

## SPECTRAL PROPERTIES OF HYDRATED POORLY CRYSTALLINE MATERIALS FOR SPECTRAL ANALYSIS OF THE MOON AND MARS.

J. L. Bishop<sup>1</sup>, N. W. Hinman<sup>2</sup>, J. M. Danielsen<sup>1,3</sup>, L. L. Baker<sup>4</sup>, T. J. Jeute<sup>4</sup>, Z. Abidin<sup>5</sup>, E. B. Rampe<sup>6</sup>. <sup>1</sup>SETI Institute & NASA-Ames (Mountain View, CA; [jbishop@seti.org](mailto:jbishop@seti.org)), <sup>2</sup>University of Montana (Missoula, MT), <sup>3</sup>San Jose State University (San Jose, CA), <sup>4</sup>University of Idaho (Moscow, ID), <sup>5</sup>Bogor Agricultural University (Bogor, Indonesia), <sup>6</sup>Johnson Space Center (Houston, TX).

Visible/near-infrared (VNIR) reflectance spectra of both Mars [1] and the Moon [2] include hydration bands that vary across the planet and are not well explained in some cases. Poorly crystalline phases have been found at ~30-70 wt.% by CheMin in Gale crater, Mars in all samples measured to date [3]. Here we report on VNIR reflectance spectra of a large collection of amorphous and poorly crystalline materials. These include opal, allophane, imogolite, iron hydroxides/oxyhydroxides (FeOx), and several synthetic materials containing Si, Al and/or Fe. All of these contain hydration bands due to water and OH that can be used to identify these materials remotely on planetary bodies.

**Introduction:** Hydrated, poorly crystalline materials are common on Earth and can provide information about the environment in which they formed [4]. Allophane and imogolite were identified on Mars [5,6] and could be indicators of a cooler climate that could not support formation of phyllosilicates [7]. Nanophase (np) FeOx have also been identified on Mars by the Mini-Mössbauer spectrometers [8] and from orbital spectrometers [9,10]. Many of these phases are common alteration products of volcanic ash and could exist together with volcanic glass on Mars or the Moon.

Hydrated species have been observed on the Moon at low abundances due to solar-implanted OH/H<sub>2</sub>O, hydrated minerals, or ices [11] but the character of

these materials is not well known. It appears that multiple hydrated components are present and may have formed through different processes. One possibility is hydrated silica related to dark pyroclastic deposits [12]. The hydration band at 2.7-3  $\mu\text{m}$  was also observed to vary diurnally to a greater extent at high latitudes than at mid-latitudes in the Lunar highlands [13], which indicates that the hydrated component is mobile and likely differs across the Moon.

**Methods:** We focus here on VNIR reflectance spectra collected at Brown University's RELAB. Mid-IR spectra of these samples are also under study. The spectra measured under ambient conditions using a bidirectional instrument from 0.3 to 2.5  $\mu\text{m}$  are typically spliced at ~1.2  $\mu\text{m}$  to data acquired from a Nicolet FTIR spectrometer while in a H<sub>2</sub>O-purged environment [e.g. 14-16]. Some samples have only been measured with an ASD spectrometer under ambient conditions to date, but will be measured at RELAB soon as well.

**Samples:** A variety of opal samples have been collected from mineral dealers and field sites. VNIR reflectance spectra are shown of selected particulate opal samples (Fig. 1) and opaline material (typically 1-3 cm across) hand-picked out of rocks (Fig. 2). Spectra

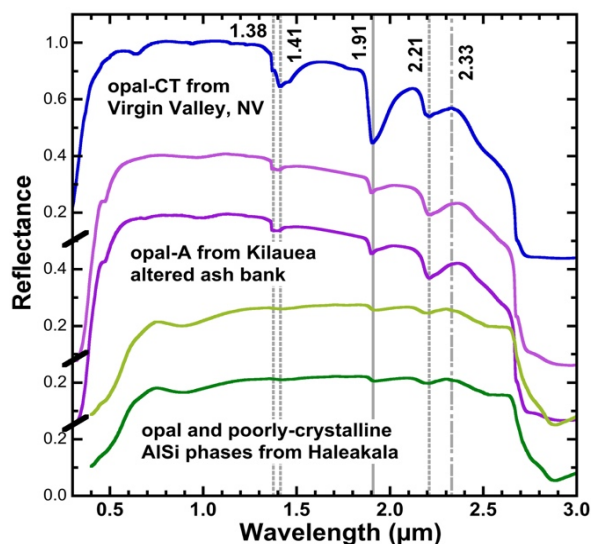


Fig. 1. Spectra of particulate (<125  $\mu\text{m}$ ) opal samples containing bands due to water (solid grey line) and OH (dashed grey lines) and a reflectance maximum near 2.33  $\mu\text{m}$ .

