SPECTRAL CLASSIFICATION OF UNGROUPED CARBONACEOUS CHONDRITES I: DATA COLLECTION AND PROCESSING. V. E. Hamilton, Southwest Research Institute 1050 Walnut St. #300, Boulder, CO 80302; hamilton@boulder.swri.edu.

Introduction: Mapping microspectroscopy of meteoritic thin sections and potted butts is a valuable technique for the identification of minerals and amorphous phases and their *in situ* distribution in rare materials. Some of the key advantages of this approach are: the ability to compare spectrally-derived information to X-ray/EPMA maps acquired on the same surface, perform point-counts, generate average/bulk spectra, and obtain spectra of phases that are otherwise difficult to obtain in isolation due to their rarity. This technique offers the potential for identifying new approaches to the classification of previously ungrouped meteorites. However, the use of microspectroscopy with thin sections introduces different measurement conditions and poses different data processing requirements relative to the analysis of chips or particulates. This work aims to describe these requirements and how they are addressed in our analyses, so that we can be confident our interpretations [1] are not negatively affected.

Instrumentation: We use a Thermo Scientific iN10 Fourier transform infrared microscope (μ-FTIR) to measure reflectance from 4,000 - 400 cm^{-1} (2.5 - 25 μm). The user may measure discrete points, or automated mapping is enabled via software control of a motorized sample stage. The number and spatial intervals of mapping measurements are user-selectable in the x and y dimensions. The instrument aperture can be set to square or rectangular sizes from 10 - 300 μm.

Calibration. Radiance spectra are ratioed to a polished gold plate to obtain reflectance. The gold plate, thin sections, and potted butts are all polished, having comparable roughness and avoiding the effects of variable particle size observed in powdered samples. The gold plate can be measured before or after every sample (e.g., when measuring discrete points) or at a set frequency during automated mapping. Typically, the instrument is very stable, the path length is short, and the sample compartment is purged with air scrubbed of gaseous CO_2 and H_2O vapor, which reduces significantly their contribution to the spectra. As a result, we find that every 30 minutes is usually a suitable frequency for calibration measurements.

Equivalence with emission. The instrument has a permanently aligned, 15X, 0.7 N.A. (half angle range 20° to 43.5°) visible/IR objective and condenser. This is a sufficiently small solid angle that our reflectance spectra do not suffer from the band broadening effects near the Christiansen feature (CF) observed in biconical systems having large solid angles that include
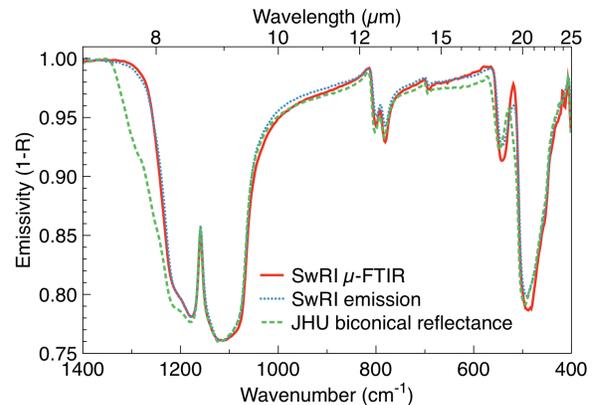

Figure 1. μ-FTIR reflectance spectrum of quartz (inverted) compared to quartz measured in emission and biconical reflectance (all scaled) [2]. No band broadening is observed in the μ-FTIR data and can be reliably compared to emission data.

(near-) grazing angles of incidence and collection (Figure 1) [2].

Diffraction. Diffraction is an instrumental effect that sets in when the aperture size is roughly equal to or less than the wavelength of light [4]. In our case, apertures <25 μm will reduce the spectral region over which the aperture size is a true representation of the area measured. Diffraction is not a problem if the aperture is >25 μm or the spectral feature of interest is at a wavelength shorter than the aperture size in microns.

Measurement parameters: The quality of a given spectral measurement depends on several parameters. The number of scans collected at each spot is user selectable; signal-to-noise ratio (SNR) increases as a function of sqrt(N) where N is the number of scans. The N scans required to obtain adequate SNR for a given analysis is dependent on properties of the sample, the aperture size, and the spectral sampling. For example, for a given spectral resolution and aperture size, a CO or CV carbonaceous chondrite (CC) lacking abundant opaques and organics may require shorter integration times than darker (CM) samples. As aperture size increases, more photons are returned in each scan, and fewer integrations are required to obtain comparable SNR on a given sample. As spectral resolution is reduced, noise is also reduced for a given aperture and sample. It is clear that there is no single set of parameters applicable to all samples; the settings must be determined by the user on a case-by-case basis depending on the fidelity of the measurement needed

to address the science in question. We note that in the scientific literature, it is exceedingly rare to see a quantitative SNR provided for laboratory spectral data. Instead, as with other methods (EPMA, SEM), the instrumental settings that were used are what is provided.

