CONSTRAINING ASTEROID RYUGU'S SURFACE PROPERTIES FROM SIMULATIONS OF THE SCI IMPACT

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Introduction: The small carry-on impactor (SCI) experiment performed by the Hayabusa2 mission on asteroid Ryugu does not only provide important insights to the properties and collisional evolution of the small body populations, but also represents an ideal test case to validate impact cratering models. The results of this experiment suggest that the surface cohesion on Ryugu must be small ($\lessapprox$ 1 Pa) and that the impact might have taken place in the gravity-dominated regime [1]. This low-strength, low-gravity cratering environment has not yet been explored before the SCI experiment and it is not clear if traditional impact models and crater scaling laws are applicable. Another important question is how much the target inhomogeneities (i.e., boulders located close to the impact point) affect the cratering process and the impact outcome, such as the crater size and morphology.

Modeling approach: Here we use the Bern SPH impact code [2–4] to study the sensitivity of the SCI impact outcome to target cohesion and target inhomogeneities (i.e., boulders). Bern SPH is a shock physics code that includes material models suitable to simulate the behaviour of geological materials, various equations of state and a porosity compaction model ($P - \alpha$). To model the entire crater formation, here we apply a recently developed numerical approach that allows for faster calculation times and for direct shock-physics code calculations of the entire process [5, 6]. We first performed a series of impact simulations on homogeneous targets to study the effects of material strength on the crater size. We systematically varied the initial cohesion (Y_0 = 0–0.5 Pa) and the coefficient of internal friction (f = 0.4–1.0).

Results from impacts into homogeneous targets: We find that the resulting crater is sensitive to our choice of cohesion and coefficient of internal friction, and that there is no unique solution. The same crater size can be produced by impacting targets with a combination of mechanical properties (e.g., friction coefficient and cohesion). To match the observed size of the SCI crater, a cohesionless (Y_0 = 0 Pa) target requires a high friction coefficient ($f > 0.8$). On the other hand, a cohesion of ~ 0.2 Pa with a small friction coefficient (f = 0.4) also produces the required crater size.

Results from impacts into targets with boulders: For a subset of target material properties, boulders with varying sizes are distributed within the target. The sizes and positions of the boulders are representative of the ones present on Ryugu close to the SCI impact point. Our simulations reproduce well the overall outcome of the SCI impact, including the displacement of the boulders. The presence of the large block leads to an asymmetric crater, similar to the observed one. We find that the presence of the boulders within the target affects the resulting crater size by less than 5%.

Crater scaling laws and consequences for asteroid surface ages: By calibrating the general form of the impact cratering scaling [e.g. 7, 8] to our simulation results, we can determine the fitting constants. Our results suggest that for a fixed f = 0.55, a cohesion of Y_0 = 0.05 Pa is required to match the SCI crater size, and that the SCI impact took place at the transition between the strength and gravity regime, where cohesive and gravitational forces determine the impact outcome concurrently. The cratering scaling-laws derived from our results predict very large cratering efficiencies ($D_{crat}/D_{proj} \sim 100$), suggesting that surfaces of small asteroids must be very young, consistent with the analysis of the recently observed Ryugu and Bennu [e.g. 9–11]. However, our results also show that the presence of a small amount of cohesion ($<$ 1 Pa) can strongly affect the cratering efficiency. Consequently, the influence of cohesion may be responsible for the varying ages of different geological surface units on Ryugu and more generally leads to a "crater reduction effect" for small-scale impacts on low-strength asteroid surfaces, contributing to the depletion of small craters in the observed crater distributions on small asteroids [12, 13].

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References: [1] Arakawa, M. et al. (2020) *Science*, 368:67–71. [2] Benz, W. & Asphaug, E. (1995) *Comput. Phys. Commun*, 87:253–265. [3] Jutzi, M. et al. (2008) *Icarus*, 198:242–255. [4] Jutzi, M. (2015) *Planet. Space Sci*, 107:3–9. [5] Raducan, S. D. & Jutzi, M. (2022) *PSJ*, accepted. [6] Jutzi, M. et al. (2022) submitted. [7] Holsapple, K. A. (1993) *Annu. Rev. Earth Planet. Sci.* 21:333–373. [8] Raducan, S. D. et al. (2020) *J. Geophys. Res. Planets*, 125. [9] Cho, Y. et al. (2021) *J. Geophys. Res. Planets*, [10] Ballouz, R.-L. et al. (2020) *Nature*,1–5. [11] Bierhaus, E. et al. (2022) *Nature Geoscience*, [12] Tatsumi, E. & Sugita, S. (2018), 300:227–248. [13] Takaki, N. et al. (2022) *Icarus*, 377.