



A coordinated spectral, mineralogical, and compositional study of ordinary chondrites

Tasha L. Dunn^{a,d,*}, Timothy J. McCoy^b, J.M. Sunshine^c, Harry Y. McSween Jr.^a

^a Department of Earth and Planetary Sciences, Planetary Geosciences Institute, University of Tennessee, Knoxville, TN 37902, USA

^b Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC 20013-7012, USA

^c Department of Astronomy, University of Maryland, College Park, MD 20742-2421, USA

^d Department of Geography–Geology, Illinois State University, Normal, IL 61761, USA

ARTICLE INFO

Article history:

Received 12 November 2009

Revised 23 February 2010

Accepted 23 February 2010

Available online 12 March 2010

Keywords:

Asteroids

Spectroscopy

Meteorites

ABSTRACT

Mineral compositions and abundances derived from visible/near-infrared (VIS/NIR or VNIR) spectra are used to classify asteroids, identify meteorite parent bodies, and understand the structure of the asteroid belt. Using a suite of 48 equilibrated (types 4–6) ordinary (H, L, and LL) chondrites containing orthopyroxene, clinopyroxene, and olivine, new relationships between spectra and mineralogy have been established. Contrary to previous suggestions, no meaningful correlation is observed between band parameters and cpx/(opx + cpx) ratios. We derive new calibrations for determining mineral abundances (ol/(ol + px)) and mafic silicate compositions (Fa in olivine, Fs in pyroxene) from VIS/NIR spectra. These calibrations confirm that band area ratio (BAR) is controlled by mineral abundances, while Band I center is controlled by mafic silicate compositions. Spectrally-derived mineralogical parameters correctly classify H, L and LL chondrites in ~80% of cases, suggesting that these are robust relationships that can be applied to S(IV) asteroids with ordinary chondrites mineralogies. Comparison of asteroids and meteorites using these new mineralogical parameters has the advantage that H, L and LL chemical groups were originally defined on the basis of mafic silicate compositions.

© 2010 Elsevier Inc. All rights reserved.

1. Introduction

Over the past few decades, an ongoing debate has centered on the identities of the ordinary chondrite parent bodies, the most common meteorites seen to fall to Earth. While earlier workers posited that ordinary chondrite-like bodies should be common in the asteroid belt, it is now generally recognized that only three parent bodies are required to account for the chemically-distinct H, L and LL chondrites. Each chondrite group is chemically homogeneous (Dodd, 1981), oxygen isotopes cluster within a narrow range (Clayton et al., 1991), and radiometric ages indicate that many H and L chondrites were ejected from the same parent body (Keil et al., 1994). Visible/near-infrared spectra have been the most widely-applied tool used in the search for these parent asteroids, due to the strong 1 μ m and/or 2 μ m absorption bands present in the dominant chondritic minerals olivine and pyroxene (Adams, 1974, 1975; Burns et al., 1972; Cloutis, 1985; Cloutis and Gaffey, 1991). This approach requires a direct comparison of spectral band parameters (e.g., Band I and II centers, band area ratios) between meteorite and asteroids. However, if robust relationships between

these spectral parameters and mineralogical parameters (abundances and compositions) could be established, these comparisons could be made using the same criteria that are used in meteoritics. Such a comparison has the advantage that the H, L and LL chemical groups were originally defined on the basis of bulk chemistry, particularly total iron abundance and mafic silicate compositions, and not on spectral parameters. The H, L and LL chondrite groups exhibit distinct compositional hiatuses, particularly with respect to mafic silicate compositions, although some authors have questioned whether L and LL chondrites are transitional (Rubin, 1990).

In this paper, we revisit spectral calibrations for asteroids using a data set of 48 measured ordinary chondrite modal abundances and corresponding silicate mineral analyses, which represent the complete petrologic range of the equilibrated ordinary chondrites (types 4–6) (Van Schmus and Wood, 1967). This is the first study in which spectral calibrations have been derived using actual measured ordinary chondrite modal abundances. Prior to this study, spectral calibrations were based on simple mixtures of mafic silicates (Cloutis et al., 1986) or normative abundances of ordinary chondrites (Burbine et al., 2003), due to the difficulty associated with quantifying modal abundances of fine-grained samples. Normative mineralogies are calculated from bulk chemistry using a standard CIPW (Cross, Iddings, Pirsson, and Washington) algorithm (Cross et al., 1902), and are used most often to determine abundances of fine

* Corresponding author at: Department of Geography–Geology, Illinois State University, Normal, IL 61761, USA.

