# Properties of the asteroid Bennu's surface based on contact measurements and their implications

D.J. Scheeres[1], G. Brown[1], R.-L. Ballouz[2], E.B. Bierhaus[3], E.R. Jawin[4], P. Sánchez[1], and K.J. Walsh[5]
[1]*University of Colorado, Boulder, CO, USA*
[2]*Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA*
[3]*Lockheed Martin Space, Littleton, CO, USA*
[4]*National Air and Space Museum, Smithsonian Institution, Washington, DC, USA*
[5]*Southwest Research Institute, Boulder, CO, USA*

When the OSIRIS-REx S/C touched the surface of Bennu to carry out its sampling operations, it opened a new view into the mechanical properties of rubble pile asteroids. The OREX S/C was able to take measurements of its deceleration as it penetrated the surface, in advance of initiating its sampling process. Based on these measurements, optical observations of surface deformations during its penetration, and detailed granular mechanics modeling of the interaction, it was determined that the surface regolith covering was highly porous and had a very low level of cohesion [1]. Figure 1 (from [1]) shows the main data used in determining the Bennu surface mechanical properties. Figure 2 shows granular mechanics simulations in a micro-gravity environment. The simulations capture the total spacecraft mass properties, the constant force spring in the sampling arm, and the geometry of the sampling head. The simulations show that for sufficiently low cohesion, the spacecraft head penetrates the regolith and displaces it, without activating the constant force spring. This is the scenario that was seen in the actual sampling event. Simulating regolith with stronger cohesive strength forces the spacecraft to stop and rebound, engaging the constant force spring.

Based on these measurements and modeling the surface packing fraction was determined to be as low as 0.25, half the inferred bulk packing fraction of the asteroid, and the cohesive strength on the order of 1 Pa or less. These properties imply that the surface regolith may be significantly weaker than the sub-surface, potentially due to the lack of fines, which have the net effect of strengthening a rubble pile structure [2]. This is also consistent with other observations of the Bennu surface geology [3] and crater profiles [4].

The implications of these regolith properties can be explored relative to the larger-scale mass distributions detected on Bennu, which found that the equatorial bulge region had a lower overall density than other regions of the asteroid [5]. Migration of regolith into Bennu's equatorial region brings this material within the rotational Roche lobe of the body where it is energetically trapped, allowing for accumulation [5]. This process should have been accelerating over time, as the YORP effect causes Bennu to spin more rapidly [6], moving the Roche lobe down to lower latitudes. Current predictions are that the surface of Bennu should start to lose regolith directly in about 400 Ky, assuming the YORP effect stays constant. In this talk, we will consider the mechanics of this overall cycle of behavior, and note what likely outcomes should be found. These can then be interpreted in light of the asteroid Ryugu, which has also been hypothesized to have undergone a period of past rapid spin [7].

**References**

[1] K.J. Walsh, et al. Near-zero cohesion and loose packing of Bennu's near subsurface revealed by spacecraft contact, Sci. Adv., 8 (27), eabm6229. • DOI: 10.1126/sciadv.abm6229
[2] P. Sánchez and D.J. Scheeres. 2014. "The Strength of Regolith and Rubble Pile Asteroids," Meteoritics and Planetary Science 49(5): 788-811
[3] E. R. Jawin, et al. 2020. Global Patterns of Recent Mass Movement on Asteroid (101955) Bennu, JGR Planets 10.1029/2020JE006475
[4] E.B. Bierhaus, et al. Crater population on asteroid (101955) Bennu indicates impact armouring and a young surface, Nature Geoscience 15, pages 440–446 (2022)
[5] D.J. Scheeres, et al. Heterogeneous mass distribution of the rubble-pile asteroid (101955) Bennu, Science Advances 6, eabc3350 (2020)
[6] C. Hergenrother, et al. (2019). The Operational Environment and Rotational Acceleration of Asteroid (101955) Bennu from OSIRIS-REx Observations, Nature Communications 10: 1291
[7] M. Hirabayashi, et al. (2019). The western bulge of 162173 Ryugu formed as a result of a rotationally driven deformation process, ApJ Letters 874(1): L10

