

**SPECTRAL ANALYSIS OF DECCAN INTRABASALTIC BOLE BEDS: IMPLICATIONS FOR PHYLLOSILICATE FORMATION ON MARS.** P. Gavin<sup>1</sup>, V. Chevrier<sup>1</sup>, M.R.G. Sayyed<sup>2</sup>, R. Islam<sup>3</sup>. <sup>1</sup>Arkansas Center for Space and Planetary Sciences, 202 Old Museum Building, University of Arkansas, Fayetteville, AR, USA 72701, <sup>2</sup>Department of Geology, Poona College, Camp, Pune 411 001, India, <sup>3</sup>Wadia Institute of Himalayan Geology, 33 General Mahadeo Rd, Dehradun, 248 001, India. [pgavin@uark.edu](mailto:pgavin@uark.edu)

### Introduction:

Phyllosilicates have been identified in some of the oldest terrains on Mars [1,2], however, their exact origins remain unclear. Some theories suggest they are the result of liquid water interactions with basalt during the Noachian [3] while others propose subsurface hydrothermalism resulting from volcanic activity [4] or surface hydrothermalism from meteorite impacts [5]. Recent observations of the Mawrth Vallis region revealed a Fe<sup>3+</sup>-mineral layer overlain by an Al-mineral layer, with a Fe<sup>2+</sup> layer between them [e.g., 2]. The varying compositions of these layers suggest varying environmental conditions in place at the time of formation.

To fully understand phyllosilicate formation on Mars, we can study analog minerals on Earth. One possible candidate for martian phyllosilicates is the Deccan Palaeosols in India because they were formed from the weathering of basaltic material [e.g., 6]. This study focuses on the spectral properties of the Deccan Palaeosols, compares them to known mineral phases, and links their formation processes with those that potentially occurred on Mars.

### Samples and Analytical Methods:

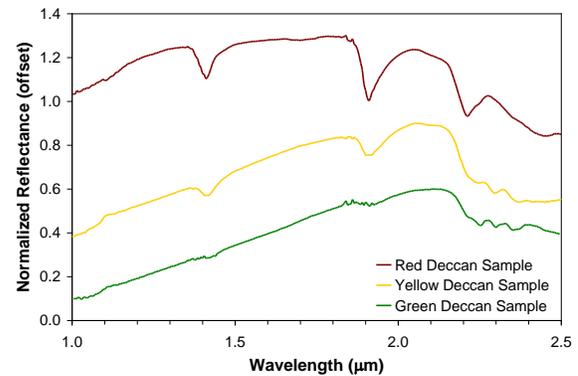
Eleven samples were first analyzed by X-ray diffraction (XRD) [7]. Each sample's reflectance spectrum was then recorded using an FTIR in the near-infrared (NIR) region (1.0-2.5 μm) and mid-infrared (MIR) region (5-15 μm). NIR spectra were recorded after two hours at 150°C under a dry N<sub>2</sub> flow [7,8], then normalized and offset for clarity.

### Results:

Eleven samples were grouped according to their color: red, yellow, or green. Previous XRD analysis show the red samples are composed of montmorillonite (Al-smectite) and hematite, yellow samples contain vermiculite (Fe<sup>2+</sup>-phyllosilicate) and green samples contain celadonite (Fe<sup>2+</sup>/Fe<sup>3+</sup>-mica) and nontronite (Fe<sup>3+</sup>-smectite) [6,7].

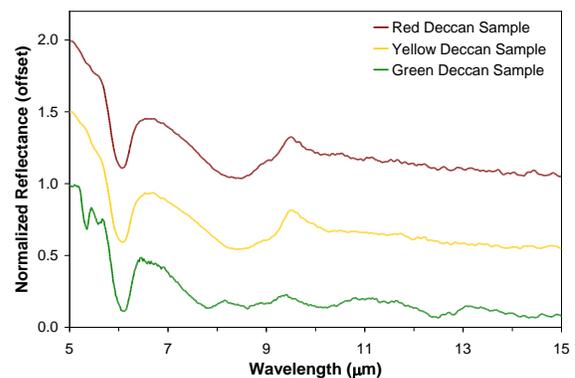
NIR spectra of the samples are mostly dominated by hydration bands at 1.4 and 1.9 μm and metal-OH bands in the 2.2-2.4 μm region (Fig. 1). Spectra of red samples show a band at 2.21 μm indicating Al and a weak band at 2.29 μm region indicating small amounts of Fe<sup>3+</sup> [9]. Spectra of green and yellow samples have bands in the 1.0-1.2 μm and 2.35-2.37 μm regions indicating the presence of Fe<sup>2+</sup> [9] as well as a band at 2.29, indicating Fe<sup>3+</sup>. This supports the XRD data showing the green and yellow samples contain nontronite (Fe<sup>3+</sup>), vermiculite (Fe<sup>2+</sup>) and celadonite

