TOPOGRAPHY OF NIGHTINGALE, THE OSIRIS-REX SAMPLE SITE ON BENNU.

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Introduction: The OSIRIS-REx spacecraft collected a sample of regolith from a site on asteroid Bennu called Nightingale in October 2020. We investigate high-resolution Digital Terrain Models (DTMs) derived from OSIRIS-REx Laser Altimeter (OLA [1,2]) and stereophotoclinometry (SPC [2,3]) to understand the geological characteristics of the area surrounding Nightingale, explore evidence for surface processes, and characterize the heights of the surface features encountered by the OSIRIS-REx Touch-and-Go Sample Acquisition Mechanism (TAGSAM). These data not only offer context for the collected sample; they also provide high-resolution views of the dynamic processes altering Bennu over time.

Digital Terrain Models: OLA was collected during an orbital phase of the mission in July–August 2019, where more than 3 billion individual altimetric returns were obtained from a range of ~650 m. These data made it possible to generate a DTM of Nightingale with a ground sample distance (GSD) of 5 cm. In each 5×5 cm bin, there were up to 100 OLA returns. We also produced a Nightingale DTM with a GSD of 1 cm obtained using SPC from OSIRIS-REx Camera Suite (OCAMS [4]) images collected throughout the encounter with Bennu, including Reconnaissance flyover images at <1 cm per pixel.

The accuracy of the OLA DTM is better than 15 cm: the median standard deviation of measurements within a 5×5 cm bin is 3.8 cm. However, much of the variation is correlated with regional roughness due to visibly evident higher densities of boulders, implying that the DTM accuracy could be probably better than this 3.8 cm. The precision of these DTMs is <2.1 cm. The rendered DTMs look very similar to images; rocks with diameters >20 cm are easily identifiable. Rough areas composed of accumulations of rocks with diameters <20 cm are also apparent, although individual rocks of this size cannot be resolved in the OLA DTMs.

The SPC DTMs complement the OLA-only products. They reveal rocks as small as 2 cm in diameter.

