OSIRIS-REX's SEARCH FOR A SAMPLE SITE: SELECTING THE PRIME (NIGHTINGALE) AND BACKUP (OSPREY) SITES ON ASTEROID (101955) BENNU. H. L. Enos[1], A. T. Polit[1], D.S. Lauretta[1], P. Antreasian[2], C.A. Bennett[1], K. Berry[3], E. B. Bierhaus[4], R. Burns[3], H. C. Connolly, Jr.[5,1], B.E. Clark[6], M.K. Crombie[7], D.N. DellaGiustina[1], S. Freund[4], D. Lorenz[3], M. Houghton[3], M. Moreau[3], R. Mink[3], M.C. Nolan[1], K.J. Walsh[8], (1) Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA. (2) KinetX Aerospace, Inc., Simi Valley, CA, USA. (3) NASA Goddard Space Flight Center, Greenbelt, MD, USA. (4) Lockheed Martin Space, Littleton, CO, USA. (5) Department of Geology, Rowan University, Glassboro, NJ, USA. (6) Department of Physics and Astronomy, Ithaca College, Ithaca, NY, USA. (7) Indigo Information Systems, Tucson, AZ, USA. (8) Southwest Research Institute, Boulder, CO, USA.

Introduction: OSIRIS-REx is unique among NASA planetary missions in that remote sensing is performed primarily to support the sample-return objective [1]. The science payload was used to survey Bennu to select and document the best candidate sample sites. The team combined coordinated observations into thematic maps of four decision-making properties: deliverability, safety, sampleability, and science value. The Site Selection Campaign concluded with selection of prime and backup sampling sites, respectively called Nightingale and Osprey (Fig. 1). We discuss the unexpected characteristics of Bennu and how they influenced the final site selection process [2,3].

Site Selection Process Evolved due to Bennu's Surprises:

Deliverability. The initial purpose of the deliverability map was to identify 25-m radius regions that the flight dynamics team could deliver the spacecraft to the desired location within. The spacecraft is equipped with two independent, autonomous guidance systems for the final contact with the asteroid surface during sample acquisition: natural feature tracking (NFT) and LIDAR-guided "Touch and Go" sampling (TAG) [1]. LIDAR was the initial baselined technique.

Upon our approach to Bennu, we discovered a much more rugged surfaced than predicted [2]. This created a significant challenge identifying potential sample sites with hazard free regions of 25-m radius. Only a small number of sites of hazard free regions, ~5-8 m in radius, were identified. As result of these tighter constraints, NFT became the prime method for delivery to the surface.

Safety. During sample acquisition, the spacecraft must avoid damage that would prevent a successful sample stow and return to Earth. Safety maps quantify the probability of safety during sampling. They include an assessment of the physical hazards (boulders) that may be present during approach to and back-away from the asteroid.

The baseline driving constraints for safety were that OSIRIS-REx shall attempt sample collection in a region with <1% probability of the TAGSAM sampling apparatus contacting a surface angle > 14° and assuming a worst-case 45° spacecraft tip-over. To open up the options for sample sites, spacecraft capabilities against these requirements were re-examined and further analysis was performed. As a result, the tilt requirement was no longer a driving constraint and the tip-over constraint was relaxed to 25°. In addition, a new capability for hazard detection and avoidance has been implemented within the NFT flight software to ensure that the spacecraft will wave off and backaway from the surface if it predicts contact with a known hazard.

Sampleability. A sample site must have characteristics that permit the TAGSAM sampling apparatus to obtain 60 g or more of regolith [4]. Sampleability is assessed at two scales: global and site-specific. Global sampleability provided a relative comparison of candidate sites, relying on the quantification of unresolved area. Site-specific sampleability determines if a site meets requirements and increases knowledge of ingestible particles <2 cm.

