

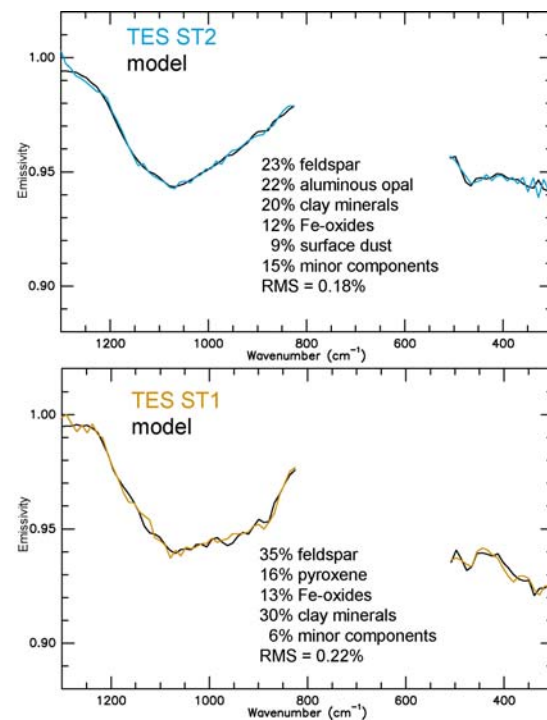
## PALAGONITE-LIKE ALTERATION PRODUCTS ON THE EARTH AND MARS I: SPECTROSCOPY (0.4-25 microns) OF WEATHERED BASALTS AND SILICATE ALTERATION PRODUCTS

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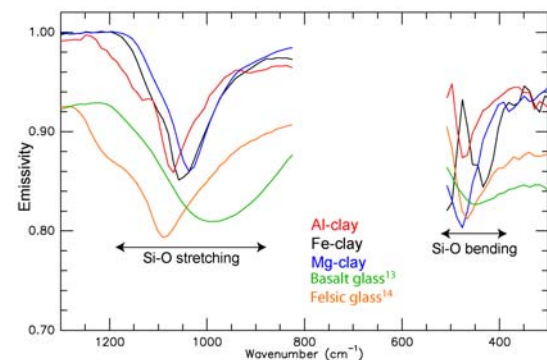
**Introduction:** Thermal infrared (TIR) spectra from the Thermal Emission Spectrometer (TES) and Mini-TES experiments suggest the presence of glasses and possibly clays and silica on the Martian surface [1-7], though visible/near infrared (VNIR) spectra show that clay minerals are not widespread and abundant on Mars [8-9]. It is plausible that glass-like and clay-like materials identified with TES could also be interpreted as poorly crystalline silicate alteration products that formed from chemical weathering and aqueous sedimentary processes on Mars. Understanding the nature of amorphous and poorly crystalline materials on the Martian surface is critical for constraining alteration processes on Mars, including palagonitization.

**Palagonite:** Much of the discussion of chemical weathering on Mars is focused on “palagonite” [8,10-11]. Often, palagonite is used in the field as a mineralogically imprecise term for altered basaltic glass. Palagonite can be an amalgamation of all or some of the following materials: residual basaltic glass, secondary silica (opal or opal-CT), zeolites, carbonates, phosphates, hematite, Fe-hydroxides, poorly crystalline aluminosilicate mineraloids, and smectite clays [12]. Palagonite can also specifically apply to a hydrated, leached, and/or oxidized glass-phase itself. In the TES spectral range (~300-500 and 800-1700  $\text{cm}^{-1}$ ) the spectral signature of palagonitic material is *dominated* by Si-O stretching of the silicate components present, including various alteration phases and residual/altered glass.