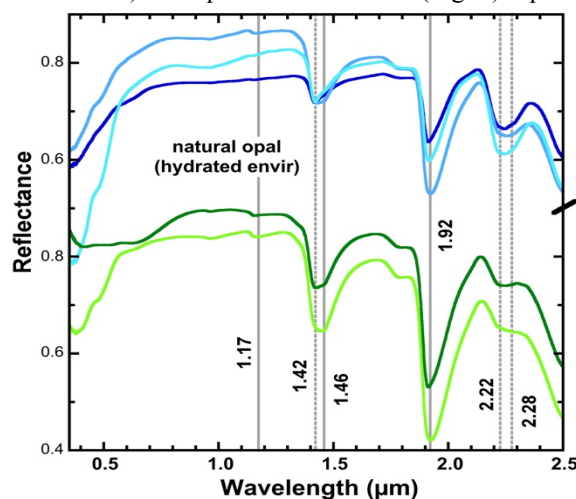


Fig. 2. Spectra of ground and dry sieved (<125  $\mu\text{m}$ ) opal rocks from Oregon containing bands due to water (solid line) and OH (dashed lines). Chemistry for these samples show that they are >92 wt.% SiO<sub>2</sub> with minor impurities. These spectra were measured under ambient conditions using an ASD spectrometer and the hydration bands are much stronger than in spectra of the other samples measured under dry conditions. Variations were observed in the band near 2.22-2.28  $\mu\text{m}$  for these samples and will be explored further.

of synthetic opal and synthetic Si-Fe materials (Fig. 3) are similar to opal spectra, but the band near 2.2  $\mu\text{m}$  extends towards longer wavelengths. The Si-Fe precipitates were synthesized by oxidizing dissolved  $\text{FeCl}_2$  in the presence of dissolved silica at different Si:Fe ratios (20, 8, 4, 2) under alkaline conditions. Spectra of selected imogolite (Fig. 4) and allophane (Fig. 5) samples exhibit similar trends with the addition of Fe. Spectra of selected np-FeOx samples are shown in Fig. 6 and typically include a broader water band that is shifted towards longer wavelengths.

**Implications:** The VNIR spectra of these hydrated, poorly crystalline materials exhibit different band centers and band shapes in their  $\text{H}_2\text{O}$  and OH features that

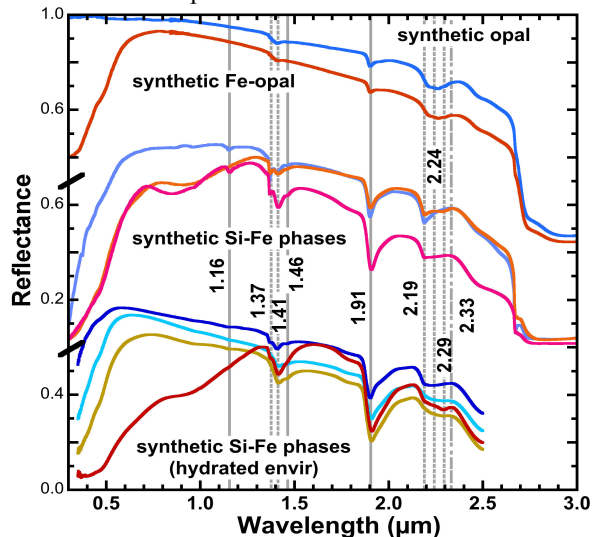


Fig. 3. Spectra of synthetic opal and synthetic Si-Fe precipitates. The addition of Fe to the system produces broadening of the band near 2.2-2.3  $\mu\text{m}$ . The lower set of spectra were measured under ambient conditions with an ASD spectrometer.