(Fe<sup>2+</sup>/Fe<sup>3+</sup>) [7]. The lack of Fe<sup>3+</sup> bands in the red Deccan sample's spectrum suggests the Fe<sup>3+</sup> in the red samples is present in the form of hematite, which has no spectral signature in the NIR range and is likely responsible for the sample's red color.



**Figure 1:** NIR reflectance spectra of red, yellow and green Deccan samples.

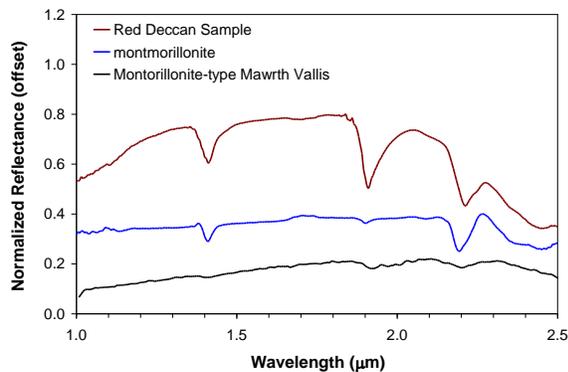
Figure 2 shows the MIR spectra of a red, yellow and green Deccan sample. All three spectra show bands at 6.1 and 8.5 μm representative of H<sub>2</sub>O and SiO<sub>2</sub>, respectively [9], and are similar to spectra of phyllosilicates [8,9]. Spectra of the red and yellow samples contain a peak at 9.5 μm indicating the Si(Al,Fe)O<sub>4</sub> vibrations [9] and the spectrum of the green sample has additional features at 5.4, 5.6, 7.9, 10.2 (OH bending), 12.5 (MgFe<sup>3+</sup>OH) and 14.5 μm (Mg<sub>3</sub>OH) [9].



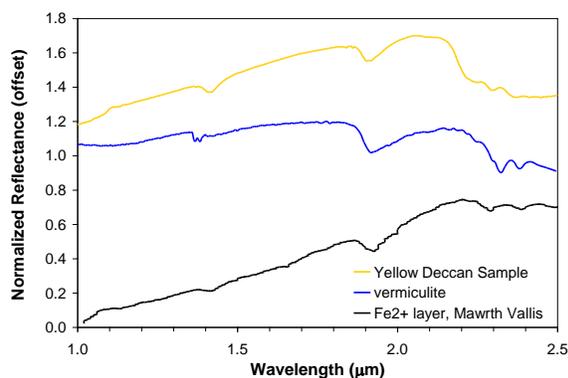
**Figure 2:** MIR reflectance spectra of red, yellow and green Deccan samples.

We compared the Deccan NIR spectra to those of known minerals and to spectra from Mawrth Vallis. Although shallow in the Mawrth Vallis spectrum, the 1.4, 1.9 and 2.21 μm bands are visible in the Deccan, montmorillonite and Mawrth Vallis spectra (Fig. 3). Bands at 2.31 and 2.37 μm and a

positive slope from 1.0-2.1  $\mu\text{m}$  is common to the yellow Deccan sample, vermiculite [10] and the middle layer from Mawrth Vallis [2] (Fig. 4). The spectra of the green Deccan sample and celadonite [9] have a very strong positive slope from 1.0-2.1  $\mu\text{m}$ , bands at 2.30 and 2.35  $\mu\text{m}$ , and very shallow hydration bands, as seen in the Mawrth Vallis spectrum (Fig. 5). Current models have concluded that up to 10% celadonite is required to produce the band at 2.35  $\mu\text{m}$  observed in the Mawrth Vallis spectrum [11].



