TYPE 1 CR CHONDRITES AS CANDIDATE MINERALOGICAL ANALOGUES FOR (101955) BENNU. V. E. Hamilton[1], H. C. Connolly, Jr.[2], C. A.Goodrich[3], N. M. Abreu[4], H. H. Kaplan[5], A. A. Simon[5], [1]Southwest Research Institute, Boulder, CO (hamilton@boulder.swri.edu); [2]Rowan Univ, Glassboro, NJ; [3]Lunar and Planetary Institute, Houston, TX; [4]Langley Research Center, Hampton, VA; [5]Goddard Space Flight Center, Greenbelt, MD.

Introduction and Background: We describe spectral evidence suggesting that Grosvenor Mountains (GRO) 95577 (CR1), is a potential analogue for asteroid (101955) Bennu's bulk surface composition.

Visible to near infrared (VNIR) and thermal infrared (TIR) spectra collected of Bennu by NASA's Origins, Spectral Interpretation, Resource Identification, Security–Regolith Explorer (OSIRIS–REx) spacecraft have revealed spectral features attributable to hydrated phyllosilicates, oxides, carbonates, and organics [1-5]. The carbonaceous chondrites (CCs) identified as the best analogues to date have been ungrouped C, CI, and CM meteorites having petrologic types 1, 1/2, and 2. The best CM analogues have Rubin [6] petrologic types ≤2.4 as no features of olivine or pyroxene have been observed aside from pyroxene-bearing exogenous boulders [7].

To date, CR chondrites have not been considered as analogues for the bulk composition of Bennu, primarily because the vast majority are petrologic type 2 and contain ~20-55 vol% olivine plus pyroxene [8], which is inconsistent with OSIRIS–REx remote sensing observations. GRO 95577 is the only meteorite classified as a CR1 (Miller Range (MIL) 090292 was initially classified as a CR1 but it is now classified as a C1 and its spectrum differs from that of GRO 95577). Its mineralogy is given by [8] (to the nearest 1 vol%) as: 67% phyllosilicate, 9% sulfide, 7% magnetite, 6% calcite, 5% olivine, 3% oxide/rust, and 2% pyroxene. This mineralogy is broadly consistent with OSIRIS–REx observations, which is why we consider it here.

During the OSIRIS–REx Touch-and-Go (TAG) sampling event, the optical surfaces of several OSIRIS-REx instruments became lightly contaminated by mobilized particles [9]. Due to the orientation of the instrument's optical surfaces, data from the OSIRIS–REx Visible and InfraRed Spectrometer (OVIRS) did not exhibit any notable contamination post-TAG and the global average spectrum previously reported [1] is unchanged. Material was observed to be present on the OSIRIS-REx Thermal Emission Spectrometer (OTES) primary mirror ("mirror dust", although the particle size is unknown), and is analogous to a surface emissivity spectrum [9]. This spectrum revealed an Mg-OH feature centered near 605 cm^{-1} that was not previously detected, but is consistent with the presence of Mg-phyllosilicates [10]. The OTES mirror dust spectrum also offers what may be a better representation of the true shape of the silicate stretching absorption (~1100-700 cm^{-1}) because it does not exhibit any volume scattering features [9].

Observations: Figure 1 shows the global average VNIR Bennu spectrum as compared to a post-TAG spectrum of Hokioi crater [9] and GRO 95577 [11]. The position and shape of the hydration feature in GRO 95577 is a good match to that of Bennu's and indicative of a strongly aqueously altered CC composition [e.g., 12]. The 0.4-2.5 µm slope of Bennu globally is distinctly bluer than that of GRO 95577, but the spectrum from the disturbed sample site is flatter than the global average.

Figure 2 shows the average T1 Bennu surface [1] and mirror dust [9] spectra measured by OTES as compared to GRO 95577 [13]. The spectrum of GRO

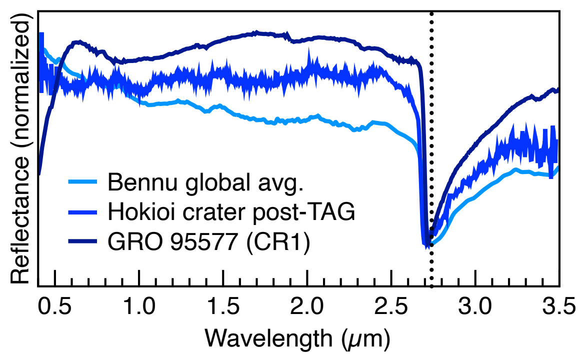

Fig. 1. Average OVIRS spectrum of Bennu, post-TAG sample site spectrum, and GRO 95577 (CR1).