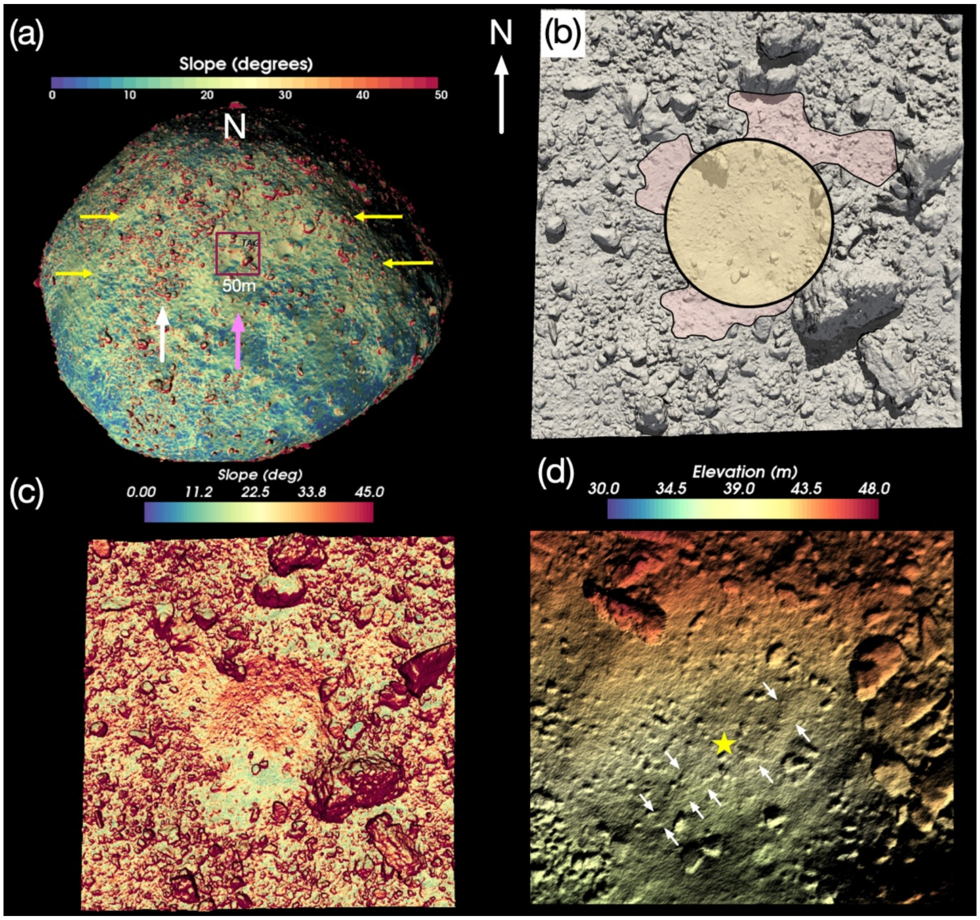

Figure 1. Regional (a) and local (b-d) OLA DTMs of the Nightingale site (55N,46E). The Nightingale site is located within a crater (b, yellow), amid steep slopes (>35 degrees, a and c), possible impact ejecta (b, pink), and flow lobes (d), some of which stop near the sample collection site.

But, because the OCAMS viewing geometries were not ideal for SPC at the highest spatial resolutions, these maps also have some artifacts. To interpret the data, we used all our products, carefully comparing the SPC DTMs to the images and the OLA data; and used prior studies if SOC quality [e.g., 5] to constrain the expected vertical accuracy of these products.

Regional Topography: The crater in which Nightingale is located is between two N-S longitudinal ridges [6; Fig 1a]. These high-standing ridges force mobile-surface material between them [7]. Just to the NE, there is an apparent rock fall channel [8]; to the S, there is a ridge or remnant large crater rim that swoops from W to E. The regional slopes north of the crater are steep (Fig. 1a), sometimes exceeding 35°. Geotechnical assessments of these regions indicate that Bennu's talus-like surface materials should be metastable and on the verge of failure, with surface creep likely. Expressions of surface creep include toppled boulders and limited regional surface slides. These are expected to occur as the rotation rate of Bennu continues to increase [9] especially at mid-latitudes between 30 and 70 degrees where the slopes on Bennu are greatest [6], exactly in and above the latitude band where the Nightingale site is located.

Local Topography: The Nightingale site is located in a 27-m-diameter crater (Fig. 1b) whose morphology is in family with other similarly sized craters on Bennu [10]. Its geometric depth-to-diameter ratio of 0.08 ± 0.03 falls on the shallow side of similarly sized craters. Its rim is somewhat irregular due to several large (3–7 m high) boulders surrounding the crater and the aforementioned steep slope. Unlike the crater at the alternate sample site, Osprey, this crater possesses no central mound, and its deepest point (with respect to geometric height, not relative to local gravity) is approximately located in its center.

The crater also appears to have a relatively fine-grained (particles < 20 cm) deposit that drapes the near-rim region, especially around the northern portion (Fig. 1b). The deposit is reminiscent of crater ejecta.

The Nightingale site shows evidence for multiple granular flow-like structures in the crater interior. These seem to have originated from the very steep crater wall, whose slope exceeds 35° (Fig 1c), and some instances stop near where sampling occurred on average slopes of 25°. These flows have distinct lobes a up to 5 cm or more in height and a pointed appearance (Fig 1d). There is evidence for more than one event, with some of the putatively earlier, more energetic flows extending further than some of the younger ones.

Interpretation: Nightingale is located below the fairly steep slopes of the encircling crater wall, where unconsolidated surface material has failed downslope. Two longitudinal ridges on either side of the crater likely direct surface material into the crater's vicinity. A ridge to the south may have retained some of the upslope debris to form a sedimentary basin in which Nightingale is located. The crater shows evidence of impact ejecta on its northern rim, the retention of which requires near-gravity-controlled impact cratering into a strengthless target. These ejecta could be the source of the flows visible in the crater interior; they could have collapsed into the crater immediately after formation because of the regional slope [e.g., 11]. Although multiple flows are present, they may not be separated by long time intervals. If they are separated by some time (but not enough for the crater to be erased), some of the flows could also be the result of the later up-slope wall collapse. The fact that some of the flows stopped on 25° slopes suggests that the friction angle for these materials is likely 10° greater, near 35°. The regional and local geology of the crater suggest that it was filled with loose, unconsolidated material before sample collection. Fine-grained sample collected from Nightingale may have originated from upslope or from shallow depths excavated or exposed by crater formation; it could also include some non-Bennu material [11] left by the crater-forming projectile.

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