ASSESSING EFFECTS OF PARTICLE SIZE ON WATER CONTENT ESTIMATES OF CARBONACEOUS CHONDRITES AND THEIR PARENT BODIES. B. A. Anzures[1], C. D. Schultz, R. E. Milliken, and T. Hiroi[1]. [1]Department of Earth, Environmental, and Planetary Sciences, Brown University, Providence, RI, 02906. Email: brendan_anzures@brown.edu

Introduction: The Hayabusa2 and OSIRIS-REx asteroid sample-return missions have recently encountered hydrous C-group asteroids 162173 Ryugu and 101955 Bennu, respectively. Mission data reveal that these objects are rubble pile asteroids with surfaces that are dominated by boulders [1,2], in contrast with previous laboratory studies that assumed asteroid regolith may be similar in size to lunar regolith [3]. As such, additional studies are warranted to understand how to convert OH/H_2O absorptions seen in spectral reflectance data to quantitative estimates of water content for objects that lack fine-grained regolith.

This study compares the strength of OH/H_2O absorption features observed for several intact carbonaceous chondrite (CM2) chips with the same spectral features as observed in several different particle sizes of their corresponding powders; spectral absorption strengths are then compared with independent estimates of sample bulk water content. The utility of the 0.7 µm Fe absorption, which is attributed to phyllosilicates and thus a potential proxy for hydration [4-6], is also evaluated, as is the position of the 12 µm phyllosilicate/olivine mid-IR peak as a purported proxy for degree of aqueous alteration [7].

This contribution addresses questions related to the 1) detection limits of OH and H_2O for the surfaces of C chondrite parent bodies, 2) physical, chemical, and mineralogical origins for variation in the 3 µm band shape, and 3) potential for different 3 µm band shapes to exist in reflectance spectra of a single meteorite parent body.

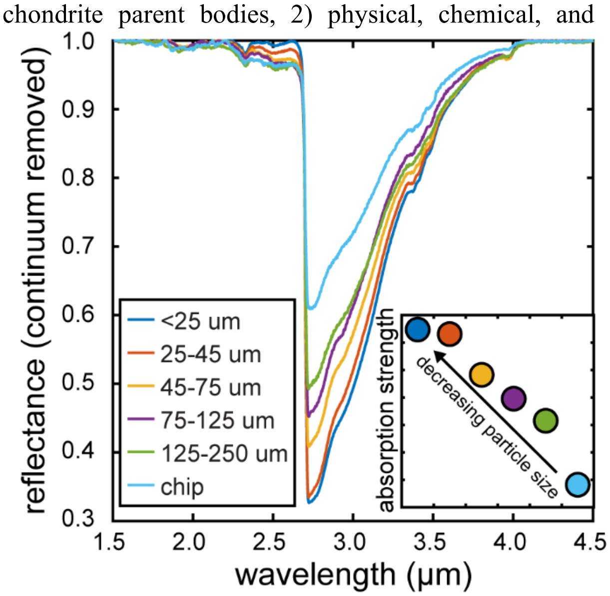

Figure 1. *Continuum removed reflectance spectra of ALH 84048 for various grain sizes that should all have the same bulk water content. The 3 µm water absorption deepens and narrows with decreasing particle size especially comparing chip to powder; the inset quantifies the increase in absorption strength as measured by band depth (y-axis scale: 0.35-0.70).*

Samples: We studied nine carbonaceous chondrites including seven CM2's (Allan Hills (ALH) 84048 and paired ALH 84040, ALH 84031, Elephant Moraine (EET) 83389, Queen Alexandra Range (QUE) 97077, Meteorite Hills (MET) 00639 and paired MET 00630), one ungrouped C2 (EET 83226), and one anomalous CM (Grosvenor Mountains (GRO) 95566). Samples were chosen to span a range in 3 µm band strength and shape based on 'bulk' chip reflectance spectra [8]. Grain size separates for up to six different grain sizes (<25 µm, 25-45 µm, 45-75 µm, 75-125 µm, 125-250 µm, and 250-500 µm) were prepared using a mortar and pestle.

