Mineralogical and Elemental Composition of Carbonaceous Chondrites by micro-Raman Spectroscopy and SEM/EDS

Analía (Yanil) Dall'Asén[1], Aaron Stokke[1], Raka Paul[1], Rohil Kayastha[1], Benjamin Bromley[2], and Scott Kenyon[3]

analia.dallasen@mnsu.edu

[1]Department of Physics & Astronomy, Minnesota State University-Mankato; [2]Department of Physics & Astronomy, The University of Utah; [3]Smithsonian Astrophysical Observatory

Introduction

Meteorites provide precious clues about the formation of planets in the solar system. In particular, carbonaceous chondritic meteorites, considered the most primitive surviving materials from the early Solar System, can contribute to understand how planetesimals (the precursors to planets, of 1-100 km in radius) formed from dust (micron-size grains) [1]. These relics are mainly composed of chondrules (micro/millimeter-sized inclusions) surrounded by a matrix of microparticles [2].

Here we present a comparative study of the mineralogical and elemental composition of the chondrules and surrounding matrix of two carbonaceous chondritic meteorites, Moss and Murray, using low/high-resolution micro-Raman spectroscopy and SEM/EDS (Scanning Electron Microscopy/Energy Dispersive X-ray Spectroscopy). We examine how these properties vary in different regions of the chondrules and matrix [3], and between these two samples, looking for signatures of the physical processes that drove their formation.

Samples and Methods

- **Meteoritic samples**

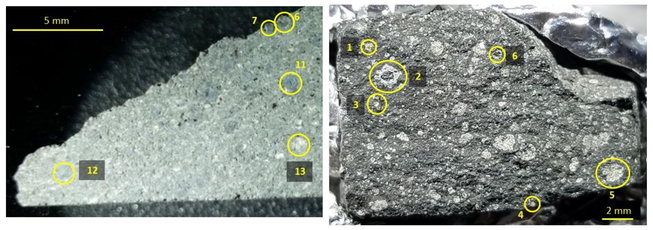

Figure 1. Fragments of carbonaceous chondrites: (a) Moss; and (b) Murray. The yellow circles mark the selected chondrules/inclusions and surrounding matrix.

- **Moss:** CO3.6, 1.300 g, observed fall in Ostfold (Sweden) in 2006.
- **Murray:** CM2, 3.367 g, observed fall in Kentucky (USA) in 1950.

- **Experimental techniques**

Micro-Raman spectroscopy

- Information about the mineralogical composition of the samples at the microscale.
- Custom-built micro-Raman spectrometer: λ_{exc} = 532 nm; P ~5 mW.
- Low- and high-resolution measurements.

SEM (Scanning Electron Microscopy)

- Information about the topography of the samples at the nano/microscale (secondary electron detection).
- JEOL JSM-6510LV system: RT, HV (10 Pa), 15 kV, magnification: 50X to 5000X.

EDS (Energy Dispersive X-ray Spectroscopy)

- Information about the elemental composition of the samples.
- Thermo Scientific UltraDry system.

