HAYABUSA'S TOUCH DOWN SITES AT THE SMOOTH TERRAIN ON ASTEROID 25143 ITOKAWA: INITIAL INVESTIGATION.

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Hayabusa and Itokawa Overview: Twenty-eight months after the launch on 9 May 2003, JAXA/ISAS's Hayabusa spacecraft (MUSES-C) [1] arrived at the Gate Position hovering above 20 km altitude of the near Earth asteroid (25143) Itokawa on 12 September 2005 (JST unless specified). At 20~7 km altitudes above Itokawa's surface, Hayabusa spent 1.5 months to perform global, in-situ scientific observations [2, 3, 4]. Itokawa is an S(IV)-type asteroid [5] of ~540 m x 256 m x 215 m in size [6, 7] which shows dichotomy between block-rich rough terrains and low potential smooth terrains [8].

Sampling Site Selection: After the completion of the scientific observation phase, the largest smooth terrain "Muses Sea" area, being as wide as ~60 m E-W x ~100 m NS, and the largest facet on the "Body" rough terrain called "Little Woomera" [6, 7] were chosen as sampling site candidates on the basis of scientific merits mainly judged from optical images and LIDAR topography, guidance navigation-control accuracy and operational safety (Fig. 1). Both were in the local dayside of the equatorial region during the real time coverage from the ground stations; they also have relatively flat plains with less obstacles of equivalent size as the spacecraft with shallow local surface inclinations such that both high solar power production and broad telecommunication to the Earth are granted.

The operation team performed two touch down rehearsals on the 4th and 12th November and two imaging navigation tests on the 9th November, respectively. Also high spatial resolution images of the both candidate sites were acquired, with the telescopic Optical Navigation Camera (ONC-T) equipping a 1024x1024 monochromatic CCD of 20 arcsec./pixel resolution and mostly a v-band filter, during each descent. As a result, the operation team concluded that the Little Woomera area still held too many large blocks within the GNC accuracy circle of 60 m diameter to conduct the safe descent operation. Thus the second rehearsal and both of the two actual touch down attempts on the 20th and 26th November were all performed at the Muses Sea area.

Sampler Performance: Hayabusa's "impact sampler"[9, 10] was designed as a single mechanism that could suit for a diverse heterogeneity of target surfaces. We performed laboratory experiments of this impact sampling system both in 1G and in reduced gravity levels ($>10^{-5}$ G), by using a vacuum drop tower, onto various analog materials such as heat resistant bricks, 3~10mm natural gravels which were equivalent size of the Ta projectiles, 200-micron glass beads and lunar regolith simulant [8, 9, 10]. As the results, the expected amount of the samples from 1G and microgravity impacts for both bed rocks and regolith were around several hundred mg to several g per shot, except oblique impacts at >45 degrees resulted on the mass less than 100 mg. Gravel impacts were performed only in the vacuum 1G but even by conservatively assuming the correction efficiency of 1~0.1 %, we estimated collection mass between bedrock and powdery targets.

Touch Down Results: In the final sequence of the touch down, the spacecraft would have (1) aligned to the local surface slope measured by four laser range finder (LRF) beams, (2) detected the contact with the surface by the tip of a 1-m long sampler horn attached on the anti-sun face at ~10 cm/s of vertical vector, (3) fired a pair of 5-g Ta projectiles at ~300 m/s, (4) fractured surface materials, (5) collected ejected rock fragments or/and regolith particles, which are concentrated through the conical horn toward the sample canister inside the spacecraft, and (6) ascended again in a few seconds [8].

On the 19th November UTC (20th in JST), the first touch down (TD1) resulted to abort projectile firing due to fan beam sensor detected an obstacle although emergency ascent was autonomously cancelled so that the spacecraft continued to free-fall to Itokawa's surface. At 21:10 UTC the sampler horn touched the asteroid surface near the 6-degree S and 39-degree E location in the middle of the Muses Sea and bounced upward and the second bouncing occurred at 21:30. Then at 21:41~22:15, the spacecraft landed on the south west of the Muses Sea region until manual emergency ascent thrust was conducted. Despite not firing the sampler projectiles, there was a chance that some regolith grains were uplifted by the tip of the horn and reached to the sample canister during slow bounces.

Surface Characteristics: Close-up images taken above the touch down sites provided the highest resolution of ~6 mm/pixel (Fig. 3). It is then clear that the Muses Sea was densely filled with size-sorted gravels ranging from mm to cm scale of similar brightness. Despite the observation of opposition surge from sub-solar point, this is far larger than sub-mm regolith powders filled in ponds on Eros [8, 11]. Unlike the surrounding rough terrains, only a few blocks larger than meter-size were discovered. The boundary with the eastern rough terrain has a "transition zone" [12] where blocks appear to exhibit imbrications. Also evident is gradual decrease of both the average size of gravels and spatial density of large blocks from the transition zone to the center of the Muses Sea. There, rocks of 10's cm size often have rounded corners and tend to flock together. These facts possibly imply comminution and transportation process still on-going at present [13]. The Muses Sea is the minimum at gravity-centrifugal potential over the entire surface of Itokawa [6]. If resurfacing process of the Muses Sea is still in progress, large blocks on the original surface might have been embedded by gravels that accumulated up to the similar depth (i.e., several meters). Yet one must be cautious that draining these regolith grains into interior pores is still a possibility, especially suggested by a relatively low bulk density estimate around ~2.1 g/cm^3 with some error range [6]. Nevertheless, energy sources for block-regolith interaction/ transportation may include electrostatic levitation [14], planetary tides during close encounters, extreme thermal cycles, impact excavation and seismic shaking [15].