As we updated the process and constraints on Deliverability and Safety, Sampleability became the primary driver for selecting the primary and backup sample sites. The process for finding small, ingestible particles went through a few iterations. Pre-encounter modelling of Bennu's thermal inertia indicated a generally smooth surface covered by centimeter-scale particles [5]. Measured thermal inertia data did *not* correlate with the observable grain size and therefore did not provide the site discriminator as initially planned [3]. The final process focused on careful mapping of resolved and un-ingestible particles, providing the quantitative assessment of sampleability (Fig. 1).

Science Value. The sample site should contain material that provides the most value toward meeting the mission objective of returning pristine carbonaceous regolith. Science value is assessed using the following metrics: presence of carbonaceous and hydrated materials, minimal alteration by surface processes, compositional diversity, and evidence of primitive materials.

All evidence point to the fact that the bulk composition of Bennu is rich in hydrated and volatile phases [6]. Although this was expected, the relative albedo, hydration bands and organic signatures do vary among the potential sample sites.

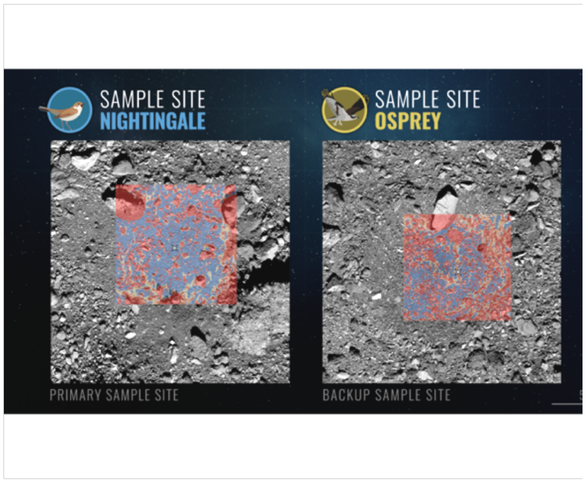

Fig. 1. Blue shading represents finer-grained (sampleable) material.

Site Selection Decisions: Imaging, spectral, and laser altimetry data were collected for about 10 months. The Science Team produced and analyzed these products, providing results to the Site Selection Board (SSB). The SSB spent nearly 6 months poring over the data products and interpreting the results, performing relative rankings among the potential sites. After careful deliberations, taking into consideration that the primary mission objective is to return ≥60 g of pristine bulk sample from Bennu, the SSB selected Nightingale (Fig. 2). as the Primary Sample Site. Nightingale is the site with the highest probability of collecting sufficient sampleable material.

Fig. 2. The primary sample site, Nightingale, is located in the northern hemisphere (lat, lon: 56.05°, 42.05°).

Nightingale is located in a northern crater 460 ft (140 m) wide. Nightingale's regolith exhibits a good amount of unobstructed fine-grained (sampleable) material. Given that the site is located so far north, temperatures in the region are lower than elsewhere on the asteroid. This thermal regime likely leads to greater preservation of hydrated minerals and volatile organics. The crater also is thought to be relatively young, and the regolith is freshly exposed [7]. Thus, this site has the highest science value.

Although Nightingale ranks the highest of any location on Bennu, the site still poses challenges for sample collection. The original mission plan envisioned a sample site with a diameter of 164 feet (50 m). The area safe enough for the spacecraft to touch is much smaller – approximately 52 ft (16 m) in diameter, resulting in a site that is only about one-tenth the size of what was originally envisioned. Nightingale does contain some nearby hazards that will need to be carefully assessed when generating the final Sample Collection hazard maps. Nightingale has a building-size (7-m height) boulder situated on the crater's eastern rim, which could pose a hazard to the spacecraft while backing away after collecting the sample.

The spacecraft has the capability to perform multiple sampling attempts. However, any significant disturbance to Nightingale's surface would make it difficult to collect a sample from that area on a later attempt, making a backup site necessary. Osprey, the backup site, is located in the equatorial region hemisphere (lat, lon: 11.62°, 88.62°). Osprey exhibits less sampleable material than Nightingale but may be more accessible owing to fewer hazards.

Conclusion: Nightingale and Osprey both provide high confidence of a successful TAG on the first attempt. Nightingale provides the best chance of collecting ≥60 g on the first TAG attempt.

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