

WEATHERING PRODUCTS OF DECCAN BASALTS AND IMPLICATIONS FOR MARS. R. N. Greenberger¹, J. F. Mustard¹, P. S. Kumar², M. D. Dyar³, E. A. Speicher³, and E. C. Skulte⁴, ¹Dept. of Geological Sciences, Brown University, Providence, RI, 02912, Rebecca_Greenberger@brown.edu; ²National Geophysical Research Institute, Council of Scientific & Industrial Research, Hyderabad, India; ³Dept. of Astronomy, Mount Holyoke College, South Hadley, MA, 01075; ⁴Dept. of Geoscience, Stony Brook University, Stony Brook, NY 11794.

Introduction: Mars has experienced a range of aqueous alteration processes from hydrothermal alteration to surface weathering. While our understanding of alteration processes on Mars has benefited from the advent of visible-near infrared (VNIR) spectroscopic measurements of the planet [1, 2], a number of key questions have emerged relating to orbital observations of mineral assemblages and determinations of alteration conditions (e.g. T, P, eH, pH). Analog environments provide excellent opportunities to better constrain interpretation of remotely-acquired data. In particular, we are interested in characterizing basalt alteration with VNIR observations. Following the work of [3] on alteration of basaltic terrains in Iceland (wet, cold) and [4] in Antarctica (dry, cold), we are investigating remotely-sensed signatures of alteration in a warm, wet environment. The goals of this work are to characterize mineral signatures of an alteration profile with spectroscopy and then constrain our interpretations with laboratory measurements of mineralogy and chemistry.

Sampling Selection: Fourteen samples were collected along and near a weathering profile of Deccan basalts near Hyderabad, India [5] at 17°54'58.8"N, 77°32'34.3"E. We will focus on the ten samples from within the profile (Fig. 1). The Deccan basalts erupted 67-64 Ma [6] and have been proposed as a good petrologic analog for Mars [7]. The laterites finished forming by the early Tertiary [8], and the profile up to at least the base of the second basalt layer was probably below the water table at that time [5].

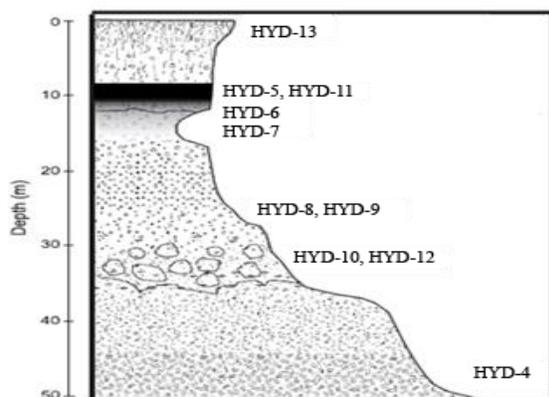


Fig. 1: Stratigraphic section showing sampling locations beginning with basalt at the base, a thick, strongly-altered saprolite, another layer of basalt, and a laterite cap at the top (modified from [5]).

Methods: Samples were ground and dry-sieved to form <45, 45-125, and 125-500 μm particle size separates. The 45-125 μm separates were then dried overnight in a desiccator, and bidirectional reflectance and FTIR spectra were acquired in RELAB from 0.3-25 μm [9]. Samples and 6 standards were prepared for elemental analyses through flux fusion: 40 mg of <45 μm separates were fused with 160 mg LiBO_2 at 1050 C for 10 min and then dissolved and diluted in 10% nitric acid for ICP-AES [10]. Loss on ignition was determined by heating ~1 g of each sample at 550 C for 4 h and calculating the difference in mass before and after to determine the volatile contents. Mössbauer spectra were acquired at Mount Holyoke College using standard methods. X-ray diffraction data are being acquired to identify mineralogy.

