Introduction: Visible to near infrared (VNIR) and thermal infrared (TIR) spectrometers onboard the Origins, Spectral Interpretation, Resource Identification, Security–Regolith Explorer (OSIRIS-REx) spacecraft have revealed evidence of hydrated phases across the surface of asteroid (101955) Bennu. Here we describe spectral features identified in data collected during the Approach and Preliminary Survey phases of the mission, from 2 November 2018 to 17 December 2018.

Background: The primary objective of the OSIRIS-REx mission is to collect and return to Earth a pristine sample of carbonaceous material from the near-Earth (and potentially hazardous) asteroid Bennu [1]. To aid in asteroid characterization and sample site selection, OSIRIS-REx carries a camera suite (OCAMS), a laser altimeter (OLA), and two hyperspectral spectrometers (see next section), along with a student-led x-ray imaging spectrometer (REXIS).

OSIRIS-REx spectrometers. The OSIRIS-REx Visible and Infrared Spectrometer (OVIRS) is a point spectrometer covering the wavelength range from 0.4 to 4.3 μm with a 4-mrad field of view (FOV) and a spectral sampling of 2 nm from 0.392 to 2.4 μm, and 5 nm from 2.4 to 4.3 μm [2, 3]. OVIRS is a derivative of the New Horizons Ralph instrument. The OSIRIS-REx Thermal Emission Spectrometer (OTES) is a point spectrometer that measures from ~100 to 1650 cm⁻¹ (~5.5 to 100 μm), with an 8-mrad FOV and a spectral sampling of 8.66 cm⁻¹ [4]. The OTES instrument is a derivative of the Mars Exploration Rovers Mini-TES and Mars Global Surveyor TES. Although the OVIRS FOV is within that of OTES, the two are not precisely co-boresighted.

Data processing: The OSIRIS-REx science team is organized around science theme working groups, and the Spectral Analysis Working Group (SAWG) is responsible for analyzing and integrating the results from OVIRS and OTES. To that end, the SAWG has developed an automated data processing pipeline to produce quicklook science (Level 3) products that are generated immediately after the data are downlinked and converted to calibrated radiance. For OVIRS data in all mission phases, this includes removal of the thermal tail and conversion to I/F, and for mapping phases, generation and application of a photometric model, production of bolometric Bond albedo, reflectance factor spectra, and the calculation of spectral indices. For OTES, this includes deriving emissivity spectra and temperature information with emissivity being an input into a linear least squares mixing model and a spectral parameter representing the presence of surface dust.

Observation sequences: Unlike either a true orbiter or fly-by mission, OSIRIS-REx has many different mission phases that incorporate different observing strategies to best characterize Bennu and aid in the selection of a sample site.

Spectroscopy in the Approach phase. Early Approach phase observations (2 to 9 November 2018) were aimed at collecting disk-integrated spectral data, both to obtain an initial view of Bennu’s composition and for comparison with ground-based spectral data. Spectra were acquired over multiple days, with two days being optimized for the OVIRS FOV and pointing (2 to 3 November), and two later days being optimized for the OTES FOV and pointing (5 and 9 November). A set of contingency observations was also acquired on 8 November. Both spectrometers acquired data on all observation days. On 2 December, during late Approach, both spectrometers acquired “ride-along” data during a sequence optimized for OCAMS imaging.

Spectroscopy during Preliminary Survey: OSIRIS-REx arrived at Bennu on 3 December 2018, marking the end of the Approach phase and the beginning of the Preliminary Survey phase. All spectral observations obtained during Preliminary Survey were acquired as part of imaging sequences aimed at characterizing Bennu’s polar and equatorial regions prior to orbit insertion (which occurred 31 December 2018). As such, these observations were not tailored for spectroscopy in terms of the acquisition of calibration data, instrument pointing, or local time. Spectral data were acquired by OTES on all days, and by OVIRS on a subset of days, between 4 and 17 December.

Preliminary Results: Approach and Preliminary Survey data have been invaluable for giving the OVIRS and OTES teams a wide range of observing sequences that allow for improvements to the calibra-
tion of both data sets and for revealing exciting insights about Bennu early in the mission.

**OVIRS results.** OVIRS disk-integrated Approach data from 2 November 2018 reveal a visible to near-infrared spectrum that is remarkably similar to the ground-based data of [5], having a blue (negative) slope and no visible features above the level of the noise. A 0.55-µm feature observed in OCAMS data [6] is not observed, but this is likely attributable to the whole-disk nature of the OVIRS observations, where the FOV was only ~40% filled as compared to the spatially resolved OCAMS imagery. OVIRS data that will be acquired during the Detailed Survey mission phase may have sufficient spatial resolution (~40 m/spot) and signal-to-noise to detect this feature. At longer wavelengths, an unambiguous 2.74-µm band is present, consistent with the presence of hydrated silicates, including those contained in petrologic type 1, 1/2, and 2 carbonaceous chondrites. There is no apparent rotational variation in the OVIRS whole-disk spectra.

**OTES results.** OTES disk-integrated spectra require special calibration due to the FOV of the instrument not being fully filled. However, spatially resolved spectra (~80 m/spot) acquired during one of the Preliminary Survey equatorial passes on 13 December 2018 reveal a spectrum with low contrast (2%) and a spectral shape that is broadly consistent with carbonaceous chondrites in the CI/CM groups, which fall into petrologic types 1, 1/2, and 2, indicating aqueous alteration. A single spectral feature at 440 cm⁻¹ (~22.7 µm) is particularly consistent with a volumetrically dominant phyllosilicate component in carbonaceous chondrites [7]. The OTES spectra do not show evidence of abundant pyroxene or olivine, but features at 555 and 346 cm⁻¹ are attributable to magnetite. This detection may support the proposed detection of a feature tentatively attributed to magnetite at ~0.55 µm in one of the darkest regions of the asteroid [6]. Derivation of modal mineralogy and the refinement of the degree of alteration. A relatively broad silicate stretching band(s) as compared to whole-rock spectra, combined with a lack of strong transparency features at >1110 cm⁻¹ (<9 µm), is potentially consistent with a mixture of relatively fine (<125 µm) and coarse (>125 µm) particles, including cobbles and rocks. There is no discernible variation in the OTES spectra at these spatial scales.

**Summary and Ongoing Analysis:** Spectroscopic results from visible through thermal infrared wavelengths are highly complementary and reveal that the surface of Bennu not only exhibits evidence of hydrated silicates, but appears to be dominated volumetrically by such minerals and is consistent with a composition similar to aqueously altered CI and CM carbonaceous chondrites. The spectral datasets are consistent with a range of particle sizes that do not vary spatially at scales down to 80 m. Analysis of Bennu’s surface geological characteristics indicates that it is a rubble pile that has experienced recent dynamical processes [8]. Redistribution of material [e.g., 9] may help explain the apparent spatial uniformity of the spectral/compositional signatures at the scales observed thus far, even as smaller-scale variability in albedo and geologic features are observed [6]. Key questions that will be addressed with these future observations include the heterogeneity of surface compositions at higher spatial scales and the degree of aqueous alteration experienced by Bennu’s parent body based on details of mineral distribution, abundance, and composition (e.g., Mg/Fe proportions in phyllosilicates and abundance of magnetite).

**Acknowledgements:** This material is based upon work supported by NASA under Contract NN-M10AA11C issued through the New Frontiers Program.