

**LABORATORY EMISSION, VISIBLE-NEAR INFRARED, AND MÖSSBAUER SPECTROSCOPY OF IRON SULFATES: APPLICATION TO THE BRIGHT PASO ROBLES SOILS IN GUSEV CRATER, MARS** M. D. Lane<sup>1</sup>, M. D. Dyar<sup>2</sup>, J. L. Bishop<sup>3</sup>, P. L. King<sup>4</sup>, and E. Cloutis<sup>5</sup>. <sup>1</sup>Planetary Science Institute, Tucson, AZ ([lane@psi.edu](mailto:lane@psi.edu)), <sup>2</sup>Mount Holyoke College, South Hadley, MA, <sup>3</sup>SETI Institute/NASA-Ames Research Center, Mountain View, CA, <sup>4</sup>Univ. of Western Ontario, Canada, <sup>5</sup>Univ. of Winnipeg, Canada.

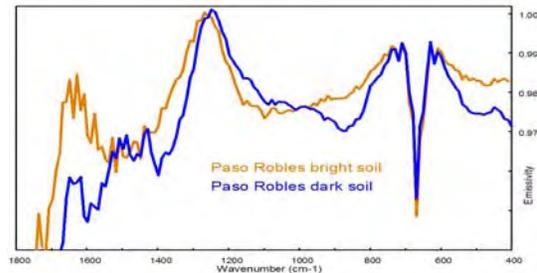
**Introduction:** The Mars Exploration Rover (MER) in Gusev Crater has exposed in its tracks an unusual occurrence of a soil high in sulfur and high in phosphorus [1, 2] at a site called Paso Robles (Fig. 1). This salty soil is thought to be composed of the following: Fe<sup>3+</sup>-, Mg-, and Ca-sulfates; Ca-phosphate; hematite, halite, allophane, and amorphous Si [1]. We are currently studying a large suite of sulfate minerals [e.g., 3-7] using a variety of methods including mid-infrared emission, reflectance, and micro-transmission spectroscopies, plus visible-near infrared (VNIR) spectroscopy and Mössbauer (MB) spectroscopy. Prior to our work, only the most common sulfates had been studied in detail in the literature using our wide variety of spectroscopic techniques. Included in our sulfate studies are numerous Fe<sup>3+</sup> sulfates that are clearly an important mineral phase of the anomalous Paso Robles soils. Hence, we are beginning to apply our spectral databases to the interpretation of various MER datasets to further explore and better understand the chemistry of these salt-rich soils. The focus of this work is to present sulfate emissivity, VNIR, and Mössbauer spectra.

**Fig. 1.** Pancam image 2P162233683EFA618-P2559L5M1.JPG of the bright Paso Robles soil exposed in the MER tracks. The image was acquired on sol 404.

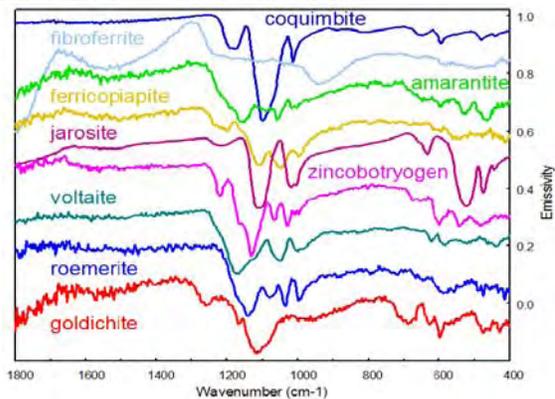


**Emissivity Spectra:** The soil exposed in the MER tracks is typically dark, and the bright soil at Paso Robles that contains ~32% sulfate [1] is rare. Fig. 2 shows Miniature Thermal Emission Spectrometer (Mini-TES) [8] emissivity spectra of these two soil types acquired on sols 400, 403, 404 and 429. The bright soil spectrum may be compared to a laboratory-suite of Fe<sup>3+</sup>-sulfates (Fig. 3). The Fe<sup>3+</sup> sulfate spectra show the sulfate ν<sub>3</sub> features in the 1300 to 950 cm<sup>-1</sup> range [3]. These features are pronounced in the spectra of crystalline, solid samples; however, for particulate samples, the fundamental vibrational features are

shallow and the overall character in the ~1280-800 cm<sup>-1</sup> range becomes bowl-shaped (not shown) and similar to the shape of the bright soil track in Fig. 2. Fine-grained Fe<sup>3+</sup> sulfates exhibit the water bending mode (δH<sub>2</sub>O) at ~1640 cm<sup>-1</sup> that is also exhibited in the Paso Robles bright soil spectrum (Fig. 2).



