

**THERMAL EMISSION SPECTRAL MODELING OF WEATHERED BASALT SURFACES.** M. D. Kraft, J. R. Michalski, and T. G. Sharp, Department of Geological Sciences, Arizona State University, P.O. Box 871404, Tempe, AZ 85287-1404, [mdkraft@asu.edu](mailto:mdkraft@asu.edu)

**Introduction:** The thermal emission spectral shape and distribution of certain spectral surface types on Mars indicates that at least some Martian surfaces may be weathered or otherwise altered [1-3]. Thermal emission spectra are particularly sensitive to vibrations of Si-O bonds as modified by the configuration of all bonds in a mineral structure, and this technique should be ideal for assessing silicate mineralogy of Mars, including the nature of secondary silicate phases [4]. Typically, mineralogical assessment of Thermal Emission Spectrometer (TES) and Mars Exploration Rover Mini-TES spectra have been performed using linear deconvolution modeling [3,5-8], which has been demonstrated to work well for unaltered coarse-grained and fine-grained rocks [9-10] and coarse-grained particulate mixtures [11]. What has remained unexplored is the efficacy of linear deconvolution to assess the mineralogy of altered rock surfaces. Here, we continue our examination of weathered basaltic rocks and their thermal infrared spectra [12-13]. We report initial results for tests of linear deconvolution modeling of naturally weathered surfaces.

**Weathered basalt:** The weathered surfaces of crystalline basalts that we have thus far examined are finely fractured by networks of  $\mu\text{m}$ -scale cracks. The cracks are partially filled with secondary material that is Si-Al-Fe-rich. X-ray and electron diffraction analyses of the secondary materials of these weathering rinds indicates that they are poorly crystalline or disordered. We interpret these weathering products to be disordered Fe-oxyhydroxides and disordered clay minerals mixed on a 10s-of-nm scale.

**Methods:** Two methods were used to assess how linear deconvolution performed in determining the mineralogy of weathered surfaces. (1) Laboratory thermal emission spectra were acquired for fresh and weathered surfaces of two Columbia River Basalts (CRBs). Polished thin sections of the rocks were analyzed by scanning electron microscopy and energy-dispersive spectroscopy to produce a set of back-scattered electron (BSE) images and X-ray chemical maps. The BSE images and chemical maps were imported into ENVI, an image analysis software program, where supervised classifications were performed on the images to determine primary mineral abundances for unweathered portions of the rocks and for the outer  $\sim 100 \mu\text{m}$  of the weathered surfaces. The abundance of secondary minerals was not measured directly, but an upper limit was determined by measuring abundance of cracks and

void in the weathered surfaces. The resulting mineralogy was compared to that derived from linear deconvolution modeling of spectra from those surfaces. (2) The weathering rinds of basaltic rocks from Arizona were carefully scraped, gently crushed, and sonicated. That material was centrifuged to concentrate the  $<1 \mu\text{m}$  size fraction, thereby concentrating the fine-grained weathering products. That material was pressed into a pellet. Thermal emission spectra were acquired for the pellet and representative weathered and unweathered surfaces of the rocks. The rock spectra were analyzed by linear deconvolution to determine how well the technique predicted the secondary material. XRD analysis of the  $<1\text{-}\mu\text{m}$  separate showed that it is a mixture of smectite clay and X-ray amorphous material.

**Results:** The initial results indicate that, while linear deconvolution modeling of unweathered surfaces performs well, modeling of weathered surfaces is problematic.

SEM image classifications show that the weathering rinds are comprised mostly of primary minerals, and the proportions of primary phases is the same in the rinds and unweathered rocks. The abundance of secondary phases is estimated to be  $\sim 20\%$  in the examined weathering rinds. By comparison, deconvolution results significantly underestimate plagioclase contents of the weathering rinds (Figure 1), indicating that primary mineral abundances derived from spectral modeling of weathered surfaces may be unreliable.

