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Physical Interpretation of Bennu's Thermal Inertia

Andrew J. Ryan (1), J.P. Emery (2,3), B. Rozitis (4), P.R. Christensen (5), V.E. Hamilton (6), M. Delbo (7), D. Pino Muñoz (8), M. Bernacki (8), K.J. Walsh (6), R.-L. Ballouz (1), B.E. Clark (9), D.N. DellaGiustina (1), C.M. Elder (10), E.S. Howell (1), L.F. Lim (11), J.L. Molaro (12), M.C. Nolan (1), B. Rizk (1), S.R. Schwartz (1), M.A. Siegler (12), D.S. Lauretta (1), and the OSIRIS-REx Team.
(1) Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona, USA, (2) University of Tennessee, Knoxville, Tennessee, USA, (3) Northern Arizona University, Flagstaff, AZ, USA, (4) Open University, Milton Keynes, UK, (5) Arizona State University, Tempe, Arizona, USA, (6) Southwest Research Institute, Boulder, Colorado, USA, (7) Université Côte d'Azur, Observatoire de la Côte d'Azur, Nice, France, (8) Mines Paris-Tech, Sophia-Antipolis, France, (9) Ithaca College, Ithaca, New York, USA, (10) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA, (11) NASA Goddard Space Flight Center, Greenbelt, Maryland, USA, (12) Planetary Science Institute, Tucson, Arizona, USA. (ajryan@orex.lpl.arizona.edu)

Abstract

Temperature and thermal inertia maps of the surface of asteroid (101955) Bennu indicate significant spatial variability in the physical properties of the surface material. Here, we provide initial interpretations of these datasets in terms of rock and regolith physical parameters that have a direct impact on thermal inertia.

1. Introduction

Asteroid (101955) Bennu is the target of the OSIRIS-REx mission, which will collect a regolith sample for return to Earth [1,2]. A wealth of information has been obtained from the onboard instrument suite to aide in the interpretation of the origin, history, and current state of the asteroid. The diurnal temperature cycles on the surface are directly related to the physical properties of the upper few centimeters of material, including density and thermal conductivity. Variations in these properties are parameterized in thermal inertia, which is currently being mapped for the surface of Bennu [3,4]. Here, we present potential interpretations of the global thermal inertia trends in terms of the distribution and material properties of the rocks and regolith on Bennu.

1.1 Thermal Inertia Background

Thermal inertia is defined as the square root of the product of specific heat, density, and thermal conductivity of the material on a planetary surface, within the diurnal heat wave penetration depth. Density and thermal conductivity can vary substantially, particularly between solid rock and particulate regolith, whereas specific heat varies only modestly with mineralogy [5]. Thermal conductivity in particular has been shown to vary by orders of magnitude within particulate regolith as a function of increasing particle size. It is typically expected that low thermal inertia terrains (e.g. ≤120 J m^{-2} K^{-1} $s^{-1/2}$) are dominated by fine particles (e.g. dust), intermediate terrains may be composed of coarser particles or a mixture of particulates and rocks, and high thermal inertia terrains (e.g. 800–2000 J m^{-2} K^{-1} $s^{-1/2}$) are dominated by rocks larger than the diurnal thermal wave e-folding depth (i.e. diurnal skin depth).

2. Bennu Thermal Inertia

Bennu was determined to have a global average thermal inertia of 350 ± 20 J m^{-2} K^{-1} $s^{-1/2}$ during the Approach phase of the mission [6], consistent with preflight estimates from telescopic data [7]. Using thermal models for the conductivity of particulate regolith, this thermal inertia was originally interpreted to represent millimeter- to centimeter-scale particulates [7,8,9]. However, Approach and Preliminary Survey phase visible photo observations revealed abundant large boulders and pervasive rock cover on Bennu [1,6,10]. Higher spatial resolution and improved coverage through the Detailed Survey phase is confirming that the surface of Bennu is composed predominantly of rocks that are larger than the diurnal skin depth, with only a few small regions distributed across the asteroid that contain unresolved terrain where particle sizes could be centimeter-scale or smaller. Furthermore, spatial thermal inertia variations have emerged from the growing spectrometer (OTES and OVIRS) datasets that do not appear to follow the typical trend where low thermal inertia corresponds to finer materials and higher thermal inertia corresponds to the coarsest materials.

In this work, we will discuss possible physical interpretations of the thermal inertia trends, with specific examples of thermally distinct terrains discussed in detail. Possible physical scenarios, if present, that are likely to influence apparent thermal inertia of Bennu include but are not limited to: high-porosity in boulders leading to low boulder thermal conductivity, dust cover, particulate “lags” on rock surfaces due to disaggregation/exfoliation or perhaps ballistic deposition, distinct rock populations with characteristic physical properties (e.g. porosity, mineralogy), and the presence of particulate regolith between rocks, especially in some apparently smooth terrains. Thermal inertia interpretation will also be aided by other new and upcoming data products, such as high-resolution PolyCam images, a dust cover index (DCI) map from OTES, spectral index maps from OVIRS, color and albedo maps from MapCam, and detailed boulder and regolith maps from sites with characteristic rock size distributions.

3. Summary and Conclusions

The surface materials on Bennu have distinct physical and thermophysical properties that, when compared to observations of abundant boulders on the asteroid surface, challenge our pre-arrival interpretations of thermal inertia using thermal models of regolith particle size [2,6]. The observations obtained by OSIRIS-REx broaden our understanding of the nature of heat transfer on small airless bodies and will not only aid in our interpretation of the history of Bennu but will improve our ability to remotely interpret thermal data from other airless bodies.

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