REGOLITH ON A TINY ASTEROID: GRANULAR MATERIALS PARTLY COVER THE SURFACE OF ITOKAWA

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Introduction: Whether small (i.e., sub-km-sized) asteroids are covered with regolith is a significant but outstanding question to understand the evolutions of asteroids [e.g., 1-3]. Regolith is generally defined as any kind of superficial layer/blanket of loose particulate rock materials, which are expected to form when meteoroids impact onto the asteroid surface. Although this happens regardless the size of asteroids, a small body may keep only a small amount of regolith due to its lower escape velocity. The presence of regolith is technically difficult to directly confirm with optical and thermal observations from the ground due to poor spatial resolutions for such small objects; thus images of Itokawa taken by the Hayabusa spacecraft gives unique opportunity to study the nature of regolith materials on the sub-km sized asteroid [4].

The target of the Hayabusa mission is 25143 Itokawa, an Apollo type, S-type, near-Earth asteroid. The spacecraft carries the telescopic Optical Navigation Camera (ONC-T), which is also called Asteroid Multiband Imaging CAmera (AMICA) when used for scientific observations. The resolution of AMICA is 20 arcsec/pixel, which represents 1m/pixel with distance of 10km [5]. From the altitude of approximately 20 km, we performed the first global imaging of the asteroid with the resolution of ~ 2 m/pixel and we reveal that such a small size of asteroid (~550m x 300m x 240m [6,7], several ten's times smaller than Eros) can have significant amount of regolith over its surface for the first time. At the altitude of ~7km, we obtained images of the entire surface of Itokawa with the spatial resolution as small as 70 cm/pixel (Figure). In addition, we obtained tens of images of touch down site candidates at both middle (~ 4 km) and lower (less than 1km) altitudes.

Global Distribution: AMICA took more than 1,300 images of the surface of the asteroid Itokawa, which show a variety of features suggesting its complex evolutional history. Two types of terrains are recognized: (1) rough terrain, which is covered with numerous boulders, and (2) smooth terrain, whose surface is apparently flat. The smooth terrains are quite distinctive because they only have several sizeable boulders as opposed to the surrounding rough terrains fully covered with large boulders. Also the smooth terrains are apparently covered with featureless, flat components with almost uniform brightness. These characteristics are consistent with the view that the smooth terrains are mantled by fine materials. Importantly, the regolith of Itokawa is not globally distributed; the smooth regolith terrains only cover the surface of Itokawa partially (approximately ~20 %). The boundaries between the smooth and rough terrains are typically very sharp. These likely indicate the existence of certain surface processes to concentrate the regolith materials on the smooth terrains after the formation of Itokawa.

We identified several smooth terrains including three major ones. The most distinctive is called the Muses Sea (Figure), whose location may indicate its depositional origin: The global shape of Itokawa appears to be composed of two parts (called the Head and the Body) while the Muses Sea is located between them as if it fills up the gap. The "Sagamihara" area is another major smooth terrain surrounding the northern polar region. We are currently working on geological mapping and detailed measurements of these areas using both the images and the three-dimensional shape models developed by several research groups [6,7,8].

Slope angles against the local gravity are generally lower than 8 degrees on the smooth terrains [8]. It is important to note that the surface gravity at the Muses Sea is estimated to be the minimum over the entire surface of Itokawa [8]; this fact may imply the gravitationally-induced movements of the finer materials after the formation of the asteroid. Smooth terrains, including the largest smooth terrain (Sagamihara sea), always locate at the local lows of gravity, however, the local lows of gravity do not always have smooth deposits.

Detailed Observations: Since the touch down sites were selected at the middle of the Muses Sea, the ONC-T could take close-up images at altitudes lower than several hundred meters during three rehearsals and two actual touch down sequences [9]. These images, whose highest resolution is about 6 mm/pix for the Muses Sea area, reveal that gravel-like grains uniformly cover the part of Muses Sea at least as wide as several thousands of squared meters (i.e., ~60m x ~100m). Preliminary analyses of these images suggest that the grain size of the gravel-like deposits likely ranges from sub-centimeter to centimeter scale, which is coarser than those of the "ponds" on Eros [9, 10,11].

Only a limited number of meter-sized boulders are found in the middle of smooth terrains [12]. Especially, boulders larger than 5m are very rare. The origins of these boulders seem to be complicated. Some boulders are surrounded by shallow depressions while most of others are not. The depressions may indicate that these boulders were softly landed after the formation of the terrain as secondary ejecta. However, a dynamic interaction between the boulders and fine particles during the resurfacing processes, such as seismic shaking [13,14], must be further investigated as their possible origin.

Findings through the preliminary image analyses of Muses Sea area include: (1) Although the boundary between the smooth and rough terrains is generally sharp, there is a ~10m-scale "transition zone" between them; (2) Boulder alignments along the boundary can be seen inside and near the transition zone; (3) The size of boulders inside the regolith area seems to become smaller gradually, as a function of the distance from the transition zone, when measured based on the lengths of shadows; (4) The depth of regolith may be several meters if the boulders inside the regolith are the remnants after the deposition of regolith; (5) The depth of the regolith appears to be shallower at the boundary between rough and smooth terrains than the middle of the Muses Sea; (6) Measured by the shades, the grain size of the regolith systematically becomes finer from the boundary to inside the Muses Sea.

Discussions: Global and close-up images of the smooth terrains reveal that these terrains are mantled by finer materials as a result of certain type of sedimentation. Evolutions of smooth terrains likely involve processes for grain-size sorting and dynamical interactions between regolith and boulders although the transport/deposition mechanisms are subject to further investigation. Evidence of the regolith material transportations on the surface of the asteroid are supported by a range of their morphologies. For example, floors of some craters are almost perfectly covered with regolith, which implies the emplacements of deposited materials. If this was the case, the materials could have high fluidity over the surface of Itokawa at the time of deposition. However, once the regolith materials deposit inside a crater, they do not move outward, even when the proximity area is gravitationally lower.

If all of the boulders inside smooth terrains were the remnants of the rough terrains, which were subsequently emplaced by the finer materials, thickness of the smooth terrains would be thicker than a typical size of boulders (say, several meters). In this sense, the average thickness of the overall regolith on Itokawa is on the order of a meter, when no regolith drains into the interior. Note that if the volume of the largest possible crater (i.e., Little Woomera [15]) were spread around the 0.39 km^2 of the surface area [7] of Itokawa (taking a nominal depth/diameter ratio ~0.15) it would contribute less than 1 m of regolith, even if 100% of ejecta was retained. This may suggest that the regolith on Itokawa is not a direct result of impact re-accumulation but may have experienced complicated evolutional history.

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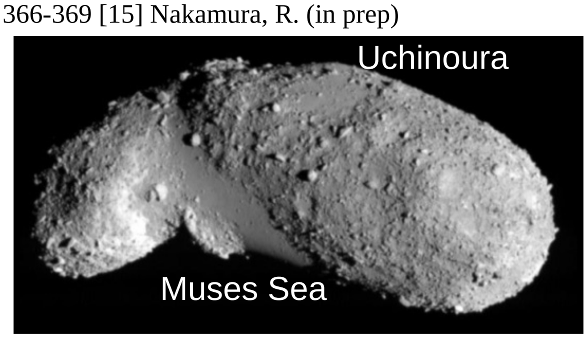

Figure. Eastern sides of Itokawa. Two major smooth terrains (Muses Sea and Uchinoura) are distinctively identified in the image due to their smoothness.