

INFRARED (2.5 TO 14 μ M) REFLECTANCE MICROSPECTROSCOPY OF METEORITIC MINERALS IN THIN SECTION. G.K. Benedix¹ and V.E. Hamilton², ¹Dept. of Mineralogy, The Natural History Museum, Cromwell Road, London, UK SW7 5BD (g.benedix@nhm.ac.uk); ²University of Hawai'i, 1680 East-West Road POST 504, Honolulu, HI 96822 USA (hamilton@higp.hawaii.edu)

Introduction: The surface mineralogy of Mars is constrained using spectral and chemical data gathered by spacecraft in orbit around and landers roving on the planet. One common technique for determining lithologies is thermal emission spectroscopy. Virtually the entire surface of Mars has been mapped using either the TES [1] or THEMIS [2] instruments. These complex spectral data can be deconvolved [3] into their constituents using a spectral database [e.g., 4] of terrestrial minerals, thus giving a good understanding of the surface composition of Mars, which in turn allows interpretation of its history. The spectral database in use is extensive and contains over 200 different phases.

Most spectral data are acquired using systems that observe spots ranging from 1mm to several cm [e.g., 5,6]. The use of microspectroscopy is limited to a few studies [e.g. 6]. This method allows expansion of spectral databases to include exotic and fine-grained minerals for which it would be difficult to obtain physical separates, but which are accessible in meteorite thin sections. Preliminary spectral measurements [7,8] using an infrared microscope attached to a benchtop FT-IR have focused on chips or thick sections of meteorites or terrestrial rocks. Using a similar system, we measured the mineral constituents of several Martian meteorites in thin section.

Samples: Building upon preliminary data for Nakhla [9], Martian meteorites Los Angeles and Zagami have been added to this study. These three meteorites represent a range of mineral compositions and textures with which to test the capability of the IR microscope. Results are shown for Nakhla.

Analytical Techniques: X-ray element and back-scattered electron maps were acquired of each thin section, using the JEOL 5900LV Analytical SEM at the Natural History Museum. These were used as a roadmap to pinpoint specific grains for measurement.

We acquired bi-directional reflectance spectra from 2.5 to 14 μ m (4000 to 700 cm^{-1}) using a Perkin Elmer AutoIMAGE FT-IR microscope attached to the SpectrumOne FT-IR spectrometer. The aperture was 25 microns and spectra were obtained at a spectral resolution of 4 cm^{-1} . We used a polished gold calibration standard to determine relative reflectance. For the quartz measurements, 480 scans were averaged. For augite in Nakhla, 10 grains were randomly chosen without noting orientation of the grains. For compari-

son to other infrared measurements, we display our reflectance data as emittance using Kirchoff's law.

Previous workers [7,8] suggested that the use of thin sections by this method was hampered by the transparency features of the glass slide and epoxy in contact with the sample. We have acquired spectra of two slides and do not find their spectra to be significant (>5%) contributors to the measured meteorite mineral spectra. If we find cases where the slide glass is observed, it should be possible to linearly remove the spectral contribution of the slide.

Results I – proof of concept: We analyzed a single quartz crystal (BM 1921,120) under the same conditions as those applied to the meteorite samples. Fig. 1 shows our measurement compared to that of randomly oriented quartz grains from the ASTER (<http://speclib.jpl.nasa.gov/> - sample “quartz.1”) and ASU (<http://speclib.asu.edu/> - sample “quartz055”) spectral libraries. The ASTER and ASU spectra are not directly comparable because the ASTER data are biconical reflectance and the ASU data are emission (equivalent to hemispherical reflectance).

Although the absolute band depths differ, on a plot of normalized emittance (Figure 1), the shapes of the spectra, and specifically, the band centers are nearly identical. The ASTER spectrum displays the short wavelength broadening of the reststrahlen band that is common to biconical reflectance data. In addition, the microscope spectrum has only one peak at ~12.5 microns, whereas randomly oriented quartz grains have two. This is no doubt due to orientation effects, which are an issue in microspectroscopy. To compensate for this, we will collect many individual grain spectra to determine what the average randomly-oriented spectrum should look like.

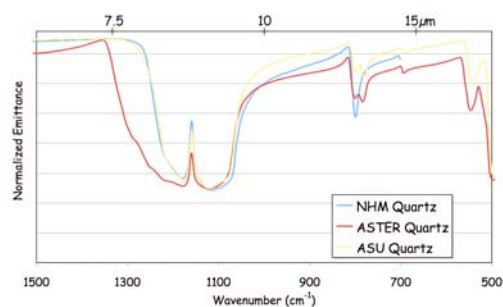


Figure 1. Comparison of quartz spectra from the ASTER spectral library (red) and the ASU spectral library (yellow) with a measurement using the IR microscope at the Natural History Museum (blue).

Results II – Preliminary meteorite data: An averaged, normalized spectrum of the randomly measured augite grains is illustrated in Figure 2, along with a terrestrial augite from the ASU spectral library (ASU_catalog# - HS-119.4B) and a Nakhla whole rock spectrum [10]. For convenience, all spectra were normalized to the maximum value between 8 and 12.5 μm (1200 and 800 cm^{-1}).

