CRACK ORIENTATIONS OF BOULDERS ON RYUGU: THERMALLY INDUCED ORIGIN? S. Sasaki[1], S. Kanda[1], H. Kikuchi[2], T. Michikami[3], T. Morota[4], C. Honda[5], H. Miyamoto[4], R. Henmi[4], S. Sugita[4], E. Tatsumi[4], M. Kanamaru[1], N. Sakatani[2], S. Watanabe[6], N. Namiki[7], P. Michel[8], M. Hirabayashi[9], N. Hirata[5], T. Nakamura[10], T. Noguchi[11], T. Hiroi[12], T. Irie[3], K. Matsumoto[7], S. Kameda[13], T. Kouyama[14], H. Suzuki[15], M. Yamada[16], R. Honda[17], Y. Cho[4], K. Yoshioka[4], M. Hayakawa[2], M. Matsuoka[2], R. Noguchi[2], H. Sawada[2], Y. Yokota[17] , and M. Yoshikawa[2], [1]Osaka Univ. (Dept. Earth & Space Sci., Toyonaka 560-0043, Japan, sasakisho@ess.sci.osaka-u.ac.jp), [2]ISAS/JAXA, [3]Kindai Univ., [4]Univ. Tokyo, [5]Univ. Aizu, [6]Nagoya Univ., [7]NAOJ, [8]Observatoire de la Cote d'Azur, [9]Auburn Univ., [10]Tohoku Univ., [11]Kyushu Univ., [12]Brown Univ., [13]Rikkyo Univ., [14]AIST, [15]Meiji Univ., [16]Chiba Inst. Tech., PERC, [17]Kochi Univ.

Introduction: Hayabusa 2 spacecraft revealed that a small carbonaceous asteroid 162173 Ryugu is a rubble pile with overall density 1.19 x 10^3kg/m^3 [1] The surface of Ryugu is covered with various sizes of boulders. On Ryugu, 4400 boulders larger than 5m are observed; the relative abundance of large boulders (>20m) is about twice as that of Itokawa or Bennu [2,3]. Those large boulders on Ryugu can be considered as impact fragments from size distribution and their axial ratio [3].

On the surface of Itokawa, several cracked boulders are observed and compared with cracked fragments from impact experiments [4]; impacts on Itokawa or its parent body would form boulder cracks. Cracks are also observed on icy boulders of 67P/Churyumov-Gerasimenko [5].

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 preliminary 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 m. Desert rocks of the Earth and Mars have preferred orientation of cracks [9,10]. This would be explained by thermal process, including freezing. Here in this study, we analyzed more than 500 cracks on Ryugu boulders and checked their orientations.

Cracked Boulders on Ryugu: We analyzed 124 images (taken from 50-4000m height at proximity operation phase such as rover deployment and touchdown sampling, or their rehearsals) by Hayabusa-2 ONC-T. Image resolution is 3mm/pixel at best. Image size is 1024 x 1024 pixels. 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 an 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 than 10cm. Assuming the same range size, about 2-5% of boulders have cracks. So far, we do not observe changes of the abundance ratio of cracked rocks on the Ryugu surface. Western bulge region (160E-70W) would have fewer abundance of the rocks both with and without cracks.

We classified cracks into four styles: examples and histograms of crack orientation are shown in Fig.1.

(a) Straight cracks: Some cracks are running linearly without bending or kinking (Fig.1(a)). Some straight cracks are associated with open fracture.

(b) Sinuous cracks: Some cracks have bowing, bending, and wavy structure (Fig.1(b)).

(c) Arrested cracks: We observed many rocks have a crack which does not go through (Fig.1(c)). It looks like a growing crack or stop of crack propagation.

(d) Complex (typically branched) cracks: Sometimes a boulder would have been broken into several pieces (Fig.1(d)).

Some boulders have multiple cracks of similar style (e.g., Fig.1(b)).

