Thermal properties of asteroid Ryugu from global, local, and micro-scale observations and the possible formation and evolution scenario of Ryugu

Tatsuaki Okada[1,2], Satoshi Tanaka[1,2], Naoya Sakatani[1], Yuri Shimaki[1], Takehiko Arai[3], Hiroki Senshu[4], Hirohide Demura[5], Tomohiko Sekiguchi[6], Toru Kouyama[7], Masanori Kanamaru[2], Takuya Ishizaki[1]

[1]*Institute of Space and Astronautical Science, JAXA, Japan,* [2]*University of Tokyo, Japan,* [3]*Maebashi Institute of Technology, Japan,* [4]*Chiba Institute of Technology, Japan,* [5]*University of Aizu, Japan,* [6]*Hokkaido University of Education, Asahikawa, Japan,* [7]*National Institute of Advanced Industrial Science and Technology, Japan..*

Thermophysical properties of C-type asteroid 162173 Ryugu have been investigated through remote sensing using the Thermal Infrared Imager (TIR)[e.g., 1-3], on the surface using the radiometer MARA on MASCOT lander [4,5], and the analysis of return sample [e.g.,6,7]. The global average and the local distribution of thermal inertia were mapped by TIR, with the typical value of 200 to 400 J m^{-2} kg^{-1} $s^{-0.5}$ (tiu, hereafter) [1], which is lower than that of typical chabonaceous chondrite meteorites of 600 to 1000 tiu [8]. Surface boulders and their surroudings have almost the same thermal inertia, indicating that most of boulders are consisted of materials with high porosity (pores and cracks in them) and not completely consolidated, and the surroundings are covered with boulders and rocks (not sandy regolith) [1], which was confirmed during the descent operations. The flat diurnal temperature profiles observed at the afternoon local time indicate the very rough surface [1]. Considering the thermal model with rough surface [9], the thermal inertia and roughness are derived simultaneously [2]. Up-close observations by TIR during the descent operations suggested that boulders have a variety of thermal inertia, with more than 80 % of them having 200 to 400 tiu, while some portions have very low (<100 tiu) or very high (>600 tiu) thermal inertias [3]. They are identified as "Hot Spots" and "Cold Spots", because they are observed exceptionally hotter or colder compared with their surroundings [1,3]. The surface experiment by MARA indicated the simiar thermal inertia for a single boulder [4], so that the rough boulders should be the representative material on the asteroid. Multi-band radiometry by MARA indicates the similarity to aqueously altered carbonaceous chondrites (CI or CM) but not like heated carbonaceous chondrites [5].

The average thermal properties of returned samples show the thermal inerita almost similar to that of typical charbonaceous chondrites for <100 µm scale [6,7], although the thermal inertia (or more directly the thermal diffusivity) in the direction where cracks exist indicate much lower, consistent with the thermal inertia by remote sensing by TIR or surface measurements by MARA. The return samples are not always representative as the intact surface on Ryugu regaring the physical properties, since fragile portions of them might have been broken during impact sampling as well as during the severe shock and vibration in the return capsule when entry to Earth. The return samples seem to be consisted of more consolidated parts of Ryugu surface materials with flatter surface, instead of fragile and porous features observed as cauliflower-like cramby boulders on Ryugu. The return sample are more like CI chondrites in mineralogy, chemistry, and textures but with darker, more porous and fragile characteristics [10,11]. The difference of thermal inertia between larger scale (> 1mm) and a smaller scale (<0.1 mm) might attribute to the existing cracks and pores inside of boulder materials. A formation scenario of Ryugu will be shown to explain the history of Ryugu formation and evolustion or even a planetary formation.

Our scenario is like this: 1) porous dust with ices of volatile species (water and CO_2) were accumulated to form a planetesimal in the outer solar system. 2) Aqueous alteration occurred by internal heating due to radioactivity of Al^{26} but not heated to drive strong thermal metamorphism. Materials were more altered at the innermost region to consolidate almost equal to typical carbonaceous chondrites, but less altered at the outermost region to leave the materials so porous and fragile. 3) The parent body migrated to inner region of the Solar System, 4) Impact fragmentation of parent body, sometimes by S-type bodies [12]. 5) Degassing of volatiles by sublimation due to exposre to space, to make freeze-dry porous materials. 6) Reaccretion of fragmented rocks and boulders with high porosity by low degree of consolidation and freeze-dry and formation of a rubble pile body. Most of surface boulders are occupied by those from the inner region of the parent body as the representative boulders, while relatively porous boulders originated from the outermost region are the "hot spots" and relatively consolidated boulders originated from the innermost region are the "cold spots". 7) Some uppermost surface processes by spaceweathering.

References

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