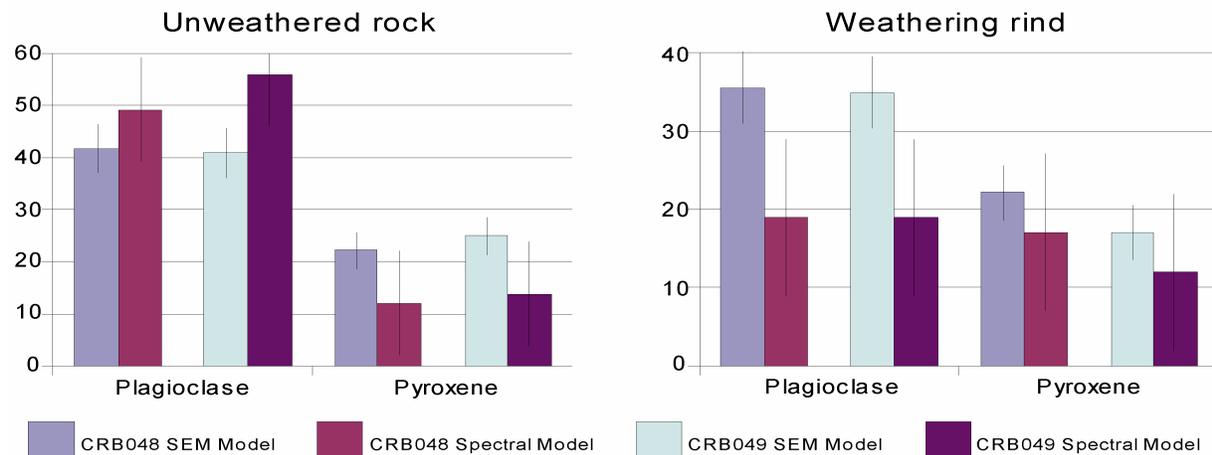
The spectrum of the  $<1\text{-}\mu\text{m}$  separate from the Arizona basalt weathering rind is shown in Figure 2, and represents the weathering product from these rocks. The spectrum has a broad absorption centered at  $\sim 1040 \text{ cm}^{-1}$  and is similar in shape to clay minerals and amorphous silicates. At long wavelengths, the  $470 \text{ cm}^{-1}$  feature common to many of these materials appears as a shoulder, perhaps due to intimate mixing with Fe-oxyhydroxides. Also shown in Figure 2 are spectra of the weathered surface and unweathered rock interior. The weathered surface spectrum shows features of both the  $<1\text{-}\mu\text{m}$  separate and the unweathered rock spectra. However, modeling of the weathered surface spectrum using the  $<1\text{-}\mu\text{m}$  separate and unweathered rock surface as the only endmembers failed to produce a good fit (Figure 2); spectral mixing of material in the weathering rind is nonlinear. Deconvolution of the weathered surface using a library of mineral endmembers plus the  $<1\text{-}\mu\text{m}$  separate suggested the presence of additional clay minerals (in greater abundance than

the  $<1\text{-}\mu\text{m}$  separate) and included orthoclase feldspar, a phase not present in the weathering rind, at  $>20\%$  abundance.

