SURFACE PHYSICAL CONDITION OF ASTEORID RYUGU USING CLOSE-UP OPTICAL AND THERMAL IMAGES.

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Introduction: In 2018, the Hayabusa2 spacecraft [1] successfully conducted some descend operations toward Ryugu's surface. They included MINERVA rover release in September, MASCOT lander release and two touchdown rehearsals in October. During these operations, we acquired high-resolved optical and thermal images from altitudes below 100 m, using Optical Navigation Camera (ONC-T) and Thermal Infrared Imager (TIR), respectively.

Close-up optical images by ONC-T show detailed physical conditions of the surface materials, such as particle size distribution of pebbles, surface morphology of small boulders and craters. Moreover, close-up thermal images by TIR indicate thermophysical properties of the surface materials and its regional difference, which cannot be resolved by higher altitude observations (e.g., home-position observations from 20 km altitude). Combination between optical and thermal observations is of great importance to understand the nature of the asteroid surface materials.

In this study, we investigate the surface particle size from close-up ONC images. Thermophysical property of the surface component materials inferred from TIR images is also discussed, especially for the range observed for the thermal inertia of boulders.

Data: Table 1 shows the specifications of the ONC-T and TIR instruments. ONC-T has a wheel with seven visible bandpass filters and a panchromatic window. Below 100 m altitude, only v-band (550 nm) imaging was conducted. TIR enables 2-dimentional imaging of thermal infrared radiation (integrated from 8 μm to 12 μm wavelength). Based on ground calibration tests of TIR, digital number images are converted to brightness temperatures for each pixel. TIR helps to understand the relative difference of thermophysical properties of the surface materials using a single image. TIR has wider FOV and lower spatial resolution than ONC-T.

The first descend operation of Hayabusa2 was the MINERVA rover deployment on September 21st 2018. The minimum altitude of the spacecraft was about 60 m from the surface. The second descending operation was the MASCOT lander release on October 3rd 2018. Observations during touch-down rehearsal named TD1-R1-A on October 15th 2018 revealed the detailed surface morphology around the touch-down candidate sites. Finally, a target marker was successfully dropped onto the surface during TD1-R3 operation on October 25th 2018. During these operations, close-up imaging by ONC and TIR was conducted. The minimum altitude of ONC-T observation was 42 m during TD1-R1-A resulting in a spatial resolution of 4.6 mm/pix, and that of TIR was about 20 m altitude during TD1-R3 resulting in a spatial resolution about 18 mm/pix.

Table 1: Specification of ONC-T and TIR onboard Hayabusa2.

	ONC-T [2]	TIR [3]
Detector	CCD	Uncooled bolometer array
Effective Pixel Num.	1024 x 1024	328 x 248
FOV	6.27° x 6.27°	16.7° x 12.7°
Filter	7 narrow-bands (ul, b, v, Na, w, x, p) and 1 wide-band	Single band (8-12 μm)
Resolution	2.2m/pix @ 20km 1.1cm/pix @ 100m	18m/pix @ 20km 8.9cm/pix @ 100m

Results and discussion: Figure 1a shows an ONC-T image acquired during TD1-R1-A. The spacecraft altitude was about 42 m, resulting in spatial resolution of about 4.6 mm/pix. A lot of boulders larger than 50 cm can be seen, but there are fine-particle regions between the boulders (see dashed rectangle in Fig.1a, for example). The particle size in this region is 10 cm or smaller (Fig.1b). The particle size frequency distribution in this region is different from other regions, so that meter-scaled horizontal mixing or migration of pebbles might have occurred effectively on Ryugu's surface.

Figure 1c shows a TIR image taken just after the ONC-T imaging of Figure 1a. The area covered by the ONC-T image is shown as a white square in this TIR image. Note that the diurnal skin depth on Ryugu is about 3 centimeters assuming the thermal inertia of 330 J m^{-2} K^{-1} $s^{-0.5}$ as the global average [4] and volumetric heat capacity of 10^6 J m^{-3} K^{-1}, such that the temperature of rocks larger than the thermal skin depth is controlled by the thermal inertia of the bulk material, which in turn is mainly controlled by the porosity of the rock [5,6]. On the other hand, the temperature of regions with particles smaller than the skin depth is determined by the effective thermal inertia of the granular layer. Boulders seen in ONC-T image are detected as somewhat colder pixels than the small pebbles region, in which the thermal inertia would be lower due to thermal insulating nature of the finer-grained materials.

