Modeling the contamination of Bennu and Ryugu through catastrophic disruption of their precursors

R.-L. Ballouz (1), P. Michel (2), O.S. Barnouin (3), K.J. Walsh (4), M. Jutzi (5), E. Tatsumi (6), M.A. Barucci (7), D.N. DellaGiustina (1), H. Campins (8), S. Sugita (9), S. Watanabe (10), H. Miyamoto (11), W.F. Bottke Jr. (4), H.C. Connolly Jr. (12,1), M. Yoshikawa (13), D.S. Lauretta (1)

(1) Lunar & Planetary Laboratory, University of Arizona, Tucson, AZ, USA, (2) Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, CS 34229 06304 Nice Cedex 4, France, (3) The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA, (4) Southwest Research Institute, Boulder, CO, USA, (5) Physics Institute, Space Research and Planetary Sciences, NCCR PlanetS, University of Bern, Switzerland, (6) Instituto de Astrofísica de Canarias, University of La Laguna, Santa Cruz de Tenerife, Spain, (7) LESIA-Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, Université de Paris, France, (8) University of Central Florida, Department of Physics, Orlando, FL, USA, (9) Dept. of Earth and Planetary Science, School of Science, University of Tokyo, Japan, (10) Graduate School of Environmental Studies, Nagoya University, Japan, (11) Department of System Innovation, School of Engineering, The University of Tokyo, Japan, (12) Department of Geology, School of Earth and Environment, Rowan University, Glassboro, NJ, USA, (13) Institute of Space and Astronautical Sciences, JAXA, Sagamihara, Japan.

Disruption and Reaccumulation:

Asteroids such as Ryugu and Bennu are likely fragments formed from a larger body that was disrupted in the main asteroid belt [1,2]. Numerical simulations of asteroid disruptions—including the fragmentation phase during which the asteroid is broken up into small pieces and the gravitational phase during which fragments may reaccumulate due to their mutual attractions—lead to a family of rubble piles over a range of sizes [3]. Considering microporous parent bodies of 100 km in diameter, we found that their disruption (Fig. 1) can lead to rubble piles with oblate spheroidal or top shapes [4]. Moreover, assuming that the parent body is hydrated, the various degrees of heating at impact can produce rubble piles with different level of hydration as a result of a single parent body disruption.

We propose two scenarios where Ryugu and Bennu could originate from the same parent body. In scenario a, Ryugu and Bennu are composed from materials sourced from near the impact point and near its antipode, respectively. In scenario b, Ryugu and Bennu are composed from materials sourced from the parent-body center and near the impact point's antipode, respectively. The detected signature of exogeneous material introduces new complexities to the collisional origin of Ryugu and Bennu [5, 6].

Rubble Pile Contamination:

Due to the apparent spectral homogeneity observed on the surfaces of Bennu and Ryugu during the first observational campaigns, our simulations in [4] only considered the fate of material originating from the parent body, assumed to be homogenous in composition. However, subsequent spectral data from the OSIRIS-REx and Hayabusa2 missions show a small fraction of anhydrous silicate material on the surface of the two bodies [5, 6]. The presence of this material can be explained by retention of a projectile on either the parent body or on the rubble piles themselves after their formation. However, projectile retention efficiencies for impacts of anhydrous silicates on hydrated minerals are poorly constrained [7, 8] for expected impact speeds in the main asteroid belt (~ 5km/s, [9]). Here, we investigate whether the family-forming catastrophic disruption can lead to the incorporation of impactor material in the reaccumulated family members, leading to the small fraction of apparently exogeneous material on their surface.

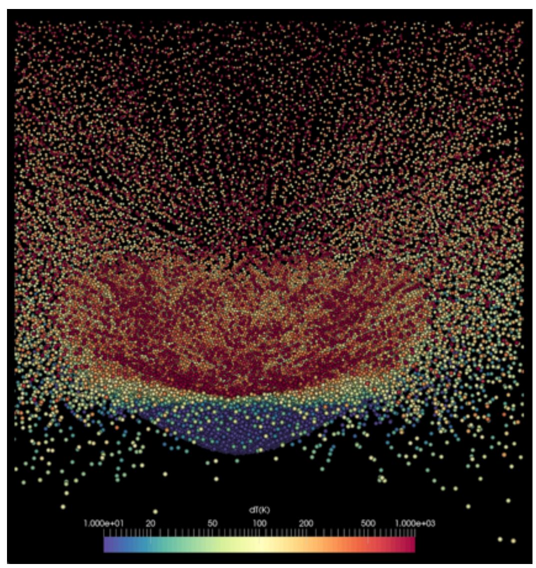

Figure 1 Outcome of a SPH simulation of the disruption of a microporous 100-km-diameter parent body. Each particle is a fragment. Colors represent the various degrees of impact heating. This outcome is the starting point of the gravitational phase during which the fragments reaccumulate to form rubble piles.

Approach:

We performed a series of numerical simulations of sub-catastrophic and catastrophic disruption of 1- and 100-km-diameter microporous asteroids. We account for both the parent body material and the projectile material in the subsequent gravitational phase when fragments re-accumulate to form the parent-body remnant and smaller rubble-pile family members. As in our previous works, the fragmentation phase was simulated using a Smoothed Particle Hydrodynamics (SPH) hydrocode, and the gravitational phase was computed using the N-body code pkdgrav, including the Soft-Sphere Discrete Element Method (SSDEM) [10]. We then track the surviving materials of both the projectile and the parent body, including their level of heating, as they reaccumulate. For each aggregate, we measure their shapes, the fractions of projectile and parent body materials that compose them, and their associated level of heating. Projectile material was neglected in previous work because asteroid families appear spectrally homogeneous, suggesting that they are mostly made of the material of their parent body. The advanced observational capabilities of space missions enabled the discovery that this scenario may be more complex.

Outlook:

Observational analysis of exogenous material on Ryugu and Bennu provide constrains for our numerical simulations. In particular, the total volume and the spectral characteristics of the exogenous material can be measured [5,6,11]. The total volume bounds the required contamination efficiency and/or the total time needed to contaminate the parent body. The spectral analysis shows that Bennu hosts HED-like material whereas Ryugu has ordinary chondrite–like material.

This difference in the spectral signature of exogenous material may render scenario b (outlined above) invalid, as our preliminary calculations show that contamination on large 100-km parent bodies is likely only limited to its outer shell. Thus, it is difficult to form a 1st generation rubble-pile that has both: i) material from the parent body core, and ii) exogenous material that originated from the contamination of the original parent body's outer shell. This scenario may be possible if the asteroid is a 2nd generation object, with its precursor being an approximately 20-km rubble-pile that incorporated material originating from both the center and exterior of the parent body [12, 13]. Our numerical simulations will provide claraity on the feasibility of these various scenarios. Ultimately, analysis and comparison of the returned samples will provide clarity on the potential shared collisional origin of Ryugu and Bennu, and the prevalence of impact contamination in the Solar System.

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