The Mineralogy and Organic Composition of Bennu as Observed by VNIR and TIR Spectroscopy

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NASA's Origins, Spectral Interpretation, Resource Identification, and Security — Regolith Explorer (OSIRIS-REx) mission characterized the surface composition of the carbonaceous asteroid Bennu at visible to infrared wavelengths (~0.4 - 100 µm). Spectral features of hydrated minerals (phyllosilicates) are dominant at both visible to near infrared (VNIR) [1, 2] and thermal infrared (TIR) wavelengths [1], with ~90 vol.% of the silicates being comprised of phyllosilicates (≤~10 vol.% olivine plus pyroxene) [3]. Features of iron oxides are observed in both the VNIR (magnetite, goethite) [4] and the TIR (magnetite) [1]. In the 3.2-3.6 µm region, we observe spatially variable evidence for carbonate minerals (some associated with meter-long, cm-wide veins) and organic compounds comparable to insoluble organic material (IOM), with classification results showing little or no evidence of any correlation between these features and surface morphology or spectral slope/band depth [5-9]. A half-dozen isolated, meter-sized boulders exhibit pyroxene signatures consistent with those in the howardite-eucrite-diogenite (HED) meteorites from (4) Vesta [10]. There is evidence for non-uniform deposits of dust (~5-10 µm thick) superposed on a largely boulder-dominated surface [3]. The majority of VNIR features show only small band depth variations across the surface [4] and the TIR features appear to vary dominantly with particle size [3]. Nanophase magnetite produced by space weathering may account for Bennu's visible blue slope [12]. Two populations of rocks are observed in visible imaging, distinguished by albedo and surface texture [11], but spectral data analyzed to date have not shown any evidence of these two populations having different compositions.

The observed mineralogy of Bennu has been identified as being most consistent with a highly aqueously altered, CI- or CM-like, carbonaceous chondrite (CC) composition. In addition, we have recently recognized that GRO 95577 (CR1) also exhibits NIR and TIR spectra that are compatible with the observed spectroscopy and inferred mineralogy of Bennu (Figures 1 and 2). (We note that none of the NIR analogues shown here are good matches to Bennu at visible wavelengths, where the best fit is to a sample of Ivuna (CI) heated to 700°C [14]; however, the effects of space weathering on Bennu are not represented by the analogue spectra.) Isolated boulders containing pyroxene are interpreted as exogenic, basaltic material from Vesta, the preserved evidence of inter-asteroid mixing that occurred after the conclusion of planetesimal formation [10]. The manifestation of carbonate veins at scales much larger than has been observed in CC meteorites suggests that Bennu's parent body experienced fluid flow and hydrothermal deposition on kilometer scales for thousands to millions of years [6]. In October 2020, OSIRIS-REx collected a sample of the surface of Bennu for return to Earth in September 2023. We predict that the returned sample will contain the minerals and compounds described here (phyllosilicates, iron oxides, carbonates, and organics), representing a significant degree of alteration. In addition, minerals that are difficult to detect with remote sensing data, such as sulfides, also may be present, as well as exogenous materials.

References

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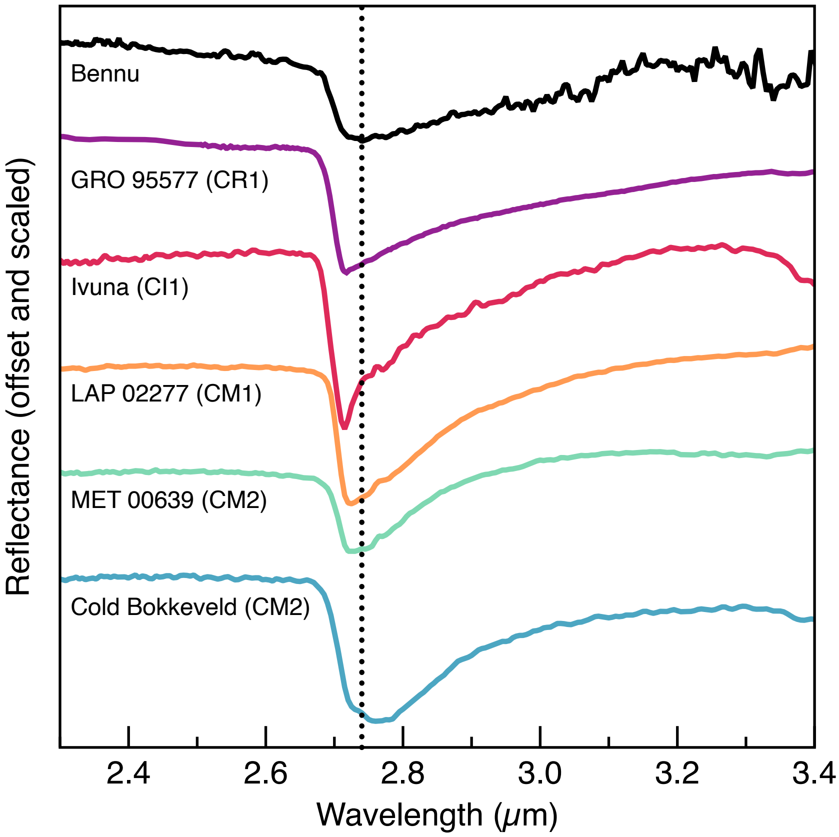

