SPECTRAL CLASSIFICATION OF UNGROUPED CARBONACEOUS CHONDRITES II: PARAMETERS AND COMPARISON TO INDEPENDENT MEASURES. V. E. Hamilton[1], N. M. Abreu[2], P. A. Bland[3], H. C. Connolly, Jr.[4], R. D. Hanna[5], D. S. Lauretta[6], D. L. Schrader[7]; [1]Southwest Research Institute 1050 Walnut St. #300, Boulder, CO 80302 USA, hamilton@boulder.swri.edu, [2]Penn State University - DuBois, [3]Curtin University, [4]Rowan University, [5]University of Texas - Austin, [6]University of Arizona, [7]Arizona State University.

Introduction: Several systems for the classification of meteorites have been developed based on isotopic, chemical, mineralogical, and shock characteristics. Recently, studies by Howard and colleagues have focused on PSD-XRD-derived modal mineralogy, specifically hydrated phases, as a component in the classification of aqueously altered carbonaceous chondrites (CC) [e.g., 1]. Microscopic infrared spectroscopy (μ-FTIR) is another technique sensitive to mineralogy, and can complement PSD-XRD by mapping mineralogy in situ on thin sections and potted butts. The μ-FTIR approach also allows for direct comparison to other in situ techniques such as electron microprobe analysis. In this work, we consider the potential for classifying three C2-ungrouped CC based on spectral parameters that incorporate samples covering petrologic types 1-6, and the consistency of quantifiable spectral characteristics with modal mineralogies [1-3] and the proposed classification of [1].

Methods: We use a Thermo Scientific iN10 FTIR microscope to measure reflectance from 4,000 - 400 cm^{-1} (2.5 - 25 μm) at a spectral resolution of 4 cm^{-1}. Maps are acquired at 300 μm/pixel resolution and averaged to produce the bulk spectrum of each sample in this work. Details of the instrument and data processing are described in a companion paper [4].

Samples: To date, we have collected μ-FTIR spectral maps from 36 samples representing 32 CC meteorites. These include two CI, ten CM, seven CR, four CO, three CV, three CK, and three C2-ungrouped: Bells (alternately an anomalous CM2), Acfer 094, and EET 83355. Analyses of a second sample for each of four meteorites (one CI, two CM, one CV) offer an opportunity to examine spectral variation within samples. Because our thin sections/potted butts are not the same samples used to determine modal mineralogies [1-3], some undetermined uncertainty should be assumed in comparing spectral parameters from our samples to those values. We lack modal mineralogies for 16 of our samples, so several analyses to date include only a subset of our data.

Spectral Parameters and Classifications: The literature has a history of developing parametric approaches to correlating spectral features with compositional data [e.g., 5-10]. Here we apply similar and new approaches to CC using a different suite of samples.

Spectral trends alone have the potential to be diagnostic of CC group and/or petrologic type. We observe a strong positive trend ($R^2 = 0.80$) between the positions of the silicate/Si-O fundamental stretching (~870 - 1020 cm^{-1}) and bending (~400 - 450 cm^{-1}) bands of CC with increasing petrologic type (Figure 1, note reversed wavenumber axis). This trend is consistent with the dominant mineralogy shifting from being dominated by more polymerized phases having higher frequency vibrational modes (e.g., phyllosilicates in CI/CM and some CR; types 1, 1/2, 2) to less polymerized phases with lower frequency vibrational modes (pyroxene and olivine in CO/CV/CK; types 3-6). By this metric, Bells is similar to type 1-2 CM, whereas Acfer 094 and EET 83355 fall very close to ALH A77307 (CO3.0) suggesting they are CO-like, and experienced little aqueous alteration. This is consistent with the strong spectral similarity of Acfer 094, EET 83355, and ALH A77307 (Figure 2), including the dominance of pyroxene and olivine features.

In an analysis similar to [9], we plotted phyllosilicate fraction (as defined by [1]) against Si-O stretching band position for CI/CM and found a moderate linear correlation ($R^2 = 0.75$, not shown). The only ungrouped/anomalous sample for which we have modal mineralogy, Bells, shares its stretching band position with one of two samples of ALH 83100 (CM1/2) and the uncertainties on these meteorites' phyllosilicate fractions overlaps between 0.85-0.87 [1]; i.e., Bells is CM-like. Adding CR/CV samples produces a slightly different and improved fit ($R^2 = 0.77$, not shown).

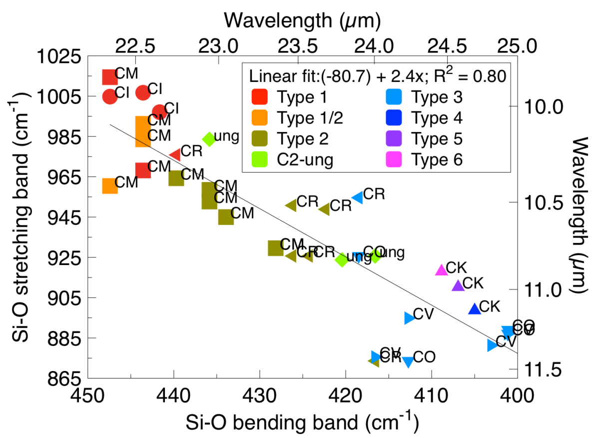

Fig. 1. Silicate stretching and bending band positions vary predictably with CC petrologic type and group.

