

**BIDIRECTIONAL REFLECTANCE PROPERTIES OF ORTHOPYROXENE.** E. A. Cloutis<sup>1</sup> M.A. Craig<sup>1</sup>, and D. T. Bailey<sup>1</sup>, <sup>1</sup>Department of Geography, University of Winnipeg, 515 Portage Ave., Winnipeg, MB, Canada R3B 2E9; [e.cloutis@uwinnipeg.ca](mailto:e.cloutis@uwinnipeg.ca).

**Introduction:** The bidirectional reflectance properties of many geological materials have been studied by numerous investigators, who have largely focused on photometric behavior at a few wavelengths [e.g., 1-3]. Less common are studies that examine full spectra [e.g., 4-6]. Improved understanding of photometric properties of minerals and rocks is essential for ensuring that phase angle effects can be discriminated from lithologic variations [e.g., 7-8]. We measured the spectra of orthopyroxene under a wide variety of viewing conditions to provide insights into this issue.

**Experimental Procedure:** A <45 $\mu$ m orthopyroxene sample was prepared by hand crushing and dry sieving. It was placed in an aluminum cup and a flat but matte surface was achieved by gently tapping and slowly drawing the edge of a glass slide across the sample surface. Spectra were measured relative to halon whose reflectance was corrected for minor irregularities in the 2-2.5  $\mu$ m range. Spectra were measured at HOSERLab [9] with an ASD FieldSpec Pro HR which has spectral resolution of 2-7 nm, and a 1 nm spectral sampling interval. Each spectrum is an average of 1000 scans. The samples were illuminated with an ASD Fiberoptic Illuminator (6.5W). The illuminated spot size was well away from the sample cup edge. An in-house goniometer was used to position the light source and the ASD fibre optic bundle that directed the reflected light to the detector. Both light source and detector fibers have a 25° field of view. A bifurcated fiber bundle which provides near-coincident illumination and detection was used for the coincident run (run 5).

All measurements reported here were made in a common vertical plane; off axis measurements are ongoing. Here we use the convention of positive signs if the illumination and detector fibers are positioned on opposite sides of the vertical axis, and negative for one if both are positioned on the same side of the vertical axis.

Three major types of measurements were made: (1) incidence angle ( $i$ ) for both the standard and sample was fixed, and emission angle ( $e$ ) varied, but was the same for both standard and sample; (2)  $e$  was fixed and  $i$  varied, but was the same for both standard and sample; and (3) the standard was measured at a fixed viewing geometry, and the sample spectra were measured at various  $i$  and  $e$  relative to this fixed viewing geometry for the standard (see Table 1 for measurement details).

**Results:** Orthopyroxene has been the focus of our investigation because it possesses two absorption bands near 1 and 2  $\mu$ m, and hence allows us to examine viewing geometry effects on band areas, as well as band depths, band positions, and overall slopes.

*Same standard and sample geometries.* Figures 1-3 show the spectra of runs 1-3 (Table 1). In most cases, with fixed  $i$  (runs 1-2) the absolute spectra are nearly identical; the spectrum with 75°  $e$  (run 1) likely includes a contribution from the sample holder, as the illuminated area is quite elongated. The 60°/60° spectrum is a bit flatter than the others in run 2. However absorption band positions and depths are fairly invariant. The greatest differences are seen in run 3 where  $e$  was fixed and  $i$  varied. However the spectra are readily recognizable as pyroxene and band positions do not vary.

*Fixed standard viewing geometry, variable sample viewing geometry.* The run 4 and 5 spectra are shown in Figures 4 and 5. This type of situation is one which would normally be encountered by planetary landers: as they may be equipped with a fixed/mounted calibration standard, but the targets (e.g., rock facets) would have various orientations.

These spectra show much more variability in terms of absolute reflectance, as expected. This is most evident in Figure 5: as phase angle increases, absolute reflectance relative to the fixed standard decreases. However in all cases, the pyroxene remains recognizable by its two characteristic absorption bands. Band positions are unaffected by the changes in viewing geometry.

**Discussion:** Bidirectional measurements with a fixed standard viewing geometry versus variable target viewing geometry have apparently not been made in the past. The data for same viewing geometry for standard and sample (runs 1-3) show that band depths vary from 35 to 48% (band I) and 23 to 31% (Band II). The band area ratio ( $I^*/I^*$ ) is quite constant, varying from 0.70 to 0.85. The runs with different standard vs sample geometries generally show greater variability: band I depth varies from 35 to 46%, band II depth varies from 16 to 30%, and band area ratio varies from 0.67 to 0.99. Overall slope, as measured by the reflectance ratio of local maxima near 0.7 and 1.4  $\mu$ m varies from 1.17 to 1.36 (runs 1-3), and 1.20 to 1.33 (runs 4-5).

In general, for same standard and sample viewing geometries, spectral differences (overall reflectance, shape, band depth) are minor. For different standard vs

sample viewing geometries, spectral properties are more variable. However, in all cases, the characteristics pyroxene spectral properties are preserved. The band area ratio does show variability with changes in viewing geometry of up to 33% and if used in isolation from other spectral parameters, could lead to errors in determining pyroxene abundances.

