**BASALT-ILMENITE MIXTURES: SPECTRAL REFLECTANCE CHANGES AS A FUNCTION OF GRAIN SIZE AND ILMENITE ABUNDANCE.** E.A. Cloutis. Department of Geography, University of Winnipeg, 515 Portage Avenue, Winnipeg, Manitoba, Canada R3B 2E9; e.cloutis@uwinnipeg.ca.

**Introduction:** The spectral reflectance properties of the lunar surface are affected by a number of factors, including abundances and compositions of the major silicate phases (pyroxene, olivine, plagioclase feldspar), opaque oxide minerals (predominantly ilmenite), and nanophase iron (npFe) which is produced by space weathering [1]. Previous studies [e.g., 2, 3] have shown that ilmenite most noticeably affects lunar reflectance spectra in the ultraviolet-visible region. This arises from the fact that the major silicate minerals exhibit a reflectance decrease shortward of ~0.4-0.5 µm; npFe also exhibits a similar decrease in reflectance toward shorter wavelengths for abundances common to the lunar surface [1]. This reflectance decrease is attributable to metal-oxygen charge transfers, particularly involving Fe. By contrast, ilmenite spectra generally show increasing reflectance shortward of ~0.5 µm [4]; this is due to the presence of an intense Fe-Ti charge transfer absorption near 0.5 µm which is more intense than the shorter wavelength metal-oxygen charge transfer bands. As a result, ilmenite reflectance increases shortward of ~0.5 µm (Figure 1). This spectral difference between ilmenite and other lunar surface components can potentially be used to constrain ilmenite abundances by incorporating both UV and visible wavelength data in analysis of lunar spectra [2, 3].

To better constrain the spectrum-altering effects of ilmenite we have measured UV-vis-NIR reflectance spectra of a series of basalt + ilmenite mixtures.

**Experimental Procedure:** Mixtures of <45 µm synthetic ($Fe^{3+}$-free) ilmenite (ILM200) with either <45µm or 90-250µm basalt (BAS204) were generated using the following abundances of ilmenite: 0, 1, 2, 4, 7, 10, 20 wt%. Reflectance spectra were measured with an ASD spectrometer (0.35-2.5 µm), and an Ocean Optics S2000 spectrometer with a deuterium light source for the 0.2-0.4 µm range, or a QTH source for the 0.37-0.86 µm interval [4].

**Results:** A previous study of ilmenite reflectance spectra [4] demonstrated that reflectance ratios utilizing one band shortward of ~0.35 µm provide good discrimination of ilmenite from other lunar surface constituents. Here we extend this work to simple binary mixtures with basalt. Our interest is to examine how differences in grain size may affect spectral discrimination of ilmenite. To overcome the practical difficulties in producing micron- and submicron-sized ilmenite, we instead chose to focus initially on <45 µm ilmenite mixed with comparable-sized (<45 µm) and larger (90-250 µm) basalt powder. One potential complication is that the two basalt powders show different spectral shapes as a function of grain size (Figure 1); this has been observed in other basalt samples as well [5]. The ilmenite spectrum shows the expected broad absorption feature in the ~0.5-0.7 µm region, a local reflectance maximum near 1.0 µm, and a broad longer wavelength absorption band centered near 1.3 µm; reflectance increases shortward of ~0.5 µm, as expected (Fig. 1). Given these spectral characteristics, we chose to focus on a few selected spectral parameters: the 502/290 nm reflectance ratio (matching available HST lunar data [2]), a 560/315 nm reflectance ratio (matching LROC band passes), some additional reflectance ratios not previously analyzed but which are available for HST and LROC band passes, and the wavelength position of the absorption feature in the 1.0-1.3 µm region. The reflectance spectra of the mixtures are shown in Fig. 2.

**Results - band minimum:** The reflectance spectra for the <45 µm series show subtle spectral variations over the 1-20 wt% ilmenite abundance range (Fig. 2a). In these spectra, the band minimum is near 1.05-1.06 µm up to 10 wt% ilmenite, then shifts to 1.29 µm for 20 wt% ilmenite, and 1.32 µm at 100 wt% ilmenite. In the <45 µm ilmenite + 90-250 µm basalt mixtures, there is no well-defined minimum in the 100 % basalt, the minimum is at 1.42 µm with 1 wt% ilmenite, and 1.32-1.33 µm for 2-100 wt% ilmenite. This indicates that ilmenite has a strong influence on absorption bands in the 1 µm region when it is finer-grained than the host silicates.

**Results - reflectance ratios:** Band ratios, particularly those involving a band in the UV, provide good discrimination of ilmenite from mafic silicates and npFe [1, 4]. The results for the basalt + ilmenite mixtures suggest that these ratios are also useful for constraining ilmenite abundances. We examined the following reflectance ratios, some of which have been used previously for analysis of HST [2] and LROC [6] data: 502/290, 560/315, 560/360, 344/290, 600/360, and 600/315 nm. We examined the % change in these ratios from pure basalt to pure ilmenite.

The 344/290 nm ratio showed a slower change when moving from the pure basalt end member to the pure ilmenite end member than any of the other reflectance ratios (which all utilized a visible region band pass ratioed to a UV region band pass). Fig. 3 shows the change in reflectance ratios as a function of ilmenite content for both mixture series; the 344/290 nm ratios for both mixture series are shown, as are the averages of all the other vis/UV region reflectance ratios for the two mixture series.

