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The Western Bulge of 162173 Ryugu Formed as a Result of a Rotationally Driven Deformation Process

M. Hirabayashi[1], E. Tatsumi[2,3], H. Miyamoto[4], G. Komatsu[5], S. Sugita[2], S. Watanabe[6], D. J. Scheeres[7], O. S. Barnouin[8], P. Michel[9], C. Honda[10], T. Michikami[11], Y. Cho[2], T. Morota[6], Naru Hirata[10], Naoyuki Hirata[12], N. Sakatani[13], S. R. Schwartz[14], R. Honda[15], Y. Yokota12,[13,15], S. Kameda[16], H. Suzuki[17], T. Kouyama[18], M. Hayakawa[13], M. Matsuoka[13], K. Yoshioka[2], K. Ogawa[12], H. Sawada[13], M. Yoshikawa[13], and Y. Tsuda[13].
[1]Auburn University, Auburn, AL 36849, USA, (thirabayashi@auburn.edu). [2]University of Tokyo, Bunkyo-ku, Tokyo 113-0033, Japan, [3]Instituto de Astrofisica de Canarias, [4]University of Tokyo, Bunkyo-ku, Tokyo 113-8656, Japan, [5]Universit degli Studi “G. d’Annunzio,” Viale Pindaro 42, 65127 Pescara, Italy, [6]Nagoya University, Nagoya, Aichi 464-8601, [7]CU Boulder, Boulder, CO 8039, USA, [8]APL/JHU, Laurel, MD 20723, USA, [9]Université Côte d’Azur, Observatoire de la Côte d’Azur, CNRS, Laboratoire Lagrange, Nice 06304, France, [10]University of Aizu, Ikki-machi, Fukushima 965-8580, Japan, [11]Kindai University, Higashi-Hiroshima, Hiroshima 739-2116, Japan, [12]Kobe University, Kobe, Hyogo 657-8501, Japan, [13]ISAS/JAXA, Sagamihara, Kanagawa 252-5210, Japan, [14]University of Arizona, Tucson, AZ 85721, USA, [15]Kochi University, Kochi, Kochi 780-8520, Japan, [16]Rikkyo University, Toshima-ku, Tokyo 171-8501, Japan, [17]Meiji University, Kawasaki, Kanagawa 214-8571, Japan, [18]AIST, Tsukuba, Ibaraki 305-8560, Japan.

Abstract

162173 Ryugu, the target of Hayabusa2, is a spinning top-shaped asteroid [1]. Observations by Optical Navigation Camera onboard Hayabusa2 have shown that the western side of this asteroid possesses a smooth surface and a sharp equatorial ridge, compared to the other side. Here, we propose that a rotationally-driven deformation process generated the western bulge. Our structural model shows that Ryugu is structurally intact in the subsurface region of the western region while other regions are sensitive to structural failure when the spin period is shorter than ~3.75 h, which is the critical spin limit that the failure model becomes global [1]. We infer that this variation is indicative of the deformation process that occurred in the past, and the western bulge is more relaxed structurally than the other region. Our dynamics analysis also implies that this deformation process might occur at a spin period between ~3.5 h and ~3.0 h, providing the cohesive strength ranging between ~4 Pa and ~10 Pa.

1. Introduction

The surface morphology of Ryugu was reported to be longitudinally divided into the eastern and western regions by Tokoyo and Horai Fossae, a trough system that is widely placed in the southern hemisphere and possibly spreads towards the northern hemisphere [2]. The western region (160 deg E - 70 deg W), later known as the western bulge, is apparently less cratered and thus smoother than the other side [2]. Also, the equatorial ridge, or Ryujin Dorsum, on the western bulge is sharper than that in other regions [1] (see also Figure 1). Using a structural and dynamics model, we consider that this east-west dichotomy might have resulted from an asymmetric shape deformation process when Ryugu was rotating with a short rotational period in the past.

