CORRELATED MICRO-SCALE ANALYSES OF FOUR CM2 AND C2 UNGROUPED CARBONACEOUS CHONDRITES. L. Flores[1], T. D. Glotch[1], P. Northrup[1], A. Muñoz[1], J. Jung[1], B. De Gregorio[2], R. Tappero[3], S. Nicholas[3], G. Flynn[4], and C. D. K. Herd[5], [1]Dept. of Geosciences, Stony Brook University, Stony Brook, NY, leonard.flores@stonybrook.edu, [2]US Naval Research Laboratory, [3]NSLS-II, Brookhaven National Laboratory, [4]SUNY Plattsburgh, [5]Dept. of Earth and Atmospheric Sciences, University of Alberta.

Introduction: Carbonaceous chondrites contain important information related to the earliest geochemical processes in our Solar System. CM2 and C2 ungrouped chondrites in particular likely share similarities with the samples that will be returned from the near-Earth asteroid Bennu by NASA's OSIRIS-REx mission [1]. As such, these types of meteorites can be used as analogs for material found on asteroids like Bennu. qIn this work, we describe correlated mineralogic and geochemical measurements of two CM2 chondrites and two C2-ung chondrites with multiple instruments at micro and nano-scales to determine the relationships between organics and minerals in these samples and the geochemical environments in which they formed.

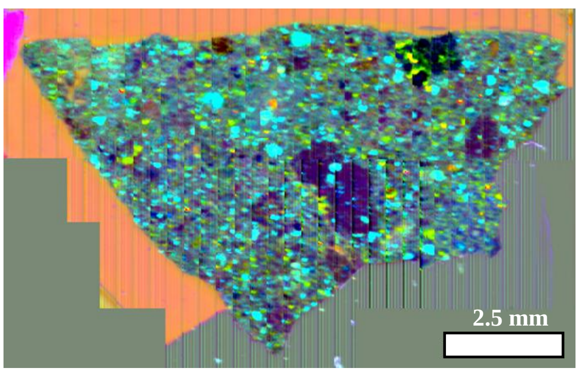

Fig. 1. Infrared PCA image of Cold Bokkeveld. Red, green, and blue correspond to three unique principal components of the FTIR dataset.

Samples: We investigated standard petrographic thin sections of CM2 chondrites Northwest Africa (NWA) 12748 and Cold Bokkeveld, and C2-ung chondrites Tagish Lake, and Tarda. NWA 12748 and Cold Bokkeveld both have a dark fine-grained matrix with chondrules mainly composed of olivine and have rare calcium-aluminum inclusions (CAIs). Cold Bokkeveld also has noticeable amount of calcium sulfate [2]. Tagish Lake has a dark fine-grained matrix with few chondrules, CAIs, olivine aggregates, and carbonates [3]. Tarda contains small chondrules with minor olivine but no CAIs [4].

Methods: We use multiple analytical techniques to investigate the mineralogy, chemistry, and organic species in the meteorites. Our initial analyses included petrographic imaging in reflected plane light of the whole thin sections. We also acquired hyperspectral infrared maps of each sample at 25 µm/pixel using a Nicolet iN10MX micro-FTIR at Stony Brook University (SBU) With this dataset, we can visualize the spectral differences between the different components in each sample through principal components analysis (PCA) [5] and spectral index mapping [6].

We also acquired synchrotron microbeam X-ray fluorescence (μXRF) maps at NSLS-II at Brookhaven National Laboratory of S, P, Mg, Ca, Al, Si, K, Cl, and U at ~2-10 μm/pixel, as well as X-ray absorption near-edge structure (μXANES) spectra of P and S using the Tender Energy X-ray Absorption Spectroscopy (TES) beamline. Also at NSLS-II we used the X-ray Fluorescence Microprobe (XFM) beamline and acquire additional XRF maps at ~7-50 μm/pixel of heavier elements including Fe, Ni, Co, Ti, Pb, Cu, and V. We also collected micro- X-ray diffraction (μXRD) measurements on the samples with ~10 μm spot sizes.

Using the comparatively coarse spatial resolution data, we identified locations of interest on each sample for further investigations at a finer spatial scale. We

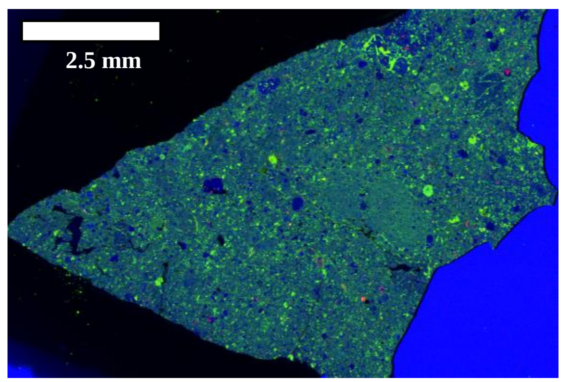

Fig 2. XRF map from TES of Cold Bokkeveld. Red, green, and blue represent the elements phosphorus, sulfur, and silica respectively.