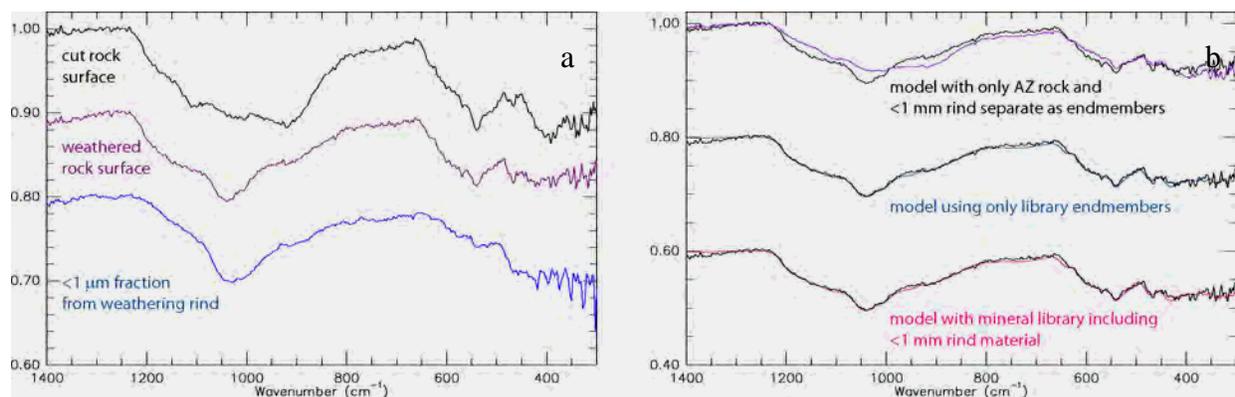
**Discussion:** In the rocks studied here, weathering rinds are composed dominantly of primary minerals. Secondary minerals infill small cracks in the rinds, and make up a relatively small percentage of the total volume. The mixture of primary minerals and fine-grained secondary phases leads to nonlinear mixing of component spectra, which is predictable based on previous work involving fine-grained materials [11]. Consequently, linear deconvolution of thermal emission spectra of weathered surfaces fails to accurately determine (1) the relative abundances of primary mineral phases and (2) the identity of secondary silicate phases. These problems stem from the fine-scale geometry of weathering rinds, where fine-grained weathering products are intimately dispersed with primary phases on the scale of a few to 10s of  $\mu\text{m}$ . We expect that similar problems would occur in any similar situation, including weathered particulates and soils. The results indicate that relatively small amounts of weathering prod-

ucts have a pronounced effect on the ability to assess mineralogy by spectral modeling, suggesting that these issues occur for lightly weathered surfaces. Determining the primary mineralogy of rocks from spectra of weathered surfaces is complicated and will require techniques beyond linear deconvolution, as will a robust assessment of the mineralogy of weathering products.

**References:** [1] Wyatt, M.B. and H.Y. McSween (2002) *Nature*, 417, 263-266. [2] Wyatt, M.B. et al., (2004) *Geology*, 32, 644-648. [3] Rogers, A.D. (2005) Ph.D. Thesis, Arizona State Univ. [4] Michalski, J.R. et al. (2005) *Icarus*, 174, 161-177. [5] Bandfield, J.L. et al. (2000) *Science*, 287, 1626-1630. [6] Hamilton, V.E. et al. (2001) *JGR*, 106, 14733-14746. [7] Christensen, P.R. et al. (2005) *Science*, 305, 837-842. [8] Ruff, S.W. et al (2005) *EOS trans.*, AGU 86, Abstract #P12A-02. [9] Feely, K. C. and P.R. Christensen (1999) *JGR*, 104, 24195-24210. [10] Wyatt, M.B. et al (2001) *JGR*, 106, 14711-14732. [11] Ramsey, M. and P.R. Christensen (1998) *JGR*, 103, 577-596. [12] Michalski, J.R. et al. (2005) *LPSXXXVI*, Abstract #1188. [13] Kraft, M.D. et al. (2005) *LPSXXXVI*, Abstract #1376.



**Figure 1.** Comparison of plagioclase and pyroxene abundances derived from SEM analysis to those from deconvolution modeling of thermal emission spectra for the unweathered and weathered surfaces of two basaltic rocks.



**Figure 2.** (a) Spectra of unweathered basalt, the weathered surface, and  $<1\text{ }\mu\text{m}$  size fraction (weathering product) separated from the weathering rind. (b) Three fits of linear deconvolution models. The top model used only the unweathered rock and  $<1\text{ }\mu\text{m}$  separate spectra as endmembers and produced a poor fit. To attain better fits, models were performed using a mineral library. Additional clay minerals (15-20 %) and orthoclase ( $\sim 22\%$ ) were required for the lower two models