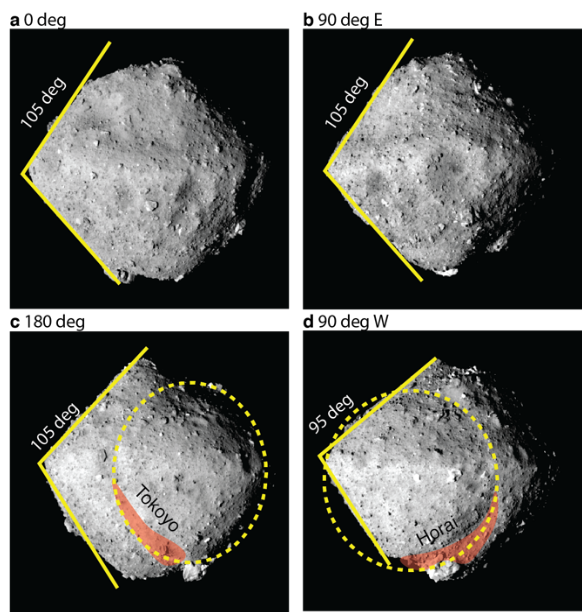

Figure 1. Surface morphology of Ryugu.

2. Analysis

To test the asymmetric deformation hypothesis, we first use a Finite Element Model (FEM) technique to investigate the failure mode of the present shape at different spin periods. We find that at a spin period shorter than 3.75 h, inelastic deformation spreads over the interior but does not reach the subsurface region beneath the western bulge (Figure 2). This failure mode infers that the western bulge is structurally relaxed compared to other areas, implying that this region might have deformation in the past that created the smoothed surface and the trough system after the formation of the initial equatorial ridge.

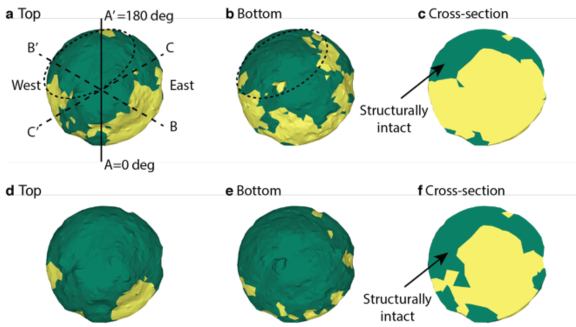

Figure 2. Structural failure of Ryugu from different views at a spin period of 3.75 hr (Panels a, b, and c) and that of 3.5 hr (Panels d, e, and f). The yellow regions are failed regions while the green regions are intact regions.

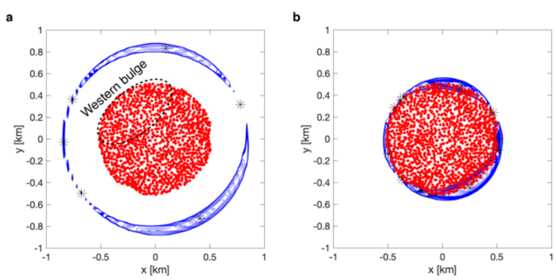

Figure 3. Zero-velocity curve at a spin period of 7.6 hr (Panel a) and that of 3.5 hr (Panel b). The red dots indicate Ryugu's body elements, the blue curves show the zero-velocity curves, and the black stars show the dynamical equilibrium points.

We then analyze a potential spin period that induced this asymmetric deformation process. Ryujin Dorsum is highly circular, which implies that its formation may have resulted from fast rotation [1]. We consider that the formation and size of Ryujin Dorsum depend on the spin period when surface materials are lofted due to the centrifugal force. Following this reasoning, we use a zero-velocity curve approach to determine this spin period. We find that when the spin period is shorter than ~3.5 hr, materials in some areas on Ryujin Dorsum are about to be lifted from the surface [1]. This also implies that the current western bulge formed at a spin period shorter than ~ 3.5 hr.

3. Considerations

Our structural and dynamics model showed that the deformation process that induced the western bulge might have occurred a spin period shorter than ~3.5 hr. Considering the precursor shape before the formation of the western bulge, we derive that Ryugu's bulk cohesive strength may range between ~4 Pa and ~10 Pa. The physical properties from this work are consistent with those by Watanabe et al. [1].

We finally note that this study provides neither the formation process during the accretion stage after catastrophic disruption of Ryugu's parent body [3] nor how the shape deformation process occurred to create the western bulge (mass movement on the surface [4] and/or internal deformation [5]). We leave these questions as our future work.

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