

SPECTRAL MIXTURES OF CLAYS AND THEIR IMPACT ON CRISM MINERAL IDENTIFICATIONS.N. K. McKeown¹, J. L. Bishop², E. Amador¹, J. Cuadros³, S. Hillier⁴, H. Makarewicz^{2,5}, M. Parente⁶, E. A. Silver¹,¹UC Santa Cruz (Santa Cruz, CA 95064, nmckeown@pmc.ucsc.edu), ²SETI Institute (Mountain View, CA 94043),³Natural History Museum (London, UK), ⁴Macaulay Land Use Research Institute (Aberdeen, UK), ⁵University of Kansas (Lawrence, KS 66045), ⁶Stanford University (Stanford, CA 94305).

Introduction: Many CRISM spectra measured at Mawrth Vallis, Mars appear to be mixtures of montmorillonite and hydrated silica or kaolinite [1, 2]. When two minerals are detected in the same pixel, their spectra may mix linearly or non-linearly. As non-linear unmixing is challenging, intimate mixtures prepared in the lab are critical for determining the spectral character of a non-linear mixture. Here we present spectra of intimate mixtures of montmorillonite with kaolinite, obsidian, and opal (the latter two being different forms of hydrated silica) and implications for CRISM data interpretation. A related study evaluates beidellite-montmorillonite mixtures [3].

Methods: Components were weighed and mixed proportionately, dry sieved to ensure homogenous mixing, then measured at RELAB, Brown University under dry conditions or with a hand-held contact-probe ASD spectrometer in ambient lab conditions. The opal-smectite samples are natural and percentages were characterized by XRD. CRISM spectra are ratioed averages of regions containing at least nine pixels (for complete CRISM processing description, see [4]).

Results: Here we focus on the 2.2 μm region where CRISM spectra show subtle variations in features that have important implications for mineralogy. Variations are also observed in the 1.4 μm region, but many bands are too weak for reliable discrimination.

Kaolinite-montmorillonite. Kaolinite spectra have a narrow doublet at 2.17 and 2.21 μm . Montmorillonite spectra have a single absorption at 2.21 μm with an asymmetry toward longer wavelengths. With decreasing kaolinite abundance, the maximum inflection point on the longward side of this absorption shifts toward longer wavelengths, similar to montmorillonite (fig. 1a). Additionally, the absorption at 2.17 μm is reduced. At 60 wt% kaolinite, this feature is a clear shoulder, while at 50 wt% it is a more gradual shoulder, and at 25 wt% it is barely detectable (fig. 1a).

Montmorillonite-obsidian. Montmorillonite spectra have an absorption at 2.210 μm due to Al₂OH and obsidian spectra have a broader absorption centered at 2.216 μm due to SiOH species; therefore, the band center of the mixtures does not shift greatly (fig. 1b). However, since the obsidian feature is broader, the maximum inflection point on the longward side shifts toward longer wavelengths with increasing amounts of obsidian. At 50 wt% obsidian the inflection still oc-

curs in the same position as for pure montmorillonite, but is not as sharp. At 80 wt% it is in an intermediate position, at 90 wt% it is slightly shorter than pure obsidian, and at 92 wt% it is in the same position as pure obsidian (fig. 1b).

Opal-smectite. This series of natural samples shows that when $\geq 50\%$ smectite is present, the spectra exhibit characteristics of smectite and little broadening of the 2.21 μm band due to opal is observed (fig. 1c). However, the samples with $>70\%$ smectite have spectra with a band center at 2.210-2.213 μm , whereas the spectra of samples with lower amounts of smectite have a band center at 2.207-2.209 μm . Other subtle changes in the spectra are observed in the asymmetry of the bands and the reflectance maxima. Ongoing Gaussian analyses may help resolve these features. Small differences in band depth at $\sim 2.2 \mu\text{m}$ are detectable, especially when scaled to the band depth of the montmorillonite spectrum (Table 1).

