Thermally Controlled Crack Orientation of Boulders on Ryugu: N-S Preference and Exfoliation Structure <gdiv></gdiv>

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Hayabusa 2 revealed that a small carbonaceous asteroid 162173 Ryugu is a rubble pile [1]. The surface of Ryugu is covered with various sizes of numerous boulders [2-4]. Thermal fatigue has been advocated for the disintegration process of surface rocks [5], where diurnal (and annual) thermal cycle may promote crack growth in the rocks on regolith over various spatial and temporal scales [6]. Growth of crack is rapid enough to fracture a few 10 cm size rock [7].

In early data analysis, we noticed that cracks on Ryugu boulders have preferred orientation. Cracks/fractures with meridional (north-south) direction are frequently observed [8] in high resolution images where boulder size is between a few tens cm and a few tens m. Desert rocks of the Earth and Mars have preferred orientation of cracks [9,10]. This would be explained by thermal process. We analyzed 777 cracks on Ryugu boulders and checked their orientations.

We analyzed 101 images by Hayabusa-2 ONC-T. Image resolution is 3mm –4m/pixel. Hayabusa 2 usually observes the surface from the direction of the sun, which provide low phase angle data with short shadow width. We carefully check images so that we do not pick up the shadowed surface structure as a crack. We classified cracks into four types (Fig.1):

(a) Straight cracks: Cracks running linearly without bending or branching.

(b) Sinuous cracks: Cracks with bowing, bending, and wavy structure.

(c) Arrested cracks: Incomplete cracks.

(d) Complex (typically branched) cracks typically for different directions.

We separated the strike of cracks into 18 directions with 10deg bin. We analyzed 538 boulders (777 cracks) and found 60% of their cracks have the meridional direction (±15deg from N-S) except complex type. This trend is common among crack types as well as rock size.

Since Ryugu’ s rotational axis inclination is 172 degree, solar irradiation would produce E-W asymmetry

in temperature. So far, solar-induced thermal stress on a surface boulder by diurnal rotation and annual revolution of Ryugu might be a possible process for the growth of boulder cracks in the meridional direction, as discussed for the preferred crack orientation of desert rocks of the Earth and Mars [7,9,10]. However, we need to explain why large boulders (> 10m, much larger than thermal length scale) have preferred crack orientation. Preferred orientation of cracks is also observed on boulders of Bennu [11]; they would be driven by solar-induced thermal stress.

Another type of thermally-driven cracks is exfoliation [12]. Stress fields induced in boulders from diurnal thermal cycle cause crack propagation in different directions at different times of day. When boulder size is smaller than 2 m, peak stress may exceed 1 MPa, leading to onion-like exfoliation in boulders of Bennu [12]. We also check cracked boulders on Ryugu and found that a couple of boulders with sinuous cracks can be interpreted by exfoliation. Two examples are shown in Figure 3: sinuous boundaries would have formed by exfoliation of surface layer.

References: [1] Watanabe, S. et al (2019) Science 364. [2] Sugita, S. et al (2019) Science 364. [3] Michikami, T. et al (2019) Icarus, 331, 179-191 [4] Nakamura et al. (2008) Earth Planets Space 60, 7-12. [5] El-Maarry, M. R., et al. (2015) Geophys. Res. Lett., 42, 5170–5178. [6] Delbo M. et al. (2014) Nature 508, 233–236. [7] Molaro, J. L. et al. (2017) Icarus 294, 247-261. [8] Sasaki, S. et al. (2019) LPSC L, #1368. [9] MacFadden et al., (2005) Geol. Soc. Am. Bull. 117, 161-173. [10] Eppes, M. C. et al. (2015) Nature Comm., 6, 6712, [11] Delbo, M. et al (2019) EPSC-DPS-176-2. [12] Molaro, J. L. et al. (2020) Nature Comm., 11, 1-11.<gdiv></gdiv>

Keywords: asteroid, thermal fatigue, boulder cracks, crack orientation, exfoliation

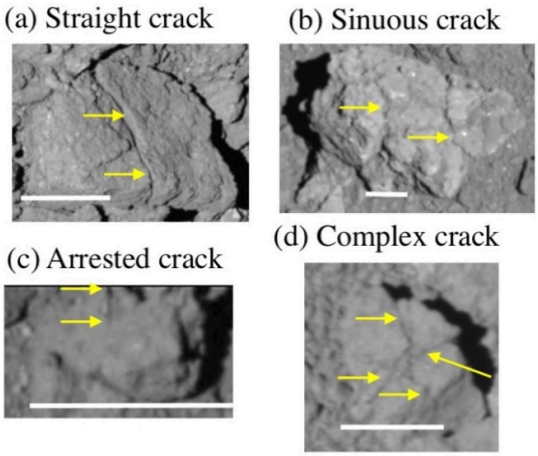

Figure 1 Examples of 4 types of cracks which are indicated by yellow arrows. White scale bars in the images indicate 1m.

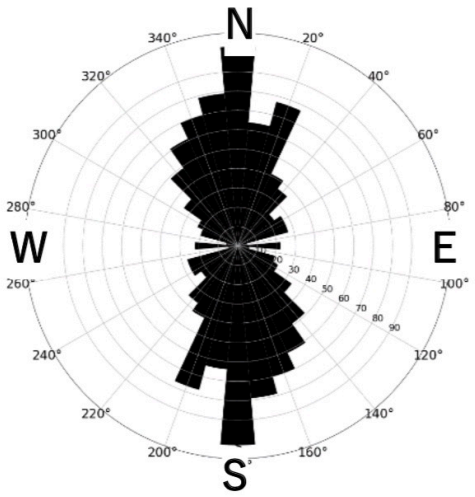

Figure 2 Distribution of crack orientation of boulders on Ryugu in a rose diagram. Each orientation bin of the rose diagram is 10 deg. The total number of cracks is 777.

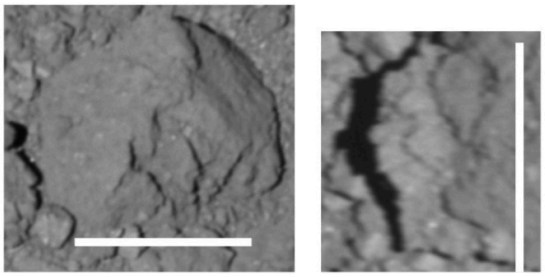

Figure 3 Exfoliation feature candidates on Ryugu. White scale bars in the images indicate 1m.