E-mail address: tldunn@ilstu.edu (T.L. Dunn).

grained terrestrial samples, such as volcanic rocks. Our new calibrations based on measured abundances should yield more accurate mineralogical interpretations of asteroid spectra.

2. Background

The primary diagnostic feature in olivine is a composite absorption feature at $\sim 1 \mu\text{m}$, which consists of three distinct absorption bands. The composite $1 \mu\text{m}$ band, which is attributed to electronic transitions of Fe^{2+} occupying both the M1 and M2 crystallographic sites (Burns, 1970), moves to longer wavelengths as FeO content increases (King and Riddle, 1987; Sunshine and Pieters, 1998). Pyroxenes have two absorption bands at $\sim 1 \mu\text{m}$ and $\sim 2 \mu\text{m}$ that are associated with crystal field transitions in Fe^{2+} , which preferentially occupy the M2 site (Clark, 1957; Burns, 1970). Low-calcium pyroxenes, which are conventionally defined as having less than 11 mol% CaSiO_3 (wollastonite or Wo) (Adams, 1974), show a well-defined relationship between absorption band positions and composition, as both Band I and Band II positions increase with increasing ferrous iron content (Adams, 1974; Burns et al., 1972; Cloutis, 1985). There is also a correlation between composition and band positions in high-calcium pyroxene, although the relationship is complicated by the presence of calcium in addition to iron.

In spectra containing both olivine and pyroxene absorptions, the combined absorption features near $1 \mu\text{m}$ (Band I) and near $2 \mu\text{m}$ (Band II) are also sensitive to the relative proportions of olivine and pyroxene. The ratio of the areas of these two bands (Band II/Band I) is commonly used to estimate olivine and pyroxene abundances in meteorites and asteroids (Cloutis et al., 1986). The linear relationship between this band area ratio (BAR) and the ratio of pyroxene to olivine + pyroxene ($\text{px}/(\text{ol} + \text{px})$) was first recognized Cloutis et al. (1986), who expressed this relationship as

$$\text{BAR} = 0.024 \times (\text{px}/(\text{ol} + \text{px})) - 1.25. \quad (1)$$

While Cloutis et al. (1986) utilized this equation to derive BARs from mixtures of known mineral proportions, Gastineau-Lyons et al. (2002) used this relationship to derive mineral abundances from BARs of asteroid spectra, recasting the Cloutis et al. (1986) calibration as

$$\text{px}/(\text{ol} + \text{px}) = 0.417 \times \text{BAR} + 0.052. \quad (2)$$

However, because the Cloutis et al. (1986) regression was based on simple mixtures of olivine and orthopyroxene, the presence of more than one pyroxene (or other additional phases) would complicate spectral interpretations of asteroids made using this calibration (Gaffey et al., 1993; Sunshine et al., 2004).

In an attempt to determine the mineralogy of the S-type asteroids, Burbine et al. (2003) used normative abundances of the ordinary chondrites, which contain olivine, orthopyroxene and clinopyroxene, to derive a relationship between BAR and $\text{ol}/(\text{ol} + \text{px})$. Burbine et al. (2003) expressed their equation as

$$\text{ol}/(\text{ol} + \text{px}) = -0.228 \times \text{BAR} + 0.768. \quad (3)$$

The Burbine et al. (2003) calibration yields ordinary chondrite $\text{ol}/(\text{ol} + \text{px})$ ratios that fall within the same general range of $\text{ol}/(\text{ol} + \text{px})$ ratios measured from normative mineral abundances of ordinary chondrites (McSween et al., 1991). However, there are systematic differences between the two data sets.