Surface friction of Muses Sea area was estimated from the TD1 average LRF data and PFM sampler ground test results by identifying touch-down and bouncing velocities; then numerical simulation on motion dynamics of the spacecraft was performed to obtain a set of possible surface characteristics satisfying the identified velocity conditions [16]. The altitude profile of the TD1 is summarized in Fig.2. Then we estimated the approaching velocity right before the contact Vz = -6.93 x 10^{-2} m/s and the bouncing velocity right after the contact Vz' = 5.79 x 10^{-2} m/s. The local gravitational acceleration associated with the above velocities are found as g = 9.4 x 10^{-5} m/s^2, which is measurably different from the GM value based upon the global shape model and constant bulk density assumption [6]. Although we do not have reliable information about the horizontal velocity Vx at the moment of TD1, it is inferred to be greater than 4.5 x 10^{-2} m/s toward –X direction, because otherwise the spacecraft cannot have the vertical velocity of Vz' = 5.79 x 10^{-2} m/s. This is due to asymmetric design of the spacecraft in terms of the attachment point of the sampler horn. The tumbling motion induced during the contact becomes very different depending on the horizontal velocity. If -5.0 < Vx < -4.5 x 10^{-2} m/s, the value of friction coefficient is estimated as μ >0.8, or even grater than 1. This represents such a situation that the tip of the sampler horn scratches rough and deformable surface materials (i.e., packed gravels), or possibly pushes and removes them.

Temperature profile of the XRS radiator was also monitored during the TD1 descent phase [4]. The temperature increased at about 28m altitude, almost reaching the thermal equilibrium. Thus the asteroid surface temperature was estimated about 310 K in order to equilibrate with the XRS radiator, also indicating the rocky or/and gravel-filled surface with higher thermal inertia than a powdery surface like lunar regolith. Okada *et al.* [4] also reported that the XRS indicated elemental spectra, which is consistent with those of ordinary chondrites.

The NIRS did not detect significant variations between the spectra acquired in ~8 m footprint from 4.5 km altitude (Home Position) and those in ~7 cm footprint during the TD1 descent; this means that at least the Muses Sea gravels may be mineralogically homogeneous in these scales [3]. On the contrary, Ishiguro *et al.* [17] reported that AMICA images of the Muses Sea appeared to change in color from blue at the western side to red at the eastern side. Together with brightness variation (e.g., maturity), this color variation must be investigated further for its cause.

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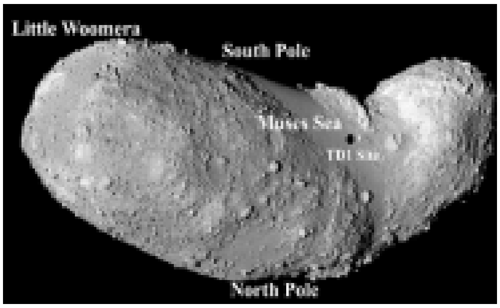

Fig.1. Location of the Muses Sea smooth terrain including the first touch down site on Itokawa

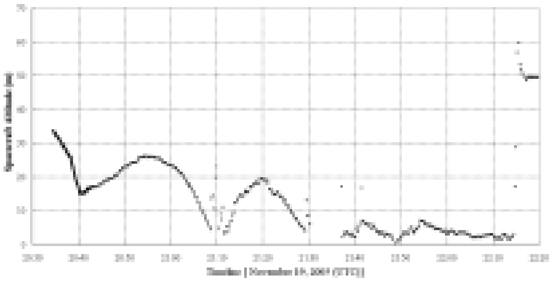

Fig. 2. Altitude and time profile of the Hayabusa spacecraft during the first touch down

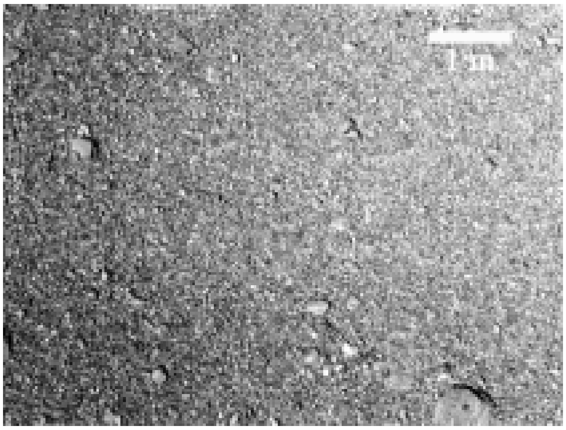

Fig.3. Close-up image near the first touch down site in the Muses Sea filled with size-sorted gravels.