IDENTIFYING ASTEROIDAL ORDINARY CHONDRITE ASSEMBLAGES AND PETROGRAPHIC TYPES FROM VNIR SPECTRA. M. J. Gaffey, Space Studies Department, John D. Odegard School of Aerospace Sciences, University of North Dakota, Box 9008, Grand Forks, ND 58202-9008. Email: gaffey@space.edu

Introduction: Because of a poor understanding of the delivery mechanisms of meteoroids from the asteroid belt, early asteroid spectral investigations often assumed that the abundance of various meteorite types among meteorite falls was approximately proportional to the abundance of such assemblages within the asteroid population. Based on that assumption, it was concluded that a large fraction of the asteroid population was composed of ordinary chondrite-type (OC) assemblages, and especially that the S-type asteroids were predominately OC assemblages. This misconception often persists even today and is commonly used - explicitly or implicitly - as a justification for assigning an OC composition to virtually any asteroid whose spectrum is generally OC-like.

Dynamical studies [1-3] have largely demolished the basis for this assumption. Instead, the meteorite flux reaching the Earth is dominated by source bodies in favorable locations adjacent to the chaotic zones associated with the mean motion (e.g., 3:1, 5:2) and secular resonances (e.g., ν_6) with Jupiter. Thus among the ~135 distinct source bodies which have contributed to the terrestrial meteorite collections [4], only three parent bodies are required for the ordinary chondrite meteorites.

Dynamical and spectral studies have linked the H-chondrites (which constitute ~1/3 of the meteorite falls) and the IIE iron meteorites to asteroid 6 Hebe which is located near the intersection of the 3:1 and ν_6 resonances [5]. The parent body of the L-chondrites (which also make up ~1/3 of the meteorite falls) must be similarly favorably located. Evidence of a major shock event ~480 Myr ago on the L-chondrite parent body raises the probability that it was broken up and dispersed to form an asteroid family close to one or more of the resonances [6,7]. Thus at the present time, the “single” L-chondrite parent body may actually be represented by multiple fragments from the breakup. The LL-chondrite parent body (~5% of meteorite falls) must be located in a somewhat less favorable location with respect to the important resonances.

None of this precludes the existence of asteroids composed of OC-like assemblages located away from the resonances. The short cosmic ray exposure ages of stony meteorites (as compared to iron meteorites) indicates that stones have short collisional lifetimes in space ($\approx\leq 5\text{x}10^7$ years). Unless a stony parent body is located favorably with respect to an “escape hatch” resonance, its fragments are unlikely to be well represented in the terrestrial collections. If it is generally OC-like, such a non-H, L, or LL “OC”-sample could easily escape identification among the vast collections of OC-meteorites.

Spectral Identification of OC-Asteroids: Too often asteroids with OC-like spectra have been identified as possible OC-parent bodies simply because the spectrum looks like an OC and it is assumed that OCs are common. It is important to keep in mind that almost any assemblage composed of a mixture of olivine and pyroxene - excepting those that are highly reduced or those that contain abundant carbon - will look like an OC-assemblage in some spectral interval. The diagnostic characteristic of an OC-assemblage is not that the spectrum looks like an OC, but that the mineralogy derived from the spectrum is consistent with an OC.

Identification of asteroidal OC assemblages must be based on mineralogy. Therefore to identify OCs, the spectra must have sufficient spectral coverage (wavelength range), resolution, and spectrophotometric precision so that mineralogically diagnostic spectral parameters can be reliably extracted. Thus no actual OC identifications can be based solely on CCD spectra (typically $\lambda_{Max} \leq 1$ µm). Nor can OCs be identified by direct comparison of observational and laboratory spectra, since space weathering can and does modify the spectra of asteroid surfaces in unpredictable ways.

Interpretive calibrations to transform such diagnostic parameters into mineralogical characterizations have been developed [8,9] but significant work remains to be done. The ratio of the relative areas of the broad ~1 µm and ~2 µm absorption bands (Band Area Ratio; BAR) provides a robust determination of the olivine-to-orthopyroxene ratio for olivine-orthopyroxene mixtures. Additional work is needed to expand the calibration to include clinopyroxenes (primarily calcic pyroxenes).

Band positions can be used to discriminate between OC types. The Band I and II centers of pyroxene show a systematic trend with increasing Fe^{2+} and Ca^{2+}. Figure 1 shows this trend for orthopyroxenes and calcic pyroxenes, and outlines the regions occupied by the H-, L-, and LL-chondrites. The systematic migration from left to right from H- to LL-type is an effect of increasing Fe^{2+} from the oxidation sequence from H- to LL-OCs. The vertical departure from the pyroxene trend line is due to the shift of the Band I center to longer wavelength with increasing olivine content. However, there is significant overlap such that the band positions could be consistent with an L- and a LL-chondrite or with an H- and an L-chondrite.

