ROCK POROSITY CONTROLS THE PRODUCTION OF FINE REGOLITH ON ASTEROIDS. S. Cambioni[1], M. Delbo[2], G. Poggiali[3], C. Avdellidou[2], A. J. Ryan[4], J. D. P. Deshapriya[5], E. Asphaug[4] , R.-L. Ballouz[6], M. A. Barucci[3], C. A. Bennett[4], W. F. Bottke[7] , J. R. Brucato[8], K. N. Burke[4], E. Cloutis[9], D. N. DellaGiustina[4], J. P. Emery[10], B. Rozitis[11], K. J. Walsh[7] , D. S. Lauretta[4]. [1]Dept. of Earth, Atmospheric and Planetary Sciences, MIT, Cambridge, MA, USA (cambioni@mit.edu); [2]Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Nice, France; [3]LESIA Observatoire de Paris, Meudon, France; [4]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA; [5]INAF Osservatorio Astronomico di Roma, Roma, Italy; [6]The Johns Hopkins University APL, Laurel, MD, USA; [7]SwRI, Boulder, CO, USA; [8]INAF – Osservatorio Astrofisico di Arcetri, Florence, Italy [9]Dept. of Geography, University of Winnipeg, Manitoba, Canada; [10]Dept. of Astronomy and Planetary Science, NAU, Flagstaff, AZ, USA; [11]School of Physical Sciences, The Open University, Milton Keynes, UK.

We present our findings [1] that the surprising lack of fine regolith on asteroids (101955) Bennu and (162173) Ryugu [2, 3] is due to the high porosity of their surface rocks, that compact rather than fragment in impacts and experience slower thermal fragmentation compared to less porous rocks. This mechanism also explains the presence of fine-regolith ponds on asteroid (25143) Itokawa [4], whose rocks are indeed less porous than Bennu's and Ryugu's [5, 1]. We argue that different rock porosities may explain the observed diversity of asteroids surfaces.

Introduction: Rocks on airless bodies comminute into regolith via meteoroid bombardment [6] and thermal cracking [7]. Early studies proposed that small asteroids could lack fine-grained regolith on their surfaces because their low gravity frustrates ejecta retention [8]. However, in September 2005 the JAXA Hayabusa mission returned images of areas covered in fine regolith on the surface of the S-type asteroid Itokawa, whose size is about 300 meters. This set the expectation that fine regolith could be present on small asteroids. But when the NASA OSIRIS-REx and JAXA Hayabusa 2 missions visited the small carbonaceous asteroids Bennu and Ryugu, they found a general lack of fine regolith [2, 3], despite signatures of regolith-forming processes [9, 10, 3].

Methodology. To investigate why the surface of Bennu is so rocky, in [1] we analyze thermal infrared data of its surface collected by the OSIRIS-REx Thermal Emission Spectrometer (OTES) during the detailed survey phase of the mission [11]. Our goal is to constrain the abundance α of fine-regolith particles smaller than the diurnal thermal skin depth (a few cm on Bennu [12]). We are also interested in measuring the thermal inertia Γ_R of nearby rocks, that is, their resistance to change temperature, which is a monotonically decreasing function of rock porosity [13]. To explore the large parameter space of surface properties (including surface roughness) and globally map the surface of Bennu, we use a machine-learning thermophysical model [5] trained to distinguish the thermal signals of fine regolith and rocks of different grain sizes, porosities and relative surface abundances.

Results. We find that the abundance of fine regolith α on the surface of Bennu directly correlates with the thermal inertia of nearby rocks Γ_R (Figure 1, [1]). The correlation is statistically robust with Pearson probability of non-correlation $< 4 \times 10^{-3}$. We run several other robustness test [1]. For example, we exclude that the correlation is a geometric effect due to a possible interplay between the thermal properties and size of boulders (e.g., [12]). Fig. 1 shows that Bennu's surface hosts rocks of different porosities, in agreement with the finding by [9] that craters on boulders on Bennu have different depth-to-diameter ratios (the depth-to-diameter ratio tend to increase with increasing impact target porosity, e.g., [14]). Our results also confirm that the value of α for the deputy sampling site Osprey is lower than that of the sampling site Nightingale, consistent with rock mapping campaigns which used limited-coverage images with a resolution of 1–3 mm/pixel [15].