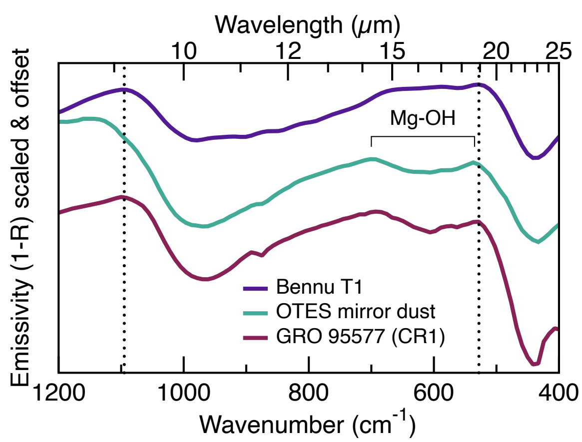

Fig. 2. Average OTES T1 (least dusty) spectrum of Bennu, spectrum of material on the OTES optics post-TAG, and GRO 95577.

95577 exhibits strong similarities with both Bennu spectra. The shape of the silicate stretching absorption (~1100-700 cm^{-1}), the Mg-OH feature (~700 - 530 cm^{-1}), and the peak at ~528 cm^{-1} in GRO 95577 are most similar to features of the mirror dust, whereas the position of the Christiansen feature is similar to that of the T1 spectrum.

Discussion: The lack of similarity between GRO 95577 and Bennu in the VNIR could be attributable to both space and terrestrial weathering. The TIR spectral similarity between Bennu and GRO 95577 offers the clearest evidence that Bennu may be CR1-like.

VNIR data. The majority of the surface of Bennu is space weathered with the least weathered surfaces being redder, darker, and having decreased spectral slopes owing to the presence of organics [e.g., 9, 14]. The degree to which "less" space weathered surfaces are representative of the *un*weathered spectrum of Bennu is unknown. Further complicating comparisons is that VNIR spectra of CR meteorites typically exhibit features of terrestrial weathering, e.g., oxyhydroxides that obscure features <1.0 µm [15, 16].

Because the global VNIR spectrum of Bennu is now known to be space weathered, we revisited the identification of Ivuna (CI) heated to 700° C as the best analogue to the 0.4 - 2.4 µm telescopic spectrum of Bennu [17]. This sample should have experienced dehydration of phyllosilicate and formation of secondary olivine and pyroxene [18 and refs. therein]. Using the full (0.3 - 25 µm) RELAB spectrum [11] of this sample (not shown), we found that the 3-µm hydration band in heated Ivuna is weaker than that exhibited by Bennu but there are no obvious silicate features; the TIR wavelengths, however, are consistent with a largely anhydrous mineralogy, being dominated by features of olivine. The TIR spectral shape suggests that olivine is in the form of small crystallites, which is consistent with the early stages of olivine formation in thermally metamorphosed CCs [19]. We conclude that Ivuna heated to 700° C is not a good *mineralogical* analogue for Bennu even if it is a good spectral analogue from 0.4 - 2.4 µm.

In summary, considering space and terrestrial weathering, it is premature to infer that unweathered Bennu materials do not match GRO 95577 (or any other hydrated analogue meteorite [1]) in the VNIR.

TIR data. The similarity between the OTES spectra and GRO 95577 suggests that this meteorite is as good a (or better) candidate analogue for Bennu's bulk mineralogy compared to previously identified compositions. In particular, the presence of a clear peak at ~528 cm^{-1}, along with a wider Mg-OH feature as compared to CM spectra makes GRO 95577 a better spectral analogue than most CMs.

Implications: Isotopic, elemental, and petrologic analysis of the returned sample will be needed to determine with certainty to which meteorite group, if any, Bennu belongs. Until that time, we consider here the implications of Bennu as a candidate CR asteroid.

[15] summarizes CR characteristics and how their matrices respond to aqueous alteration. Unlike CMs, a major phase in most CRs is amorphous Mg-Fe silicate, which can be hydrated. In the most altered CRs, GRO 95577 (CR1) and Al Rais (CR2-an), this amorphous material has largely been converted to phyllosilicate at sub-micron scales. Among the CR meteorites analyzed by [8], carbonate, which is present on Bennu, occurs at detectable levels only in GRO 95577. Unfortunately, the large gap in aqueous alteration between the type 2 CRs and GRO 95577 makes it impossible observe the mineralogical and spectral evolution with increasing aqueous alteration.

CR-like parent bodies are targets of interest because they contain some of the most pristine materials from the solar nebula and can contain substantial amounts of H_2O and OH^- even in samples without abundant phyllosilicates, which makes them a potential in situ resource. There may be more than one CR parent asteroid, and these may have experienced different thermal histories. Because there is only one CR1, such materials must either be rare in the asteroid population or are preferentially destroyed during impact with Earth. If Bennu is comprised of CR material, in whole or in part, the OSIRIS–REx returned sample represents a tremendous opportunity to explore what currently is a unique material among CC meteorites.

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