3. Analytical methods

A total of 48 ordinary chondrite samples representing each of the ordinary chondrites groups (H, L, and LL) and petrologic categories 4–6 (Van Schmus and Wood, 1967) were selected for analysis.

To ensure that samples represented a single petrographic type, visibly polymict samples were excluded from the study, and only unbrecciated falls with minimal terrestrial weathering were selected for analysis. Reflectance spectra of ordinary chondrites were acquired using a bidirectional spectrometer at Brown University's Keck/NASA Reflectance Experiment Laboratory (RELAB) (Pieters and Hirio, 2004). Spectra of 37 chondrite falls in this study (samples with RELAB IDs TB-TJM-XXX; Table 1) were collected by Burbine et al. (2003) from powders originally prepared for bulk chemical analysis by Jarosewich as part of the Smithsonian Institution's Analyzed Meteorite Powder Collection. Small chips of the remaining 11 chondrites (samples TH-HYM-XXX; Table 1) were acquired from the Natural History Museum in London and from the Smithsonian Institution. Consistent with sample preparation described in Burbine et al. (2003), samples were ground with mortar and pestle into a fine powder ($< 150 \mu\text{m}$), and the metal fraction of the samples was then magnetically removed from the powder in preparation for spectral analysis. Only the silicate portion of each sample was analyzed. Although removing metal from the sample may alter the slope of the spectrum, it should not affect silicate spectral features (i.e. BAR, Band I or Band II center) or spectrally-derived silicate mineral abundances.

For the 11 chondrites obtained for this study (TH-HYM-XXX; Table 1), availability of material was limited, and the mass of material used to prepare these samples was significantly smaller than the multi-gram masses used by Jarosewich (1990, 2006). It is possible that these powders may not be as representative as those prepared by Jarosewich (1990, 2006), but they were necessary to ensure that the H, L, and LL ordinary chondrite groups were equally represented. Unrepresentative sample powders may be expected to yield modal abundances that are higher or lower than actual values, thereby skewing trends based on modal data. For example, measured abundances of low-Ca pyroxene in two L5 chondrites with limited material (Ausson and Blackwell) are 1–2 wt.% higher than abundances in the remaining L5 chondrites. This results in $\text{ol}/(\text{ol} + \text{px})$ ratios that are lower than those of the remaining L5 chondrites. However, most samples obtained for this study do not appear to show anomalous modal abundances, and it is unlikely that a few potentially unrepresentative samples would alter conclusions based on 48 samples.

Spectra for all 48 samples were collected over a range of $0.32\text{--}2.55 \mu\text{m}$ at a sampling interval of $0.01 \mu\text{m}$. An incident angle of 30° and an emission angle of 0° were used for spectral measurements. Band area ratios and band centers were determined by first dividing out a straight-line continuum using points on either side of Band I and Band II (with $2.5 \mu\text{m}$ as the furthest data point). The area of each band was measured as the area between the absorption band and a tangent line drawn between two peaks on either side of the absorption, and the band area ratio (BAR) was calculated by dividing the area of Band II by the area of Band I. The average error associated with BAR is $0.01 \mu\text{m}$. Band center was determined by fitting a second order polynomial to the bottom of the continuum removed feature, and the minimum point of the polynomial was used as the band center. The uncertainty of band centers is typically between 0.01 and $0.03 \mu\text{m}$, with an average error of $0.02 \mu\text{m}$. Classifications, grain sizes, and spectral parameters (BCI, BCII, and BAR) are listed in Table 1.

XRD data were collected using an INEL curved position-sensitive detector (PSD) at the Natural History Museum in London, England. Mineral abundances were determined using a whole-pattern XRD fitting procedure, first introduced by Cressey and Schofield (1996) and further developed by Batchelder and Cressey (1998). Experimental configurations and a detailed description of the XRD fitting procedure are reported in Dunn et al. (2010a). Olivine and low-Ca pyroxene compositions in 38 of the ordinary chondrites in this study were determined using a Cameca SX-50 electron microprobe

Download English Version:

<https://daneshyari.com/en/article/1774080>

Download Persian Version:

<https://daneshyari.com/article/1774080>

[Daneshyari.com](https://daneshyari.com)