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µ-FTIR spectroscopy for the analysis of clasts in hydrated carbonaceous chondrites and potential applications to remote sensing observations of asteroids

V. E. Hamilton (1) and T. J. McCoy (2)
(1) Department of Space Studies, Southwest Research Institute, Boulder, CO, USA (hamilton@boulder.swri.edu), (2) Department of Mineral Science, National Museum of Natural History, Smithsonian Institution, Washington, DC, USA.

Abstract

Microscopic Fourier transform infrared (µ-FTIR) spectroscopy of meteorite thin sections is a valuable technique for the identification of minerals and amorphous phases and mapping of their *in situ* distribution in these 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, generate average/bulk spectra, and obtain spectra of phases that are otherwise difficult to obtain in isolation. Furthermore, in contrast to petrologic and geochemical studies, these spectra also allow us to extend observations to the meter-, kilometer- and disk-integrated scale of asteroid observations. Here we describe the application of this technique to hydrated carbonaceous chondrites, which are the meteorites most relevant to published results from the Hayabusa2 and OSIRIS-REx missions [1, 2].

1. Introduction

Among carbonaceous chondrites, the majority exhibit evidence of aqueous alteration, ranging from modest (CR chondrites) to extensive (CM2 to CM1 and CI1) [3]. As aqueous alteration progresses, fine-grained olivine in the matrix is altered to phyllosilicates, metal is oxidized to magnetite, and carbonates form. Between the groups, progressive aqueous alteration differs in style and extent. In CR chondrites, large chondrules and metal grains exhibit minor to modest alteration. In contrast, CM chondrites exhibit complete alteration of the matrix that comprises ~80% of the meteorite, with modest (CM2) to complete or nearly-complete (CM1) alteration of chondrule silicates, leaving pseudomorphic textures. In CI chondrites, alteration is nearly complete and chondrule pseudomorphs are absent. Saponite and serpentine dominate the matrices of CI chondrites, whereas cronstedtite predominates in CM matrixes.

Overprinted on this alteration is extensive brecciation, with 100% of hydrated carbonaceous chondrites (CI, CM, CR) containing solar wind implanted gases indicative of formation as regolith breccias. These breccias are typically genomict, with formation on the same parent asteroid through various degrees of alteration [4]. Scales of brecciation range from millimeters to centimeters, but, despite the very limited number of large hydrated carbonaceous chondrites, do not appear to extend to the decimeter scale.

Spatially-resolved laboratory spectra can provide complementary information to petrologic and geochemical studies about the mineralogy of various components in hydrated carbonaceous chondrites, their juxtaposition as a result of aqueous alteration (e.g., chondrules vs. matrix), and their juxtaposition as a result of brecciation at the mm- to cm-scale.

Finally, laboratory spectral data long have been used for the interpretation of remote sensing data of planetary surfaces but have focused primarily on measurements of powdered bulk materials. Such materials are easiest to measure with traditional bench-top spectrometers and separation of meteoritic components can be very challenging, too. Bulk powders are also good analogues for small body surfaces having significant exposures of fine particulate materials (e.g., <65-100 µm). µ-FTIR complements these measurements by permitting the targeted analysis of specific phases and clasts in breccias. They are also complementary to powder spectra in that measurements like the ones presented here better represent the spectral response of coarse particulate and rocky surfaces.

2. Sample(s)

We are using spectral data (section 3) collected by [5, 6] on thin sections representing a large suite of carbonaceous chondrites spanning the range of petrologic types from 1 to 6. In this work, we are focusing on a subset of these data representing hydrated lithologies. These samples include, among others, the CM2 chondrites Nogoya and Murchison, and the CI chondrite Orgueil (in some cases, we have data for multiple splits of the same meteorite, which can be used to examine heterogeneity). In addition, we are making measurements on the CR2 chondrite EET 92042. All of these show evidence of brecciation on the scale of millimetres to centimeters.

3. μ-FTIR spectroscopy

We are using a Thermo Scientific iN10 Fourier transform infrared microscope at SwRI-Boulder to measure reflectance on thin sections from 4,000 - 400 cm^{-1} (2.5 - 25 μm). Details of the instrument features, calibration, and other factors are described by [7].

In brief, the user is able to measure discrete points, transects, or maps via software control of a motorized sample stage. The instrument aperture can be set to square or rectangular sizes from 10 - 300 μm and rotated to fit within irregularly-shaped areas. Radiance spectra are ratioed to a polished gold plate to obtain reflectance. The gold plate and thin sections are all polished, having comparable roughness and avoiding the effects of variable particle size observed in powdered samples.

There are a couple of factors to consider in applying μ-FTIR data to remote planetary surface measurements. First is the equivalence of the meteorite reflectance spectra in the thermal infrared to emissivity spectra measured by spacecraft at these wavelengths. The optical geometries must be similar enough that Kirchhoff's Law is applicable, and reflectance can be converted to emissivity (where $\varepsilon=1-R$). [7] has shown this equivalency for the spectrometer we are using. Secondly, we are measuring thin sections, which produce spectra comparable to coarse particulate (e.g., >65 μm) and solid surfaces. The surfaces of the asteroids Bennu and Ryugu are dominated by large rocks and boulders that are not ideally represented by finely powdered meteorite spectra (although the presence of fine particulates is not ruled out) [2, 8]. As such, these measurements can contribute to the understanding of these asteroids' compositions.

4. Work Plan

Spectral metrics for distinguishing petrologic types among carbonaceous chondrites using features associated with bulk/whole-rock hydration and silicate mineralogy have been presented previously by [5, 6]. Those results revealed clear trends in band strength and position that correlate with petrologic type and/or meteorite group. As has been done previously for Martian meteorite lithologies within Northwest Africa 7034 [9], we are now investigating individual phase spectra and bulk clast spectra in hydrated carbonaceous chondrites to better understand their relationships, their diagnostic spectral features, and how these relate to the bulk characteristics and spectral parameters observed by spaceflight missions.

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