DETECTION OF PYROXENES ON BENNU WITH THE OSIRIS-REX VISIBLE AND INFRARED SPECTROMETER.
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Introduction: The OSIRIS-REx Visible and InfraRed Spectrometer (OVIRS) recently conducted a global mapping campaign revealing the spectral variation of asteroid (101955) Bennu's surface. During this campaign, OVIRS detected regions of the surface with spectral properties consistent with pyroxene minerals. These pyroxenes, initially identified with the OSIRIS-REx Camera Suite (OCAMS) MapCam instrument, are associated with Bennu's brightest rocks [1, 2]. We describe the search for pyroxene features in OVIRS spectra, their composition, and implications for the source material.

Methods: The OVIRS instrument measures visible – near-infrared wavelengths (0.4 – 4.3 microns) with ~20 m spatial resolution during global mapping. Although we see minor differences in spectral slopes and albedo [3], Bennu is mostly spectrally homogenous at the spatial scale of these observations [4].

We searched for a pyroxene signature in data acquired at two spacecraft stations: 10 am and 12:30 pm local solar time. These data were converted from calibrated radiance to I/F. We divided each I/F spectrum by a global average spectrum, an average of all spectra from the same station, to distinguish subtle variations and remove spectral artifacts. We searched these ratioed spectra both manually and using spectral indices and identified ~14 OVIRS footprints acquired during a single global survey with broad absorptions features at 1 and 2 microns that are consistent with the mineral pyroxene [e.g., 5].

We characterized the band centers and depths for each spectrum, and performed a Gaussian deconvolution to determine the composition of these pyroxenes. To find band centers, we removed the spectral continuum from the OVIRS data between 0.4 and 2.6 microns using a two-part linear continuum [e.g., 6]. We fit Gaussian curves at 1 and 2 microns to the continuum removed data and find the Gaussian center wavelength, which we use as the band center. Using a fit to the spectrum keeps noise spikes from influencing the derived position of the minimum.

Additionally, we deconvolved the pyroxene 1 and 2 micron bands into individual absorptions using the Modified Gaussian Model (MGM) [7], which enables identification of contributions from low calcium pyroxene (LCP) and high calcium pyroxene (HCP). We applied the MGM to OVIRS data from 0.4 to 2.6 microns and fit five or more Gaussians to the region. The MGM simultaneously fits the Gaussian curves and a continuum. We used the Gaussian amplitude value to estimate band strengths for the LCP and HCP components. We employed a Monte Carlo approach to ensure that the model converges and to estimate uncertainties on each parameter in the model. We used the relative proportions of LCP and HCP to estimate the degree of melting experienced by the pyroxene parent body [8].

Context: There are five sites on Bennu with strong pyroxene detections in the OVIRS data, each associated with a bright boulder. The boulders are ~1.4 – 4.3 m in size, representing 1% or less of the OVIRS footprint. As a result, the pyroxene signatures are weak, with band depths < 1% at 0.92 microns. We likely only see these pyroxenes in OVIRS because the material is bright compared to average Bennu and therefore contributes more strongly to the spectral signal.

OCAMS observations reveal that the pyroxene boulders correspond to the brightest areas on Bennu's surface and have a distinct color signature [1, 2]. These properties, along with geologic context, support an exogenous origin.

Spectral Features and Interpretation: We used band centers and the MGM to constrain pyroxene composition after initially comparing the spectra to pyroxene-rich meteorites. Pyroxenes can crystallize in different crystal systems (monoclinic – clinopyroxenes and orthorhombic – orthopyroxenes) and with variable cation composition, including variable amounts of calcium, all of which will influence the absorption features at 1 and 2 microns.

Band centers at 1 and 2 microns shift position with pyroxene composition and can be used to distinguish between orthopyroxene and clinopyroxene endmembers [e.g., 5, 9]. The pyroxenes on Bennu have band centers similar to laboratory orthopyroxenes, suggesting all boulders have similar compositions. Some ordinary chondrites (H and LL groups) and the Howardite-Eucrite-Diogenite (HED) meteorites can have band centers with similar positions [10].

The MGM is useful for further determining composition where pyroxene mixtures are present and has been used in a number of planetary applications [e.g., 8, 11, 12]. For the Bennu pyroxenes, a total of seven Gaussians are fit to the spectrum, with two of those Gaussians fit to LCP absorptions (~0.92 and 1.90 microns) and three fit to HCP absorptions (~1.00, 1.20, and 2.30 microns) [10]. We use the relative strength of the HCP and LCP bands to estimate HCP%, which is indicative of igneous differentiation [e.g., 8, 13, 14]. We find an HCP% that matches those of the eucrite meteorites, which indicates that the pyroxenes experienced partial melting to a degree similar to the eucrites on their parent body, Vesta [14].

We use this compositional information to narrow down the source of the pyroxenes. First, we confirm that the pyroxene compositions are not indicative of material indigenous to Bennu. In terms of band center and HCP%, the pyroxenes are most similar to the eucrites and would be consistent with material from the Vesta family.

Summary and Conclusions: We present the discovery and analysis of spectral signatures associated with exogenous material in the OVIRS visible – near-infrared spectra. These meter-scale bright boulders were first identified in the OCAMS albedo and color data. OVIRS spectra confirmed that these bright boulders are dominated by the mineral pyroxene, despite accounting for one percent or less of the field of view of the instrument. Analysis of the OVIRS pyroxene spectra suggests that these boulders are compositionally similar to the eucrites and may be fragments of Vesta on Bennu.

Given the size of the OVIRS footprint compared to the boulders on Bennu, it is possible that additional exogenous material is present [2] that is not discernable at the current OVIRS ~20 m spatial resolution. Upcoming reconnaissance of the candidate sample sites will provide an opportunity to search for spectral signals associated with pyroxenes and other exogenous materials that may not have been identified to date.

Acknowledgements: This material is based upon work supported by NASA under Contract NNM10AA11C issued through the New Frontiers Program. We are grateful to the entire OSIRIS-REx Team for making the encounter with Bennu possible. INAF participation was supported by Italian Space Agency grant agreement n. 2017-37-H.0.

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