It is interesting and important that the temperature of boulders seems variable. For example, two boulders denoted as B1 and B2 shown at the right bottom of the ONC-T image have temperatures of about 312 K and 290 K, respectively. This temperature difference implies that the B2 boulder has higher thermal inertia. Simple analysis using 1D thermal calculations of a single facet around the observed region results in a thermal inertia of roughly 300 J m^{-2} K^{-1} $s^{-0.5}$ for B1 and 700 J m^{-2} K^{-1} $s^{-0.5}$ for B2. Such variation in the thermal inertia or porosity of boulders on Ryugu's surface might reflect the degree of thermal metamorphism (source of the depth) in the parent body [7,8]. If the constituents of Ryugu originate from variable depths inside the parent body, this supports the idea of a rubble pile formation of Ryugu after the catastrophic disruption of the parent body. This will place important constraints on the thermal evolution of the parent body.

Acknowledgments: The authors would express thanks to the Hayabusa2 team members for their technical and operational supports and for helpful scientific discussions, N.S. is supported by JSPS Grant-in-Aid for Scientific Research on Innovative Areas (Aqua Planetology, No.17H06459) and JSPS Core-to-Core Program "International Network of Planetary Sciences". MDB acknowledges support from CNES

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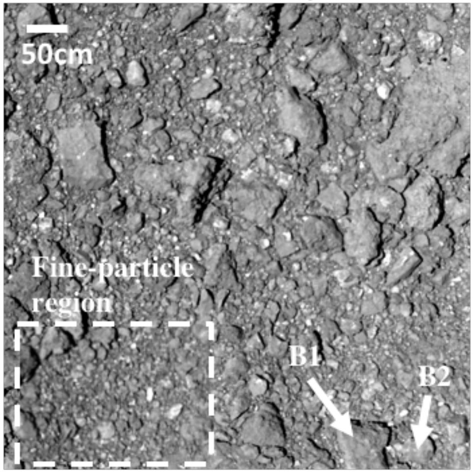
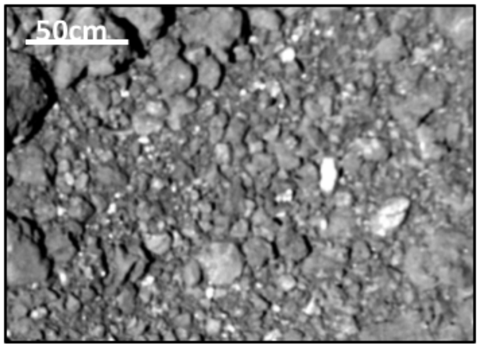
(a) ONC-T image



(b) Close-up image from (a)



(c) TIR image

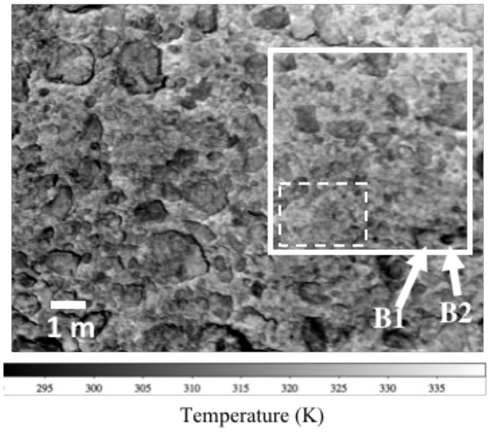


Figure 1: (a) ONC-T image taken during touch down rehearsal (TD1-R1-A) from an altitude of about 42 m. This is the highest resolution image taken in 2018. Pixel resolution is about 4.6 mm/pix. (b) Close-up of dashed rectrangle in (a). TIR image taken just after the ONC-T imaging. The white solid square shows the region covered by the ONC-T image in Figure 1(a). The spatial resolution is about 37 mm/pix.