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What if Ryugu hits on Earth?

Satoshi Tanaka [1], Koji Wada [2], Masatoshi Hirabayashi[3] , Yuya Mimasu[1], Makoto Yoshikawa[1], Takanao Saiki[1], Satoru Nakazawam[1] and Yuichi Tsuda [1]

[1]Institute of Space and Astronautical Science , Japan Aerospace Exploration Agency, Sagamihara Kanagawa Japan, +81-70-1170-2768, tanaka@planeta.sci.isas.jaxa.jp, [2]Planetary Exploration Research Center, Chiba Institute of Technology, Narashino Chiba Japan, +81-47-478-4744, wada@perc.it-chiba.ac.jp, [3]Auburn University, Auburn AL, U.S.A., +1-334-844-5220, thirabayashi@auburn.edu

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1: Introduction

The hayabusa2 mission arrived at C-type asteroid Ryugu in June 2018 and conducted detailed remote sensing observations for approximately 1 year and 5 months before leaving in November 2019. It also completed two touchdown operations during the rendezvous, collected samples, and returned to Earth in December 2020. The data obtained greatly advanced the science of the origin of asteroids and the solar system, but also provided important data from the perspective of planetary defense. The following is a discussion of the possible effects of Ryugu's impact on the Earth, although it is unlikely, based on the latest analysis of the data.

2: Remote sensing observation data important for planetary defense

The first is with respect to data obtained by remote sensing. The exact size and shape of Ryugu were obtained by optical camera (ONC) observations, and the equatorial radius of 502 ± 2 m, polar-to-equatorial axis ratio of 0.872 ± 0.007, and a volume of 0.377 km^3. This volume corresponds to a diameter of 850 m in spherical form. Furthermore, the object's mass was calculated to be 4.50 $\times$ 10^{11}kg based on the gravity acceleration data obtained from the spacecraft's free-fall operation. The object's porosity was estimated to be more than 50% (Watanabe et al., 2019).
There are no direct observations on the mechanical strength of the rock, but it is inferred from the thermal inertia determination by the mid-infrared camera. Temperature data were observed on Hayabusa2 by the TIR (Thermal InfraRed camera) on the spacecraft and MARA on the MASCOT lander (Okada et al.,(2020), Grott et al.,(2019)). These results showed thermal inertia on the Ryugu surface, which is 225 $\pm$ 25 ($Jm^{-2}K^{-1}s^{-1/2}$) over most of the surface (Shimaki et al.,(2020)). This is a very small value for a material covered by meter-order rock masses, and from this, the tensile strength is estimated to be about 0.2-0.3 MPa(Grott et al.,2019). In addition to the above, another important piece of information for planetary defense is the successful impact test on the Ryugu surface in April 2019. This experiment involved impacting an approximately 2 kg projectile on the Ryugu surface at 2 km/s, forming a crater approximately 20 m in diameter. This success provided information not only on the surface of Ryugu, but also on its interior, and showed that the cohesion force between rocks is 130-300 Pa.

3: Important sample analysis data regarding planetary defense

Next, we summarize the results of the sample analysis. Hayabusa2 successfully collected a total of 5.6 g of samples from two touchdown operations. The obtained samples were analyzed by the initial analysis team, and physical properties were measured of the third largest sample collected (Nakamura et al., 2022, Tanaka et al., 2022).
This sample (C0002) had a mass of 94 mg and a density of 1820 kg/m3, from which the sample was successfully cut and shaped into a disk shape. A total of 16 physical properties were measured, including mechanical, thermal, electrical, and magnetic properties that characterize the rock. Of these, the mechanical properties are particularly relevant to planetary defense. Since the samples were allowed to fracture at the end of the analysis, a bending fracture test was performed to directly measure the tensile strength of the samples.

4: Effects of Ryugu's impact on Earth

The impact of this material on the Earth was taken from Collins et al., (2005) and data from remote sensing and sample analysis were applied.
Table 1 lists the physical properties used in the analysis. The major difference is that Collins et al. (2005) used empirical equations for tensile strength, while this study uses values measured by remote sensing and samples.

