LANDING SITE SELECTION FOR HAYABUSA2: SCIENTIFIC EVALUATION OF THE CANDIDATE SITES ON ASTEROID (162173) RYUGU. H. Yabuta¹, S. Watanabe², T. Nakamura³, N. Hirata⁴, S. Sugita⁵, T. Okada⁶, K. Kitazato⁷, Y. Ishihara⁷, T. Morota⁷, N. Sakatani⁷, K. Matsumoto⁷, K. Wada⁷, S. Tachibana⁷, M. Komatsu⁷, E. Tatsumi⁷, M. Matsuoka⁷, C. Honda⁷, T. Hiroi⁷, S. Senshu⁷, R. Honda⁸, Y. Yokota⁹, R. Noguchi⁹, Y. Shimaki⁹, D. L. Domingue¹², L. Le Corre¹³, A. M. Barucci¹⁴, E. Palomba¹⁴, S. Kikuchi¹, A. Miura¹, T. Yamaguchi¹, Y. Yamamoto⁶, T. Saiky⁶, S. Tanaka⁶, M. Yoshikawa⁶, Y. Tsuda⁶, Hayabusa2 LSSAA & LSS-IDS Teams¹, Hiroshima University, Japan (Kagamiyama 1-3-1, Hiroshima, 739-7526 Japan. E-mail: hyabuta@hiroshima-u.ac.jp), Nagoya University, Japan, ²Tohoku University, Japan, ³University of Aizu, Japan, ⁴The University of Tokyo, Japan, ⁵ISAS/JAXA, Japan, ⁶NIES, Japan, ⁷NAOJ, Japan, ⁸Chiba Inst. Tech., Japan, ⁹Sokendai, Japan, ¹⁰Brown University, USA, ¹¹Kochi University, Japan, ¹²Planetary Science Institute, USA, ¹³Observatoire Paris-Site de Meudon, LESIA, France, ¹⁴INAF, Italy.

Introduction: On June 27, 2018, the Japan Aerospace Exploration Agency (JAXA)’s Hayabusa2 spacecraft arrived at its target C-type asteroid Ryugu. Ryugu is a top shape asteroid with a very dark surface. The mean radius of the asteroid is about 450 m and the rotation period is 7.6 hours. Ryugu is likely a rubble pile, surmised from the large number of boulders seen across the surface and the low density of the asteroid.

Immediately after arrival, remote-sensing observations were carried out with the on-board scientific instruments: the Optical Navigation Camera (ONC), the Near Infrared Spectrometer (NIRS3), the Thermal Infrared Imager (TIR), and the Laser Altimeter (LIDAR). Based on data from this suite of instruments, we carried out the landing site selection (LSS) for the first touch-down (TD1). Since the mission aims to understand i) the origin and chemical evolution of the solar system and ii) the formation process and structure of the asteroid, we have set the most scientifically valuable TD1 site as the least altered region where water and/or carbon are potentially abundant.

Methodology: Landing candidate sites were first selected by engineering evaluation for operational safety followed by scientific evaluations based on criteria such as science and sampeability for the most interesting sites (Fig. 1). The process was repeated using the observations from the altitudes of 20 km (Box-A), 6 km (Box-C), and 5 km (mid-altitude).

Data products used for evaluation: Scientific evaluations of the landing site candidates were conducted based on the data products from the ONC, NIRS3, TIR, and LIDAR instruments. The shape modeling team produced two different shape models, one using a Shape-from-Motion (SfM) technique and a second using Stereophotoclinometry (SPC) modeling. ONC produced multiband images and reflectance spectra, as well as maps of spectral indices (0.7-μm absorption band depth, spectral slope from 0.48 to 0.86 μm [b-x slope], 0.40 μm reflectance excess [ul index], 0.95 μm absorption depth, PC scores) and X-means clustering analysis. Measurements of boulder size-frequency and Hapke parameters in the candidate landing areas were examined. NIRS3 produced four types of spectral feature maps: (i) 3-μm band depth (ii) 3-μm band center (iii) spectral slope, and (iv) NIR albedo. TIR provided maps of maximum temperature (Tmax) from the October 22, 2018 TD1 practice operations, apparent thermal inertia, and typical grain size determinations. LIDAR provided (i) time series range data, (ii) topography, and (iii) corrected spacecraft trajectory.

Engineering evaluation: The possible landing site candidates were selected from the engineering safety score map evaluated based on the sub-Earth distance, local solar angle, local slope and elevation maximum difference (Fig. 1). Thermal prediction results for TD1 were obtained by TIR. Temperatures of each site are less than 350 K, confirming the safe conditions. The regions that satisfied all the conditions were L05, L07, L08, L12 (the equatorial regions) and M01, M03 and M04 (the mid-latitude) (Fig 1).

![Fig. 1. The seven potential landing sites on asteroid Ryugu (L05, L07, L08, L12, M01, M03 and M04) overlaid on a color-coded topographic map (Credit: Hayabusa2 LSSAA Team/Shape Model Team).](image)

Scientific evaluation:

1) Distribution of Boulders. The landing site candidates were narrowed down by counting boulders. Figure 2 shows the distribution of boulders with a dia-
ter larger than 3 m for each potential landing site. Regions L07, L08, and M04 show smaller percentages of boulder coverage (10.7 – 16.8%) than other areas (17.2 – 20.3%), and are regarded as safer sites for landing.

4) Carbon contents. It is likely that visible reflectance at 0.55 μm (R(0.55)) is influenced mostly by carbon content. R(0.55) is almost homogeneous across the surface with a low value, regardless of the candidate sites, except for M01 that shows slightly lower reflectance compared to the other regions.

Based on the relationship between total carbon contents and R(0.55), the reflectance of Ryugu (0.018-0.019) could contain more than 3% of carbon content in the observed regolith. Although, there still remains uncertainties about the nature of the darkening agent on Ryugu’s surface. It may be necessary to consider the possible effects of grain sizes, porosity, and space weathering to explain the very low reflectance.

5) Secondary processes. Although the surface of Ryugu is almost homogeneous at the macro scale in our box spectral slope map, a slight heterogeneity is observed across the candidate regions. L-regions are relatively bluish and M-regions are reddish. There is a slight but linear variation among the candidate sites in a plot between the reflectance at 0.55 μm and spectral slope from 0.48-0.86 μm. Considering that spectral reddening is observed by laser irradiation of dehydrated carbonaceous chondrites [2], M-region may have experienced a higher degree of space weathering than L-regions. Thus, L regions are probably less altered and preferable for sampling.

Final evaluation and the current status: In the final evaluation, scientific scores, safety scores, and sampleability scores were summed. As a result, the regions with the highest scores, L08, L07 and M04 were selected as the TD1 candidates on August 17, 2018. In September 2018, many boulders > 50 cm were additionally found for L08, L07 and M04 sites during the rehearsal of TD1 that provided higher resolution images. Thus, the originally scheduled TD1 in October was postponed. Further search for a flat and safe site continued, and a circular area 20 m in diameter in L08 site was determined as the best possible candidate site for TD1. The TD1 will be scheduled in the week of Feb 18, 2019.