Meteorite Samples: Standard petrographic thin sections are slices of rock 30 μm in thickness, mounted on a silica glass slide substrate using an adhesive such as epoxy or resin. Geologic thin sections typically are produced by grinding down a billet after it has been attached to the slide. In the case of CC samples, somewhat different methods have been employed to address their variable physical properties (e.g., hardness) and delicate nature. For example, [3] describe the impregnation of CC with epoxy prior to mounting and lapping, which can result in the presence of epoxy throughout the sample, especially for porous samples. A distinct advantage of measuring thin sections and potted butts is the virtual absence of adsorbed water that is a perpetual concern with powdered samples.

Potential artifacts associated with microspectroscopy of meteorites in thin section: Thin section preparation can result in some spectral artifacts that must be identified and their impact assessed.

Interference fringes. Some spectra exhibit sinusoidal "ringing", typically most apparent in the transparent (non-absorbing) regions of the spectrum. These features signify reflectance from or between parallel surfaces having different path lengths (e.g., the meteorite upper/lower surfaces or the meteorite and substrate), and the distance between fringes can be used to measure the thickness between the surfaces. These fringes are apparent in only few percent of our CC thin section data**.** As expected, we have not encountered any cases of interference fringing with potted butts. There is no strong correlation of fringing with petrologic type or group, as this is a marker of a physical property of the sample, not its composition. In the case of averaged mapping analyses (tens to hundreds of spectra), the fringes average out and do not contribute noticeably to the average map spectrum.

If interference fringes are observed in individual spectra, they can distort slightly the fundamental absorption features of the CC phases. One approach to avoiding such interference is to measure a different or thick section. Another approach, facilitated by the use of an FTIR, is to cut out the interfering frequency from the interferograms prior to the Fourier transform.

Epoxy. Epoxy exhibits weak spectral features (Figure 2). In measurements of some CC samples, we have observed evidence of epoxy signatures, such as in fractures. Such cases are easily identified under a petrologic microscope or in X-ray maps and are excluded from subsequent spectral analysis. If the section was pre-

pared following the process described by [2], spectral measurements of a sample with significant porosity can detect epoxy along with the meteorite phases throughout the sample, rather than in localized areas.
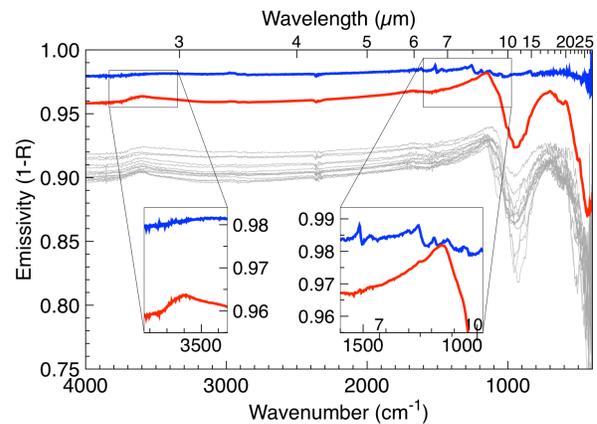

Fig. 2. Epoxy (blue, top) has weak features compared to map average (red) and example individual (gray, offset -0.05) Murray spectra.

Fortunately, the spectral features of epoxy are very weak relative to the features found in CC meteorites and do not overlap significantly with CC spectral features. Figure 2 shows the epoxy spectrum measured on a thin section of Murray (CM2), as compared to the average Murray spectrum from the same section (a map containing 170 spectra) and 14 individual spectra from the same map. The two major spectral features at ~950 cm^{-1} and ~430 cm^{-1} have contrasts of ~5.8% and >10%, respectively (typical for CC). The epoxy is virtually flat across the entire region; its strongest feature (~1190 cm^{-1}) has a contrast of ~0.7% and is located in a transparent region of the Murray spectrum -- as a result, epoxy is a very minor contribution to the average as well as the individual spectra. Epoxy does not have any features that overlap with H_2O/OH^- features in the 3200 - 3800 cm^{-1} region (Figure 2). In sum, although it should be recognized when present, epoxy does not significantly distort the absorption features of CC phases and remediation is not generally required.

Carbon coat. It is common to receive thin sections that have been carbon-coated for microprobe analysis. These coatings can be removed but this is not necessary because they are spectrally inactive (have no features) in the region of our measurements and the coatings are exceedingly thin, ~20 nm, so do not contribute in a volumetrically significant way.

References: [1] Hamilton, V. E. et al. (2018) *LPS, LXIX,* Abstract #1753. [2] Salisbury, J. W. et al. (1991) *Icarus, 92,* 280-297. [3] Harrington, R. and Righter, K. (2017) *LPS XLVIII,* Abstract #6304. [4] Hofmeister, A. (1995) *Practical Guide to Infrared Microspectroscopy,* Ch. 10, 377-415.