

**SPECTRAL REFLECTANCE PROPERTIES OF MARS-RELEVANT MINERALS SUBJECTED TO HEATING IN A LOW-PRESSURE CO<sub>2</sub>-ENRICHED ENVIRONMENT.** Z. U. Wolf<sup>1</sup>, N. N. Turenne<sup>1</sup>, E. A. Cloutis<sup>1</sup>, D. M. Applin<sup>1</sup>, P. Mann<sup>1</sup>, and S. Mertzman<sup>2</sup>. <sup>1</sup>Center for Terrestrial and Planetary Exploration (C-TAPE), University of Winnipeg, 515 Portage Avenue, Winnipeg, Manitoba, Canada R3B 2E9; <sup>2</sup>Department of Earth and Environment, Franklin and Marshall College, P.O. Box 3003, Lancaster, PA, USA 17604-3003. \*wolf-z@webmail.uwinnipeg.ca.

**Introduction:** Heating events on the surface of Mars may be widespread due to a variety of processes. These may include impact heating, impact-generated hydrothermal systems, emplacement of hot ejecta, surficial lava flows, ashfall deposits, and near-surface igneous intrusions. Thus, there are several surficial modification processes seen on Mars that could generate heat and potentially alter pre-existing minerals. In addition, subsurface processes could heat surface and near-surface materials which could subsequently become exposed at the surface via exhumation.

A number of these processes can heat minerals to low temperatures (<300°C), including burial under ashfall deposits or lava flows [1-5], burial under impact ejecta [6, 7], or in areas beyond the immediate point of an impact [8-12]. Thus, low-temperature heating may be an important factor on Mars, and the ability to identify heated minerals could provide insights into surface modification processes.

**Methods:** This study analyzed a total of 46 minerals from diverse classes, including phyllosilicates, carbonates, sulfates, zeolites, pyrites, oxides/hydroxides, organic-bearing minerals, palagonitic soils, and silica sinters. The samples were hand crushed using an alumina mortar and pestle and dry sieved to <45 µm using stainless steel sieves. To minimize any alteration from mechanical heating or liquid solvents, the samples were hand crushed instead of mechanically crushed and dry sieved instead of wet sieved.

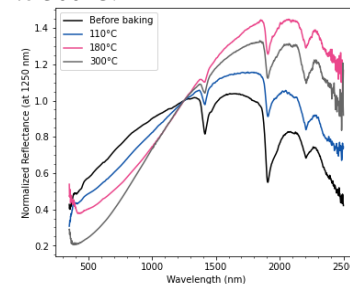
Reflectance spectra were collected with an ASD FieldSpec spectrometer (350-2500 nm) at a viewing geometry of  $i=0^\circ$ ,  $e=0^\circ$  with a bifurcated cable.

The samples were exposed to several elevated temperatures to replicate impact-induced heating that may occur on Mars and under Mars-like surface conditions. Each <45 µm sample was put into an 8 mm diameter and 6 mm deep aluminum sample cup. The samples were heated using a vacuum oven to 110°C, 180°C, and 300°C for one week each with a continuous flow of CO<sub>2</sub> gas to create CO<sub>2</sub>-rich atmospheric conditions, with pressures between 20 and 100 millibars. This experimental setup was conducted due to the importance of understanding the effects of temperature as a separate process from pressure and in a Mars-relevant atmosphere. French (1998) determined that the nonlinear relationship between temperature and pressure in im-

perfect environments would make it unlikely that temperatures would exceed 500°C in shocked materials. The samples were removed from the vacuum oven for spectral measurements and returned to the vacuum oven for the next temperature interval. Sample spectra were acquired both before and after heating to each temperature, without and through a 10 mm-thick sapphire window after the sample was removed from the oven, allowed to cool to ambient temperature, and briefly exposed to terrestrial ambient conditions. Reflectance spectra measured through a sapphire window were to enable direct comparison with samples exposed to Mars-like atmospheric pressure and composition [13, 14, 15].

**Results:** Reflectance spectra were collected for all 46 minerals through the sapphire window, in air/without the sapphire window, and in the Mars box [13, 14]. The figures shown below are reflectance spectra for a few phyllosilicates (beidellite, nontronite), sulfates (alunite, kieserite), oxide (magnetite), and carbonate (calcite) samples.

The reflectance spectra for beidellite (Fig. 1) show a reduction in the depth and shape of hydration bands near 1400 and 1900 nm. Most notably, the longer wavelength shoulders associated with adsorbed water were greatly reduced in intensity. The Al-OH band near 2182 nm is spectrally stable at all temperatures up to 300°C.



