Fatigue-driven boulder exfoliation as a driving mechanism for Bennu's activity

J. L. Molaro (1), C. W. Hergenrother (2), S. R. Chesley (3), R.D. Hanna (4), C. W. Haberle (5), R.-L. Ballouz (2), S. R. Schwartz (2), W. F. Bottke (6), K. J. Walsh (6), H. Campins (7), and D.S. Lauretta (2).

(1) Planetary Science Institute, Tucson, AZ, USA (jmolaro@psi.edu); (2) Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA; (3) Jet Propulsion Laboratory, Caltech Institute of Technology, Pasadena, CA; (4) Jackson School of Geosciences, University of Texas at Austin, TX, USA; (5) School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA; (6) Southwest Research Institute, Boulder, CO, USA; (7) University of Central Florida, Orlando, FL, USA;

Thermally driven fracture processes, such as thermal fatigue, have been hypothesized to drive rock breakdown and regolith production on asteroid surfaces [e.g., 1-7]. Thermal cycling induces mechanical stresses in rocks that drive the propagation of microcracks, which may grow into larger-scale features. This can drive the development of morphological signatures such as surface fracturing and disaggregation, and through-going fractures that split boulders apart. The nature and rate of boulder breakdown is controlled by rock composition, as well as the rotation period and solar distance of the body, suggesting its signature varies widely across the diverse asteroid population. Understanding how the process operates is critical to characterizing their surface properties and evolution.

Images from the Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) spacecraft of the surface of Bennu provide the opportunity to search for *in situ* evidence of thermal breakdown over a wide range of scales. Recent works by the authors [7-9] show observations of boulder morphologies consistent with terrestrial observations [e.g., 10] and models of fatigue-driven boulder exfoliation [e.g., 11], i.e., the flaking of thin layers or shells of material from boulder surfaces. Relating these observations to thermally induced stress fields in phyllosilicate boulders reveals that such features develop via the propagation of surface-parallel fractures during periods of day when boulder surfaces are heating. The magnitude of these stress fields ranges from ~0.3 to 3 MPa for boulders up to 6 m in diameter, which is comparable to the tensile strengths of terrestrial phyllosilicate rocks (e.g., serpentinite) and sufficient to drive subcritical crack growth (thermal fatigue). The thickness of resulting exfoliation layers predicted by the model ranges from ~1 mm to 10 cm, which is consistent with terrestrial observations of exfoliation cracks [10] and with the thicknesses of exfoliation layers observed on Bennu's boulders [9].

Further, we explore how boulder exfoliation may lead to the ejection of particles observed at Bennu's surface [9] in an analogous manner to mobilization of rock fragments during large-scale, terrestrial dome exfoliation events [12]. We have observed particle ejection events from Bennu's surface repeatedly since first entering orbit in January 2019. Observed particles range in size from <1 to 10 cm [7], consistent with our predictions for exfoliation. We quantified the available thermal strain energy in boulders beyond what is needed to propagate cracks and converted it to kinetic energy to constrain the speed of ejected particles. We find particles may be ejected with speeds up to ~2 m/s for boulders smaller than or equal to 6 m in diameter, which is comparable to the maximum observed particle speed of 3.3 m/s [7]. These results suggest that fatigue-driven exfoliation is a viable mechanism for producing or contributing to the activity observed at Bennu.

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