REDDER/BLUER, BRIGHTER/DARKER, DEEPER/SHALLOWER ABSORPTION BANDS: EFFECTS OF PHYSICAL PROPERTIES, SPACE WEATHERING, AND OBSERVING GEOMETRY ON REFLECTANCE SPECTRA OF THE MURCHISON CM2 CARBONACEOUS CHONDRITE. E.A. Cloutis[1], V.B. Pietrasz[2], C. Kiddell[1], M.R.M. Izawa[3], P. Vernazza[4], T.H. Burbine[5], F. DeMeo[6], K.T. Tait[7], J.F. Bell III[8], J.P. Mann[1], D.M. Applin[1], and V. Reddy[9]. [1]University of Winnipeg, Dept. of Geography, 515 Portage Ave., Winnipeg, MB, Canada R3B 2E9, e.cloutis@uwinnipeg.ca; [2]CalTech; [3]Misasa University; [4]Aix Marseille Universite; [5]Mt. Holyoke College; [6]MIT; [7]Royal Ontario Museum; [8]Arizona State University; [9]University of Arizona.

Introduction: Albedo, spectral slope, and absorption band depth variations exist within and among C-class asteroids and carbonaceous chondrite (CC) meteorites [1, 2]. Spacecraft observations also show that small C-class asteroids (Bennu, Ryugu) can show variations across their surfaces and at depth in terms of albedo and spectral slope. Such spectral variations and differences may be attributable to non-compositional parameters such as differences in viewing geometry and physical properties (e.g., grain size, porosity). To disentangle the spectrum-altering effects of composition from observing conditions and physical properties, we undertook a spectroscopic (0.35-2.5 µm) examination of the Murchison CM2 carbonaceous chondrite.

Experimental Procedure: A 10 gram piece from a ~1kg mass of Murchison was used for this study. Spectra were examined as a function of: (1) viewing geometry; (2) porosity; and (3) grain size. We also discuss previous laboratory space weathering experiments [3].

Results: Below, we first discuss changes or differences in albedo, spectral slope, and absorption band depths as a function of viewing geometry, followed by changes in the context of physical "evolution" of Murchisone from an intact bedrock (slab spectra). Selected spectral results are shown on the following page.

(1) Viewing geometry. For a <150 µm powder, spectral changes are controlled by whether the sample is viewed in forward or backscattering geometry. In backscattered geometry, increasing phase angle (*p*) leads to an initial increase and then decrease in spectral slope, and a general decrease in visible region reflectance (albedo). In forward scatter geometry, increasing phase angle leads to small non-systematic changes in spectral slope, general decrease in albedo, and increase in band depth. For fixed incidence or emission angle and forward or backscattering geometry, albedo and band depth generally decrease and the spectra become more blue-sloped and concave-down.

(2) Slabs versus powders. Saw-cut rough faces of Murchison slabs are bluer-sloped and generally as dark or darker than powders; band depths are variable (regardless of powder grain size).

(3) Slabs with fine-grained powder coatings. As a slab is coated with increasing amounts of fine-grained dust (as may occur during physical weathering of an asteroid), band depths decrease, while albedo and spectral slope show no discernible trends.

(4) Decreasing maximum grain size of powders. As a powdered surface becomes progressively finer-grained, band depths increase slightly and the spectra become redder and brighter.

(5) Increasing fine-grained component. As the ratio of fine (<45 µm) to coarse (500-1000 µm) powder increases, band depths decrease, and the spectra become redder and brighter.

(6) Decreasing porosity. When a powdered sample is compressed (decreasing porosity), spectral variations seem to be sensitive to viewing geometry. At low phase angles (30°), decreasing porosity shows no systematic trends for band depth or spectral slope, but albedo increases. At higher phase angles (90°), band depths seem to increase, and the spectra get bluer and brighter.

(7) Heating. Laboratory heating experiments on Murchison result in significant spectral changes. Progressive heating leads to bluer slopes. Albedo initially decreases to ~600°C, and then increases to higher temperatures. Absorption band depths in the 0.7-1.2 µm region generally decrease, and their shapes and positions also change.

(8) Mineral fractionation. Murchison enriched in specific components show spectral variations. Enrichment of olivine may lead to a slight decrease in albedo and small changes in spectral slope; the most noticeable change is an increase in the depth of the 1 µm region olivine absorption band. For matrix-enriched samples, albedo decreases, spectra become bluer, and the 0.7 µm region absorption band becomes deeper.

(9) Space weathering. Laboratory space weathering of Murchison (pressed powder pellets) [3] showed that increasing space weathering leads to darker and bluer spectra that have reduced absorption band depths.