Overall the shapes of the spectra are similar with a broad absorption around 8.75 μm ($\sim 1100\text{cm}^{-1}$) and another at 11 μm ($\sim 875\text{cm}^{-1}$) and consistent with clinopyroxene [11]. The Nakhla whole rock spectrum is broadly consistent with the Nakhla thin section augite, especially in the 10-12 μm region. The main difference between the spectra occurs between 10 and 12 μm , where a weak triplet is seen in the IR microscope data. This is commonly found in the spectra of clinopyroxenes with low (<15%) Ca contents [11]. There is a 6 wt% difference in CaO (table 1) between the two augites, with Nakhla having the lower CaO content. Other elements where the two augites differ significantly are Mg and Fe, although the difference is much less and therefore no concomitant variation in spectra is seen.

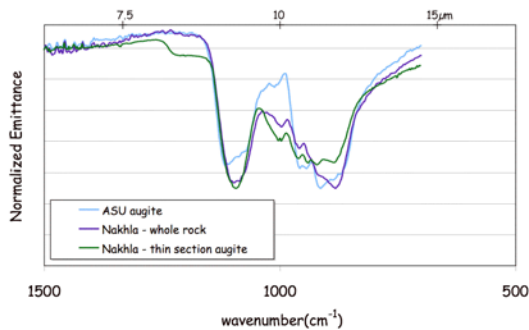


Fig. 2. Normalized emittance spectra of augite from Earth and Mars, compared with Nakhla whole rock [10]. An augite from the ASU spectral library (blue line) is compared to an average of 10 augite grains from Nakhla in thin section.

Table 1. Augite compositions for the spectra illustrated in Figure 2. Composition of Nakhla augite from [12].

	ASU Augite	Nakhla Augite
SiO ₂	52.87	52.13
TiO ₂	0.02	0.20
Al ₂ O ₃	0.92	0.75
Cr ₂ O ₃	--	0.38
FeO	10.20	14.09
MnO	0.29	0.43
MgO	11.91	13.41
CaO	24.08	18.05
Na ₂ O	0.65	0.19
Total	100.94	99.63

Furthermore, preliminary results indicate that there are spectral differences between cores and rims of the highly zoned Nakhla augites (figure 3).

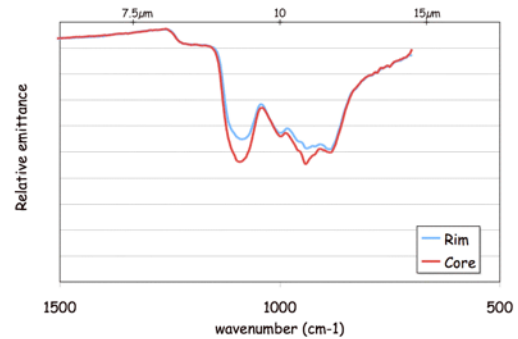


Figure 3. Comparison of core and rim spectra from a zoned augite grain in Nakhla. The rim is more Fe-rich relative to the core.

Limitations: As discussed previously [7,8], we found that crystal orientation effects are an issue. Our preliminary method was to randomly measure 10 grains and average those spectra, which produces a spectrum (Figure 2) that can be compared to the whole rock spectrum, however there are several features in the averaged spectrum which are likely due to orientation. We will further explore other methods to compensate for these effects.

Conclusions: Microspectroscopy provides a way to obtain spectra of Mars-specific mineral phases or phases that are well characterized and/or difficult to obtain as physical separates. Although these spectra can not be used directly for TES deconvolutions (because they do not extend to 25 - 50 μm), the data from this microscope do overlap very well with the THEMIS wavelength range and may be resampled for use in interpreting THEMIS data.

Future work: Future work will include measurement of spectra of other Mars-specific mineral phases such as pigeonite as well as non-Martian meteorite phases such as the abundant phyllosilicate minerals found in carbonaceous chondrites. In addition, we will explore the possibility of using these latter spectra as endmembers in analysis of THEMIS spectra.

References: [1] Christensen et al. (2001) *JGR*, 106, 23823-23871. [2] Christensen P.R. et al., (2004) *Space Sci. Rev.*, 110, 85-130. [3] Ramsey M. and Christensen P.R. (1998) *JGR*, 103, 577-596. [4] Christensen et al., *JGR*, 105, 9735-9739, 2000. [5] Pieters C.M. and Hiroi T. (2004) *LPS XXXV* Abstract #1720. [6] Ruff S.W. et al., (1997) *JGR*, 102, 14899-14913. [7] Klima R.L. and C.M. Pieters (2006) *JGR* 111, E01005. [8] Morlok A. et al. (2006) *Meteoritics and Planet. Sci.* 41, 773-784. [9] Palomba et al (2006) *Icarus* 182, 68-79. [10] Hallis L. et al. (2006) *AGU Fall Meeting* Abstract #P23C-0073. [11] Hamilton et al., (2003) *Meteoritics and Planet. Sci.* 38, 871-885. [12] Hamilton V.E. (2000) *JGR* 105, 9701-9716. [12] Friedman Lentz R.C. et al. (1999) *Meteoritics and Planet. Sci.* 34, 919-932.