Table1 Density and tensile strength used in the calculation of the impactor

	Density	tensile strength
	kg/m^3	MPa
Remote sensing	1200	0.2-0.3
Sample measurement	1800	5
Empirical	1200-1800	0.019-0.057

According to the empirical equation, the tensile strength is 0.019-0.057 MPa for densities of 1200-1800 kg/m3, whereas the observed values are one to two orders of magnitude larger.

The strength to be included in the calculation is debatable (Collins et al.,2005), and empirical formulas have been adopted as values that are at least one order of magnitude lower than the physical properties of actual meteorites. However, this study adopted the values estimated from in-situ observations of small objects and measured return samples.

Impactor size is important information when considering impact effects; Ryugu is definitely considered to be a rubble pile. The cohesion force between each rubble is considered to be nearly zero based on the results of the SCI impact experiment, but the maximum size of the rubble is unknown, so we treated it as a parameter.
In both cases, impactor velocity and angle of incidence were assumed to be 17 km/s and 45 degrees, respectively.

The breakup altitude varies greatly with the material's tensile strength, showing that the altitude is reduced to about half (35-40 km) compared with the empirical formula (60-80 km). The values estimated by remote sensing and obtained from sample measurements differ by one order of magnitude but do not vary much with respect to breakup altitude (Fig.1).

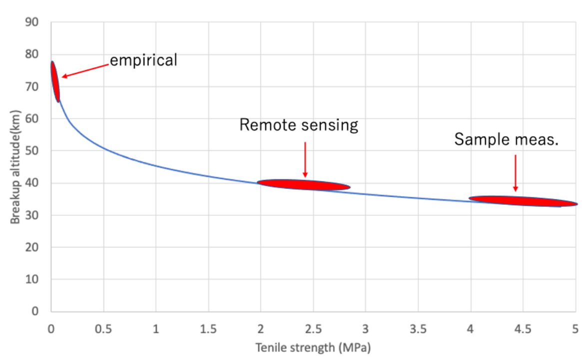

Fig1. Breakup altitude as a function of tensile strength of the impactor.

The transient craters generated on the ground (Fig. 2) are calculated assuming a surface density of 2500 kg/m^3. From the calculation results, there is no significant difference in the results between the intensity difference obtained from the empirical equation and remote sensing. Still, significant differences were obtained from the intensity obtained from the sample analysis results.

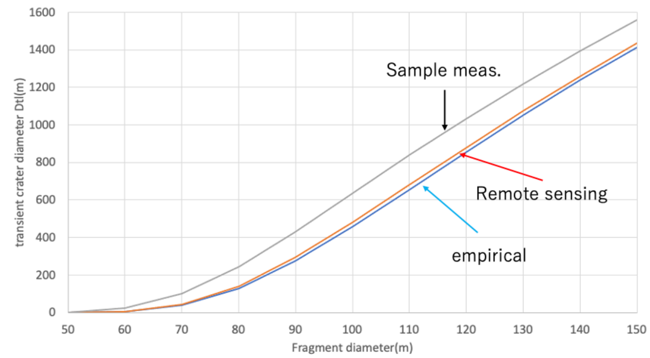

Fig2. Transient crater diameter as a function of rubble size of the impactor.

5: Summary and conclusion

This paper reconsiders the impact of small bodies impacting the Earth based on remote sensing observations and analysis of the returned samples. Ryugu's detailed remote sensing survey and sample analysis have revealed the mechanical properties of the asteroid for the first time. Tensile strength may be more than one to two orders of magnitude greater than empirically estimated values, which could alter the impact on Earth. With regard to sample analysis, more measurements of more samples would be needed, as the number of measurements is still too small to be statistically significant.

Ryugu is a rubble pile structure, but the maximum size of the rubble is unclear. Internal structure exploration will be important in the future to more precisely assess the impact on the Earth.

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