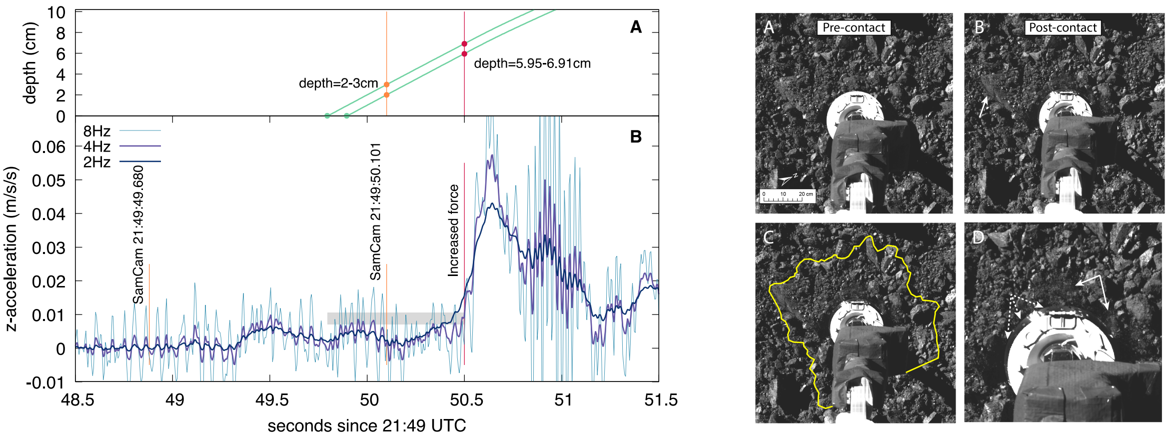


Figure 1: From Reference [1], these figures show the acceleration and surface imaging data used to constrain the mechanical properties of the regolith surface.

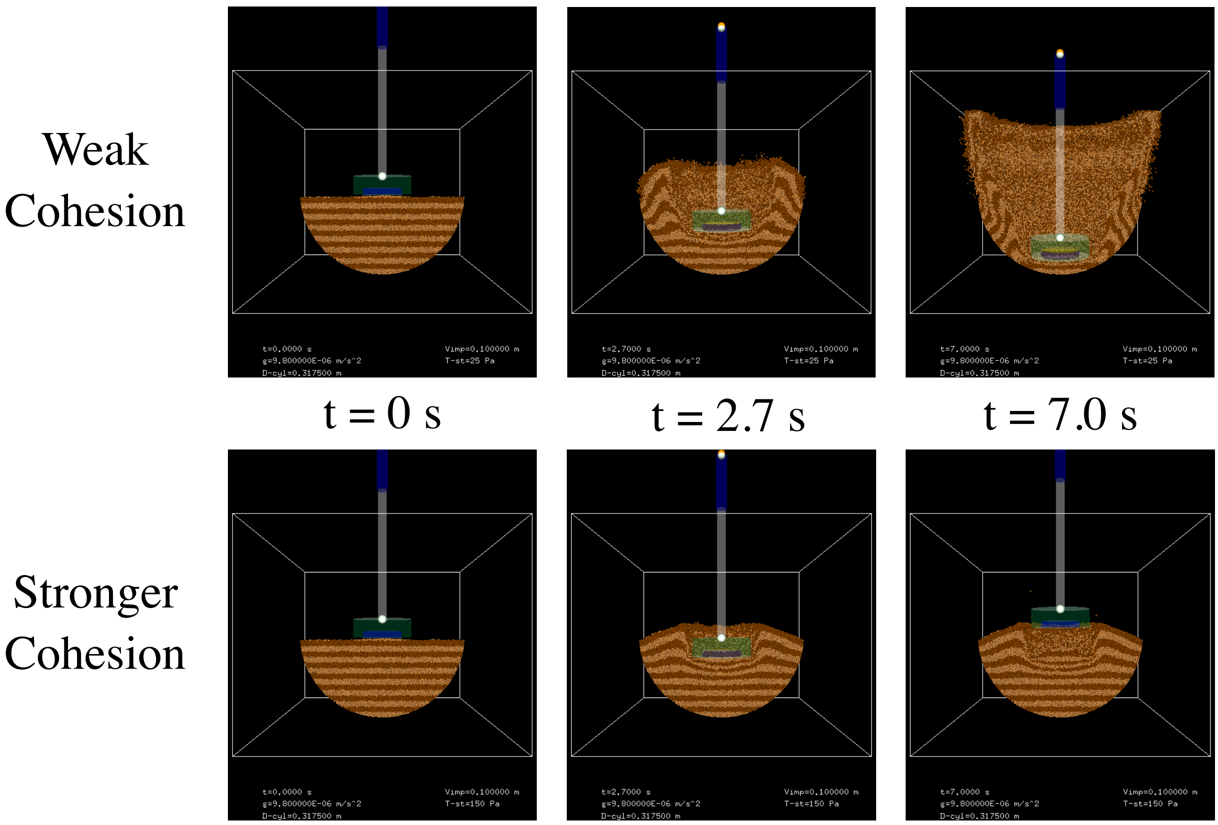


Figure 2: Granular mechanics simulations of the OSIRIS-REx TAGSAM sampling in a micro-gravity environment. Weakly cohesive regolith (top) allow the sampler head to penetrate and push the regolith. Stronger cohesion will stop the spacecraft and cause a small rebound. The actual sampling event mimics the weakly cohesive case.