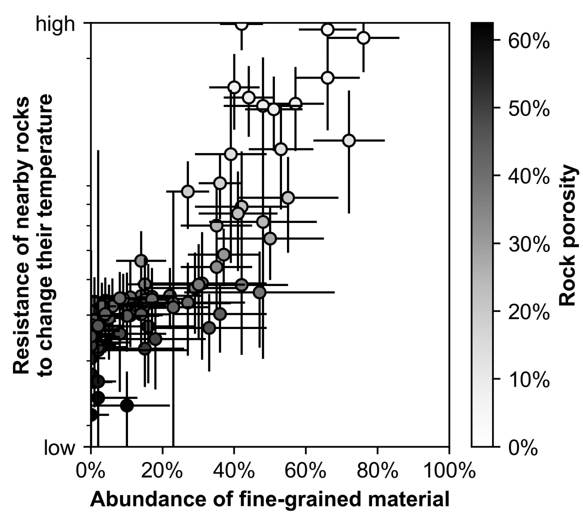

Figure 1. The abundance of fine regolith on Bennu inversely correlates with the porosity of nearby rocks. The rock porosity is computed by applying the method by [13] to the measurements of thermal inertia of the rocks derived from OTES data, that is, their resistance to change temperature, which decreases with increasing porosity.

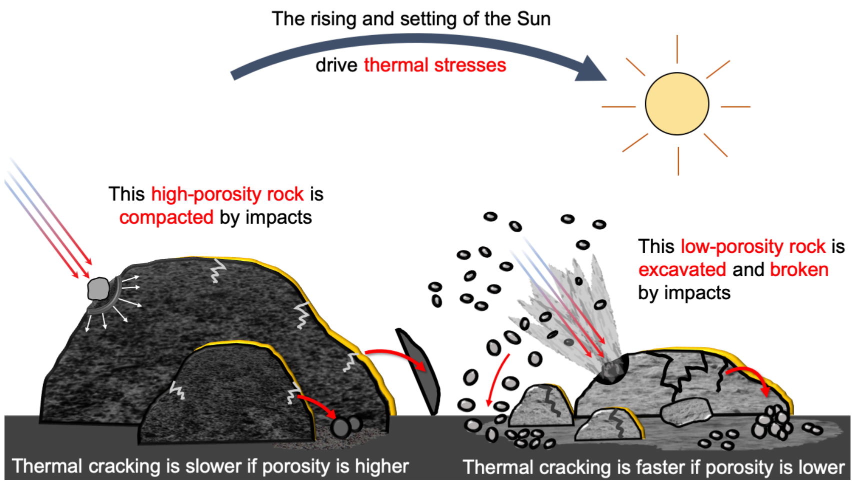

Figure 2. Evolution of two types of rocks on asteroids via regolith-forming processes. The rocks on the left have high porosity and get compacted rather than excavated by impacts. The rocks on the right have low porosity and get excavated and broken in situ by impacts (for evidence of in-situ rock breakup on Bennu, see [1]). Thermal stresses propagate cracks into the rocks; the higher the rock porosity, the more slowly the propagation.

Porosity controls rock fragmentation. The correlation of Figure 1 implies that there is less fine regolith on Bennu where rocks are more porous. Laboratory experiments of meteoroid bombardment [14, 16] show that more energy is spent in pore-space collapse and compaction in initial crater formation, and less energy goes in excavating the rock, if the target rock has a high porosity. The mass of ejecta — which may contribute to the fine regolith — also decreases with increasing rock porosity [14], and spalling, which is observed in laboratory experiments of hypervelocity impacts on simulants of Bennu's rock with porosity ~ 25% [17], was rarely seen on boulders on Bennu [9]. We further simulate the breakup of two rocks with porosity 20% and 40% via thermal fatigue and show that more porous rocks take longer to break because they suffer weaker thermal stresses [1]. We conclude that where rocks are more porous on Bennu, less rock fragmentation occurs, and thus the production of fine regolith is frustrated (Figure 2, [1]). This explains the correlation of Figure 1 and the general lack of fine regolith on Bennu, where most rocks were found to be highly porous (Figure 1 and [12]).

Evidence from other asteroids. Analysis of data of asteroid Ryugu by the JAXA Hayabusa2 team found that most rocks on Ryugu have porosity similar to that of Bennu's [13, 18] and that the surface similarly lack fine-regolith ponds [3]. Conversely, the JAXA Hayabusa mission observed ponds of cm-sized particles on asteroid Itokawa [4]. Analysis of ground-based infrared observations of Itokawa [5] revealed that its rocks have a thermal inertia consistent with a porosity of ~20% [1], which is substantially lower than the porosity of most rocks on Bennu and Ryugu, which is ~ 40–50% (Figure 3 in [1]). This is consistent with the correlation of Figure 1.

A general phenomenon of asteroids. We argue that the differences in asteroid rock porosity explain the diversity of surfaces observed by spacecraft over the years [1]. We predict that carbonaceous asteroids like Bennu and Ryugu, which are the most populous type [19], should lack fine-regolith ponds, while S-complex asteroids like Itokawa, the second-most populous group [19], should have abundant fine regolith. Future asteroid missions, such as NASA Lucy and ESA Hera, will allow testing our prediction.

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