent body [1], thus it is likely to have experienced shock and post-shock heating. However, it is also possible that the weak OH absorption is because the degree of aqueous alteration on Ryugu was never extensive to begin with, perhaps due to low water-to-rock ratios or slow/incomplete hydration reactions on the parent body.

Alternatively, it has been suggested that Ryugu's orbit might have had shorter perihelion distances in the past, a characteristic that would have increased radiative heating from the Sun [7] and altered the mineralogy of the uppermost surface. Similarly, the surface of Ryugu has experienced solar-wind irradiation and micrometeorite impacts (space weathering), which can alter surface composition and spectral properties. These processes represent near-surface phenomena that continue to operate at Ryugu today, whereas the other interpretations for the apparent low hydration state represent inherent chemical and mineralogical attributes of the asteroid as a result of its early geological history.

In April 2019, Hayabusa2 mission successfully conducted an impact experiment designed to expose material from the subsurface. These materials will be observed by NIRS3, providing further insight into whether the observed low albedo and weak OH features are near-surface phenomena or intrinsic bulk properties of Ryugu.

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