RAPID CLASSIFICATION OF ORDINARY CHONDRITES USING RAMAN SPECTROSCOPY.

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Introduction: Classification of ordinary chondrites is typically done through measurements of the composition of olivine and pyroxenes. Historically, this measurement has usually been performed via electron microprobe, oil immersion or other methods [1-4] which can be costly through lost sample material during thin section preparation. Raman microscopy can perform the same measurements but considerably faster and with much less sample preparationallowing for faster classification. Raman spectroscopy can facilitate more rapid classification of large amounts of chondrites such as those retrieved from North Africa and potentially Antarctica, are present in large collections, or are submitted to a curation facility by the public. With development, this approach may provide a completely automated classification method of all chondrite types.

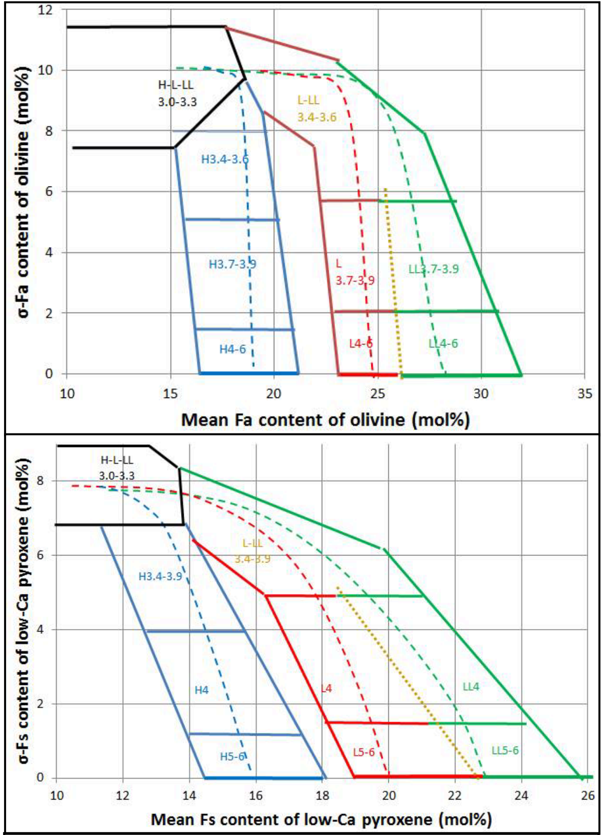

Figure 1: Classification of chondrites by type and petrographic grade by composition vs. standard deviation of composition values. These graphs are from the Meteoritical Society Database website [6] with a detailed description provided on that site. These graphs show that ordinary chondrites can be classified using a statistically relevant number of olivine and/or pyroxene composition analyses, regardless of technique used.

Description: A confluence of factors permit rapid classification of chondrites via Raman spectroscopy, described here individually.

Raman Spectroscopy: Raman spectroscopy involves excitation of a sample by laser, usually in a visible wavelength. The reflected light is then collected and dispersed on a detector. A small fraction of the laser light excites molecular or crystalline vibrational modes in the material, and then reflects off of the sample with the initial photon energy minus the energy required to excite the vibrational mode. The resulting spectrum is specific to the material examined. This relatively simple method is effective for the predominance of known minerals (over 3,700 examples are shown at http://rruff.info [5]) as well as for every known polymorph of carbon. Raman spectroscopy also requires little to no sample preparation and can generally produce a usable Raman spectrum from any clean surface. This allows measurement directly from rock surfaces without the need for thin section preparation.

Chondrite Classification: Classification of chondrites in terms of both meteorite type and petrographic grade is possible by measurement of the composition of olivine and pyroxenes (Figure 1). Regardless of technique used, ordinary chondrites can be assigned a classifieation based on a statistically relevant number of olivine and/or pyroxene analyses [7,8].