It seems that the crack might be controlled by pre-existing structure which would be visible at higher resolution data. Most of boulders on Ryugu are brecciated conglomerates (e.g., Fig.1(b)), 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 500 boulders and found 60% of their cracks have the meridional direction (+-15deg from N-S) except complex type (Fig. 1) This trend is common among crack types as well as rock size. We first considered that large boulders would have less preferred crack orientation.

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 (including its disruption) 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. As for complex crack shown in Fig.1(d), contribution of impacts would prevail but still N-S preferred orientation remains.

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, 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.

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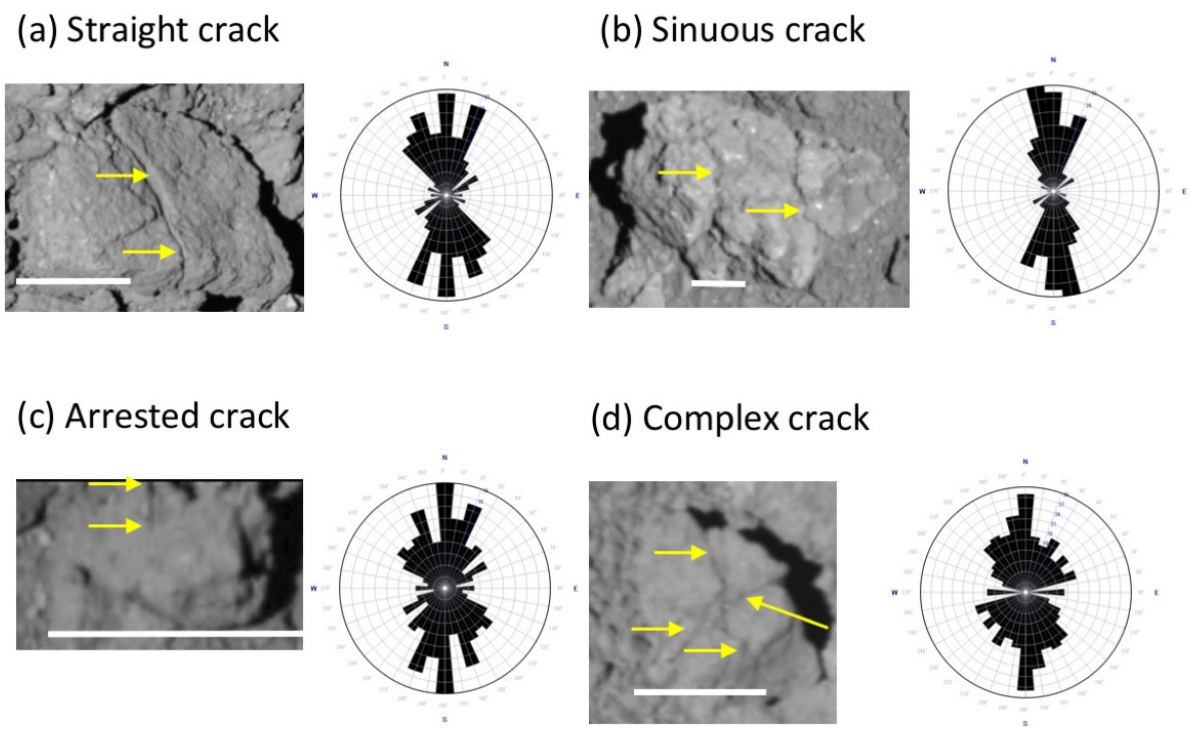

Fig. 1 Examples of 4 styles of cracks and their orientations (rose diagram). White scale bars in the images indicate 1m. Direction of cracks (strikes) of boulders on Ryugu. Each orientation bin of the rose diagram is 10 deg.
(a) Straight crack. ID: hyb2_onc_20181003_015004_tvf_l2b. (b) Sinuous crack. ID: hyb2_onc_20190221_213610_tvf_l2c
(c) Arrested crack. ID: hyb2_onc_20180921_040402_tvf_l2c. (d) Complex crack.