NEAR-IR REFLECTANCE SPECTRAL PROPERTIES AND METAMORPHIC HISTORY OF UNEQUILIBRATED (TYPE 3) ORDINARY CHONDRITES.

A. Sissay[1, 3], D. Ostrowski[3], K. M. Gietzen[3], & D.W.G. Sears[2,3]. [1]Southern Univ. and A & M College, Baton Rouge, LA 70813. [2]Dept. of Chemistry & Biochemistry, Univ. of Arkansas, Fayetteville, AR 72701. [3]Arkansas Center for Space & Planetary Sciences, Univ. of Arkansas, Fayetteville, AR 72701.

Introduction: The largest meteorite group (the ordinary chondrites) is sorted into chemical classes (H, L, and LL) by the FeO in silicates and the amount of metallic Fe. They represent fairly anhydrous conglomerates of early asteroid surface materials. Additionally, these three classes are sorted into petrographic types that reflect parent body metamorphism, the least altered or "unequilibrated" ordinary chondrites (UOC) are subdivided into type 3.0 to 3.9, while the "equilibrated" ordinary chondrites (EOC) are subdivided into types 4-6 [1,2].

Among the many mineralogical, petrographic, and physical properties that reflect the considerable range metamorphic alteration throughout the type 3s, is the nature of the pyroxene. In the EOC the pyroxene is predominantly orthopyroxene (OPX), whereas in the UOC significant amounts of clinopyroxene (CPX) are present [3]. In the present paper we are interested in determining whether reflectance spectra can be used to detect CPX in the UOC, and whether the amount measured varies with petrographic type. Another important aspect of our studies are that since reflectance spectra currently provide the best means of determining asteroid surface compositions, these data provide ground truth for that effort [4,5].

Experimental: The spectra we used were obtained from the RELAB database and from measurements made on our laboratory using a Nicolet FTIR spectrometer (Table 1). Where previous data were available, our spectra showed reasonable agreement. The near-IR spectra for pyroxene contains two deep absorption bands, one at ~1 µm and one at ~2 µm, the exact wavelength and depth depending on the relative proportions of CPX and OPX (with a possible effect from other minerals). We determined calibration curves using data from a detailed study of Sunshine and Pieters [6]. The wavelength calibration curve for the 1 µm band, for seven CPX/OPX mixtures and a range of grain size, is shown as an example (Fig. 1). We estimated the position and depth of the 1 µm and 2 µm bands by direct measurement from the raw spectra and refer to the resulting CPX values as "visual" estimates. Replicate measurements suggest that the CPX values this determined have 1 σ uncertainties of ~35% for the 1 µm band and ~15% for the 2 µm band.

As a second approach we performed a spectrum analysis using the MGM software, which attempts to separate absorption bands associated with different minerals [7]. Olivine has a band at ~1 µm and feldspar has bands at ~1 µm, ~2 µm and other wavelengths depending on composition. The ratio of the band strength of the OPX component to the band strength of the CPX component is determined from the MGM output and this is again calibrated using Sunshine's laboratory measurements to find the amount of CPX in the pyroxene. Replicate measurements suggest that 1 σ uncertainties for this method are about 5%.

Table 1: Samples used in the present study, their classifications, and the calculated CPX (as a percentage of total pyroxene) determined by (1)naked eye determination of band wavelengths ("visual") and (2) spectrum analysis with the MGM software ("MGM"). [+].

Name	Class	N	1 µm	% CPX		2 µm	% CPX	
				Visual	MGM		Visual	MGM
Dimmit	H3.7	1	0.94	44	na	1.93	55	Na
Y-74191	L3.7	5	0.90	14	64	1.90	43	28
ALHA77214*	L3.4	2	0.92	28	78	1.94	58	73
Mezo-Madaras	L3.7	4	0.92	28	43	2.00	71	30
Krymka	LL3.1	2	0.94	44	77	1.95	62	75
Hallingeberg	L3.4	1	0.94	44	61	2.01	70	63
Moorabie	L3.8	1	0.91	21	42	2.00	70	53
Bishunpur	LL3.1	1	0.93	36	78	Bd	Bd	73
Dhajala	H3.8	1	0.90	14	bd	1.92	52	Bd
Hedjaz	L3.7	1	0.91	21	67	1.89	36	43
Suwahib (Buwah)	H3.8	1	0.92	28	bd	1.92	52	Bd
Khohar	L3.6	1	0.92	28	bd	1.96	64	Bd
GRO95505*	L3.4	1	0.93	36	na	1.94	58	Na
GRO95504*	L3.5	1	0.91	21	na	1.87	24	Na
GRO06054*	L3.6	1	0.94	44	na	1.98	69	Na

[+] N, number of spectra analyzed, na, data not available; bd, data below detection limit.

Data from RELAB unless indicated with an asterisk in which cases data were obtained in our laboratory.

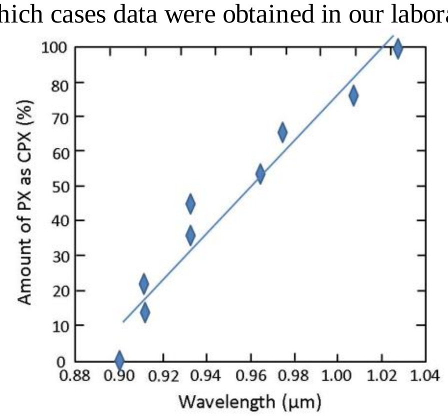

Fig. 1. Calibration plot for the amount of CPX in the pyroxene as a function of wavelength for the 1 µm band. A similar plot was produced for the 2 µm band. (Data from ref 7).

