THE MINERALOGY OF RECENTLY FALLEN CARBONACEOUS METEORITES, MUKUNDPURA AND SUTTER'S MILL, IN THE CONTEXT OF ASTEROID (101955) BENNU. C.W. Haberle[1], P.R. Christensen[1], L.A.J. Garvie[2], V.E. Hamilton[3], R.D. Hanna[4], H.C. Connolly Jr. [5], D.S. Lauretta[6], and the OSIRIS-REx Team. [1]Arizona State University, School of Earth and Space Exploration – Mars Space Flight Facility (chaberle@asu.edu), [2]Arizona State University, School of Earth and Space Exploration – Center for Meteorite Studies, [3]Southwest Research Institute, [4]University of Texas at Austin, Jackson School of Geosciences, [6]Rowan University, School of Earth and Environment, [6]University of Arizona, Lunar and Planetary Laboratory.

Introduction: The CM and CI carbonaceous chondritic meteorites were predicted to be the best analogs for asteroid (101955) Bennu based on telescopic observations [1]. Data acquired by the OSIRIS-REx spacecraft, during its Approach phase, has confirmed this prediction through the identification of hydrated silicates [2]. For comparison, we present new observations of recently fallen carbonaceous chondrites, Mukundpura (CM2; June 6, 2017) and Sutter's Mill (C; April 22, 2012). These meteorites were collected rapidly after an observed fall, minimizing their exposure to the terrestrial atmosphere. Chemically, both Mukundpura and Sutter's Mill exhibit a bulk geochemical and isotopic affinity to the CM group [3,4]. Sutter's Mill is a regolith breccia composed of surface materials from a carbonaceous asteroid [4]. These characteristics make these meteorites timely analogs to C-complex asteroid regolith.

Mineralogy: Mineralogy was determined through X-ray diffraction (XRD) analysis of powdered samples deposited on a low-background, single-crystal quartz plate using a Rigaku MiniFlex 600 diffractometer with a post-diffraction monochromator. Infrared spectra were collected using a Thermo-Scientific iN10 FTIR microscope following the methods of [5].

Mukundpura. The XRD profile of Mukundpura is dominated by crystalline phyllosilicate with a *001* basal reflection consistent with serpentine (**figure 1a**). The *hk0* reflections are broad and diffuse indicating the serpentine is fine-grained or disordered. Minor calcite, tochilinite, olivine, and pyrrhotite are also apparent in the profile. The infrared spectrum from 1400-400 cm^{-1} shows a broad absorption centered near 950 cm^{-1} and a sharp absorption near 450 cm^{-1} corresponding to the stretching and bending modes of Si-O, respectively. The lack of fine structure in the Si-O stretching and bending regions, as compared to the serpentine standard shown in **figure 1b**, is further evidence for the presence of poorly crystalline/disordered silicate material. The distinct absorption near 650 cm^{-1} is attributable to librations of the inner and surface OH^{-1} molecules within the octahedral sheet of 1:1 phyllosilicates [6]. The position of this absorption is consistent with Mg^{2+} as the octahedrally coordinated cation indicating the presence of abundant Mg-serpentine within Mukundpura.

Sutter's Mill 41. The XRD profile of SM41 shows a weak serpentine *001* basal reflection, broad *hk0* bands, and an amorphous scattering background. Collectively, this indicates the presence of disordered phyllosilicate and amorphous material. Minor calcite, pentlandite, pyrrhotite, and troilite are evident in the pattern. The infrared spectrum of SM41 exhibits broad Si-O bending and stretching absorptions with a less distinct stretching region than Mukundpura, consistent with poorly ordered silicates. The absence of a distinct Mg-OH libration absorption further indicates that serpentine has been structurally altered, likely through increased stacking disorder during mild heating. An absence of tochilinite and presence of calcite constrains the degree of thermal metamorphism based upon decomposition temperatures of 245° and 600° C, respectively [7]. However, it is not apparent that tochilinite was initially present in SM41.

Sutter's Mill 8. The XRD pattern of SM8 hosts reflections consistent with abundant olivine superposed on a less intense amorphous scattering background. Absent are distinct reflections for calcite and phyllosilicate. The apparent loss of calcite and phyllosilicate along with abundant olivine suggests SM8 had experienced heating >600° C and pre-existing serpentine was transformed to olivine [8]. The infrared spectrum of SM8 shows broad Si-O stretching and bending absorptions with features similar to but distinct from that of well crystalline olivine. These weaker and less defined absorptions may indicate that olivine is poorly ordered.

Sutter's Mill 3. The XRD profile of SM3 is dominated by reflections for olivine of intermediate composition (~fo 60-70). The infrared spectrum of SM3 is more similar to well-crystalline olivine than that of SM8, though distinct differences remain. Features in SM3 are more defined than SM8 but still lack the fine structure and depth of well-crystalline igneous olivine. SM3 likely experienced a higher degree of thermal metamorphism [9], though the heating was not sufficient to produce well-ordered crystals like those of the standard spectrum shown in **figure 1b**.

Implications: The infrared spectrum of asteroid (101955) Bennu exhibits diffuse Si-O stretching and bending absorptions consistent with disordered phyllosilicates and CM and CI meteorites [2]. Within this meteoritic sample set, Bennu is most similar to the spectrum of SM41. Both lack a defined Mg-OH libration absorption at 650 cm^{-1}. This absence may indicate that 1)

the materials exposed on Bennu's surface have experienced mild heating, similar to SM41 or 2) the phyllosilicates on Bennu's surface are not dominated by the Mg-serpentine common within CM chondrites. However, the SNR of the OTES data may not yet be great enough to resolve this band on the surface of Bennu. Future full field, spatially-resolved observations may reveal this band and its potential variability across the surface.