Methods: Reflectance spectra from 0.8 to 25 µm were collected using the bidirectional reflectance (BDR) spectrometer and a Nicolet NEXUS 870 FT-IR spectrometer in the Reflectance Experiment LABoratory (RELAB) at Brown University. Bulk chip and powder spectra were acquried under ambient and dry air (RH<1%) conditions. Reflectance spectra were converted to single scattering albedo to minimize effects of multiple scattering. Band centers, band depths (BD), integrated band depth (IBD), band depth sum (for 2.7 + 2.8 µm and 2.75 + 2.8 µm), band ratios (for 2.9/2.53 and 3.2/2.53), full width half max (FWHM), degree of absorption asymmetry, aspect ratio, and effective single-particle absorption-thickness (ESPAT) were calculated for the complex 3 µm water absorptions using both reflectance spectra and single scattering albedo spectra.

Thermogravimetric analysis (TGA) was used to quantify volatile loss up to 750 °C using a TGA/DSC 1 Mettler-Toledo instrument at Brown University. Approximately 10 mg of meteorite chip and powder were heated from 25-125 °C and from 125-750 °C at 5 °C/minute, with holds at 125 °C for 15 minutes to ensure removal of adsorbed water and at 750 °C to stabilize high temperature volatile loss. Nitrogen gas at 80 ml/minute flowed through the instrument to prevent oxidation of the sample that could result in anomalous mass gain.

Results: The reflectance spectra of CM chondrites are characterized by low overall albedo and several phyllosilicate absorptions indicative of OH/H_2O and phyllosilicate iron abundance. Peak reflectance values in the visible-near-infared (VIS-NIR) region range from 0.04 (MET 00630 and MET 00639) to 0.22 (EET 83389). Many CM chondrites contain organics (up to 4 wt.% C), but the meteorites chosen for this study have absent or weak C-H organic absorptions at 3.4 µm.

Assuming all differences observed in the spectra are caused by differences in particle size, spectra in **Figure 1** show a systematic deepening and broadening of the 3 µm water absorption with decreasing particle size.

Thermogravimetric analysis confirmed similar bulk water contents of meteorite chip and <25 µm powder (within 1 wt.% for volatile loss up to 750 °C) as shown in **Figure 2**. Little varability was observed in replicate measurements for EET 83389 in both chip (21.14-22.77 wt.%) and powder (19.03-19.51 wt.%). Importantly, even though there is ~1 wt.% difference in intrinsic volatile loss in a given meteorite, lower water content is observed in the powder, which is opposite the trend expected for increased surface adsorbed water for fine particulates.

Implications: The many changes observed in CM2 reflectance spectra due to particle size highlight the need for improved methods to extract quantitative information from remote sensing of regolith-poor (rubble pile) asteroids as summarized below.

Remotely quantifying hydration with 3-µm absorption: We find that as particle size decreases, a variety of band parameter values related to OH/H_2O absorptions increase in value. Previous studies of C chondrite powders showed that certain spectral parameters (e.g., sum of 2.7 and 2.8 µm band depth) are highly correlated with bulk water content [9,10]. The data for our nine C chondrite samples indicate that particle size effects (chip versus various powders) can produce similar correlations even when the bulk water content is largely unchanged. If particle size is not properly accounted for in the interpretation of asteroid spectra, then this may lead to absolute water content estimates that differ by as much as 6 wt.% as seen in **Figure 3**.