On average, the vis/UV ratios showed a greater change with increasing ilmenite content when the ilmenite is finer-grained than the basalt. For the <45 µm ilmenite + 90-250 µm basalt series, the vis/UV reflectance ratios reach the midpoint (50% change) between the pure basalt and pure ilmenite at an ilmenite content of ~7 wt%; reaching the same 50% change for the <45 µm ilmenite + <45 µm basalt requires ~35 wt% ilmenite. For the 344/290 nm ratio, the ilmenite abundance required to reach the same (50% change) value requires ~13 wt% ilmenite (for the mixtures involving 90-250 µm basalt), and ~45 wt% ilmenite (for the mixtures involving <45 µm basalt).

**Discussion:** While these mineral mixtures obviously do not reproduce the physical characteristics of the lunar surface, they do provide some insights into how ilmenite may affect lunar surface spectra:

- the finer the average grain size of the non-ilmenite components, the more ilmenite is required to effect a specific spectral change.
- ilmenite detection and characterization is probably best determined using a combination of visible region (~500-500 nm) and UV (<~400 nm) region band passes.
- Even a few wt% ilmenite will lead to measurable changes in reflectance ratios regardless of grain size.

**References:** [1] Noble, S.K. et al. (2007) *Icarus, 192*, 629. [2] Robinson, M.S. et al. (2007) *GRL, 34*, L13203. [3] Lucey, P.G. et al. (2000) *JGR, 105*, 20297. [4] Cloutis, E.A. et al. (2008) *Icarus, 197*, 321. [5] Harloff, J., and G. Arnold (2001) *Planet. Space Sci., 49*, 191. [6] Chin, G. et al. (2007) *Space Sci. Rev., 129*, 391.

**Acknowledgements:** This study was supported by research grants and contracts from the Canadian Space Agency, NSERC, and the University of Winnipeg. Our research facility was established through the generous support of the Canada Foundation for Innovation, the Manitoba Research Innovations Fund, and the Canadian Space Agency.

**Figure captions:** ***Fig. 1.*** ASD (0.35-2.5 µm) reflectance spectra of the two grain sizes of basalt and <45 µm sized synthetic ilmenite. ***Fig. 2.*** Reflectance spectra of the two series of basalt+ilmenite mixtures (a) <45 µm basalt and ilmenite; (b) <45 µm ilmenite + 90-250 µm basalt. ***Fig. 3.*** Percent change in the average of various vis/UV reflectance ratios and the 344/290 nm reflectance ratio for the two mixture series. The % change is a measure of how the reflectance ratio changes from pure basalt (0% change) to pure ilmenite (100%), plotted as a function of ilmenite content.

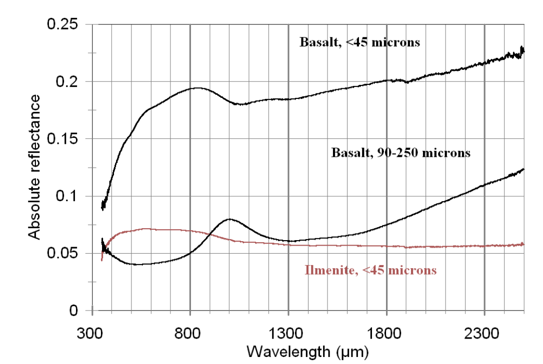
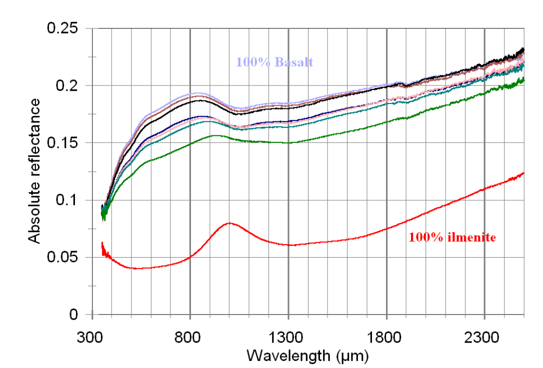
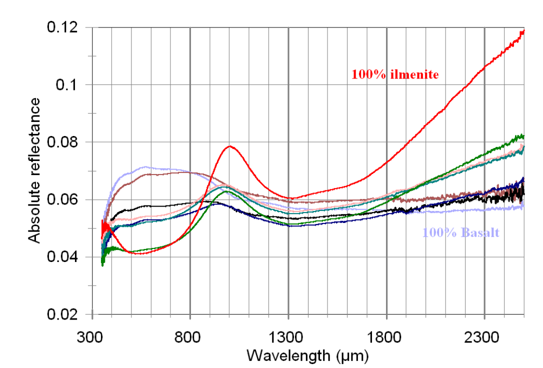



Figure 1




Ilmenite (ILM200, <45µm) + basalt (BAS204, <45 µm); Fig. 2a




Ilmenite (ILM200, <45µm) + basalt (BAS204, 90-250 µm); F2b

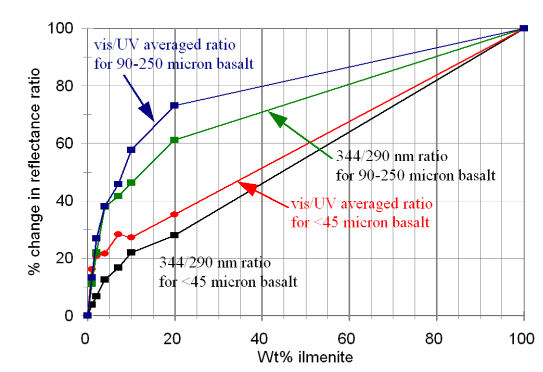



Figure 3