Figure 1. OVIRS spectrum of Bennu [1] in the "3-μm region" as compared to spectra of CC meteorites from [13] and a RELAB spectrum of GRO 95577.

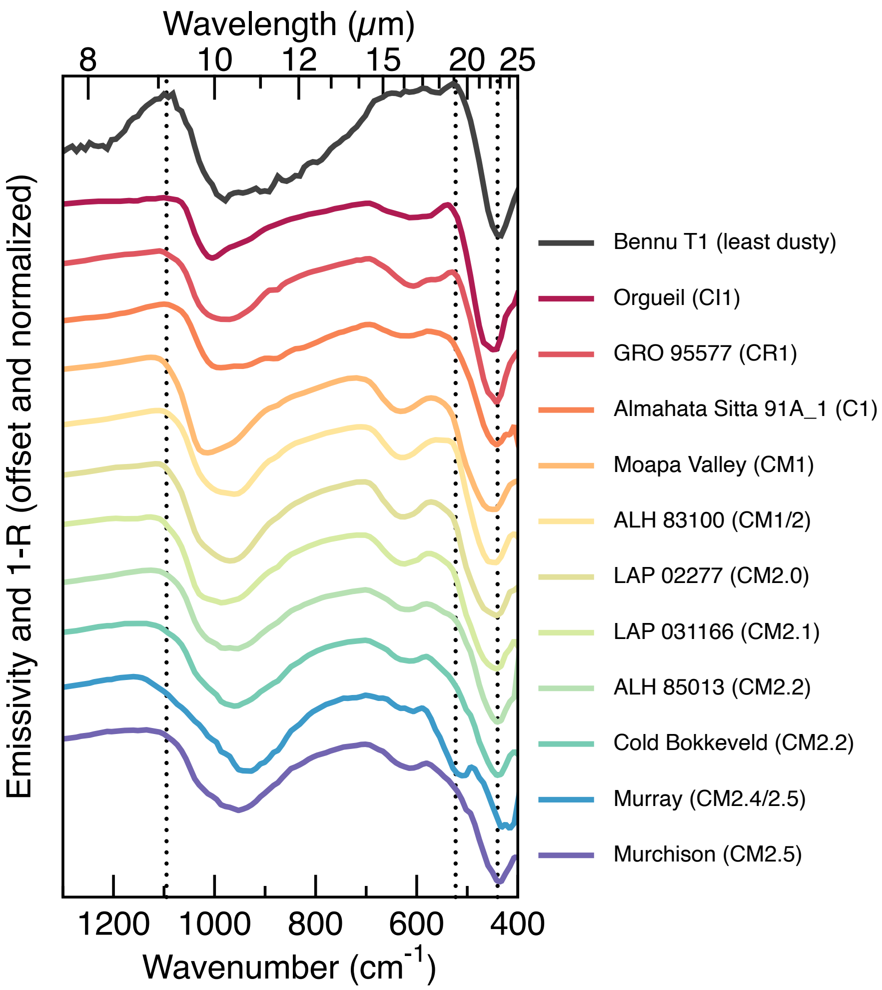

Figure 2. OTES spectrum of Bennu [3] as compared to CC analogues. The Christiansen feature (~1090 cm^{-1}, ~9.2 μm) is not particularly diagnostic. However, the peak at 528 cm^{-1} (18.9 μm) is a diagnostic feature in the Bennu spectrum, and it weakens and shifts with increasing abundances of anhydrous silicates (e.g., pyroxene and olivine). As the abundance of anhydrous silicates increases, the Si-O bending mode (the minimum at ~440 cm^{-1} or 22.7 μm) broadens and features of pyroxene and olivine become apparent (e.g., Cold Bokkeveld, Murray, Murchison).