Olivine/Pyroxene Composition by Raman Spectroscopy: Composition of olivine is a straightforward measurement by Raman spectroscopy, as described in detail by Kuebler *et al* who demonstrate semi-quantitative Fe composition measurements (Figure 2)[9]. The composition of pyroxenes has likewise been demonstrated in a semi-quantitative fashion [10,11]. Measurment precision for both analyses is low, which will require acquisition of a relatively large number of measurements in order to achieve representative values of Fo, Fs and $\boldsymbol{\sigma}$ for both olivine and pyroxene. Raman analyses require only 10-300s (seconds per?) (this broad?) each depending on the instrument, however, so a large number of analyses is reasonable. We are currently engaged in preliminary trials using 16 samples representing all classes and petrologic types with various weathering grades of ordinary chondrites from a

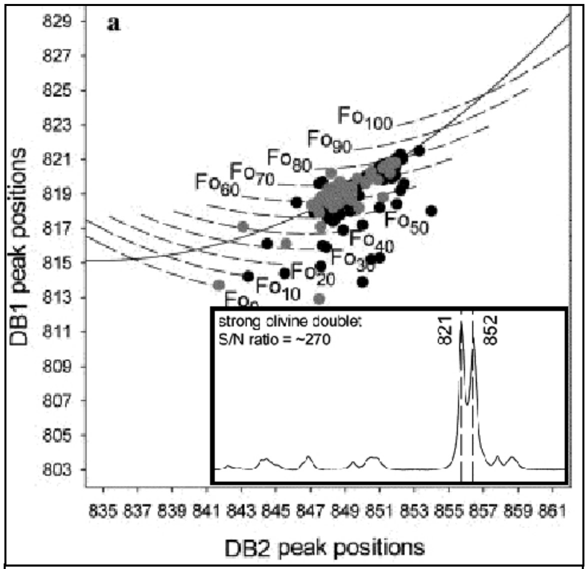

Figure 2: Raman spectrum (inset) of olivine showing two strong Raman peaks around ~820 and ~850 cm^{-1} ("DB1" and "DB2", respectively). The positions of these peaks are an indicator of olivine Fo number. The graph shows the Fo number calculated from individual spectra collected from EETA79001 as a function of positions of the Raman peaks. Figure adapted from [9].

variety of northern African localities to test the feasibility of this approach, and the initial results are encouraging (Figure 3).

Application: Classification of ordinary chondrites by Raman spectroscopy has the dual advantages of rapid individual analyses (at room temperature and pressure, and without coating the sample) and the ability to collect data on exposed interior rock surfaces (even weathered ones) without the necessity for cutting, grinding, polishing, thin section or other preparation. However, the relatively low measurement precision requires a large number (~tens) of measurements per sample. In order to make this work, the following is required:

1) Automated Raman spectral acquisition: Optimally, an operator should select a number of grains visible on the sample surface and the instrument will collect spectra from them in an automated fashion.
2) Automated spectral analysis: Analysis of individual spectra "by hand" would be a laborious process that would negate much of the innate speed of this approach. However, software routines already exist for automated spectral background subtraction, artifact removal, and peak fitting. These techniques must be validated in use on classified ordinary chondrites before unknown samples are analyzed.

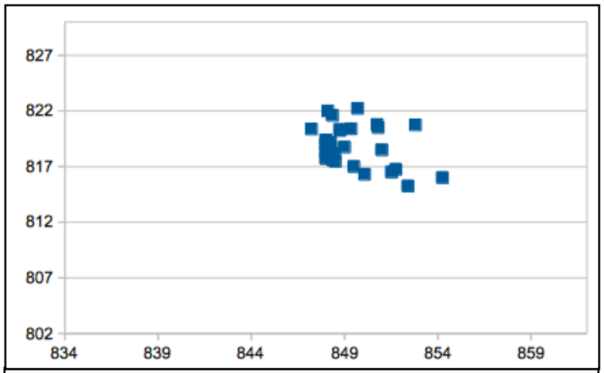

Figure 3: Intital results of Raman analysis on the Acfer 245 H5 chondrite. This graph shows positions of the two principal olivine Raman peaks (~820 and ~850 cm^{-1}) from 29 individual spectra. **These spectra were collected in ~5 minutes from a weathered fracture surface on the meteorite, requiring no sample preparation.** Olivine Fo values can be derived from these data as per [5]. Compare to the graph in Figure 2. The Fo values and standard deviation are reasonable for an H5 chondrite, and we are currently analyzing a large number of classified ordinary chondrites in this manner.

3) Regular spectral calibration: This is standard spectroscopic technique, but consistent measurements of cm^{-1}-accuracy would be best served by inclusion of calibration lines in each spectrum and automated calibration during spectral analysis.

Each of these requirements can be met with existing software and hardware.

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