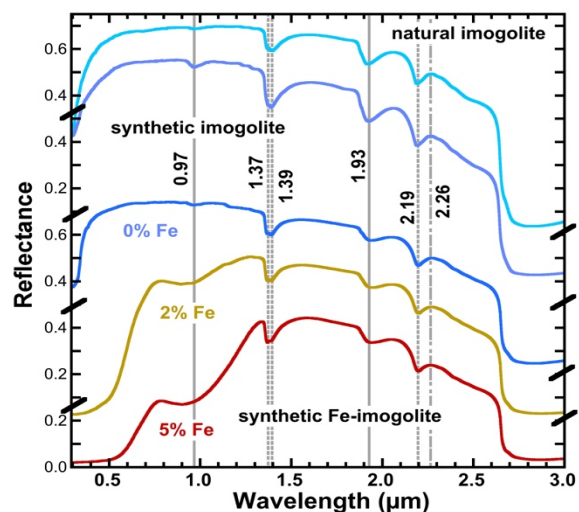


Fig. 4. Spectra of natural and synthetic imogolite samples. The addition of Fe to the system produces some broadening of the bands near 1.9 and 2.2  $\mu\text{m}$ .

could be used for identification of specific hydrated phases on Mars and perhaps also the Moon.

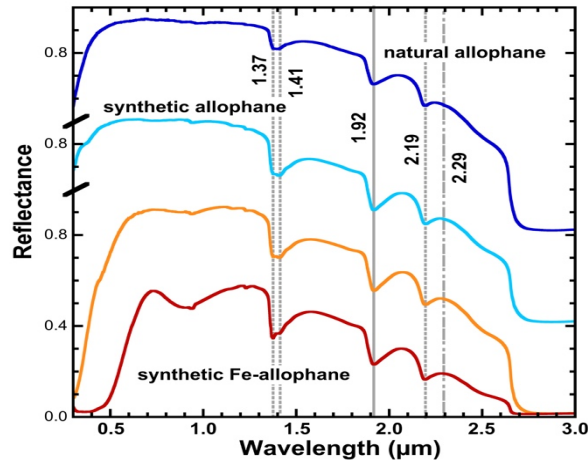


Fig. 5. Spectra of natural and synthetic allophane samples. The synthetic samples exhibit a more clearly defined doublet near 1.4  $\mu\text{m}$ . The addition of Fe during synthesis produces some broadening of the band near 2.2  $\mu\text{m}$ , darkening of the spectra across the VNIR region, and saturation of the 3  $\mu\text{m}$  band.

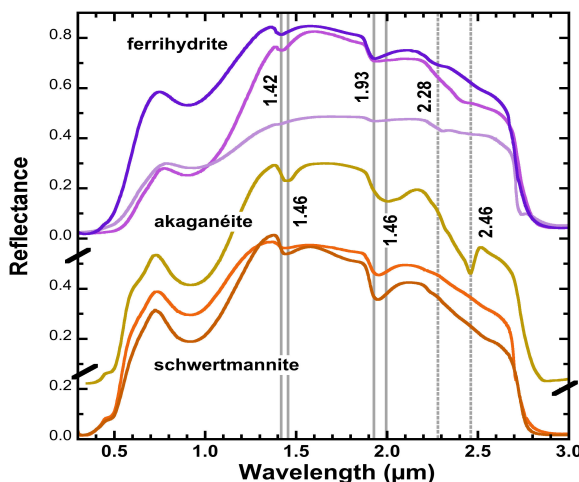


Fig. 6. Spectra of natural and synthetic ferrihydrite, akaganéite, and schwertmannite samples. The  $\text{H}_2\text{O}$  and OH bands in akaganéite spectra are shifted longer due to constrained sites in the mineral structure [15].

**References:** [1] eg Murchie et al. (2009) *JGR*, **114**, E00D06. [2] eg Pieters et al. (2009) *Science*, **326**, 568. [3] eg Bristow et al. (2018) *Science Adv.*, **4**, eaar3330. [4] eg Chamley (1989) *Clay Sediment*. Springer, NY. [5] Rampe et al. (2012) *Geol.*, **40**, 995. [6] Bishop & Rampe (2016) *EPSL*, **448**, 42. [7] Bishop et al. (2018) *Nat. Astro.*, **2**, 206. [8] Morris et al. (2008) *JGR*, **113**, E12S42. [9] Carter et al. (2015) *Icarus*, **253**, 296. [10] Poulet et al. (2014) *Icarus*, **231**, 65. [11] McCord et al., (2011) *JGR*, **116**, E00G05. [12] Li & Milliken (2017) *Science Adv.*, **3**, e1701471. [13] Wöhler et al. (2017) *Science Adv.*, **3**, e1701286. [14] Bishop et al. (2013) *CCM*, **61**, 57. [15] Bishop et al. (2015) *Am.Min.*, **100**, 738. [16] Jeute et al. (2018) *LPSC* #2137.

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