ANALYSIS OF REFLECTANCE SPECTRA OF ORDINARY CHONDRITES: IMPLICATIONS FOR ASTEROIDS. K. M. Gietzen[1] <kgietze@uark.edu>, C. H. S. Lacy[1,2], D. R. Ostrowski[1], D. W. G. Sears[1,3], [1]Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, AR 72701, [2]Department of Physics and Astronomy, University of Arkansas, Fayetteville, AR 72701 [3]Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR 72701

Introduction: Chondritic meteorites have a composition very similar to that of the photosphere of the Sun. They are classified into nine or more groups based on subtle variations in bulk phase and mineral compositions. The most abundant of these are the ordinary chondrites, which comprise ~85% of all meteorite falls and make up three of the chondrite classifications, namely H, L and LL. They are additionally sorted into petrographic types 3, 4, 5 and 6 according to the degree of metamorphism. The pyroxene structures convert from clinorhombic (CPX) to orthorhombic (OPX) form with metamorphism.

In the search for parent bodies for meteorites, asteroids have always seemed the logical solution. In particular, the S asteroid population has long been the center of the search for a connection with the ordinary chondrites due to their relative abundance to the asteroid population and the seemingly similar composition. The subtle spectral variations in the S asteroids and the ordinary chondrites and in the asteroids themselves have made this connection difficult to make. Recent work has found the clinorhombic form of pyroxene on surfaces of S asteroids which may be able to aid in the connection of these two groups of solar system bodies [1].

Experimentation: Reflectance spectra (.3 – 2.5 μm) for seven ordinary chondrites (Table 1) were obtained through the NASA Planetary Data Systems database [2]. The spectra were analyzed using the Modified Gaussian Model (MGM) [3] as were the asteroids in our earlier work.

Results: Our analysis indicated that there are absorption features in both the 1 and 2 μm regions present in all seven chondrites. This would suggest the presence of pyroxenes in all. However, there is an indication that the structure of the pyroxenes is different in the type 3 chondrites compared to the type 6 chondrites. As shown in the upper plot in Fig. 1, there is an additional absorption feature in the 2 μm region of the type 3 chondrites that is not present in the spectra of the type 6 (Fig. 1 lower plot). This additional feature represents the presence of clinorhombic pyroxenes (CPX).

Discussion: There are two or three individual absorption bands that combine to make up the 1 μm and 2 μm bands characteristic to pyroxenes which MGM can separate. The component band strength ratio (CBSR) was calculated for both the 1 and 2 μm regions using the methods of Sunshine and Pieters [3]. The CBSR allowed us to determine the percentages of clinopyroxenes relative to total pyroxenes for each chondrite (Table 1).

Table 1. Type 3 and 6 ordinary chondrites analyzed in the present study, their class and the percent clinopyroxene determined by spectral analysis(1)

Meteorites	Class	% CPX	
		1 μm	2 μm
Type 3 Ordinary Chondrites			
Bishunpur	LL3.1	78±5	73±5
Parnallee	LL3.3	77±2	64±1
Hedjaz	L3.7	66±6	44±5
Dhajala	H3.8	84±7	63±4
Type 6 Ordinary Chondrites			
Manbloom	LL6	84±2	n.d.
Colby (Wisconsin)	L6	79±2	n.d.
Brudenheim	L6	76±2	n.d.

1. n.d., not detected

In the 2 μm region, we found CPX percentages to range from 44 – 73% for the type 3 chondrites and found no evidence of CPX for the type 6 chondrites. The CBSR also shows percentages for CPX in the 1 μm region for all the type 3 chondrites. In general, the 1 μm percentages are greater than those for the 2 μm for type 3. The type 6 chondrites show no indication of CPX. Other minerals such as plagioclase and olivine have absorption features in the 1 μm region in the same range as the clinorhombic pyroxenes that are responsible for these numbers. These minerals do not, however, have a 2 μm feature.

Gietzen, et al. [1] found abundant clinorhombic pyroxenes in seven of eight S asteroids ranging from 42 – 61%, similar results to what is found for the type 3 ordinary chondrites in this work. This would suggest that the surfaces of S asteroids are type 3 ordinary chondrite material and provides an explanation of the asteroid-meteorite mismatch. We are not, however, the first to observe abundant clinopyroxene in S asteroids. Gaffey et al. [4] reported finding calcic pyroxene in many of their S asteroid subclasses. They attributed it to be igneous in origin which further muddled the meteorite-asteroid connection since there is not a large representation in the terrestrial meteorite collection [5]. However, if the pyroxenes were not calcic, but still clinorhombic in structure, there may be a connection with the S asteroids.

