Hydrothermal history of (162173) Ryugu's parent body inferred from remote-sensing data

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1. Summary

Small rubble pile asteroids record the thermal evolution of their much larger parent bodies. However, recent space weathering and/or solar heating create ambiguities between the uppermost layer observable by remote-sensing and the pristine material from the parent body. Hayabusa2 remote-sensing observations find that on the asteroid (162173) Ryugu both north and south pole regions preserve the least space-weathered material, which is spectrally blue carbonaceous chondritic material with a 0 – 3% deep 0.7-μm band absorption, indicative of Fe-bearing phyllosilicates [1]. We report that spectrally blue Ryugu's parent body experienced intensive aqueous alteration and subsequent thermal metamorphism at 570 – 670 K (300 – 400 ˚C), suggesting that Ryugu's parent body was heated by radioactive decay of short-lived radionuclides possibly because of its early formation 2-2.5 Ma. The samples being brought to Earth by Hayabusa2 will give us our first insights into this epoch in solar system history. Moreover, we found the NUV-VIS spectral similarity between Ryugu and Polana–Eulalia family members, suggesting plausible origin from inner main belt predicted by the dynamical simulation [2].

2. Observation on polar regions

Ryugu could be an ideal body to study the thermal history and water/rock ratio of pre-disruption parent bodies, much larger (~100 km) than Ryugu. Our objective is to find the most pristine material on Ryugu and to study evidence for proposed thermal metamorphism of its original parent body and consequent processes after its catastrophic disruption and re-accumulation. Stratigraphic analyses have suggested that the possible surviving, unprocessed materials are bluer than the average Ryugu reflectance spectrum [3,4]. Slightly bluer materials than the average were found on the equatorial ridge, which might be uncovered by regolith migration from the ridge to the middle latitudinal regions. Furthermore, the global observations obtained by the Hayabusa2 spacecraft discovered that the bluest materials are distributed at the polar regions of Ryugu [3]. This motivated us to conduct detailed surveys of the polar regions to investigate the unprocessed materials. Effects after the formation of Ryugu, such as solar wind irradiation, micrometeoroid bombardment, and radiative heating caused by close encounter to the Sun, need to be deconstructed.

Spectrally blue (negative visible spectral slope) material is concentrated on both poles, as clearly shown. Furthermore, blue material is associated with a relatively deeper 0.7-μm band absorption. Phyllosilicates in CM/CI chondrites become progressively enriched in Mg (and depleted in Fe) as aqueous alteration proceeds [5]. Thus, Fe-bearing phyllosilicates showing 0.7-μm band absorption are a strong indication of the specific water/rock ratio condition during the parent body formation. To examine the cause of the distribution of blue materials with 0.7-μm band absorption, the maximum temperature in an asteroidal year and the normalized solar photon dose were calculated based on the TIR measurements [6], the shape model and current orbital elements. The comparison indicates that areas and facets with low solar wind irradiation fluxes exhibit blue spectra and relatively deeper 0.7-μm absorption, while the influence of solar heating does not clearly correlate with the spectral characteristics. On the north pole, the concentration of the material with blue spectral slope, and deeper 0.7-μm band absorption were well correlated with the regions experiencing the lowest temperatures and least solar wind irradiation due to the large incidence angle during the whole asteroidal year. The correspondence between the color variation and those processes shows that solar wind irradiation is a more likely cause for the color changing from blue to red and the decrease in the 0.7-μm band absorption depth

3. Possible connection with (3200) Phaethon

(3200) Phaethon, the target of the DESTINY+ Mission, exhibits blue spectra in the visible wavelength range and turn-up in the UV. Recently, many ground-based observations were made over a wide wavelength range, which reported that the variation in visible spectral slope depends on rotational phase. The range of spectral slope variation in one rotation is -0.5 to 0.05 μm^{-1} and that of the relative R-band magnitude is ± 0.15 [7,8]. Moreover, a correlation between brighter and bluer spectra was also observed [7]. The similarity for both Ryugu and Phaethon, that neither exhibits a strong UV nor 2.7-μm OH-band absorption for the entire rotational phases [9], might result in similar spectral changes due to space weathering on both asteroids. Thus, the majority of Phaethon's surface could be explained by freshness due to rejuvenation caused by the recent encounter with the Sun, i.e. fresh cometary activity.

4. Search for F types in the main belt

Ryugu is an F-type asteroid with a flat spectral shape in near-ultraviolet (0.4 – 0.55 μm) [10]. In order to put in context the results from the Hayabusa2 spacecraft and of its returned sample analyses, it is critical to know the abundance of F-types across the Solar System. However, after Eight Color Asteroid Survey (ECAS) [11], there is no major spectroscopic survey that covers the near-ultraviolet wavelength range. We started ground-based near-ultraviolet observations using telescopes at Roque de Los Muchacho Observatory, La Palma, Spain. Also we revisited our previous observations and reanalyzed the data in this wavelength range. We collected the spectral data of Themis, Polana, and Eulalia family members from our observations and ECAS. The largest members of these families are known to have negative visible spectral slope. Polana and Eulalia families are the plausible origin of Ryugu based on the dynamical calculation [2]. When we compared only the visible slope, those family members cannot be distinguished. However, if we use near-ultraviolet spectral slope, Themis family members are quite different from Polana and Eulalia family members. While Themis members show deep absorption in near-ultraviolet, Polana and Eulalia members exhibit flatter in this region. Ryugu is consistent with variation of the Polana and Eulalia members. Moreover, Bennu, the target asteroid of NASA's OSIRIS-REx [12], is also consistent with the Polana and Eulalia group. We found the connection between Ryugu and Polana and Eulalia members spectroscopically. Thus, now the idea that Ryugu is originated from the inner main belt is supported also from spectroscopy.

References

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