References: [1] Clark B. E. et al., (2011) *Icarus, 216,* 462-475. [2] Hamilton V. E. et al. (2019) *LPSC 50, Abstract 1956* [3] Ray and Shukla (2018) *PSS, 151* 149-154. [4] Jenniskens P., (2012) *Science, 338* [5] Hamilton, V.E. (2018) *LPSC 49, Abstract #1759* [6] Farmer, V. C. (1974) *Min. Soc. Great Britain and Ireland* Monograph vol. 4 [7] Tonui, E. et al., (2014) *Geochm Cos Acta., 126,* 284-306. [8] Brindley, G. W. and Zussman, J. (1957) *Am. Min., 42*, 461-472. [9] Haberle C. W. and Garvie, L. A. J. (2017) *Am. Min., 102*, 2415-2421.

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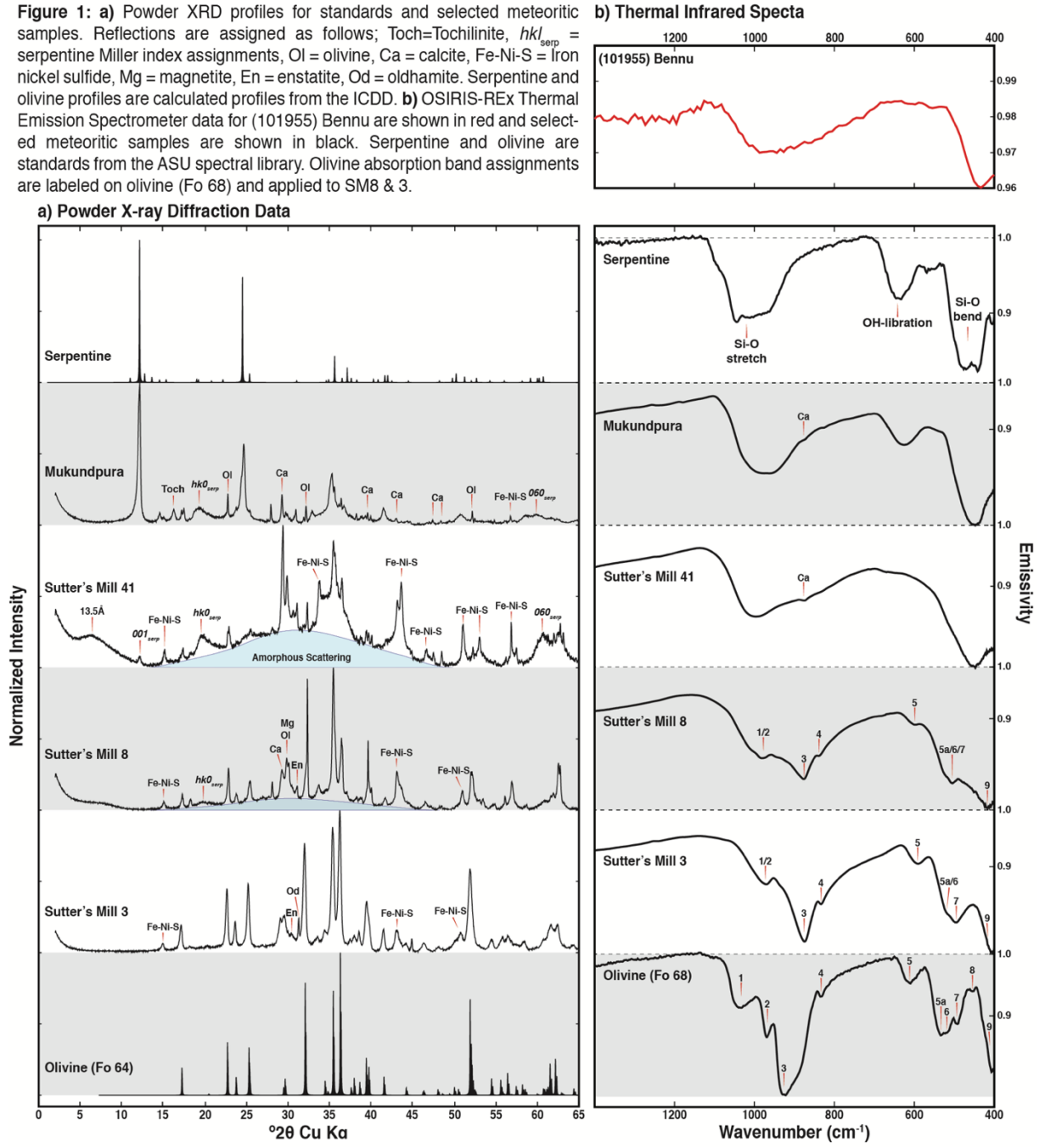

Figure 1: a) Powder XRD profiles for standards and selected meteoritic samples. Reflections are assigned as follows; Toch=Tochilinite, hkl_{serp} = serpentine Miller index assignments, Ol = olivine, Ca = calcite, Fe-Ni-S = Iron nickel sulfide, Mg = magnetite, En = enstatite, Od = oldhamite. Serpentine and olivine profiles are calculated profiles from the ICDD. **b)** OSIRIS-REx Thermal Emission Spectrometer data for (101955) Bennu are shown in red and selected meteoritic samples are shown in black. Serpentine and olivine are standards from the ASU spectral library. Olivine absorption band assignments are labeled on olivine (Fo 68) and applied to SM8 & 3.