**TES spectra of disordered materials:** Both global TES spectral surface types (ST1 and ST2) [1] can be modeled with significant components of glasses and/or clay minerals [1-5, this study] (Figure 1). ST1, common in equatorial regions, can be modeled with 10-20% clay minerals at TES wavelengths. ST2, common in Acidalia Planitia and at northern latitudes in general, can be modeled with ~30-40% combined felsic glass and clay minerals. At TES wavelengths, the spectral structure of clay minerals is primarily controlled by their tetrahedral sheet chemistry – the TES identification of clay minerals is an identification of silicate materials of intermediate composition (polymerization) with little spectral structure (Figure 2). Likewise, the TIR spectra of glasses are dominated by absorptions corresponding to a disordered network of (Si,Al,Fe)-O bonds. The position of the major spectral features of silicates is a function of their composition – with decreasing silica content, the Si-O stretching features



**Figure 1:** The TES spectral surface types can be modeled with considerable components of clay minerals and aluminous opaline silica. These model components may correspond to silicate alteration products on the Martian surface.



**Figure 2:** TIR spectra of silicate glasses and clay minerals are dominated by Si-O stretching and bending absorptions at TES wavelengths.

shift to longer wavelengths (lower wavenumbers). Relatively disordered materials, be they primary glasses, poorly crystalline clay minerals, or other high-silica, poorly ordered alteration products, will be spectrally similar to each other if they have similar silica contents. Therefore, the Martian surface spectra show evidence, fundamentally, for poorly crystalline

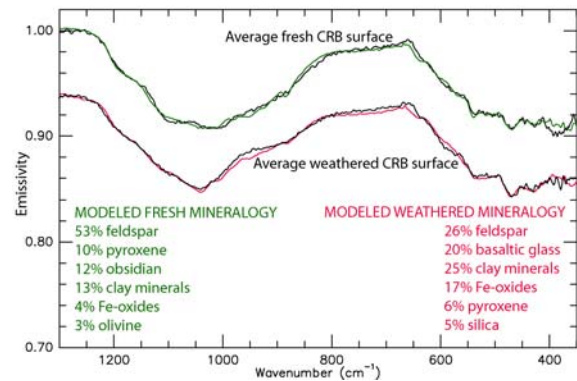
silicate materials of intermediate composition ( $\text{Si/O} = \sim 0.3\text{-}0.4$ ) at equatorial latitudes and poorly crystalline materials of intermediate to silicic composition ( $\text{Si/O} > 0.4$ ) at high latitudes (especially in Acidalia Planitia). This may be an indication of chemical weathering in low-water surface conditions (similar to present conditions) or during episodic wet periods on Mars (*i.e.* during catastrophic flooding). However, there is evidence that even in many terrestrial rocks from semi-arid environments, poorly crystalline materials may be the dominant alteration products.

**Spectra of weathered basalts:** We collected TIR and VNIR spectra of a suite of fresh and weathered basaltic rock surfaces (Columbia River Basalt). Linear spectral deconvolution of TIR spectra of natural rock surfaces suggests that the weathered surfaces are enriched in basaltic glass, Fe-oxides, and clay minerals, and deficient in plagioclase feldspars and pyroxenes, relative to the fresh surfaces (Figure 3). Preliminary VNIR interpretations suggest that cation-OH absorptions near  $2.2\text{-}2.3\ \mu\text{m}$  are not commonly observable (Figure 4), which may indicate that clay minerals are not common and abundant in these rock surfaces. We interpret the enrichment in “basaltic glass” and “clay minerals” on weathered surfaces (from TIR) as enrichment in poorly crystalline aluminosilicate alteration products which have similar compositional and structural properties to glasses of mafic to intermediate composition ( $\text{Si/O} = \sim 0.3\text{-}0.4$ ). VNIR spectra of weathered rock surfaces show evidence of  $\text{Fe}^{3+}$ , which probably corresponds to Fe-oxides,  $\text{Fe}^{2+}$  in pyroxene, and minor OH absorptions, which may be related to hydrated, silicate alteration products. The spectrally derived mineralogy of natural rock surfaces is *dominated* by primary minerals, albeit in different ratios than in the fresh rock, and amorphous materials which could be interpreted as glasses or alteration products. A companion abstract by Kraft *et al.* [this meeting] discusses the detailed alteration mineralogy of our CRB rock samples.