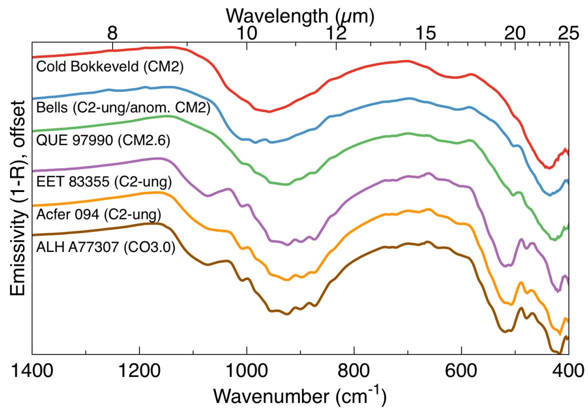

Fig. 2. Comparison of C2-ung spectra with other CC having similar spectra and band positions.

Compositional data have not been compared against lower wavenumber Si-O bending modes in the literature, but these features are equally, if not potentially more, diagnostic based on our analysis. A strong correlation ($R^2 = 0.83$) is observed for CI/CM phyllosilicate fraction vs. Si-O bending mode position and addition of CR/CV data produces a fit having $R^2 = 0.85$ (Figure 3). In this comparison, Bells plots in the same location as Cold Bokkeveld (see also Figure 2), which may be consistent with Bells being considered by some to be an anomalous CM2. We do not yet have modal mineralogies for Acfer 094 or EET 83355.

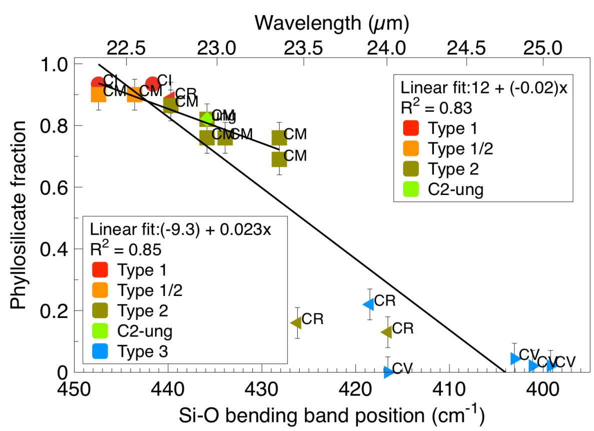

Fig.3. Correlation between phyllosilicate fraction in CC and silicate bending band position.

The petrologic type classification proposed by [1] is based on phyllosilicate fraction (including amorphous phases) and is applicable to all groups of hydrated CC (including ungrouped/anomalous). Our CV are all type 3.0, and our CI are type 1.1. Thus, for the 18 samples in our suite that can be assigned a type, we obtain a strong correlation with Si-O bending band position ($R^2 = 0.85$, Figure 4). The CR2 plotting farthest off the best-fit line (LAP 02342) contains more amorphous material than phyllosilicate and also contains a large quantity of olivine (~44 vol%) relative to unheated CRs [1]. Thus, use of this plot/fit for assigning a petrologic type may need to consider the contributions of additional phases to the classification definition and/or to spectral features in this region. A similarly good, but slightly different, fit is obtained if we consider only the CI/CM ($R^2 = 0.83$).

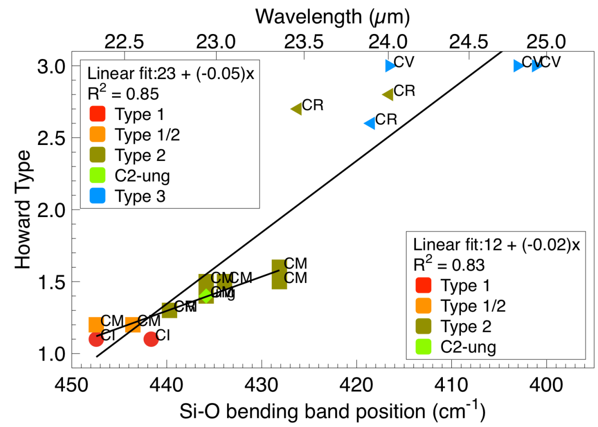

Fig.4. Correlation of petrologic type [1] and Si-O bending feature position vs. group and original type.

Summary and Future Work: Our preliminary analyses suggest that trends in simple spectral parameters can be used to help classify the petrologic type and group of unknown or ungrouped samples (e.g., Figure 1). There are also trends between spectral features and phyllosilicate fraction and the type/classification of [1] (Figures 3-4), and these are also suggestive of group.

Future work will fold in hydration bands [e.g., 11], plus other chemical measures and mineral abundances contributing to the observed spectral features. Abundant information is contained in the numerous additional features that occur in these spectra (Figure 2), and we will look into deriving modal mineralogy directly from spectral maps (point counts) and linear least squares modeling [e.g., 12], as demonstrated for Martian lithologies [13].

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