EVIDENCE OF ORGANICS AND CARBONATES ON (101955) BENNU. H. H. Kaplan[1], A. A. Simon[2], J. P. Emery[3], H. Campins[4], S. A. Sandford[5], D. C. Reuter[2], V. E. Hamilton[1], E. A. Cloutis[6] , S. Fornasier[7], M. A. Barucci[7], B. E. Clark[8], D. P. Glavin[2], J. P. Dworkin[2], and D. S. Lauretta[9]. [1]Southwest Research Institute, Boulder, CO (Kaplan@boulder.swri.edu), [2]Goddard Space Flight Center, Greenbelt, MD, [3]Northern Arizona University, Flagstaff, AZ, [4]University of Central Florida, Orlando, FL, [5]NASA Ames Research Center, Moffett Field, CA, [6]University of Winnipeg, Winnipeg, MB, Canada, [7]LESIA, Observatoire de Paris, Paris, France, [8]Ithaca College, Ithaca, NY, [9]University of Arizona, Tucson, AZ.

Introduction: We report the discovery of widespread carbon-bearing compounds on (101955) Bennu identified by the Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) Visible and InfraRed Spectrometer (OVIRS) [1, 2]. OVIRS spectra display a complex group of absorption features near 3.4 µm that we attribute to carbonates, organics, and mixtures of the two phases. These absorption features are present in spectra of the primary and back-up sample sites, as well as most of the surface of Bennu, suggesting that the OSIRIS-REx mission will return a sample of primitive carbonaceous regolith, which is one of the primary mission goals [3]. Organic compounds returned from Bennu will advance our understanding of the carbonaceous matter that may have been delivered to the early Earth as a source of prebiotic material required for the emergence of life [4].

Observations: The OVIRS instrument collected global spectral data from 25 April through 6 June 2019 at multiple local solar times (LST) with a spatial resolution of ~20 m/footprint. Additional, higher-resolution data were collected from 5 October through 27 October 2019 at ~4x9 m/footprint. A more complete description of these observations is found in [5].

Each OVIRS spectrum was radiometrically calibrated and radiance data were resampled to a common wavelength axis [6]. We subtract a single temperature/emissivity thermal tail from the radiance by fitting a graybody curve to the data. We divide the radiance spectra by range adjusted solar flux to get I/F or reflectance spectra. We used a boxcar function over 12 channels to detect and remove noise spikes at this step and remove the continuum between 3.1 and 3.6 µm to isolate the absorption features of interest.

We detect spectral features that are consistent with aliphatic organic matter (i.e., -CH_2 and -CH_3 bonds) with absorptions near ~3.38 µm, 3.42 µm, and 3.50 µm and a characteristic "triplet" shape. Elsewhere, we find carbonate spectral features (i.e., due to CO_3^{2-} bonds) with absorptions at ~3.31 – 3.35 µm and 3.45 – 3.5 µm. Complex spectral features due to a mixture of both organics and carbonates are evident in most OVIRS spots.

Spatial Distribution: We find evidence of this 3.4 µm feature across Bennu's surface with an average band depth at 3.4 µm of ~2%, though some spots have up to ~9% bands. Band area and shape are highly variable, and the widespread presence of mixed organic and carbonate features implies heterogeneity below the spatial scale of OVIRS observations. A similar 3.4 µm band shape is seen in repeated observations of the same area at different LST and viewing conditions [1], indicating that this variation is due to composition rather than instrument conditions.

We find band shape varies considerably from one OVIRS spot to the next, and we are able to find band shapes similar to other asteroidal organic/carbonate detections [e.g., 7,8,9] at different places on the surface of Bennu [1].

Spectral Interpretation: We compared the Bennu spectra with laboratory spectra of carbonaceous (C) chondrite spectra, as well as laboratory spectra of pure organic materials and carbonate minerals [2]. Where the organics dominate on Bennu, band depths and spectral shapes are similar to those in the C chondrites and specifically the CM and CI groups, which typically have not undergone significant thermal alteration [10]. Although the infrared is sensitive to aliphatic organics, it is possible that aromatic, amorphous, or graphitized carbon materials can be present without evidence in the 3.4 µm region [10]. A recent study proposes that the bluing in the UV observed on Bennu could be a result of one of these forms of carbon being present on the surface in abundances greater than those found in the C chondrites [11].

Carbonates on Bennu range from Ca-rich ($CaCO_3$: calcite) to Mg-rich ($CaMg(CO_3)_2$: dolomite and $MgCO_3$: magnesite), and the majority of carbonate features can be modeled with varying proportions of calcite and dolomite. These carbonates are also the most common in carbonaceous chondrites, typically at relatively low (<0.5 wt.%) abundances compared to bulk carbon abundances (~1.5 – 4 wt.%) in CM and CI chondrites that is mostly attributed to organic matter [12]. Carbonate cation composition changes (Ca -> Mg) with progressive aqueous alteration and carbonate abundance increases relative to organics as a result of fluid oxidation [12,13].

Although organic spectral features are common in the C chondrites at 3.4 µm, it is rare to see carbonate spectral features. There are no known examples of carbonate and organic spectral mixtures at 3.4 µm in the C chondrites. The lack of carbonate features in C chondrite spectra could be the result of: 1) a low abundance of carbonate that is below detection limits for infrared reflectance measurements, 2) a lesser abundance of carbonate than organics, leading the organic signature to dominate, or 3) a weaker absorption coefficient for carbonates than organics at 3.4 µm with a similar result. Thus, our observation of organics and carbonates on Bennu implies that there is either a greater abundance of carbonates on the asteroid's surface than in the C chondrites, a greater proportion of carbonates to organics, or OVIRS is more sensitive to carbonates than typical laboratory measurements of the meteorites.

We do not see any evidence for carbonates (or organics) in the thermal infrared with the OSIRIS-REx Thermal Emission Spectrometer (OTES), which places an upper limit on the abundance of carbonates possible on the surface.

Discussion: The heterogeneity of the carbonate/organic distribution on Bennu can be attributed to the mixture of material accreted during its time in the Main Belt and transit to a near-Earth orbit, or it may result from heterogeneity within the parent body. The presence of Mg-carbonates, potentially in greater abundance than in the C chondrite meteorites and/or in greater abundance than the organics, would indicate that aqueous alteration progressed beyond the alteration typical of the C chondrites, yet not so far as the extreme alteration scenario (and resulting carbonate abundances) observed on Ceres [8,13]. Therefore, it is possible that Bennu's composition is distinct from the C chondrite meteorites in our collection.

However, there is also no observed spatial correlation between the organic/carbonate features and other visible–near-infrared spectral features or thermal properties on Bennu. One possibility is that space weathering is primarily affecting the organic material and leading to removal of aliphatic organics in locations that have been exposed to the space weathering environment for enough time [14]. Recent detection of particle ejection events on Bennu [15] are one mechanism that could be exposing aliphatic-rich organic material on Bennu.

Conclusion: The detection of carbonaceous material with OVIRS is an exciting result from the OSIRIS-REx mission [1, 2]. We find a heterogeneous distribution of organics, carbonates, and mixtures of the two, which has not been seen on other asteroids, or in spectra of the C chondrite meteorites. Although the spectral dataset enriches our understanding of the composition of these materials, we will also be able to study them in much more detail with the analysis of the returned sample.

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