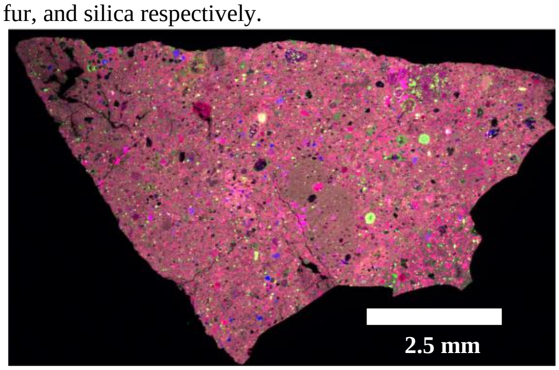

Fig 3. XRF map from XFM of Cold Bokkeveld. Red, green, and blue represent the elements iron, nickel, and titanium respectively.

acquired Raman maps of several locations on each sample at ~0.5 µm/pixel using a WiTEC alpha300R confocal Raman microscope system at SBU.

We also acquired nano-IR imaging and spectroscopy at a much finer scale (30 nm/pixel) using a neaspec neaSNOM near-field infrared system.

We were able to acquire a focused ion beam (FIB) section from NWA 12748 for energy dispersive X-ray spectroscopy (EDS) at the Naval Research Laboratory and scanning transmission X-ray microscopy (STXM) at the Advanced Light Source at Lawrence Berkeley National Laboratory.

Results: Figure 1 shows an example of a false color infrared PCA map of Cold Bokkeveld. The colors seen in Figure 1 do not directly correspond to the composition of the sample, but instead indicate which portions of the sample are spectrally different or similar. Using various derived principal components to create different RGB images helps us visualize the variability between materials in the sample.

Elemental μXRF maps at various spatial scales acquired at TES (Figure 2) and XFM (Figure 3) complement the mineralogical micro-FTIR. We find correlations in features between the two element maps such as sulfur and nickel appearing in the same locations or iron appearing in the XFM map at a spot where there is no distinct feature in the TES map. We also collected μXANES at the TES beamline which allowed us to identify the presence of sulfides. The μXRD patterns we collected at XFM gives us insight into what minerals may be present.

We also acquired broadband nano-IR images (Figure 4) and point spectra (Figure 5) to investigate the mineralogy and organic speciation in the sample at ~ 30 nm/pixel spatial scales. Targeting of these measurements was aided by the micro-FTIR, micro-Raman, and μXRF measurements we acquired for each sample. Figure 4 maps a chondrule rim in NWA 12748 (5μm field of view) which demonstrates sample heterogeneity at sub-100 nm scales. Nano-IR spectra from xx-yy cm^{-1} covering the silicate Reststrahlen Band region (Figure 5) identify individual mineral and organic phases in this region, including likely carbonates.

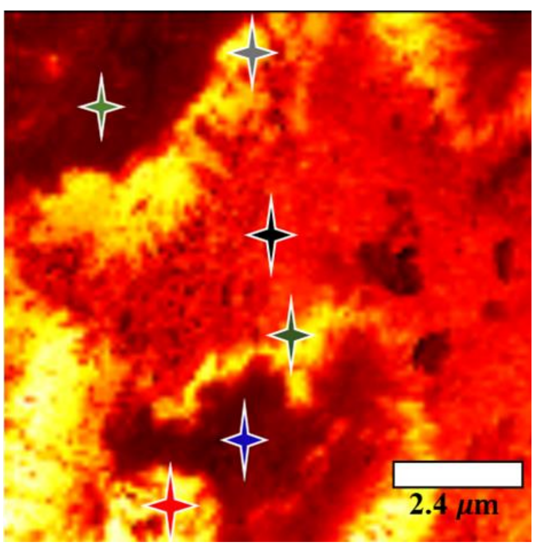

Fig. 4. Near-field IR amplitude image of a chondrule's rim in NWA 12748. Bright regions correspond to high IR amplitude (reflectance). The colored stars correspond to the spectra in Figure 5.

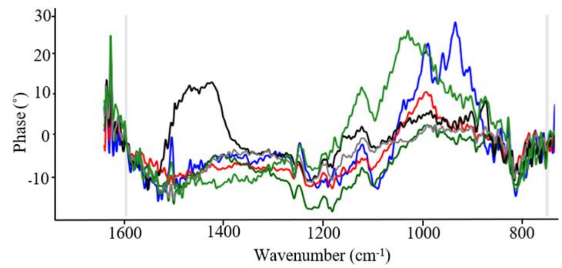

Fig. 5. Spectra of locations found in Figure 4.

Conclusions: When observing our samples using the maps and spectra we have acquired using the various techniques we can see there is spectral heterogeneity within each sample at various spatial scales. This method of observation gives us insight into how complex the composition of such meteorites can be from coarse to fine spatial scales.

The μXRD maps from TES and XFM allow us to observe relationships between lighter and heavier elements such as those seen in Cold Bokkeveld in Figures 2 and 3. We then look at those areas of interest with the Raman and nano-IR and collect spectra of those areas. We then identify what minerals may be present in these areas. Our future work is then to identify their significance in these meteorites.

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References: [1] Laurette, D. S. et al. (2019) *Nature, 568*, 55-60. [2] Lee, M.R. (1993) *Meteoritics, 28*, 53-62 [3] Brown, Peter G., et al. (2000) *Science, vol. 290, no. 5490*, pp. 320–325. [4] "Meteoritical Bulletin: Entry for Tarda." *Meteoritical Bulletin RSS.* [5] Le Maitre, R. W. (1982) *Numerical Petrology: Statistical Interpretation of Geochemical Data.* Elsevier, Amsterdam, 106-121. [6] Viviano, C. E. et al. (2014) *JGR Planets, 119*, 1403-1431.