**NEAR-IR REFLECTANCE PROPERTIES OF CLINOPYROXENE IN UNEQUILIBRATED ORDINARY CHONDRITES.**

M. Trivedi[1,2], H. D. Smith[1], & D.W.G Sears[1]. [1]Space Science and Astrobiology Division, NASA Ames Research Center, Moffet Field, CA 94035. [2]Bellarmine College Preparatory, San Jose, CA 95126.

**Introduction:** Ordinary chondrites, the largest meteorite group, are divided into three main chemical classes (H, L, LL). Each of these classes is divided intro petrographic groups, which reflect the metamorphism of their parent body. Unequilibrated Ordinary Chondrites (UOC) are subdivided into types 3.0-3.9, while Equilibrated Ordinary Chondrites (EOC) are subdivided into types 4-6 [1,2].

The nature of the pyroxene within these type 3 UOCs reflects the metamorphism that the meteorite underwent. The pyroxene in type 4-6 (EOC) meteorites are principally orthopyroxene (OPX), whereas UOC have significant amount of clinopyroxene (CPX) present [3]. We are interested in determining whether near-IR reflectance spectra can be used to detect the amount of CPX in UOC, and how that amount changes relative to their petrographic type (3.0-3.9). This is a continuation of work done by Sissay et. al. in 2010 [4]. The meteorites used in this study were specific to UOC observed falls which are non-Antarctic. This sample set allows for analysis on the spectra on the least weathered meteorites, as desired, since the technique is preliminary. The challenge with Antarctic meteorites is that they have been on the Antarctic ice for an unknown amount of time, exposed to an unknown amount of weathering and change in composition.

**Experimental:** The spectral data that we used for this project was obtained from the NASA Reflectance Experiment Laboratory (RELAB) database, an online database from Brown University. In the near-IR spectrum, pyroxene has two main absorption bands, one at ~1µm and another at ~2µm. Among other minerals, the amounts of CPX and OPX play a large role in the measurements of these absorption bands [5]. The first step was to visually inspect the spectra.

To do this, a program using the Python programming language was created to easily plot data from RELAB. It takes in an id number (found in a RELAB spreadsheet that correlates a sample name to an id number). The program then automates the process of finding the file(s) corresponding to the id. The spectra are then plotted on a graph, with error bars, if standard deviation is given with the data file. Next, the MGM (Modified Gaussian Model) software was used to analyze the spectra. MGM attempts to separate the different absorption bands associated with different minerals [6]. To separate the absorption bands, MGM uses a startup file, containing parameters about the curve-fit of the spectra. Once the fit is complete, the Component Band Strength Ratio (CBSR) is determined.

$$CBSR = \frac{Band\ Strength\ of\ the\ OPX\ component}{Band\ Strength\ of\ the\ CPX\ component}$$

The output from this ratio was then calibrated using measurements made by Sunshine and Pieters to find the amount of CPX [5]. The CBSR values for all sample are shown in Table 1. Numerous spectrometer problems kept us from measuring the spectra of the recent Vincencia meteorite.

*Table 1: Table lists the name of the samples used in this study, class, and corresponding Component Band Strength Ratio (CBSR).*

| Name | Class | CBSR - 1µm | CBSR-2µm |
|---|---|---|---|
| Dhajala | H3.8 | 2.2617 | 2.4599 |
| Hallingeberg | L3.4 | 1.5762 | 1.3611 |
| Chainpur | LL3.4 | 1.4923 | 1.5010 |
| Parnallee | LL3.6 | 1.0307 | 2.0094 |
| Krymka | LL3.2 | 1.0861 | 1.0703 |
| Bishunpur | LL3.1 | 0.9560 | 0.8556 |
| Hedjaz | L3.7 | 1.6608 | bd* |
| Khohar | L3.6 | 1.6472 | 2.6178 |
| Tieschitz | H/L3.6 | 2.5193 | 1.2925 |
| Mezo-Madaras | L3.7 | 2.0244 | 2.0431 |

*Table 2: Names of the samples used in this study, their classes, and the percentage clinopyroxene (of total pyroxene) for both 1*µm and 2µm bands.

| Name | Class | 1µm | %CPX | 2µm | %CPX |
|---|---|---|---|---|---|
| Dhajala | H3.8 | 0.90 | 43 | 1.93 | 40 |
| Hallingeberg | L3.4 | 0.94 | 56 | 2.01 | 61 |
| Chainpur | LL3.4 | 0.92 | 59 | 1.92 | 58 |
| Parnallee | LL3.6 | 0.94 | 69 | 2.05 | 47 |
| Krymka | LL3.2 | 0.94 | 68 | 1.95 | 68 |
| Bishunpur | LL3.1 | 0.93 | 71 | 1.91 | 73 |
| Hedjaz | L3.7 | 0.91 | 54 | 1.89 | bd* |
| Khohar | L3.6 | 0.92 | 51 | 1.96 | 33 |
| Tieschitz | H/L3.6 | 0.93 | 38 | 1.97 | 62 |
| Mezo-Madaras | L3.7 | 0.92 | 46 | 2.00 | 46 |

**bd, data unable to be calculated due to unavailable spectra*

**Results:** The results of MGM data reduction are shown in Tables 1 and 2. Table 1 shows the CBSR, and Table 2 shows the percent CPX, calibrated with the measurements of Sunshine and Pieters [5]. The centers of the bands for each sample had ranges from 0.90 to 0.94 in the 1µm band, and from 1.89 to 2.05 in the 2µm band. The percent clinopyroxene (of total pyroxene) is given next to the center of each (1µm and 2µm) band.