Results: The results of our CPX determinations by our visual method are shown in Table 1 and Fig. 2. The method indicates the presence of 15-70% CPX in the pyroxene. The data for the 1 µm band show a decreasing abundance from ~40% to ~20% with petrographic type. Data for the 2 µm band are generally 70%-50% and independent of type although three samples of petrographic type >3.5 have amounts <50%.

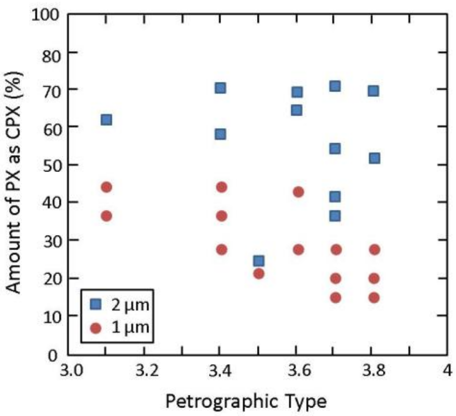

Fig. 2. The amount of UOC pyroxene that is CPX form as determined by visual inspection of the 1 µm and 2 µm peaks as a function of petrographic type. The method indicates the presence of 15-70% CPX in the pyroxene with the data for the 1 µm band showing a decreasing trend with type while the data for the 2 µm band seems independent of type.

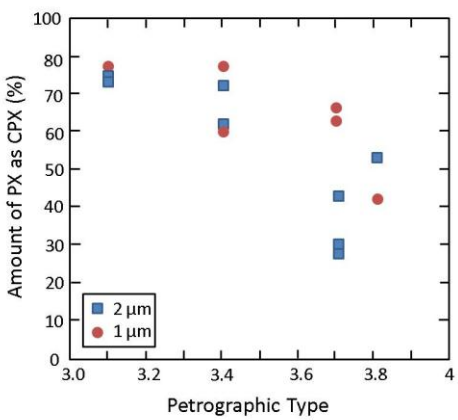

Fig. 3. The amount of UOC pyroxene that is CPX form as determined by spectrum analysis using the MGM software for the 1 µm and 2 µm peaks as a function of petrographic type. The method indicates the presence of ~40 to ~80% CPX in the pyroxene with reasonable agreement between the1 µm and 2 µm bands. The amount decreases in a non-linear fashion with increasing petrographic type.

The results of our CPX determinations based on data extracted by the MGM program are shown in Table 1 and Fig. 3. To date we have not completed data reduction on all the samples, but the data currently available suggest that (1) CPX in the lower petrographic types is higher than determined previously, (2) there is reasonable agreement between the data obtained for the 1 µm and 2 µm bands, and (3) the amount of CPX in the pyroxene seems to decrease from nearly 80% to less than about 40% with increasing petrographic type.

Discussion: Type 3 ordinary chondrites undergo a great many changes in response to low grade metamorphism, some of them very marked. Thus it is often a challenge to decipher primary, premetamorphic, properties of these meteorites. The quantitative determination of CPX by reflectance spectroscopy is therefore a valuable addition to the armory for studying metamorphic history of these important meteorites in the laboratory.

What is particularly significant is that reflectance spectroscopy is a remote sensing technique that can be applied to the analysis of asteroid surfaces. For the first time, we have a means of recognizing UOC material on the surfaces of asteroids [8,9]. When asteroids have the spectral and photometric properties of ordinary chondrites (say, the S(IV) asteroids of Gaffey et al. [4]), but have significant CPX in the pyroxene, they are clearly UOC material. In fact, it seems that most of the S(IV) asteroids have UOC material on their surfaces.

The present study suggests that in addition to recognizing UOC material on asteroids, it is possible to determine a petrographic type 3.0-3.9. This will have major implications for such issues as the thermal history of the asteroids, their internal structure, the degree of excavation, or the degree of surface mass loss.

Conclusion: An additional method for assessing the metamorphic history of low-grade ordinary chondrites is determining their pyroxene crystallography through near-IR reflectance spectroscopy. The method is complementary to numerous existing techniques, surpassed only by thermoluminescence which utilizes crystallization of the feldspar [2]. However, these techniques all require laboratory samples. Determination of CPX in the pyroxene by reflectance spectroscopy enables these important determinations to be made for asteroid surfaces.

Acknowledgements: We are grateful to the NSF REU (AST) program for support.

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] Gaffey *et al.* (1993) *Icarus* **106**, 573-602. [5] Gaffey *et al.* (2002) In *Asteroids III*, 183-204. [6] Sunshine and Pieters (1993) *J. Geophys. Res.* **98**, 9075-9087. [7] Sunshine *et al.* (1990) *J. Geophys. Res.* **95**, 6955-6966 [8] Sears *et al.* (2009) *72nd Ann. Mtg. MetSoc*, abs #5170. [9] Sears *et al.* (2010) *73rd Ann. Mtg. MetSoc*, abs #5056.