*Figure 1:  
Reflectance  
spectra for  
beidellite.*

The reflectance spectra for nontronite (Fig.2) show a gradual loss of hydration bands near 1400 and 1900 nm, Fe<sup>3+</sup>-associated features, and Fe-OH bands below 1000 nm. A single Fe atom-associated absorption band is the 2280 nm feature (Fe-OH combination band), while the absorption features below 1000 nm involve two Fe atoms bridged by OH. The dual-atom versus single-atom nature of the various bands likely accounts for the fact that the (single Fe atom) 2280 nm absorp-

tion feature becomes shallower at a slower rate with increasing temperature than the features below 1000 nm. This also indicates that the 2280 nm band is the best feature for identifying the presence of nontronite.

The reflectance spectra for two sulfate minerals heated to 300°C, alunite and kieserite, are shown in Fig. 3 and Fig. 4, respectively. Both the alunite and kieserite hydration bands at 1400 and 1900 nm persisted but with variable changes in depth. Kieserite also shows a decrease in the depth and change in the shape of the Fe<sup>2+</sup> absorption band at ~1000 nm as temperature increases.

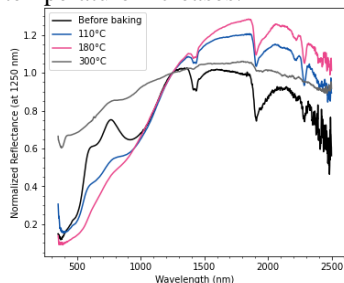


Figure 2:  
Reflectance  
spectra for  
nontronite.

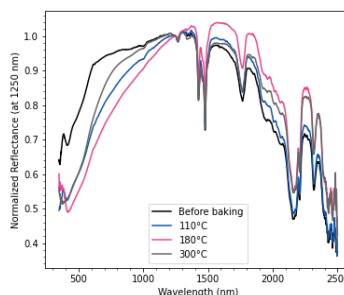


Figure 3:  
Reflectance  
spectra for  
alunite.

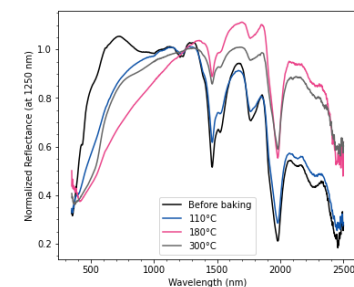


Figure 4:  
Reflectance  
spectra for  
kieserite.

The reflectance spectra for magnetite (Fig. 5) show that the sample potentially oxidized to form a mixture of magnetite, hematite, and maghemite of varying proportions depending on temperature. The flat spectrum at 300°C could be due to a mixture of magnetite and maghemite.

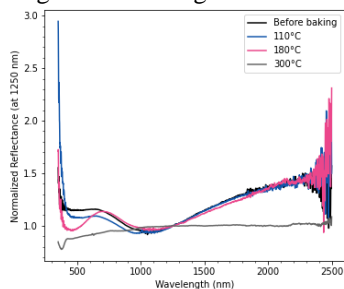


Figure 5:  
Reflectance  
spectra for  
magnetite.

The spectra of calcite (Fig. 6) show that the CO<sub>3</sub> band at 2350 nm and the band just beyond 2500 nm are spectrally stable upon heating, suggesting it should be spectrally detectable on Mars using these features.

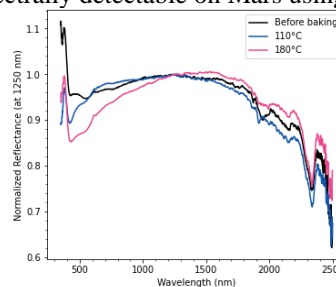


Figure 6:  
Reflectance  
spectra for  
calcite.

**Discussion:** Because dehydroxylation proceeds at generally higher temperatures than dehydration, OH-associated absorption bands will persist to higher temperatures (and higher shock pressures) than H<sub>2</sub>O-associated absorption bands. In addition, Fe-OH bonds that involve a single Fe atom and a single OH molecule (in the 2300 nm region) should be more resistant to degradation than those involving two Fe atoms and a bridging OH (below 1000 nm).

This accounts for the fact that lower wavelength absorption bands (<1000 nm) that involve such double bonds are more affected by exposure to elevated temperatures.

**Future work:** The results shown here are part of a larger set of 46 minerals that were baked in a CO<sub>2</sub>-rich environment. Additional data will be presented at the conference and in an upcoming paper.

**Acknowledgments:** Thanks to CSA, NSERC, CFI MRIF, and UWinnipeg for supporting this study.

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