Results: Mineral identifications from VNIR and Mössbauer are given in Table 1, along with descriptions of rock types found at each point in the section. Selected VNIR and Mössbauer spectra are shown in Figs. 2 and 3, respectively. Of the basalts, HYD-4 shows more alteration than HYD-11 in VNIR spectroscopy and thus probably contains a small amount of smectite. HYD-5 has been altered the most, showing bands typical of Fe/Mg smectite clays. HYD-8 and HYD-9 were adjacent to each other, forming a mottled pattern. HYD-8 has absorption features at similar wavelengths to HYD-9, but because HYD-8's absorption features are much weaker, HYD-9 has been more altered than HYD-8, despite the fact that they occur together stratigraphically. The depth of HYD-6's absorption features indicates that it may be more strongly altered and/or contains more water/volatiles than HYD-8. Overtone and combination tone absorption features of HYD-6 and HYD-8 are not uniquely diagnostic, so XRD will help constrain their mineralogies. HYD-13 from the laterite cap at the top above the second layer of basalt has undergone extensive alteration.

HYD-7 and HYD-12 are examples of zeolites that occur throughout the profile in vesicles and fractures. Based on small shifts in the positions of combinations and overtones of water features, HYD-7 contains more Na than HYD-12, which is more Ca-rich [11].

Chemical data suggest that HYD-4, -5, and -11 show elemental abundances typical of the Deccan basalts. All these samples contain <2.5% volatiles. With alteration of the basalts, the volatile content (probably mostly H_2O) increases and the bulk chemistry shows

changes due to leaching. Most of the altered, non-zeolite samples have less Ca, Mg, Na, and Si than the basalts and more Ti. The volatile content of the phyllosilicate-bearing samples range from 13.9% to 19.2% and this is readily identified in the spectra. For example, HYD-6 has more volatiles than HYD-8 and HYD-9 has more volatiles than HYD-10. Though HYD-6 has a weaker 1.9 μm band than HYD-10, it actually has more volatiles. HYD-9, which contains the most volatiles, has lost the most K and Na and has the highest concentration of Mg relative to the other saprolite samples. A kaolinite-rich sample from the laterite and two other nearby laterite samples had the highest Fe contents of any of the samples due to hematite. Laterites also have high Al and Ti contents but low Ca, K, Mg, Na, and Si.

Implications for Mars: Previous work showed that much of this weathering profile was completely saturated with water in the past [5], yet two layers of mostly-unaltered basalt are still present. Although these basalts have weak absorption features near 1.9 μm and most have 1.4 μm absorption features, the spectra and bulk samples otherwise look like crystalline igneous rocks. The higher layer of basalt is between a saprolite and a laterite, so it must have been exposed to water but it did not become extensively altered with phyllosilicates. Saprolites can be readily recognized with spectroscopy and retain few of the spectral properties of the original basalt lithologies. Relative degrees of alteration (e.g. between the weakly altered basalt and the saprolite) are readily seen. Laterite samples come from the region that experienced the greatest flux of water and contain a mixture of kaolinite and hematite, an important association to be searched for on Mars. Finally, all samples contain volatiles, probably as water. The least-altered basalt contains 0.75% volatiles while the most altered basalt contains 2.2%. Saprolites, laterites, and zeolites all have 11-20% volatiles. Based on the common occurrence of phyllosilicates [1, 2], the Martian crust interacted with water in the past and could still have a high water content today. We will further characterize these samples to assess the amount of water that might be sequestered in the Martian crust.