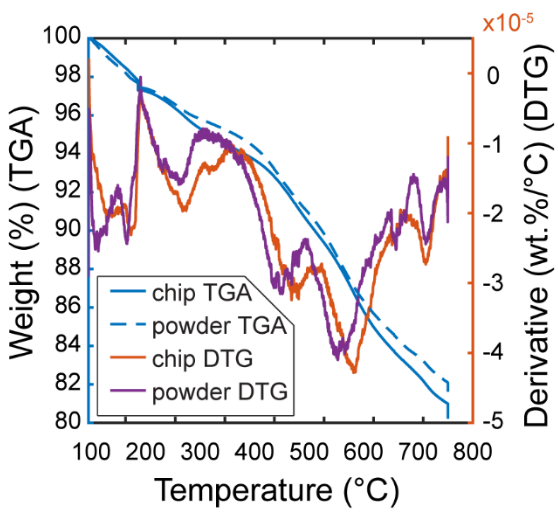

Figure 2. *TGA and DTG curves for ALH 84048 showing total volatile loss up to 750°C. Overall, <25 µm powder has ~1 wt.% less volatiles than the chip. Importantly, this decrease is opposite the trend expected from reflectance spectra that shows an increase in water absorption strength.*

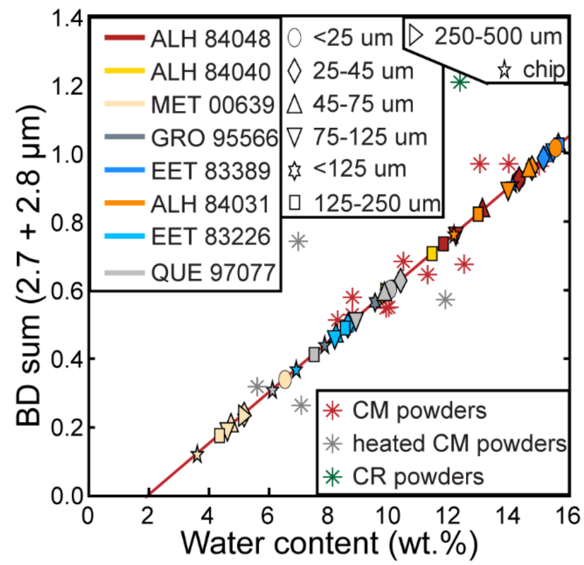

Figure 3. *Band depth sum (2.7 + 2.8 µm) plotted against water content for C chondrites. If particle size is not properly accounted for, water content estimates may differ by as much as 6 wt.%, highlighting the need for improved methods to extract quantitative information from reflectance spectra of regolith-poor (rubble-pile) asteroids. The red line is a linear regression of the CM powder data along which band depth sum values for this study are plotted and for which water content is estimated based on those sums. CM powder, heated CM powder, and CR powder water contents determined by TGA* [11] *with spectral data from a previous study with grain sizes between 50 and 100 µm* [10].

Conclusions and Future Work: Incorrect assumptions of a regolith dominated surface on asteroids may result in a significant underestimate of water content (up to 6 wt.%) through interpretations of VIS-NIR reflectance data. Band parameter – water content relationships that have been validated and calibrated for different particle sizes are crucial tools to properly quantify absolute water content of planetary surfaces with different grain size distributions. These will aid not only in improving our understanding of detection limits of water on hydrous asteroids like Ryugu and Bennu, but also other airless rocky bodies throughout the solar system.

References: [1] Michikami T. et al. (2019) *Icarus, 331*, 179-191. [2] Walsh K. et al. (2019) *Nature Geoscience, 12*, 242-246. [3] Gundlach B. & Blum J. (2013) *Icarus, 223*, 479-492. [4] Rivken A. S. et al. (2015) *Asteroids IV*. [5] Hiroi T. et al. (1996) *MaPS, 20*, 72-75. [6] Vilas F. & Gaffey M. J. (1989) *Science, 246*, 790-792. [7] McAdam M. M. et al. (2015) *Icarus, 245*, 320-332. [8] Schultz C. D. et al. (2020) *LPSC LI*, Abstr # 2303. [9] Garenne A. et al. (2016) *Icarus, 264*, 172-183. [10] Beck P. et al. (2018) *Icarus, 313*, 124-138. [11] Garenne A. et al. (2014) *GCA, 137*, 93-112.