CRACKS OF BOULDERS ON RYUGU: POSSIBILITY OF 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 low overall density [1] The surface of Ryugu is covered with various sizes of boulders. On Ryugu, 4400 boulders larger than 5m are observed. A relative surface abundance of large boulders (>20m) is about twice as that of Itokawa or Bennu [2,3]. Each boulder can be considered as an impact fragment from aspect ratio study [3]. On the surface of Itokawa, several cracked boulders are observed and compared with fragments from impact experiments, where some fragments have cracks [4]. Impacts on Itokawa would form cracks on boulders. Recently, thermal fatigue is 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].

In preliminary data analysis, we noticed that cracks on Ryugu boulders have preferred orientation. Cracks/fractures with meridional (north-south) direction are frequently observed [7]. Desert rocks of the Earth and Mars have preferred orientation of cracks [8,9]. 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 directions.

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 high 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.

To check if a rock has a crack or not, 15-20 pixels are necessary. At the highest resolution, we may check a rock smaller 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. In general, mid to high latitude data, more cracked rocks are observed.

We classified cracks into four categories.

(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 or wavy structure (Fig.1(b)).

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

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

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 Direction: We separated the strike of cracks into 6 directions with 30deg bin. We analyzed 500 boulders (after removing complex type with multiple directions) and found 60% of them have the meridional direction (+-15deg from N-S) (Fig. 2) This trend is not changed among crack types as well as rock size. (We considered that large boulders would have have less preferred crack orientation.)

As in the case of Itokawa, we should discuss where and when the cracks are formed. If a surface boulder is a fragment of accreting 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 induced through large mass movement [1] along the change of rotation speed,

and thermally-induced stress is also a candidate process.

If those cracks on Ryugu are formed by impact processes, whether impacts occur before or after formation of Ryugu, the direction of cracks should distribute more random. 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,

So far, thermally-induced stress by diurnal rotation and annual revolution of Ryugu might be a possible process for the growth of cracks in meridional direction, as discussed for preferred crack orientation on desert rocks of the Earth and Mars [6,8,9]. It is reported that preferred direction of cracks is also observed on boulders of Bennu [10]; they would be driven by solar-induced thermal stress.

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]Delbo M. et al. (2014) Nature 508, 233–236. [6]Molaro, J. L. et al. (2017) Icarus 294, 247-261. [7]Sasaki, S. et al. (2019) LPSC L, #1368. [8]MacFadden et al., (2005) Geol. Soc. Am. Bull. 117, 161-173. [9]Eppes, M. C. et al. (2015) Nature Comm., 6, 6712, [10]Delbo, M. et al (2019) EPSC-DPS-176-2.

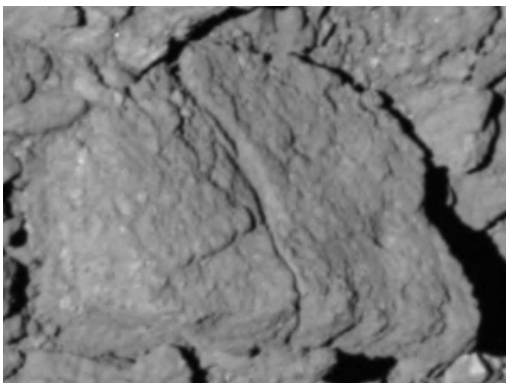

Fig. 1(a) Straight crack. Figure width is 2.5 m.
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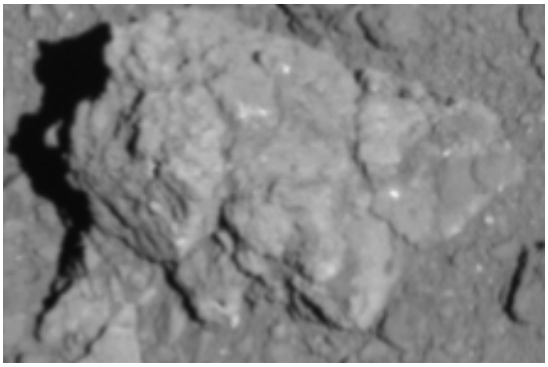

Fig.1(b) Sinuous crack. Figure width is 6m.
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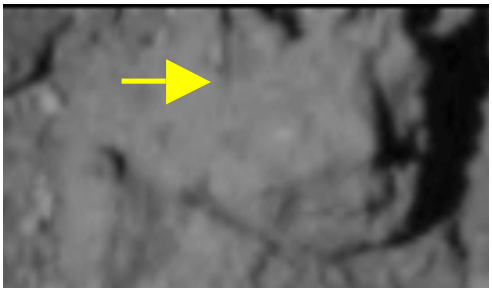

Fig.1(c) Incomplete crack. Figure width is 1.1 m.
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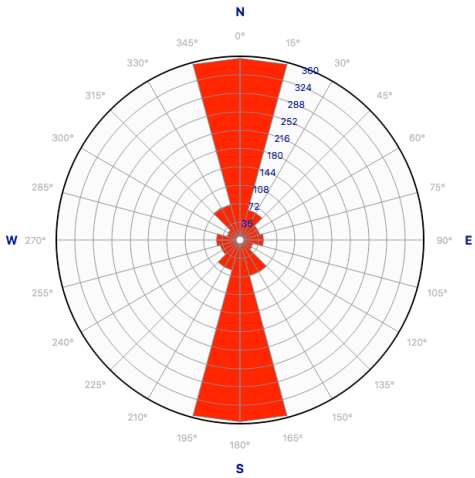

Fig. 2 Direction of cracks (strikes) of boulders on Ryugu. Each bin of the rose diagram is 30 deg.