Summary: Changes in the physical state of CCs can lead to changes in all key spectral parameters (albedo, slope, band depths). However, some diagnostic spectral properties (absorption band position and shape) are unchanged, unless accompanied by changes in composition, such as preferential enrichment of phases, space weathering, and heating.

References: [1] Vernazza P. et al. (2016) *Astron. J., 152,* 54. [2] Cloutis E.A. et al. (2018) *Icarus, 305,*

203-224. [3] Matsuoka M. et al. (2015) *Icarus, 254,* 135-143.

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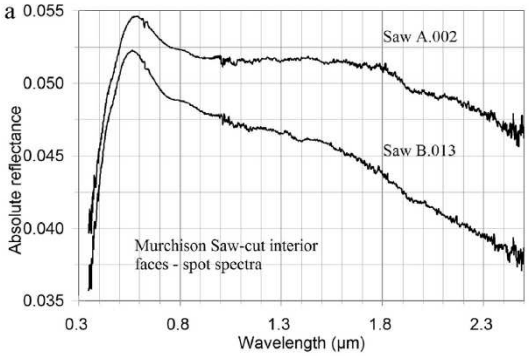
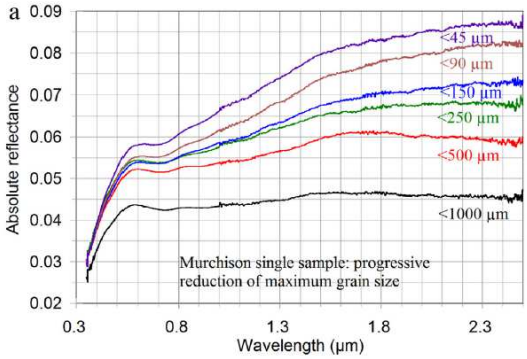
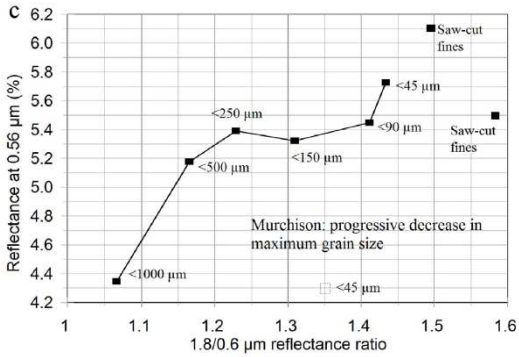


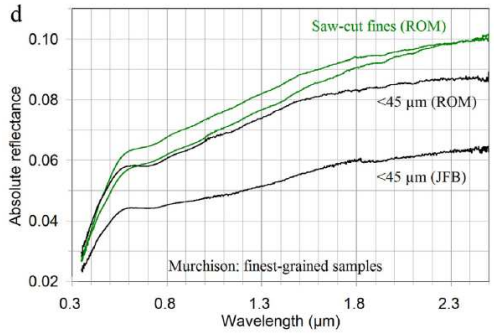
Reflectance spectra of saw-cut faces of Murchison.



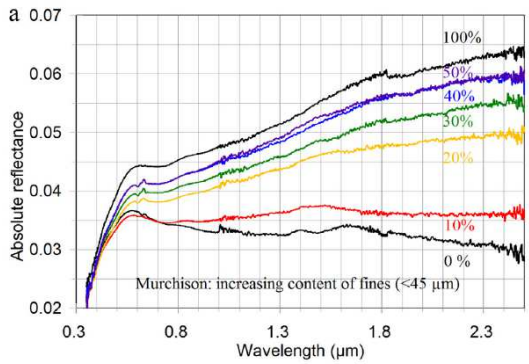
Reflectance spectra of Murchison with progressive decrease in maximum grain size of a single subsample.



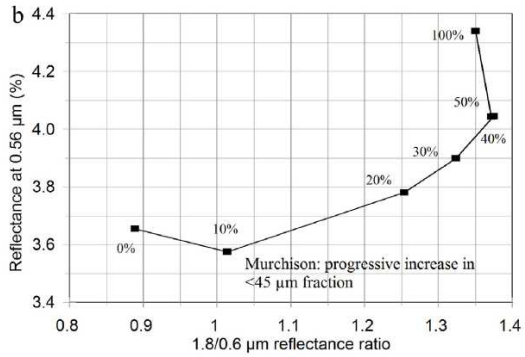
Changes in slope and albedo for the above Murchison grain size series spectra.



Reflectance spectra of Murchison <45 µm powders versus saw-cut fines (>99% <<5 µm grain size).



Reflectance spectra of Murchison powder with increasing content of fines (<45 µm) relative to coarse grains (500-1000 µm).



Increase in reflectance and slope with increasing proportion of fine grains (<45 µm) relative to coarse grains (500-1000 µm)