

**VISIBLE-NEAR INFRARED SPECTROSCOPIC PROPERTIES OF OLIVINES: EFFECTS OF PHYSICAL, OBSERVATIONAL, AND COMPOSITIONAL VARIATIONS.** E.A. Cloutis<sup>1</sup>, <sup>1</sup>University of Winnipeg, 515 Portage Avenue, Winnipeg, MB, Canada R3B 2E9; [e.cloutis@uwinnipeg.ca](mailto:e.cloutis@uwinnipeg.ca).

**Introduction:** Mafic silicates such as olivine are widespread throughout the inner solar system [1]. Detecting and characterizing them (compositionally, physically) can provide insights into planetary processes such as emplacement conditions and igneous source regions. To enable robust quantitative analysis, it is necessary to understand how compositional and non-compositional factors, as well as alteration/weathering and presence of accessory phases affect their spectra.

**Methods:** We have characterized a wide range of olivines and olivine-bearing mixtures to understand and facilitate olivine detection and characterization. We focus on the 350-2500 nm region. Relevant samples have been characterized at the Brown University RELAB facility [<http://www.planetary.brown.edu>], and the University of Winnipeg C-TAPE lab [<http://www.uwinnipeg.ca/c-tape>].

**Background:** olivine reflectance spectra are characterized by a broad reflectance maximum in the 570-690 nm region, along with a shallow trough near 620 nm. At shorter wavelengths, weak, narrow absorption bands may appear near 450 and 495 nm due to spin-forbidden  $\text{Fe}^{2+}$  transitions [2]. In the 1040-1090 nm region, a broad absorption band is present that consists of three partially overlapping absorptions due to crystal field transitions of  $\text{Fe}^{2+}$  located in two different crystallographic sites (M1 and M2). With increasing  $\text{Fe}^{2+}$  content, this band shifts to longer wavelengths [2, 3].

**Results 1 - Grain size variations:** With increasing grain size (Fig. 1), a number of systematic spectral changes are seen: (1) overall reflectance decreases; (2) the minor absorption bands near 450 and 495 nm become deeper; (3) the relative strengths of the ~570 and ~680 nm peaks change, with the lower wavelength peak becoming more prominent; (4) the ~1050 nm absorption band becomes deeper and broader, appearing to reach optical saturation for the largest grain size.

**Results 2 – Compositional variations:** Complete substitution is possible between  $\text{Fe}^{2+}$  and Mg. With increasing  $\text{Fe}^{2+}$ :Mg (Fig. 2): (1) the ~1050 nm minimum moves to longer wavelengths (full range being ~1048 – 1095 nm [4]); (2) reflectance decreases; (3) the reflectance maximum is skewed toward 700 nm; (4) the ~1050 nm absorption band becomes wider and deeper.

**Results 3 – Viewing geometry:** Phase angle will affect on reflectance spectra (e.g., [5]). For olivine, increasing phase angle leads to lower overall reflectance, a slightly bluer overall spectral slope, but little change in absorption band depth (Fig. 3).

**Results 4 – Incipient alteration:** Among the major igneous minerals, olivine is generally the most prone to chemical weathering, with the formation of Fe-oxyhydroxides and hydrated phyllosilicates [6]. This can lead to the appearance of spectral features characteristic of this weathering (Fig. 4). These can include OH/ $\text{H}_2\text{O}$ -associated absorption bands in the 1400 nm region, an  $\text{H}_2\text{O}$ -associated absorption feature in the 1900 nm region, and metal-OH absorption features in the 2250-2450 nm region; the most prominent and widespread being an Mg-OH band near 2320 nm [7].