**Fig.2.** Mini-TES spectra of bright, sulfate-rich soil exposed in the MER tracks and of dark soil tracks.



**Fig.3.** Emissivity spectra of a suite of Fe<sup>3+</sup> sulfates.

**VNIR Spectra:** Recent studies of the OMEGA/Mars Express spectral images have identified kieserite, gypsum and other hydrated sulfates in the layered terrains in Valles Marineris and Terra Meridiana based on VNIR features [9-11]. A collection of Fe<sup>3+</sup> sulfates are shown in Fig. 4. These hydrated sulfates exhibit spectral features due to H<sub>2</sub>O near 1.45 and 1.95 μm, plus additional Fe bands. Many of these Fe<sup>3+</sup> sulfate spectra exhibit a band near 0.43 μm that is also present in jarosite [e.g., 12]. Amaranite, copiapite, ferricopiapite, and fibroferrite have Fe<sup>3+</sup> absorption bands centered between 0.85-0.88 μm, jarosite and schwertmannite have bands close to 0.9 μm, and coquimbite has two bands centered near 0.56 and 0.78 μm. These hydrated sulfates also have absorption features near 2.4-2.6 μm that are similar to features observed in

OMEGA spectra that have not yet been associated with specific minerals.

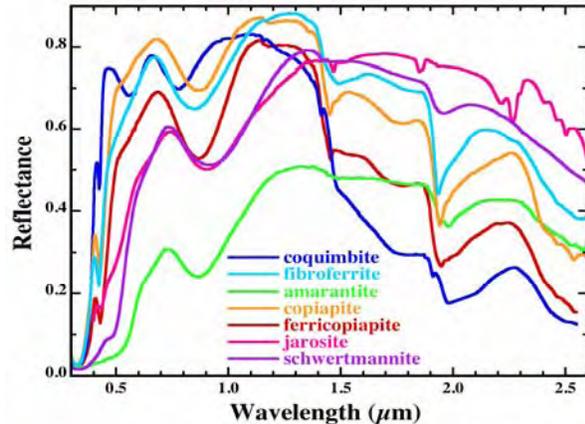


Fig. 4. VNIR spectra of  $\text{Fe}^{3+}$  sulfates. The spectra are colored in order of increasing  $\text{Fe}^{3+}$  band center.

**Mössbauer Spectra:** Paso Robles MB spectra were processed using *MERView* [13]; all temperatures were then added together and fit using quadrupole splitting distributions. Data are shown in Table 1 and fits are given in Figure 5. The sol 426-427 data set is dominantly  $\text{Fe}^{2+}$  (70% of the total Fe) and 401-403 and 429A are  $\text{Fe}^{3+}$ -rich (87 and 82%, respectively).

Table 1. Mössbauer Fits to Paso Robles Spectra

Sol		IS	Width	QS	Field(T)	Area
401	Mag	0.36	0.42	-0.09	52.3	24
	$\text{Fe}^{2+}$	1.32	0.56	1.98		13
	$\text{Fe}^{3+}$	0.42	0.47	0.51		63
426 427		0.24	0.30	0.03	51.2	8
		0.27	0.30	0.23	44.9	7
	$\text{Fe}^{2+}$	1.15	0.29	3.03		25
	$\text{Fe}^{2+}$	1.16	0.61	2.17		45
	$\text{Fe}^{3+}$	0.37	0.30	0.54		7
	$\text{Fe}^{3+}$	0.40	0.30	1.17		8
429A		0.42	0.30	0.02	52.4	7
		0.38	0.30	0.22	48.1	4
	$\text{Fe}^{2+}$	1.17	0.30	2.93		8
	$\text{Fe}^{2+}$	1.29	0.45	1.85		10
	$\text{Fe}^{3+}$	0.42	0.47	0.47		46
	$\text{Fe}^{3+}$	0.39	0.62	1.06		26