**References:** [1] Tomita N. and Nakamura A.M. (2002) *LPS XXXIII*, Abstract #1100. [2] Kamei A. and Nakamura A.M. (2002) *Icarus*, 156, 551-561. [3] Capaccioni F. et al. (1990) *Icarus*, 83, 325-348. [4] Mustard J.F. and Pieters C.M. (1989) *J. Geophys. Res.*, 94, 13,619-13,634. [5] Gradie J. and Veverka J. (1982) *Icarus*, 49, 109-119. [6] Gradie J. and Veverka J. (1986) *Icarus*, 66, 455-467. [7] Yingst R.A. and Smith P.H. (2000) *LPS*, XXXI, Abstract #1422. [8] Thomas N. et al. (2000) *J. Geophys. Res.*, 105, 26,739-26,744. [9] Cloutis E.A. et al. (2006) *LPS XXXVII*, Abstract #2121.

**Table 1.** Run parameters; *i* = incidence angle, *e* = emission angle (both in degrees).

Run	Standard <i>i</i>	Standard <i>e</i>	Sample <i>i</i>	Sample <i>e</i>
1	0	30,45,60,75	0	30,45,60,75
2	60	60,30,0,-30	60	60,30,0,-30
3	30	-60,0,30,60	30	-60,0,30,60
4	30	0	60	-30,0,30,60
5	30	0	0	0
	30	0	30	-30
	30	0	45	-45
	30	0	60	-60

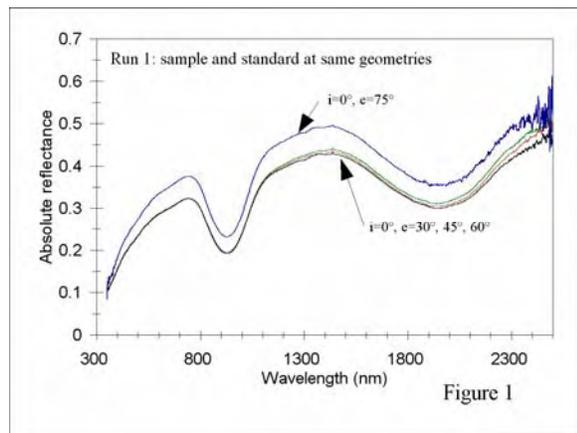


Figure 1

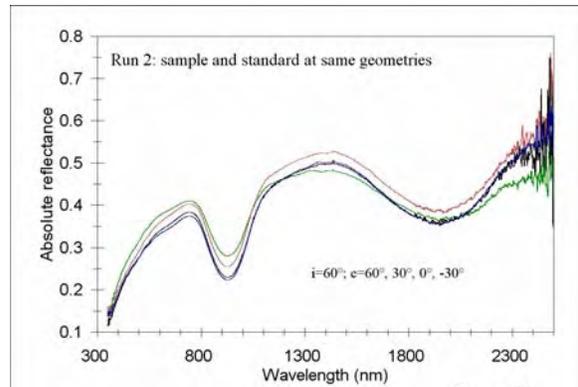


Figure 2

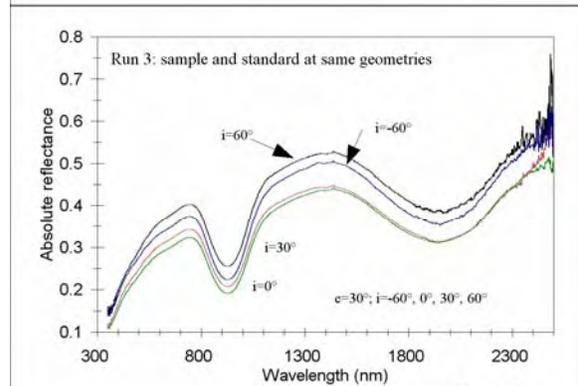


Figure 3

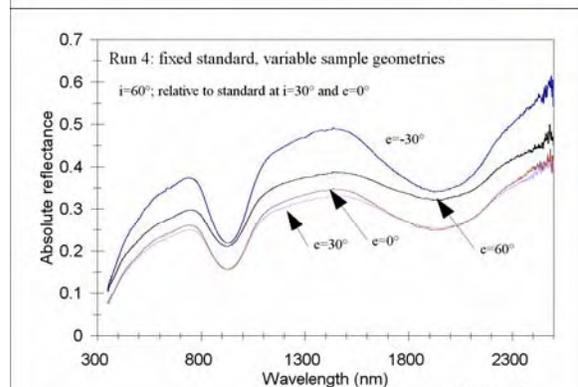


Figure 4

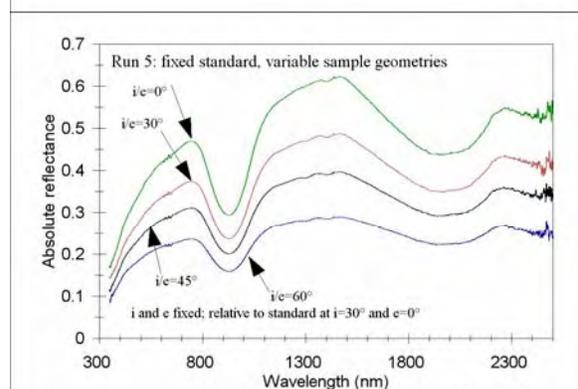


Figure 5