THE OSIRIS-REX TOUCH-AND-GO SAMPLE ACQUISITION EVENT AND IMPLICATIONS FOR THE NATURE OF THE RETURNED SAMPLE. D. S. Lauretta[1] and the OSIRIS-REx TAG Team, [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA.

On October 20, 2020, NASA's Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) spacecraft [1] contacted the surface of asteroid (101955) Bennu with the Touch-and-Go Sample Acquisition Mechanism (TAGSAM) and collected a sample of regolith. This event was the culmination of an extensive remote-sensing campaign to characterize the surface of Bennu and identify an optimum sample site. The site selected, dubbed Nightingale [2], is one of the rare locations on Bennu that contains abundant small particles (<2 cm) ingestible by TAGSAM and is also relatively free of hazards (particles from 10 cm to tens of meters).

To initiate the sampling sequence, the spacecraft fired its thrusters to depart from orbit around Bennu. It extended the 3-m-long TAGSAM arm as it transited across the sunlit side of Bennu. Four hours after orbit departure, the spacecraft executed the Checkpoint maneuver to begin its descent towards Nightingale. Ten minutes later, the spacecraft executed the Matchpoint maneuver to match the surface velocity resulting from Bennu's rotation. The TAGSAM head contacted the surface with a downward velocity of 10 cm/s within 1 m of the targeted center of the Nightingale site, in an area with multiple ingestible particles visible.

TAGSAM [3] acquired the bulk sample by releasing a jet of high-purity nitrogen gas that excites and "fluidizes" at least 60 g of regolith into the collection chamber. During the collection time, gas is injected into the surface and subsurface, mobilizing particles into the collection volume. The baseplate of the TAGSAM head contains 24 contact-pad samplers made of stainless-steel Velcro. These pads collect small grains up to 1 mm in diameter upon contact with the asteroid surface.

Surface contact was indicated by a signal from the spacecraft's accelerometer, which registered a small but measurable surface contact force. The surface responded like a compliant, viscous fluid, similar to discrete-element simulations of TAGSAM interacting with regolith with low intergranular cohesion [4]. The spacecraft's downward velocity did not decrease substantially after contact. Post-contact, surface disturbance was visible in all directions around the TAGSAM head, indicating that the head was flush with the surface.

The surface location where TAGSAM touched down offered a high likelihood of successful sampling. Prior to sample collection, a "sampleability" score was assigned to each facet of a 5-cm-resolution digital terrain model of Nightingale [5], based on empirical data collected during TAGSAM characterization testing [6]. Analysis of imagery collected during the final descent indicates that at least 35 ingestible particles (<2 cm) were present at the surface contact point. Because the surface is highly compliant, these particles and other material from the surface were ostensibly "pre-loaded" into the head when TAGSAM touched down, prior to gas firing. When the gas bottle valve opened, the pre-loaded regolith should have been driven into the head instantly. The predicted sample mass based on the sampleability assessment is 258–575 g.

About 1 second after sensing contact, the TAGSAM gas valve opened, initiating gas flow. Abundant sampleable material was lofted and moved. A dust cloud is visible in images taken just after gas firing, which precedes coarser lofted debris. Post-sampling checkouts of the imaging systems revealed substantial degradation in the throughput of optics. All of these factors indicate that there was a substantial reservoir of dust available for sampling from the surface and near sub-surface.

Six seconds after making contact with the surface, the spacecraft fired its thrusters and initiated the back-away maneuver. At this point, the spacecraft still retained a downward velocity of ~4 cm/s. The back-away thrusters fired for 3 seconds before the downward velocity was arrested and the spacecraft began to safely move away from Bennu. At this point the TAGSAM head had penetrated about 50 cm into the surface without much resistance. The TAGSAM head rose above the original surface location 16.6 seconds after initial contact. The spacecraft departed Bennu on a hyperbolic trajectory at 40 cm/s.

Two days after the TAG event, the spacecraft acquired a series of TAGSAM images using the SamCam instrument [7]. SamCam is designed to document the sample-collection process and to aid in determining whether visible sample made it into the collector head. Immediately upon downlink of these images, the team faced an unfolding contingency scenario: TAGSAM appeared to contain abundant sample but was overflowing and losing particles. Multiple large pebbles (with long axes up to 3 cm) were visibly wedged into the chamber, propping open the flap that was intended to prevent escaping material.

The team responded to the contingency rapidly. Instead of braking, which could have jostled more sample loose, the spacecraft was allowed to continue to recede from Bennu. In addition, the planned experiment to measure the sample mass was cancelled, as it would have involved rotating the spacecraft with TAGSAM fully extended, exacerbating mass loss. The team instead expedited the sample stow procedure to preserve as much material as possible. This decision required confirmation that mission had achieved its primary requirement to collect >60 g of sample.

The collected sample mass was estimated using image analysis to determine visible particle volumes, assuming regolith particle densities of 1800 kg/m^3 and bulk densities of 1200 kg/m^3. Three different reservoirs of sample were characterized. First, the team measured the dimensions of the five particles visibly propping open the mylar flap. These particles have a collective volume of 15.6 cm^3 and an estimated mass of ~28 g. The second technique relied on the observation that the outer screen of TAGSAM was opaque to transmitted sunlight, in contrast to images taken when the head was empty. The small amount of light seen passing through the head suggests that at least 57 g of regolith is covering the outer screen. The third approach analyzed a separate visible portion of the collector head's volume, behind the mylar flaps. The uniform appearance across multiple images with varying exposure times suggested that the observable volume was full of material, corresponding to ~312 g. Thus, all the evidence together suggests that ~400 g of sample was visible in TAGSAM when these images were acquired.

These analyses, combined with the favorable positioning of TAGSAM during sampling and the large amount of mobilized material, convinced the team to proceed with stowing the sample. The stow procedure involved articulations of the TAGSAM arm, resulting in additional sample loss. A second set of SamCam images was acquired during this process. These images documented the additional mass loss, totaling hundreds of particles and tens of grams. The arm movements allowed the spacecraft guidance, navigation, and control team to constrain the mass of sample in the head at the time of stow based on corresponding momentum build-up. These analyses provide high confidence that >60 g of sample is stowed and ready for Earth return.

Based on what we have learned from our science campaign during asteroid operations, we can make several predictions about the returned sample that will assist in the preparations needed for the sample analysis phase. The physical nature of the returned material is expected to be in a size range from sub-microns to several centimeters. We expect the sample to contain hydrated silicates [8], carbonates [9], magnetite [10], and organic components [11]. Whether these occur together as assemblages or in monomineralic particles is to be determined. Nonetheless, we are confident that the material collected in the TAGSAM head and contact pads will be heterogenous. TAGSAM and the sample return capsule have witness plates mounted in strategic locations to document any contamination acquired in flight [12].

OSIRIS-REx is scheduled to depart Bennu for Earth in May 2021. This maneuver places the spacecraft on a trajectory to deliver the sample to Earth in September 2023. The capsule will land at the Utah Test and Training Range. The team will recover the capsule and transport it to the curation facility at NASA Johnson Space Center. One of the first measurements will be determination of the total collected mass.

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