BOULDERS ON BENNU: INVESTIGATING THE STRUCTURE OF LOW THERMAL INERTIA ROCK USING THERMAL MODELING. C. M. Elder[1], [1]Jet Propulsion Laboratory, California Institute of Technology.

Introduction: Spitzer Space Telescope observations suggested that asteroid (101955) Bennu's surface has a low thermal inertia consistent with millimeter to centimeter scale regolith [1]. Observations by the Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer (OSIRIS-REx) Visible and InfraRed Spectrometer (OVIRS) and Thermal Emission Spectrometer (OTES) confirmed this low apparent thermal inertia [2, 3]. However, images revealed a surface covered in boulders with very little fine-grained regolith [2] (Figure 1). A similar low thermal inertia surface, covered in boulders, was also observed at asteroid (162173) Ryugu [4].

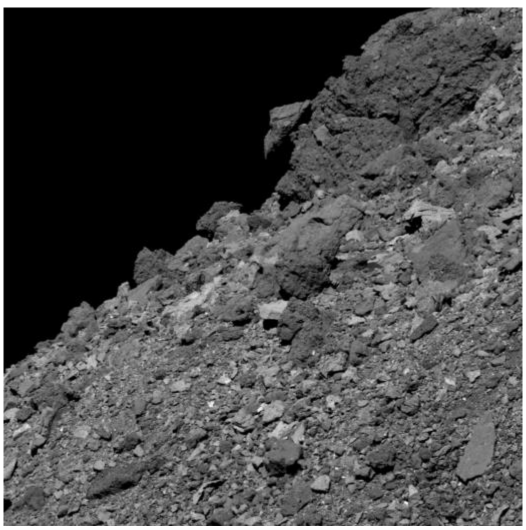

Figure 1: Boulders on Bennu. The field of view is 64.4 m. Credit: NASA /Goddard /University of Arizona.

Porosity is the most likely cause for the low thermal inertia inferred from infrared observations of boulders on Bennu and Ryugu [e.g. 3, 5]. [6], [3], and [5] estimated boulder porosities using two different empirical fits to the thermal conductivity of meteorites as a function of porosity. However, the highest porosity of those meteorites was ~20%, and the two empirical fits diverge at higher porosities [6], which are more relevant for the boulders on Bennu and Ryugu. Bennu has two classes of boulders, high reflectance boulders with inferred porosities of 24-38% and low reflectance boulders with inferred porosities of 49-55% [3]. Typical boulders on Ryugu have inferred porosities of 30-50% with some boulders having inferred porosities higher than 70% [5]. Here I conduct two-dimensional thermal modeling to investigate how the distribution of subsurface void space in boulders influences surface temperatures on Bennu.

Methods: I use COMSOL Multiphysics to model the temperature of chondritic material on the surface of Bennu considering a range of subsurface void space configurations. My models place Bennu at 1.2 AU from the Sun which is consistent with observations during the Equatorial Stations phase of the OSIRIS-REx mission. I assume the same rotation period, albedo, and emissivity which were assumed in previous thermophysical modeling such as [3]. For most models, I assume a density, heat capacity, and thermal conductivity consistent with the measured thermal inertia of Cold Bokkeveld, a CM chondrite, which is believed to be a good analog for Bennu. Most model domains are 0.5 m wide by 0.5 m deep, which is significantly deeper than the skin depth on Bennu. My preliminary work, presented here, considers one case with vertical fractures (Figure 2, top) and several cases with horizontal fractures including cases with a 1 mm thick fracture at a depth of 1 mm (Figure 2, bottom), 2 mm, 3 mm, or 4 mm below the surface and cases with a

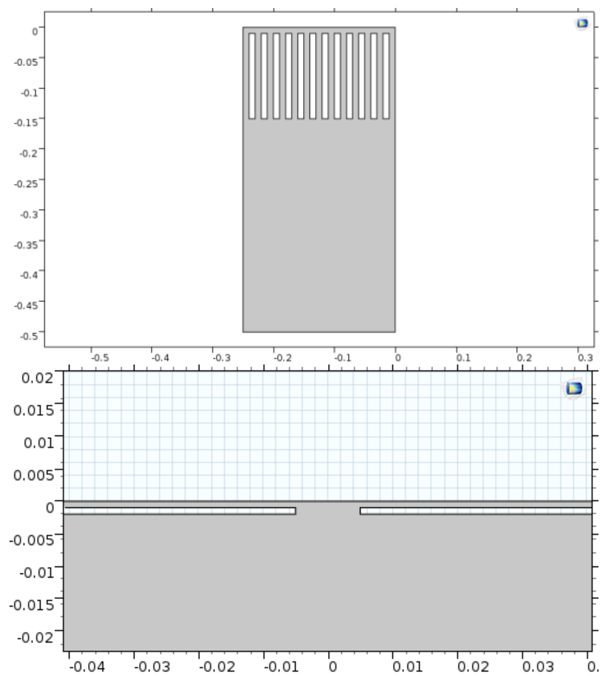

Figure 2: Two of the fracture geometries considered. Axes are in meters. The top shows the geometry for vertical fractures. The bottom shows a 1 mm thick fracture located 1 mm below the surface. The full domain extends 0.5 m in depth and width. The fractures are closed at the edges of the domain (not shown). Temperature was measured over the center of the left fracture.

1 mm, 2 mm, 3 mm, or 4 mm thick fracture 1 mm below the surface. I also consider one case with a second horizontal fracture such that there are two 1 mm thick horizontal fractures parallel to the surface, one 1 mm below the surface and the other 3 mm below the surface.