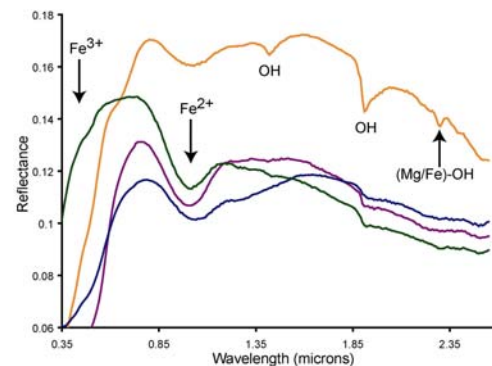
**Discussion and conclusions:** Chemical weathering of rocks is largely degradational on Earth [*e.g.* 15]. The preliminary results from this study suggest that poorly ordered aluminosilicates may be the dominant alteration products in weathered basalt rocks, even if the rocks were weathered under semi-arid (*i.e.* relatively wet) conditions [Kraft *et al.*, this meeting]. The spectrally observed crystalline components of altered rocks are dominated by primary phases.

Mars may be clay-poor, but widely altered [16]. On Earth, clay minerals are most abundant in mineralogically mature sedimentary rocks (*i.e.* shales and mudstones), mature soils, and hydrothermally altered rocks (*e.g.* serpentinized MORB). The lack of evidence for widespread, abundant clay minerals on

Mars may be more an indication that aqueous sedimentary processing of surface materials has been limited, rather than an indication of a lack of chemical weathering on Mars. Both TES spectral surface-types seem to include significant spectral components of poorly crystalline materials, which could be an indication of palagonite-like alteration products on Mars.



**Figure 3:** TIR emission spectra of the average of all of our weathered CRB surfaces and the average of all of our fresh CRB surfaces. Results from linear spectral deconvolution are shown.



**Figure 4:** VNIR spectra of some weathered CRB surfaces. Some surfaces show evidence for clay minerals, but most weathered spectra are dominated by  $\text{Fe}^{2+}$  absorptions related to pyroxene and  $\text{Fe}^{3+}$  absorptions related to Fe-oxides.

- References:** [1] Bandfield, J. L., *et al.*, *Science*, 287, 1626-1630, 2000. [2] Christensen, P. R., *et al.*, *JGR*, 106, 23,823-23,871, 2001. [3] Hamilton, V. E., *et al.*, *JGR*, 106, 14,733-14,746, 2001. [4] Wyatt and McSween, *Nature*, 417, 263-266, 2002. [5] McSween, H. Y., *et al.*, *JGR*, 108, 10.1029/2003JE002175, 2003. [6] Christensen, P. R., *et al.*, *Science*, 305, 837-842, 2004. [7] Christensen, P. R., *et al.*, *Science*, 306, 1733-1739, 2004. [8] Soderblom, L. A., *et al.*, *Mars*, UA Press, Tucson, 557-593, 1992. [9] Mustard, J. F., *et al.*, *Eos trans. AGU*, 85(47), P24A-07, 2004. [10] Gooding, J. L., *et al.*, *Mars*, UA Press, Tucson, pp. 626-651, 1992. [11] Morris, R. V., *et al.*, *Sixth Int. Conf. Mars*, 2003. [12] Stronck, N. A., *IJES*, 91, 2002. [13] Cherednik, L., *M.S. Thesis*, ASU, 2001. [14] Wyatt, M. B. *et al.*, *JGR*, 106(E7): 14,711-14,732, 2001. [15] Colman, S., *USGS Prof. Pap.*, #1246, 1982. [16] Morris, R. V. *et al.*, *LPSC XXXV*, abstract #1606, 2004.