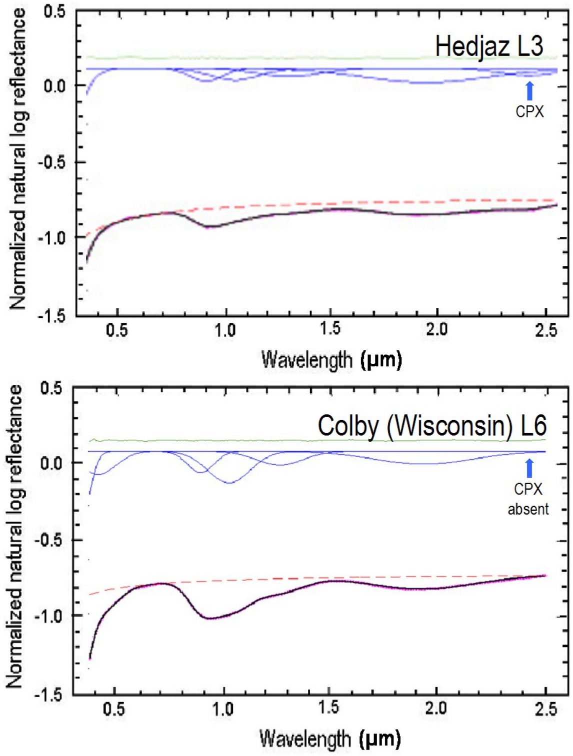
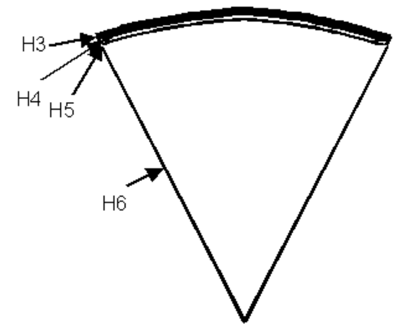


Fig. 1. Application of our data reduction methods to CPX-bearing type 3 chondrites and CPX-free type 6 chondrites confirms our interpretation of the S asteroid spectra contain evidence for clinopyroxene on the surfaces.

The lower petrographic unequilibrated ordinary chondrites (UOC) are known to contain calcium-free CPX which converts to OPX with metamorphism. The UOC are rare, but the equilibrated ordinary chondrites (EOC) are much more common. The division of the ordinary chondrites into types 3 – 6 is based on the degree of metamorphic alteration, with type 3, (unmetamorphosed or unequilibrated chondrites) gradational to type 6, (metapmorphosed and equilibrated) chondrites. ^{26}Mg was discovered in high aluminum-low magnesium minerals in meteorites, including ordinary chondrites indicating that ^{26}Al was once present in these meteorites [7-10]. The presence of ^{26}Al would have been an important source for internal heating of early solar system bodies that could cause the metamorphism of the meteorite parent bodies. Objects that formed in the early solar system would have onion-skin structures with metamorphosed interiors and increasingly less metamorphosed materials toward their surfaces. Thermal models have indicated that the relative proportion of types 3, 4, 5 and 6 produced this way (Fig 2) are in agreement with statistics for terrestrial meteorite falls [11].



Akridge et al. (11)

Fig 2. Recent model for the interior of an ordinary chondrite parent body, in this case the H chondrites. The numbers (3, 4, 5, 6) refer to the temperatures experienced as a result of internal heating, the level of metamorphism caused by the heating increasing along the series 3, 4, 5, and 6.

Conclusions: The implications of our findings suggest that there is a strong relationship between the S asteroids and ordinary chondrites. The meteorite-asteroid mismatch between these two groups may not be due to space weathering or other suggested processes. The onion-skin models such as that of Akridge et al. [11] shown in Fig. 2 can account for the rarity of the type 3 ordinary chondrites and the abundance of type 6 ordinary chondrites implying their parent bodies experienced internal heating and are spherically zoned. The meteorite-asteroid mismatch can be largely explained by the fact that the meteorites are a sampling of the interiors of asteroids and astronomical spectroscopy is sampling their surface. This would imply that the S asteroids would be good candidates as ordinary chondrite parent bodies.

References: [1] Gietzen, K. M., et al. (2007) *AAS/DPS, #39*, 33.11. [2] Gaffey, M., Meteorite Spectra. EAR-A-3-RDR-METEORITE-SPECTRA-V2.0. NASA Planetary Data System, 2001. [3] Sunshine, J. M. and Pieters, C. M. (1993) *JGR, 98,* 9075-9087. [4] Gaffey, M. J., et al. (1993) *Icarus, 106*, 573 [5] Gaffey, M. J. (2007) *Meteorit. Planet. Sci. Suppl*., *42*, 5296. [6] Van Schmus, W. R and Wood, J. A. (1967) *Geochim. Cosmochim. Acta, 31,* 737. [7] Lee, T., et al. (1973) *Astrophys. J. 121,* L107. [8] Grimm, R. E. and McSween, H. Y. (1993) *Science, 259,* 653. [9] Hutcheon, I. D. and Hutchison, R. (1989) *Nature, 337,* 238. [10] Rudraswami, N. G. and Goswami, J. N. (2007) *Earth Planet Sci. Lett., 257,* 231. [11] Akridge, D. G., et al. (1998) *Icarus, 132,* 185.