CRACK ORIENTATIONS OF BOULDERS ON RYUGU: N-S PREFERENCE AND EXFOLIATION FEATURE.

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Introduction: Hayabusa 2 successful mission revealed that a small carbonaceous asteroid 162173 Ryugu is a rubble pile with average density 1.19 x 10^3 kg/m^3 [1]. The surface of Ryugu is covered with various sizes of numerous boulders. On Ryugu, 4400 boulders larger than 5m are counted; the relative abundance of large boulders (>20m) is about twice as that of Itokawa or Bennu [2,3]. On the surface of Itokawa, several cracked boulders are observed and compared with cracked fragments from impact experiments [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].

Recently, thermal fatigue has been advocated for the disintegration process of surface rocks [6], where diurnal (and annual) thermal cycle may promote crack growth in the rocks on regolith over various spatial and temporal scales [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.

Cracked Boulders on Ryugu: We analyzed 101 images (taken from 29-4083m height at proximity operation phases) by Hayabusa-2 ONC-T. Image resolution is 3mm/pixel at best. We confirm the image position and resolution from shape model matching (SPC) and/or altimetry data by LIDAR. 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. Some cracks are confirmed using the image with different (larger) solar phase angle.

To check if a rock has a crack or not, 15-20 pixels are necessary. At the highest resolution, we may check a rock as small as 20cm. Assuming the same range size, about 2-5% of boulders have cracks.

We classified cracks into four types:

(a) Straight cracks: Some cracks are running linearly without bending or kinking.

(b) Sinuous cracks: Some cracks have bowing, bending, and wavy structure.

(c) Arrested cracks: We observed many rocks have a crack which does not go through the boulder apparently.

(d) Complex (typically branched) cracks.

It seems that the crack might be controlled by preexisting structure which would be visible at higher resolution data. Most of boulders on Ryugu are brecciated conglomerates, which contain pre-existing structure reflecting parent body processes such as layering (due to thermal evolution) and impact mixing.

Crack Orientation: 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.

How these cracks are formed? If a surface boulder is a fragment of accreted rubble piles, the crack could be formed either before Ryugu formation at the parent body or after Ryugu formation. Meteoroid impact on the boulder is a possible process. And dynamic stress could be induced through large mass movement [1] along the change of rotation speed, and thermally-induced stress is also a candidate process.

If boulder cracks on Ryugu are formed by impact processes, whether impacts occur before or after Ryugu formation, the direction of cracks should distribute more randomly. There would be discussed boulder distribution and direction of the long axis, according to sorting through mass movement toward mid latitude [3]. However, it is difficult to control the direction of a crack in the boulder. We found N-S preferred orientation in all types of cracks (Fig. 2). 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.

Exfoliation: 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]. Actually boulders with exfoliation feature are found on Bennu's surface. We also check cracked boulders on Ryugu and found that some can be interpreted by exfoliation. Two examples are shown in Fig. 3: sinuous boundaries would have formed by exfoliation of surface layer. The cracks in Fig. 1(b) may have been formed also by exfoliation.

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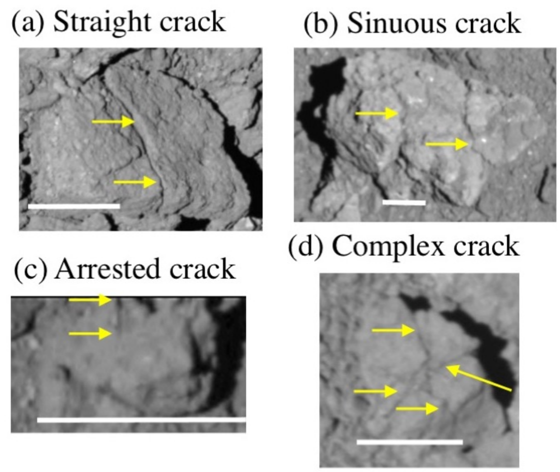

Figure 1 Examples of 4 types of cracks. White scale bars in the images indicate 1m.

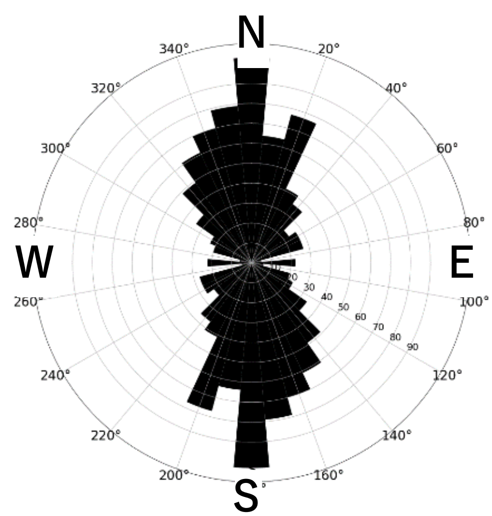

Figure 2 Crack orientation distribution. Each orientation bin of the rose diagram is 10 deg. Total crack number is 777.

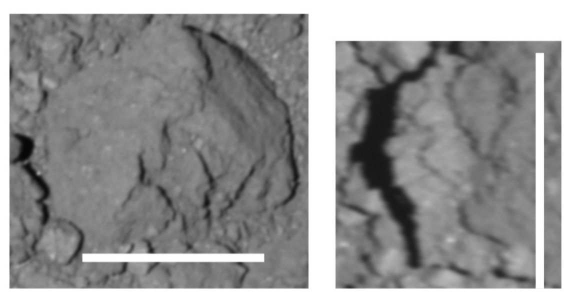

Figure 3 Exfoliation feature candidates on Ryugu. White scale bars in the images indicate 1m.