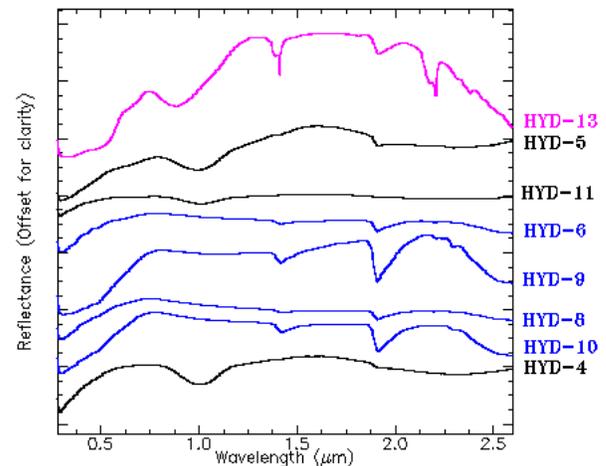


Fig. 2: VNIR reflectance spectra of selected samples. The magenta spectrum is a laterite, black spectra are basalts, and blue spectra are saprolites.

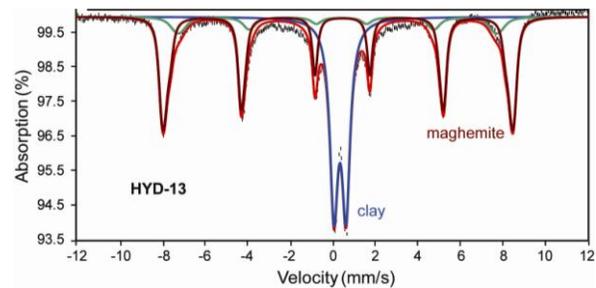


Fig. 3: 295K Mössbauer spectrum of sample HYD-13 showing contributions from a clay mineral (blue) and an Fe oxide that is probably maghemite.

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References: [1] Bibring J. P. et al. (2005) *Science*, 307, 1576-1581. [2] Mustard J. F. et al. (2008) *Nature*, 454, 305-309. [3] Ehlmann B. L. et al. (2010) *LPS, XLI, Abstract #1858*. [4] Salvatore M. R. et al. (2010) *LPS, this meeting*. [5] Kisakürek B. et al. (2004) *Chemical Geol.*, 212, 27-44. [6] Bhattacharji S. et al. (1996), *J. Geol.* 104, 379-398. [7] Christensen P. R. et al. (2000) *JGR*, 105, 9609-9621. [8] Schmidt P. W. et al. (1983) *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 44, 185-202. [9] Pieters C. M. (1983) *JGR*, 88, 9534-9544. [10] Murray R. W. et al. (2000) *ODP Tech. Note*, 29. [11] Cloutis E. A. et al. (2002) *JGR*, 107, 5067.

Table 1. Results

	#	VNIR	Mössbauer	Interpretation
top ↑ ↓ bottom	HYD-13	Kaolinite, Hem	Clay, Hem	Extensively-altered mix of Kao and Hem, high Fe and Al content
	HYD-5	Px, Fe/Mg smec	Cpx, Ilm, Opx	Weakly-altered basalt with small amount smectite
	HYD-11	Px	Cpx, Ilm, Mag	Weakly-altered basalt
	HYD-6	Palag, Sap, or Smec?	Clay, Ilm, Hem, Mhm	Phyllosilicate-rich rock similar to HYD-8 with more water
	HYD-7	Zeolite	sample too low in Fe	Chabazite, laumontite, or stilbite, more Na than HYD-12
	HYD-8	Smec?	Clay, Mhm	Phyllosilicate-rich rock similar to HYD-8 with less water
	HYD-9	Fe,Al Smec	Clay, Mhm	More strongly altered than HYD-8, highest volatile content
	HYD-10	Phyllosilicate	Clay, Mhm	Phyllosilicate-rich rock with iron oxides
	HYD-12	Zeolite	sample too low in Fe	Chabazite, laumontite, or stilbite, more Ca than HYD-7
	HYD-4	Px, Smec	Cpx, Ilm, Lep or Hem	Weakly-altered basalt with small amount smectite

Px = pyroxene, Ilm = ilmenite, Lep = lepidocrocite, Hem = Hematite, Mag = magnetite, Mhm = maghemite, Smec = smectite, Palag = palagonite, Sap = saponite