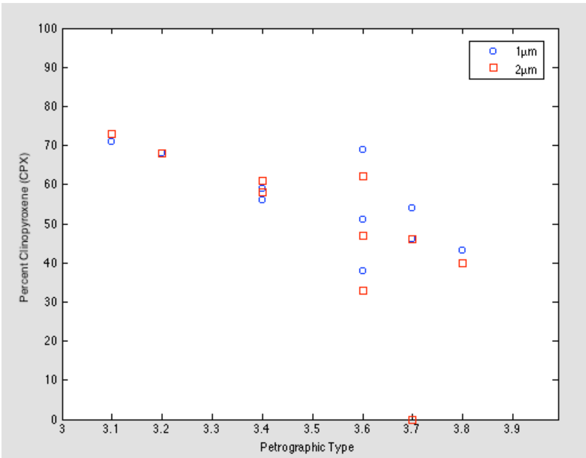


*Figure 1: Graphed data from Table 1 of both 1µm and 2µm regions. Red squares are 2µm, blue circles are 1µm.*

Figure 1 shows that there is a downward trend in the amount of clinopyroxene as the petrographic type approaches class 4, or EOC. The 2µm data point on the 3.7 is at 0% CPX because its percentage could not be determined through MGM. Another characteristic of the data is that, except for a few samples, the 1µm and 2µm percentages have a reasonable agreement. The data also shows that there is a change of ~40% CPX in the petrographic types 3.1-3.8.

**Discussion:** It is often difficult to analyze the compositions of UOC as they undergo many changes through metamorphism. Measuring these changes and properties of the meteorites is challenging. The ability to detect CPX is therefore valuable for studying the metamorphic history of these meteorites in the laboratory [4]. The disparity in the percent clinopyroxene for the 3.6 petrographic type is clearly visible in Figure 1. There are many reasons as to why this could be. Since MGM attempts to separate the mineralogy of the spectra, other minerals than pyroxene could have affected the quality of the MGM fit. In addition, since these meteorites are UOC, the heterogeneity could have caused some parts to have higher amounts of CPX than other. Finally, there is a possibility that any (or more than one) of the meteorites has been misclassified at type 3.6.

The technique of using spectroscopy can be used for the remote sensing and detection of CPX/OPX of UOC material on asteroid surfaces. The data could then be used to classify the material into petrographic types 3.0-3.9.

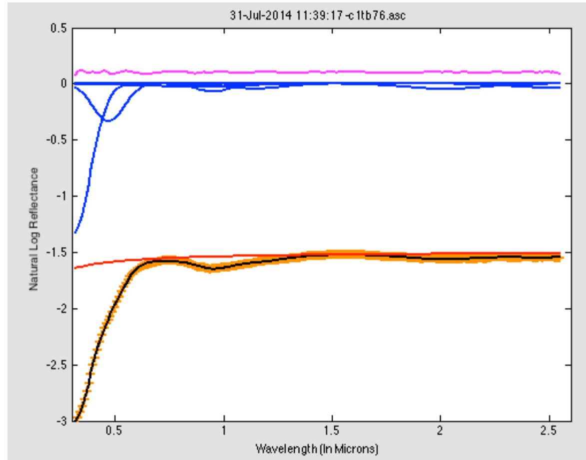


*Figure 2: MGM-fit to L3.4 meteorite Hallingeberg. The Component Band Strength Ratio was obtained from the data of this fit. It was then calibrated and the 56% CPX for the 1µm and 61% CPX for the 2µm band was obtained.*

**Conclusion:** The use of spectroscopy and spectral data can be used for the analysis of percentage CPX in UOC material, as well as the classification (3.0-3.9) of this material. In the future, it is possible that this technique could be used for the analysis of asteroids, and the detection of UOC material on them [7,8]. This method is surpassed only by thermoluminescence, which utilized the crystallization of feldspar [2]. However, this technique does not require a laboratory sample like thermoluminescence and can be applied remotely.

**Acknowledgements:** We are thankful to NASA Ames, and to the many scientsists who have been helpful in discussions and facilty use. Especially, Ted Roush, Andy Mattioda, and Chris Mckay. M.T. wishes to thank the V.I.P. program, H.S. the NPP program, and D.S., BAERI.

**References:**
[1] Van Schmus and Wood (1967) Geochim. Cosmochim. Acta 31, 747-765. [2] Sears et al. (1980) Nature 287, 791-795. [3] Dodd et al. (1967) Geochim. Cosmochim. Acta, 31, 921-934. [4] Sissay et al. (2011) 42nd LPSC, abs #1601. [5] Sunshine and Pieters (1993) J. Geophys. Res. 98, 9075-9087. [6] Sunshine et al. (1990) J. Geophys. Res. 95, 6955-6966 [7] Sears et al. (2009) 72nd Ann. Mtg. MetSoc, abs #5170. [8] Sears et al. (2010) 73rd Ann. Mtg. MetSoc, abs #5056.