I also considered one scenario where the rock has a density, heat capacity, and thermal conductivity consistent with the thermal inertia that best fits observations by OSIRIS-REx (labeled "Bennu observed TI" in figures below). In future work, I will compare my models to actual observations of Bennu, especially observations of the several large boulders, which are fully resolved by OTES.

Results: I find that a single horizontal fracture 1 mm below the surface has a significant effect on the surface temperature and would imply an even lower thermal inertia than that which was inferred for Bennu (Figure 3A). The thickness of the fracture has a negligible effect on the diurnal temperature curve (Figure 3B), but the depth of the fracture controls how quickly the surface cools just after sunset with all cases reaching a similar temperature by sunrise (Figure 3C). A second fracture, also parallel to the surface but deeper, has a negligible effect on the surface temperature. My preliminary modeling shows that vertical fractures have a much smaller effect on the surface temperature than horizontal fractures (Figure 3), but further modeling is needed to investigate whether this is true for vertical fractures of any depth and width.

Discussion and Preliminary Conclusions: High porosities may not be necessary to explain the observed surface temperatures of boulders on Bennu and Ryugu. A single thin subsurface fracture can have a significant effect on the surface temperature. Preliminary results suggest that surface temperature is sensitive to the depth of the fracture but independent of the thickness of the fracture and the presence of additional deeper fractures.

Fractures parallel to the boulder's surface are consistent with expectations for thermally driven exfoliation [7]. However, my preliminary work focuses on fractures shallower (~mm depth) than those originating from thermal cycling (~cm – dm depth), which were observed and modeled by [7]. On the other hand, the OSIRIS-REx Camera Suite would not have resolved mm scale fractures. Future work will investigate how deeper fractures affect surface temperature.

References: [1] Emery J. P. et al. (2014) *Icarus 234*, 17-35. [2] DellaGiustina D. N., Emery J. P. et al. (2019) *Nat. Ast. 3*, 341-351. [3] Rozitis B. et al. (2020) *Sci. Adv. 6*, eabc3699. [4] Sugita S. et al. (2019) *Science 364*, eaaw0422. [5] Sakatani N. et al. (2021) *Nat Ast. 5*, 766-774. [6] Grott M. et al. (2019) *Nat Ast. 3*, 971-976. [7] Molaro J. L. et al. (2020) *Nat Com 11:* 2913.

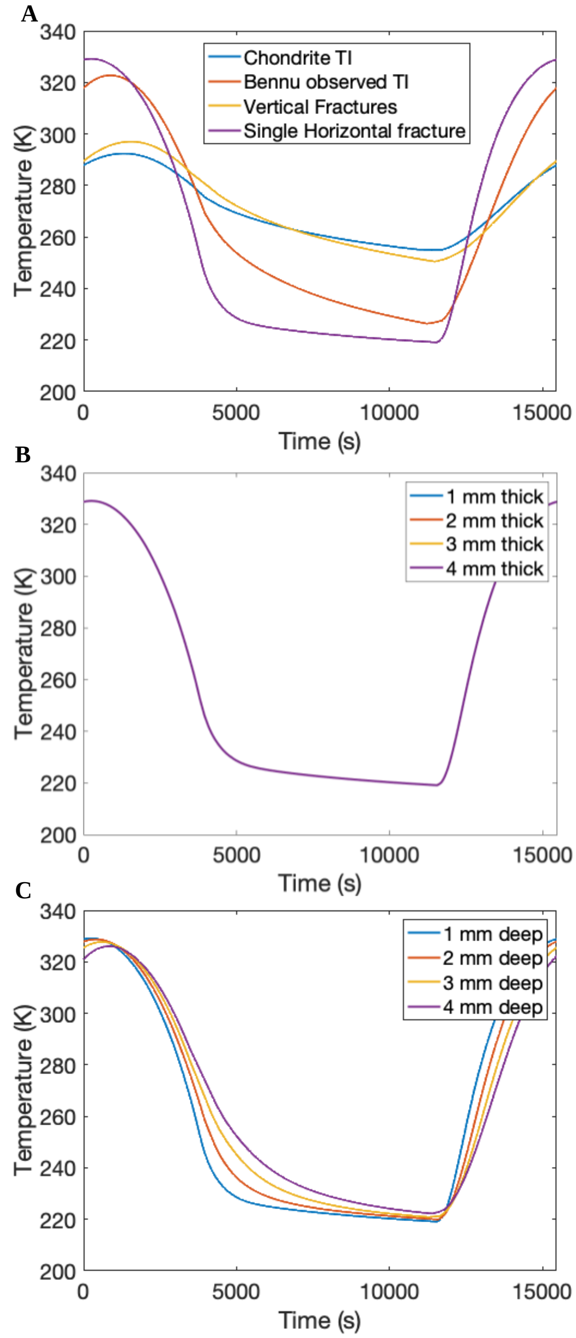

Figure 3: Model diurnal temperature curves for: (A) various materials on Bennu's surface including chondritic material (blue), the thermal inertia that best fits observations (red), vertical subsurface fractures (yellow), and a 1 mm thick horizontal fracture 1 mm below the surface (purple); (B) chondritic material with a subsurface fracture 1 mm below the surface with a thickness of 1 mm (blue), 2 mm (red), 3 mm (yellow) and 4 mm (purple); (C) chondritic material with a subsurface fracture 1 mm thick at a depth of 1 mm (blue), 2 mm (red), 3 mm (yellow), and 4 mm (purple).