More advanced alteration as well as the presence of pyroxene can lead to more complex spectra (Fig. 4). An olivine-rich sample (OLV103) containing 6 wt.% “volatiles” (i.e., weight loss due to heating to 950°C), plus some pyroxene and likely plagioclase feldspar, as well as both  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$ , exhibits additional spectral features.  $\text{Fe}^{2+}$ - $\text{Fe}^{3+}$  charge transfers result in a shallow absorption feature near 650-700 nm. OH/ $\text{H}_2\text{O}$ -associated absorption feature are present near 1380 nm, while a broad band centered near 1920 nm is likely due to small amounts of a low-Ca pyroxene. Metal-OH absorption features are seen near 2250, 2320, and 2380 nm. A steeper dropoff below ~550 nm is due to an intense  $\text{Fe}^{3+}$ -O charge transfer [7].

**Results 5 – Komatiites:** Komatiite, an ultramafic, high-Mg olivine-dominated rock can also provide insights into the spectrum-altering effects of chemical weathering. Reflectance spectra of a relatively unaltered 2.7 Ga komatiite [8] vary with sample “type” (Fig. 5). XRD analysis indicates major olivine, and minor chrysotile and clinopyroxene. A low degree of alteration is suggested by its low loss-on-ignition (2.3 wt.% loss upon heating to 950°C). Spectrally, the exterior surface shows an overall blue-sloped spectrum >~750 nm with alteration-associated absorption bands near 1400, 1900, and 2300 nm. Interior surface and 90-1000  $\mu\text{m}$  powder spectra are also blue-sloped down to ~400 nm and do not show deep alteration-associated absorption bands. The fine-grained (<45  $\mu\text{m}$ ) interior-derived powder shows spectral features most consistent with olivine, but with some spectrum-altering effects of alteration: a local maximum near 820 nm, an absorption band slightly shortward of the pure olivine field (~1020 nm), and narrow alteration-associated absorption features in the 1400 and 2300 nm regions.

**Discussion:** Compared to many other common rock-forming minerals, olivines are generally brighter with less intense absorption bands. This makes them

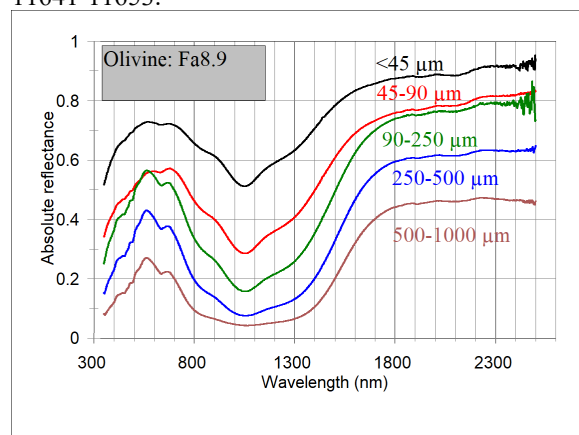
particularly sensitive to the presence of accessory phases and weathering. For instance, the presence of even low abundances of pyroxene (e.g., 10-30 wt.%) can cause many of their diagnostic spectral features to shift out of the olivine “field” (i.e., peak position, ~1050 nm absorption band position) [9] and appearance of a broad band in the 1900 nm region.

Our results also show that incipient alteration (i.e., iron oxyhydroxides) can strongly affect the <1000 nm region, leading to a steeper reflectance dropoff toward the UV, and a shift to longer wavelengths of the 600 nm region local maximum. Phyllosilicates will lead to the appearance of absorption bands in the 1300, 1900, and 2300 nm regions. The most persistent diagnostic olivine feature is the 1050 nm region absorption band.

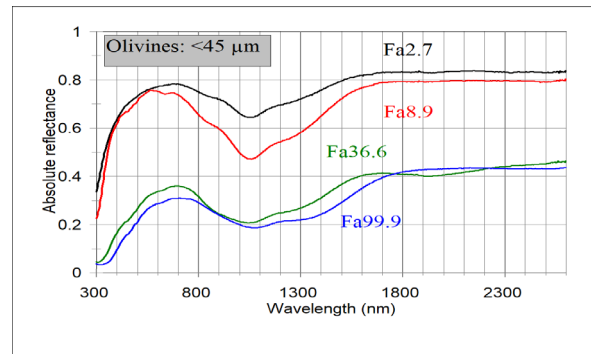
As discussed above, the physical nature of the sample will also affect our ability to quantify olivine compositional properties; for instance absorption band saturation can lead to uncertainties in absorption band position. Viewing geometry also affects some spectral properties, particularly overall reflectance.