All three show evidence for the presence of a magnetic sextet, and unconstrained fits to 401-403 identify the oxide as magnetite. A doublet with olivine-like parameters of  $\text{QS} = 2.93\text{-}3.03$  mm/s is found in 426-427 and 429A, suggesting a contribution from a substrate. In 401-403, the  $\text{Fe}^{2+}$  phase has parameters consistent with halotrichite, bilinite, and botryogen group minerals but could be consistent with  $\text{Fe}^{2+}$  in related sulfates such as römerite and coquimbite as well (or, possibly, pyroxene in the substrate). The other doublets have parameters similar to those of numerous  $\text{Fe}^{3+}$  sulfates such as sideronatrite, copiapite, schwertmannite, and fibroferrite. There is no evidence for jarosite group minerals in the MB spectra.

Because there are only sparse spectral data on many of these phases (very little for MB, especially at Mars temperatures) and the data that do exist are often on phases of uncharacterized composition or mineral species, more work is needed to refine our interpretations. Our ongoing spectral characterizations of sulfates at all the wavelengths discussed here will be critical to proper interpretation of these results.

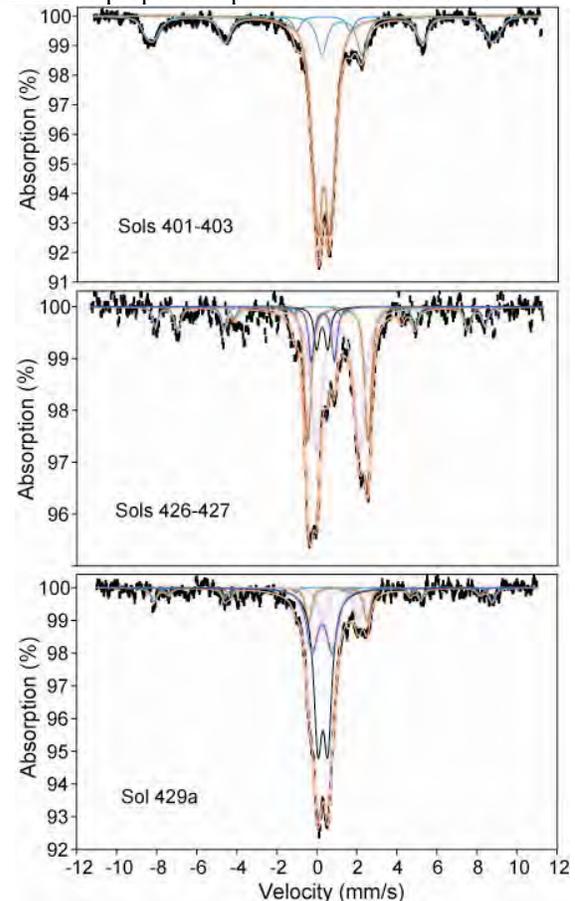


Fig. 5. Mössbauer fits corresponding to Table 1.

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**References:** [1] Ming, D. W. and R. V. Morris (2005) *Fall AGU*, abs. P12A-03, 2005. [2] Arvidson, R. E. and S. W. Squyres (2005) *Fall AGU*, abs. P11E-04. [3] Lane, M. D., *Am. Miner.*, subm. [4] Dyar, M. D. et al. (2005) *LPS XXXVI*, abs. 1622. [5] Lane, M. D. et al. (2005) *LPS XXXVI*, abs. 1442. [6] Bishop, J. L. et al. (2005) *Euro. Geosci. Union*, abs. EGU05-A-05737. [7] King, P. L. et al. (2005) *5<sup>th</sup> Can. Space Expl. Wksp*, abs. SE0539. [8] Christensen, P. R. et al. (2003) *JGR*, 108, 8061. [9] Bibring J.-P. et al. (2005) *Science*, 307, 1576-1581. [10] Gendrin A. et al. (2005) *Science*, 307, 1587-1591. [11] Arvidson R. E. et al. (2005) *Science*, 307, 1591-1594. [12] Bishop J. L., E. Murad (2005) *Am. Miner.*, 90, 1100-1107. [13] Agresti D. (2006) this vol.