**Figure 3:** Red Deccan sample compared to montmorillonite [8] and the top Al-phyllsilicate layer in Mawrth Vallis [2].



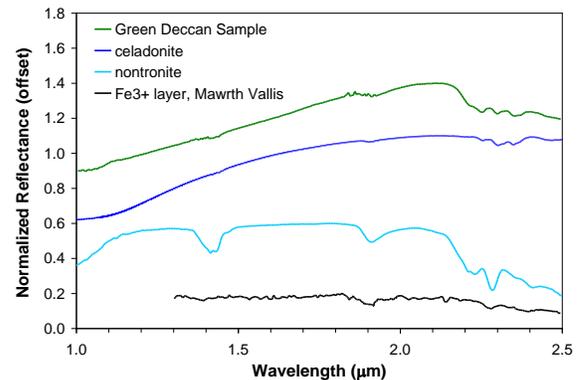
**Figure 4:** Yellow Deccan sample compared to vermiculite [10] and the middle Fe<sup>2+</sup> layer in Mawrth Vallis [2].

#### Discussion:

The stratigraphy of the Deccan soils is relatively similar to that found in Mawrth Vallis, Mars – Fe<sup>3+</sup>-mineral layer overlain by an Al-phyllsilicate/iron oxide layer with a Fe<sup>2+</sup>-mineral layer between them. This suggests that similar processes could have acted in both units. Chemical weathering of basalts often leads to the formation of phyllosilicates, but the transition from Fe<sup>3+</sup>-rich minerals to Fe<sup>2+</sup>-minerals to Al-rich minerals indicates changes of environmental conditions at the time of each mineral's formation. If the lower layers in Mawrth Vallis are in fact composed mainly of celadonite and nontronite, then it is possible that those lower celadonite layers transformed into the upper montmorillonite/hematite

layers with the vermiculite as an intermediate step [12,13].

Elemental analysis of the bole beds shows they are very similar to their respective underlying basalts and to each other [6]. While the mineralogy is very different, the chemistry of each layer is similar, suggesting mineral (trans)formation without ion significant transfer or loss. This formation pathway suggests that initial hydrothermal alteration of the basaltic layers evolved into surface weathering. However, it is difficult to determine whether this formation pathway is global on Mars or local to Mawrth Vallis or other regions.



**Figure 5:** Green Deccan Sample compared with celadonite [9], nontronite [8] and the lower Fe<sup>3+</sup>-phyllsilicate layer in Mawrth Vallis [11].

#### Conclusions:

The Deccan intrabasaltic bole beds are a good analog to the phyllosilicates in Mawrth Vallis not only because of their similar spectral properties but also their similar stratigraphy. If the lower layers in Mawrth Vallis are indeed composed of celadonite and nontronite, they most likely resulted from the surface weathering and/or low-temperature hydrothermalism of basalt, then further transformed into the vermiculite and montmorillonite/hematite layers. This formation pathway could have occurred without ion transfer or loss. While we cannot rule out other formation processes, especially in other regions of Mars, we have strong evidence that formation of phyllosilicates in Mawrth Vallis probably resulted from temperature changes during the alteration process.

**References:** [1] Poulet, F., et al., (2005) *Nature* 481, 623-627. [2] Bishop, J., et al., (2008) *Science* 321, 830-833. [3] Chevrier, V., et al., (2007) *Nature* 448, 60-63. [4] Ehlmann, B., et al., (2011) *Nature* 479, 53-60. [5] Fairen, A., et al., (2010) *PNAS* doi: 10.1073/pnas.1002889107. [6] Ghosh, P., et al., (2006) *Palaeogeography, Palaeoclimatology, Palaeoecology* 242, 90-109. [7] Gavin, P., et al., (2011) *LPSC XLI* #1905. [8] Gavin, P., and Chevrier, V., (2010) *Icarus*, 208, 721-734. [9] Bishop, J., et al., (2008) *Clay Minerals* 43, 35-54. [10] Clark, R., et al., (2007) *USGS data series* 231. [11] Poulet, F., Carter, J., (2011) *MSL Landing Site Workshop* [12] Reid, D., et al., (1988) *Clays and Clay Min.* 36, 425-431. [13] Robert, M. (1973) *Clays and Clay Min.* 21, 167-174.