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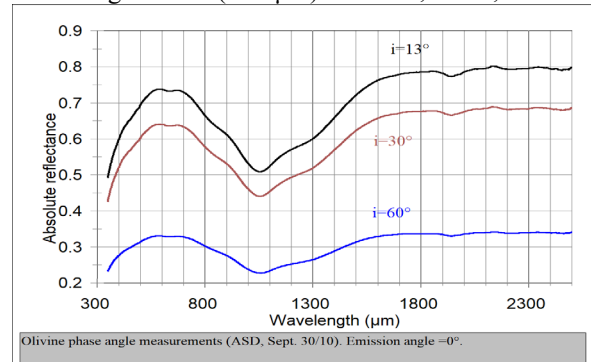
**References:** [1] *Basaltic Volcanism Study Project* (1981). [2] Burns R.G. and Huggins F.E.(1972) *Am. Mineral.*, 57, 967-985. [3] King T.V.V. and Ridley I.W. (1987) *JGR*, 92, 11457-11469. [4] Reddy V. et al. (2011) *Planet. Space Sci.*, 59, 772-778. [5] Hapke, B. (1981) *JGR*, 86, 3039-3054. [6] Velbel M.A. (2009) *GCA*, 73, 6098-6113. [7] Clark R.N. et al. (1990) *JGR*, 95, 12653-12680. [8] Puchtel I.S. et al. (2009) *GCA*, 73, 6367-6389. [9] Cloutis E.A. et al. (1986) *JGR*, 91, 11641-11653.



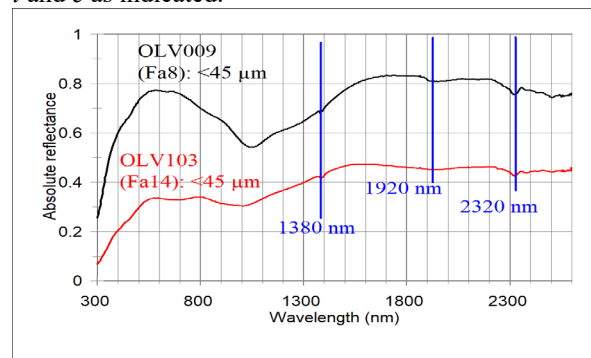
**Fig. 1.** Reflectance spectra of a single olivine measured for multiple grain sizes. C-TAPE:  $i=30^\circ$ ,  $e=0^\circ$ .



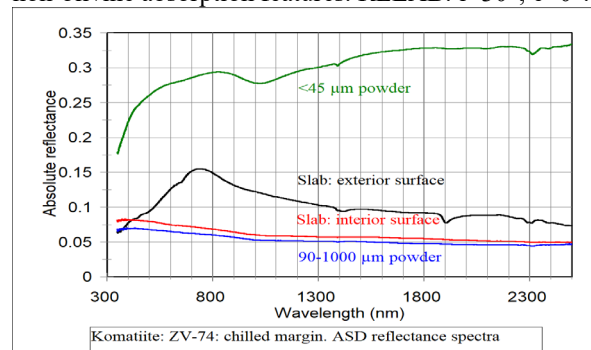
**Fig. 2.** Compositional effects on olivine spectra for a constant grain size (<45  $\mu\text{m}$ ). RELAB,  $i=30^\circ$ ,  $e=0^\circ$ .



**Fig. 3.** Phase angle effects on olivine spectra. C-TAPE:  $i$  and  $e$  as indicated.



**Fig. 4.** Mildly-altered olivine spectra. Lines indicate non-olivine absorption features. RELAB:  $i=30^\circ$ ,  $e=0^\circ$ .



**Fig. 5.** Reflectance spectra of an olivine-rich komatiite: exterior and interior (rough) surfaces and powders. C-TAPE:  $i=30^\circ$ ,  $e=0^\circ$ .