	<i>Band depth (reflectance)</i>	<i>Scaled</i>
montmorillonite	0.17157	1
99.2% opal	0.0638766	0.372306347
54.5% smectite	0.0915477	0.53358804
58.2% smectite	0.108554	0.632709681
69.2% smectite	0.118248	0.689211401
70.3% smectite	0.11726	0.683452818
72.2% smectite	0.122311	0.712892697

Table 1. Natural opal-smectite sample band depths at $\sim 2.2 \mu\text{m}$ in absolute reflectance and scaled to the montmorillonite band depth.

Implications for CRISM mineral identification:

Many of the clay-bearing rocks on Mars are likely mixtures of multiple components. Our experiments show that as low as 30% kaolinite is detectable when mixed with montmorillonite. For obsidian, however, $>50\%$ must be present in order to detect it in a mixture with montmorillonite (fig. 1d), likely because of the similarity in band position. Opal mixed with montmorillonite is very difficult to detect in proportions $<50\%$ because it has little effect on the shape of the band.

Beidellite-montmorillonites are similar to kaolinite-montmorillonite mixtures: there is a primary absorption at $\sim 2.21 \mu\text{m}$ with a shoulder at 2.18 μm and an additional absorption at 2.44 μm [3]. However, direct comparison shows that the two can be differentiated

