Remote Boulder counting and thermal IR temperature curves constrain strength, microporosity, thermal conductivity and grain density of rubble pile Ryugu's rocks

Jens Biele[1], Matthias Grott[2], Maximilian Hamm[2,11], Patrick Michel[3], Seiji Sugita[4], Naoya Sakatani[7], Wladimir Neumann[2,6], Shingo Kameda[7], Tatsuhiro Michikami[8], Hideaki Miyamoto[9] and Chikatoshi Honda[10]

[1]German Aerospace Center, Cologne, Germany, [2]German Aerospace Center, Berlin, Germany, [3]Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Nice, France, [4]University of Tokyo, Tokyo, Japan, [5]Japan Aerospace Exploration Agency, ISAS, Sagamihara, Japan [6]Klaus-Tschira-Labor für Kosmochemie, Institut für Geowissenschaften, Universität Heidelberg, Heidelberg, Germany, [7]Rikkyo University, Tokyo, Japan, [8]Kindai University, Hiroshima, Japan, [9]Dept of Systems Innovation, University of Tokyo, [10]University of Aizu, Aizu-Wakamatsu, Japan, [11]Institut für Mathematik, Universität Potsdam, Potsdam, Germany

Abstract

In this paper, we summarize the findings and deductions for small asteroid Ryugu from Hayabusa2 remote sensing as well as from MASCOT radiometer (MARA) data. Observations cover the VIS (broadband) and MIR (broadband) wavelength ranges. For a typical rock on Ryugu's surface, we find a thermal inertia of 295±18 $Jm^{-2}K^{-1}s^{-1/2}$ (Hamm+ 2020), a microporosity of 50 ± 3% (Grott+ 2020, Hamm+, 2020), and assuming a CM composition and thus an inferred specific heat capacity of c_p = 890 $Jkg^{-1}K^{-1}$ (± 10%, at an average temperature of 277 K), we estimate a thermal conductivity of 0.069 ± 0.012 $Jm^{-1}K^{-1}$ at ~277 K. These estimates are based on MARA surface brightness temperature measurements of an arguably (Biele+ 2019) dust-free boulder at MASCOT's landing site obtained over a full diurnal cycle. Those values are consistent with the TIR instrument's global findings (Okada+ 2020). The main source of uncertainty in the thermal inertia estimate is due to the uncertain surface orientation of the boulder top that determines the insolation power. Including a Digital Terrain Model (DTM) of the observed boulder, embedded in the MASCOT landing site (Scholten+, 2019), into the thermal model could reduce this uncertainty significantly. The very high deduced microporosity lets us reasonably estimate the tensile strength of those abundant "cauliflower rocks" (Jaumann+, 2019), ~200-280 kPa (Grott+, 2019).

Furthermore, also from orbital data (ONC imaging and counting, plus radiometric data for GM), we have estimated the macroporosity of Ryugu, assumed to be a homogeneous rubble pile, based on granular mixing theory and the size-frequency distribution of boulders ranging from ~0.1 m to ~100 m diameter. We find that the macroporosity of Ryugu is very low, 16±3% and that if the underlying homogeneity assumption is true, taken together with Ryugu's bulk density and the average microporosity of its boulders, the average grain density can be estimated as 2.85±0.15 g/cm^3, consistent with the mineralogy of CM meteorites or the ungrouped carbonaceous chondrite Tagish Lake.

It will be exciting to compare these values to actual laboratory measurements of the returned samples (later in 2021). For example, if our values for Ryugu's macroporosity and rock microporosity (and/or grain density) do not agree with what is found from the samples, the assumption of homogeneity might be wrong. This would mean that Ryugu's surface has a significantly different boulder SFD than its interior implying regolith size sorting processes which may result in bulk density variations. Or, simpler, the assumed relationship between rock porosity and thermal conductivity is incorrect.

As for the strength of rock pieces, besides possible size, i.e., scale dependencies and sampling bias (weak pieces tend not to survive the sampling process intact), a higher strength than predicted here would have to be reconciled with the very low thermal conductivity of Ryugu's blocks, which dictates rather small grain-grain neck diameters, that are either sintered, volatile condensates, or salts.

More laboratory data (and theory/simulations) on the thermal conductivity and strength of very porous rocks are urgently needed. To this end, we are currently studying UTPS, a cold pressed Phobos (Asteroid type) simulant (Miyamoto+ 2018) that can be produced with porosities of ~30 to ~50% and is competent, yet weak.

References

Hamm, M., et al. (2020). "Thermophysical modelling and parameter estimation of small Solar system bodies via data assimilation." Monthly Notices of the Royal Astronomical Society **496**(3): 2776-2785.

Grott, M., et al. (2019). "Low thermal conductivity boulder with high porosity identified on C-type asteroid (162173) Ryugu." Nature Astronomy **3**(11): 971-976.

Biele, J., et al. (2019). "Effects of dust layers on thermal emission from airless bodies." Progress in Earth and Planetary Science **6**(1): 48.

Okada, T., et al. (2020). "Highly porous nature of a primitive asteroid revealed by thermal imaging." Nature **579**(7800): 518-522.

Jaumann, R., et al. (2019). "Images from the surface of asteroid Ryugu show rocks similar to carbonaceous chondrite meteorites." Science **365**(6455): 817-820.

Miyamoto, H., et al. (2018). "Phobos Environment Model and Regolith Simulant for MMX Mission." 49th Lunar and Planetary Science Conference 2018 (LPI Contrib. No. 2083)

Scholten, F., et al. (2019). "The Hayabusa2 lander MASCOT on the surface of asteroid (162173) Ryugu – Stereo-photogrammetric analysis of MASCam image data." Astronomy & Astrophysics **632**: L5.