References

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Results: SEM/EDS

Moss

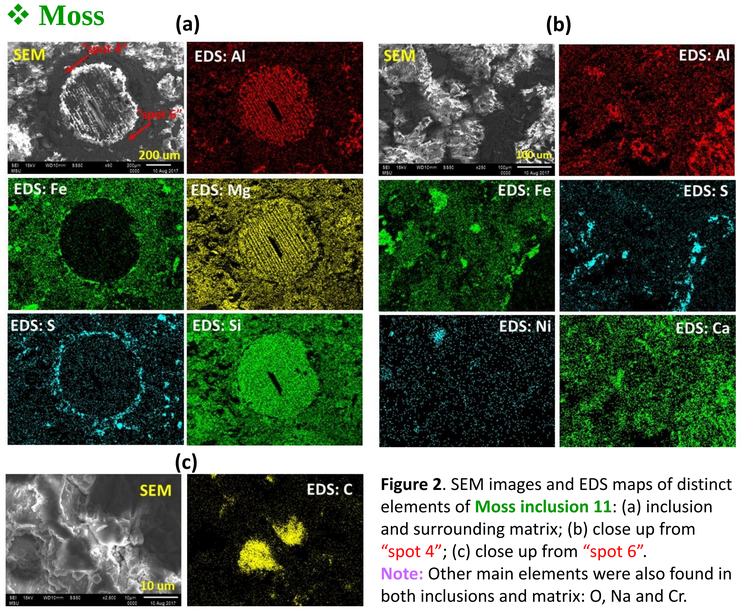
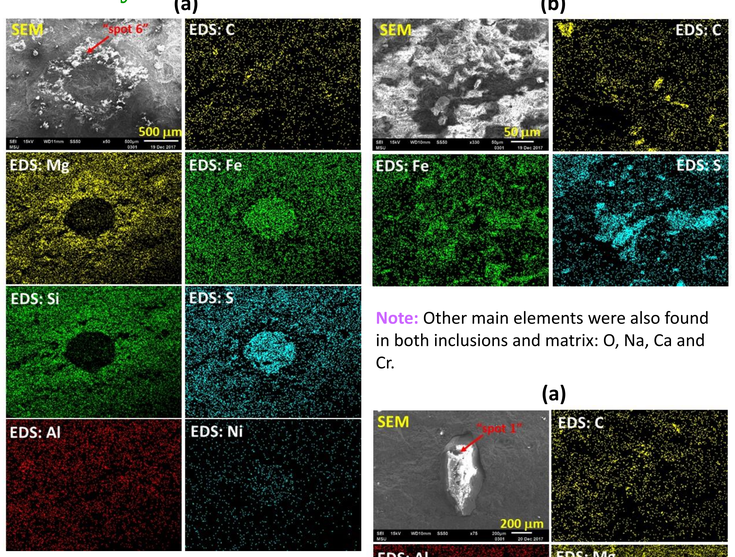


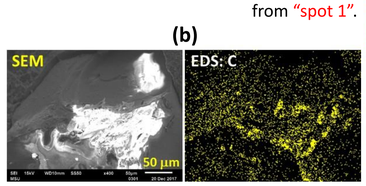
Figure 2. SEM images and EDS maps of distinct elements of **Moss inclusion 11**: (a) inclusion and surrounding matrix; (b) close up from "spot 4"; (c) close up from "spot 6".
Note: Other main elements were also found in both inclusions and matrix: O, Na and Cr.

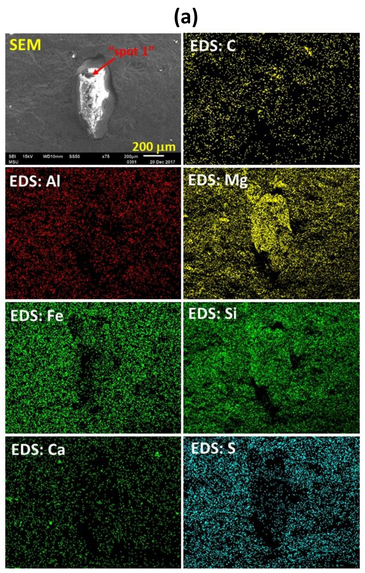
Murray



Note: Other main elements were also found in both inclusions and matrix: O, Na, Ca and Cr.

↑ **Figure 3**. SEM images and EDS maps of distinct elements of **Murray inclusion 2**: (a) inclusion and surrounding matrix; (b) close up from "spot 6".

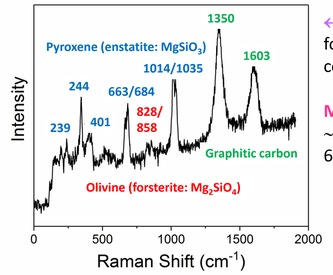




→ **Figure 4**. SEM images and EDS maps of distinct elements of **Murray inclusion 3**: (a) inclusion and surrounding matrix; (b) close up from "spot 1".