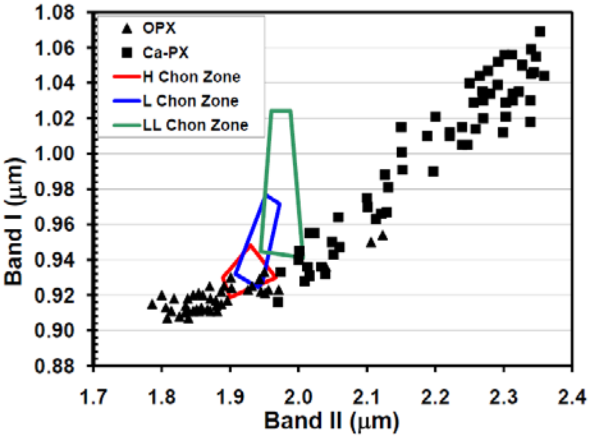

Figure 1: Band-Band plot for pyroxenes [10,11]. OC regions are outlined by the tetragonal shapes.

A set of equations have been defined to convert the band positions and BAR in a mafic-dominated asteroid spectrum to mean pyroxene composition [9]. These equations are set up as an Excel spreadsheet with empirical parameters specific to the H-, L- and LL-chondrites. Even with these specific parameters, the equations are limited when applied to OC spectra because they are derived to fit a wide range of pyroxene compositions [10,11]. Equations derived specifically from OC-assemblages would improve the calibration. However, one cannot treat the OCs as a single group.

OCs underwent oxidation which involved the conversion of pyroxene and Fe metal into olivine and an increase in the Fe^{2+} content of the olivine and pyroxene [12,13]. Figure 2 [from 12] shows the systematic variation in mineral composition with metamorphic grade. Figure 3 - from the data of [14] - shows that each OC type has a clear trend of relative mineral abundance (in this case olivine and low Ca pyroxene), but that the trends are offset. The result is that the "slope" of the equations needs to be adjusted to compensate for the changing mineral chemistry within each OC-type.

Although the current interpretive calibrations produce reasonable mineral determinations for OC-type assemblages, these determinations could be improved by deriving specific calibrations for the H-, L- and LL-types from high quality samples of those meteorites. An initial pass has been made using existing OC spectra, but the final calibrations will require a program of measuring OC spectra to provide a sufficient data set for the analysis.

References: [1] Wisdom J. (1985) *Icarus, 63*, 272-289. [2] Farinella P. et al. (1993) *Icarus*, *101*, 174-187. [3] Morbidelli et al. (1994) *Astron. Astrophys.*, *282*, 955-979. [4] Keil K. (2000) *Planet. Space Sci.*, *48*, 887-903. [5] Gaffey M. J. and Gilbert S. L. (1998) *MAPS*, *33*, 1281-1295. [6] Schmitz B. and Häggström T. (2006) *MAPS*, *41*, 455–466. [7] Nesvorný D. et al. (2007) *Icarus*, *188*, 400–413 [8] Cloutis E.A. et al. (1986) *JGR 91*, 11641-11653. [9] Gaffey M. J. et al. (2002) In *Asteroids III* (W. F. Bottke et al. Eds.), U. Arizona Press, pp. 183-204. [10] Adams J. B. (1974) *JGR 79*, 4829-4836. [11] Cloutis E. A. and Gaffey M. J. (1991) *JGR - Planet*, *96*, 22809-22826. [12] McSween H. Y., Jr. (1992) *Icarus*, *95*, 239-243. [13] McSween H.Y Jr. and Labotka T. C. (1993) *GCA*, *57*, 1105-1114. [14] McSween H.Y., Jr. et al. (1991) *Icarus, 90*, 107-116.

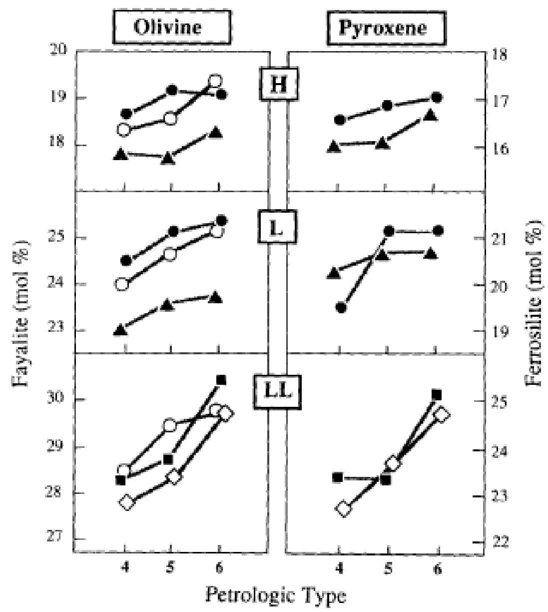

Figure 2: Variations in OC olivine and pyroxene compositions with metamorphic grade [from 12]

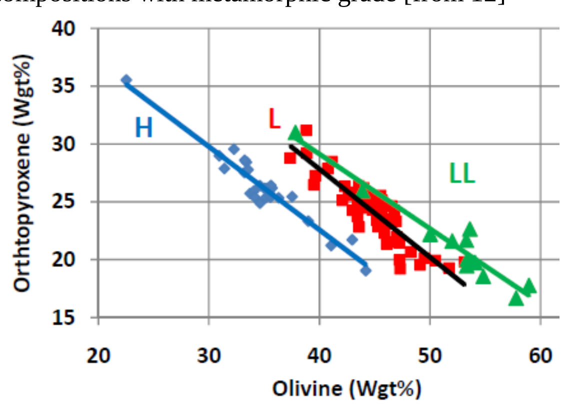

Figure 3: Normative abundances of orthopyroxene and olivine in H-, L-, and LL-chondrites. Data from [14].