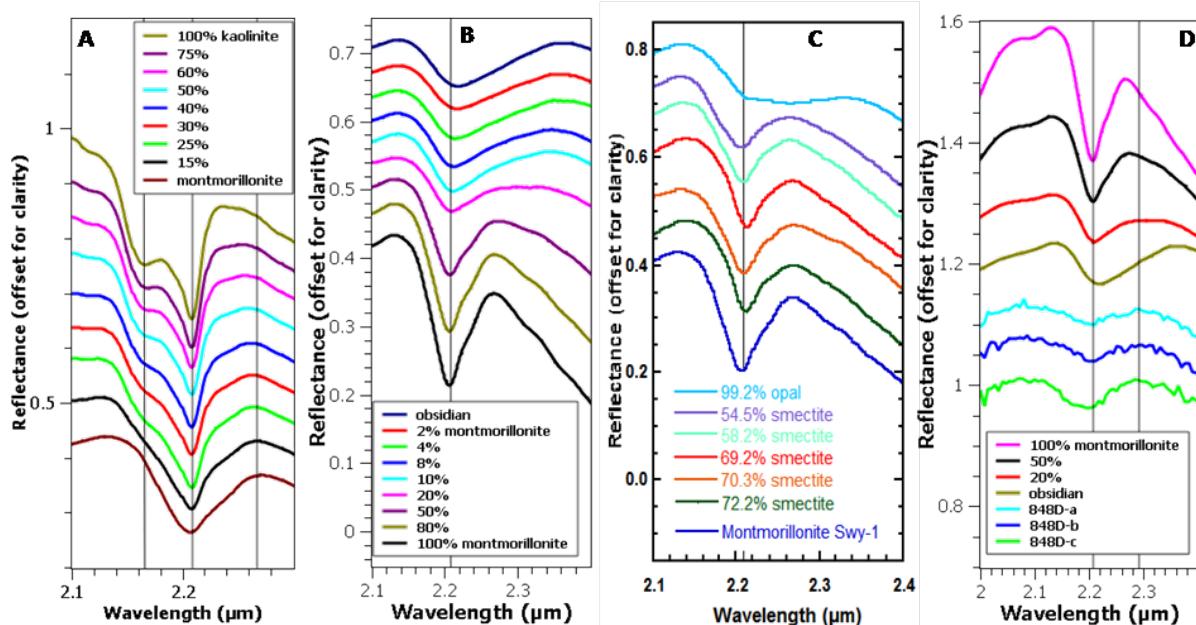


Figure 1. (A) Spectra of intimate mixtures of kaolinite (gold, top) with montmorillonite (maroon, bottom). Vertical lines (from left to right): 2.17 μm kaolinite absorption, 2.21 μm kaolinite and montmorillonite absorptions, and the maximum inflection point of montmorillonite (~2.265 μm). (B) Spectra of intimate mixtures of obsidian (navy, top) and montmorillonite (black, bottom). Vertical line at 2.21 μm . (C) Spectra of natural samples containing smectite (montmorillonite; example spectrum at bottom) and opal (top). Vertical line at 2.208 μm . (D) Examples of CRISM spectra containing a mixture of montmorillonite and hydrated silica (bottom three spectra) compared to some of the intimate mixtures of montmorillonite and obsidian (top four spectra). In this case, the mixture containing 20% montmorillonite is a good match, although we cannot use this method to determine modal mineralogy.

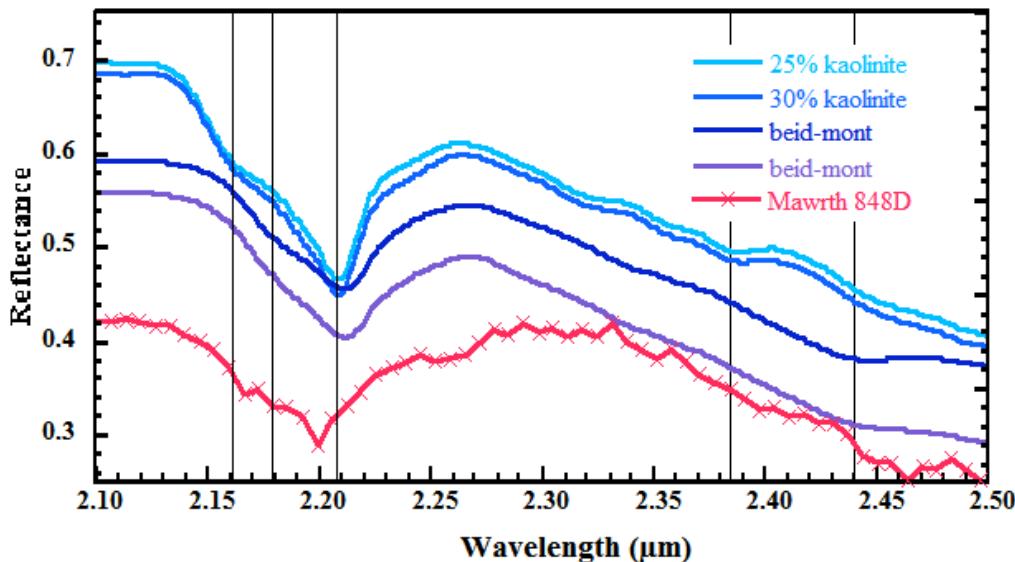


Figure 2. Comparison of kaolinite-montmorillonite mixtures with natural beidellite-montmorillonites from [3] and a CRISM kaolin-group ratio spectrum from Mawrth Vallis, image FRT0000848D. The CRISM spectrum is offset for clarity.

(fig. 2). The shoulder in 25-30% kaolinite-montmorillonite mixtures occurs at shorter wavelengths (2.16 μm) and they have an absorption at 2.38 μm rather than 2.44 μm . An example CRISM spectrum matches neither perfectly but is more similar to a kaolinite-montmorillonite mixture than a beidellite-montmorillonite with a shoulder at 2.165 μm , an absorption at 2.4 μm , and possible weaker absorptions from 2.30-2.37 μm that are consistent with kaolinite (fig. 2).

References: [1]Bishop, J. L., et al. (2008) *Science*, 321, 830-833. [2]McKeown, N. K., et al. (2009) *JGR- Planets*, 144, E00D10. [3]Bishop, J. L., et al. (2010) *LPI XLI*. [4]Murchie, S. L., et al. (2009) *JGR- Planets*, 114, E00D07.

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