Results: Raman Spectroscopy

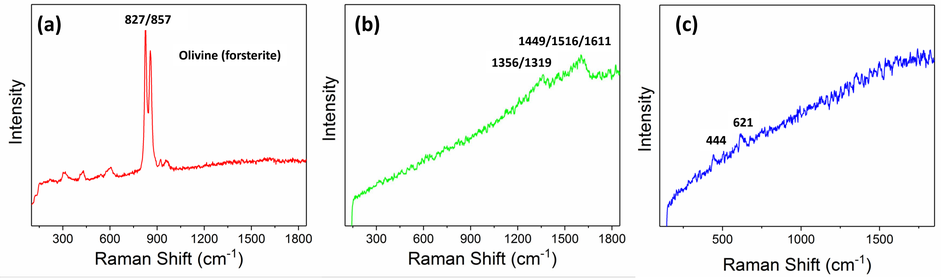
Moss



← **Figure 5**. Representative high-resolution Raman spectra of main materials found in the Moss inclusions (e.g. inclusion 11) : pyroxene (high enstatite content), graphitic carbon; and olivine (high forsterite content) [3].

Magnetite (with main peak at ~670 cm^{-1}) and **hematite** (with main peaks at ~591, 481, 392, 282 and 217 cm^{-1}) [3] were found in the matrix (e.g. inclusion 6). Not shown.

Murray



↓ **Figure 6**. Representative high-resolution Raman spectra of main materials found in **Murray**: (a) Olivine (high forsterite content) found mainly in the inclusions (e.g. inclusion 3) [3]; (b) graphitic carbon [3] with unidentified mineral found mainly in the matrix (e.g. inclusion 2); and (c) unidentified mineral found mainly in the matrix (e.g. inclusion 2).

Discussion

- Raman and SEM/EDS results are mutually consistent and also yield complementary information.
- High-resolution Raman spectroscopy allowed to find more clearly bands/peaks of minerals, helping in the certain identification of these minerals (e.g. forsterite olivine and enstatite pyroxene).
- From the **Raman spectroscopy** results, several minerals were found in Moss and Murray:
  - All the **Moss** chondrules/inclusions mainly contained graphitic carbon, olivine (forsterite) and pyroxene (enstatite). The surrounding matrix not only contained these minerals but also hematite and magnetite.
  - For **Murray**, only olivine was mainly found in the chondrules/inclusions, and graphitic carbon in the matrix.
  - At least two minerals that could have not been identified yet were found in the Murray matrix.
  - The strong signal of graphitic carbon at 1350 cm^{-1} (D-band) indicates disordered structure, consistent with formation in the solar nebula [4]. Some of the graphite is likely presolar (star dust from the interstellar medium) [5].
- From the **SEM** images, better defined chondrules/inclusions were obtained from Moss than from Murray.
- For both Moss and Murray, the **EDS** results showed that:
  - All chondrules/inclusions have higher relative composition of Mg and Si.
  - The matrix has higher relative composition of Fe. This was also found in other meteoritic samples, such as NWA 3118 (CV3) [3]. The matrix was also rich in S.
  - Well-defined rims with higher relative content of Fe and S were found in Moss. This may indicate that the chondrule/inclusion spent some time in the solar nebula before being incorporated into its parent body.
  - Some well-defined C spots at lower scales were found in both Moss and Murray, in inclusions and matrix.
  - Other elements were also found in both Moss and Murray: O, Al, Ca, Ni, Na and Cr.
  - Compositional differences between chondrules/inclusions and the surrounding matrix reflect diffusive processes during formation: molten chondrules/inclusions can not retain Fe, which ends up in the small grains that form the matrix [6].
- Some of the mineralogical and elemental components found in the present work were also reported in other works [7-12].
- Future work: with the present findings and other results obtained from different meteoritic samples, we expect to understand the conditions that are required for these minerals to form, and thus obtain clues about how the local environment was when planetesimals were created.