THERMOPHYSICAL PROPERTIES OF ASTEROID 162173 RYUGU REVEALED BY HIGH-RESOLVED THERMAL IMAGING – A LINK TO POROUS ASTEROID FORMATION.
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Introduction: C-type Near-Earth asteroid 162173 Ryugu is the target of the JAXA Hayabusa2 asteroid sample return mission, and its surface properties have been investigated through remote sensing and surface experiments. The TIR [1] is a thermal infrared imager on Hayabusa2 and based on uncooled micro bolometer array of 328 x 248 effective pixels, with the field of view of 16.7° x 12.7°, corresponding to 0.051° per pixel. The thermographic instrument has revealed the thermophysical properties of the primitive asteroid, which indicate its possible formation process.

Global Thermal Images of Ryugu: The first two-dimensional high-resolved thermal infrared imaging for an asteroid has been conducted in history, using the thermal infrared imager TIR, on 30 June 2018, from the Home Position (HP), 20 km earthward from the surface of Ryugu. A set of thermal images were taken for one asteroid rotation with the step of every 6°. Since this time, the one-rotation thermal image sets have been obtained so far under various conditions at the solar distance from 0.98 to 1.41 au, and at the solar phase angle from -48° to -4° (morning side) and 0° to +41° (afternoon side).

The average and the maximum temperatures in a day suggest the suitable thermal inertia (TI) to the surface of Ryugu from 300 ± 100 J m^{-2} K^{-1} $s^{-0.5}$ (hereafter, tiu). This TI value is consistent with the prediction by on-ground and in-space observations of 150 to 300 tiu [2]. It is also consistent with the surface measurement by MARA on MASCOT which measured the thermal inertia of a single boulder [3]. This TI value is much smaller than that of carbonaceous chondrites (> 600 tiu) [4]. In addition, the boulders and the surroundings show almost the same maximum temperature and diurnal profile. The surface materials, even the boulders, must be super porous, and the surroundings must be covered with flakes of porous materials but not with sandy regolith which is typical for high gravity celestial bodies like the Moon and Mars.

Higher resolved global thermal images have been taken during the Mid-Altitude Observation Campaign, on 1 August 2018, at 5 km altitude from the asteroid. During this campaign, the spatial resolution of 4.5 m/pixel have been taken and the most of large boulders larger than 10 m across were discriminated from the surroundings and have proven the results of the global thermal imaging from HP.

TIR mainly imaged the afternoon side of Ryugu before the solar conjunction in November to December 2018, while it takes the morning side since then. The night temperature was included in the morning side images, and the lowest temperature was below 200 K (although no set of precise calibration data exists). This suggested that the surface TI seems to be below 300 tiu.

Close-up Thermal Images of Ryugu: The first opportunity to take thermal images below 50 m altitude was on 21 September 2018, during the release of MINERVA-II-1 twin hopping rovers. More close-up thermal images have been taken around 20 m altitude during two rehearsal descents on 15 and 25 October 2018. Close-up thermal images of the surface of Ryugu have discriminated each of boulders larger than a few tens of centimeter across.

Most boulders have the size of > 10 cm across and show within a same range of temperature about 300 to 310 K at those times, corresponding to 300 ± 100 tiu. We also discovered a few cold boulders apparently below 280 K, corresponding to 600 to 1000 tiu, which were like typical carbonaceous chondrites [5].

A Super-Porous Asteroid Formation: A possible scenario of Ryugu formation is proposed [5] to explain how to build a primitive asteroid consisted of mainly super porous boulders with some minor dense rocks.

Fluffy dust particles in the solar nebula have been accumulated to form planetesimals in the early solar system. Most of planetesimals were kept porous due to a low degree of consolidation under a very low gravity condition. The parent body of Ryugu were formed was kept porous for most of its volume. If the lithostatic pressure at the center of interior reached the level of its bulk modulus (50 MPa or so for CM chondrite), the region might be more consolidated and altered to form a dense core. Intense impact fragmentation occurred part of impact fragments accreted to form the current asteroid Ryugu. Most surface is consisted of porous materials, and some dense rocks might be from the central part of parent body. Alternative scenario might be that a dense small asteroid impacted and fragmented the porous parent body to form Ryugu by re-accretion of fragments. In this scenario, the dense rocks might be from the impactor (exogenic origin). The hypothesis of asteroid (and planetesimals) consisted of super-porous material should be confirmed by sample return.

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