

# Are oxidized shergottite-like basalts an alternative to “andesite” on Mars?

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[1] We acquired new thermal emission spectra of oxidized synthetic Martian meteorite-like basalts for comparison to Martian surface spectra acquired by the Mars Global Surveyor Thermal Emission Spectrometer (MGS TES). We find that true thermal emission spectra of the oxidized basalts do not provide good spectral matches to the Martian spectra. By contrast, previous biconical reflectance spectra, converted to emission spectra, appeared to fit the Mars observations well. Attempts to model the mineralogies of the oxidized basalts using a linear deconvolution algorithm and an end member set previously used to derive mineralogies for the Martian surface were unsuccessful, suggesting that the oxidized basalts contain altered phases not present in the end member set. Successful modeling of Martian surface mineralogies using the end member set indicates that it sufficiently represents the phases present on the Martian surface and does not require the altered phases needed to model the oxidized basalt mineralogies. Although oxidized Martian meteorite-like basalts may be viable analogues for some Martian materials, our results suggest that they cannot explain the two primary surface mineralogies measured by MGS TES.

*INDEX TERMS:*

5410 Planetology: Solid Surface Planets: Composition; 5464 Planetology: Solid Surface Planets: Remote sensing; 5470 Planetology: Solid Surface Planets: Surface materials and properties; 5494 Planetology: Solid Surface Planets: Instruments and techniques; 6225 Planetology: Solar System Objects: Mars. **Citation:** Hamilton, V. E., and M. E. Minitti, Are oxidized shergottite-like basalts an alternative to “andesite” on Mars?, *Geophys. Res. Lett.*, 30(18), 1915, doi:10.1029/2003GL017839, 2003.

## 1. Introduction and Background

[2] The composition of the Martian crust is a direct indicator of the geologic processes that have occurred on Mars. Distinguishing between materials that have been chemically weathered, altered, or left relatively intact is also important in understanding what chemical processes have operated on the uppermost surface. Large provinces of dark, relatively dust-free material on Mars have visible/near infrared spectral characteristics of pyroxenes that are consistent with, but not unique to, the spectral character of pyroxenes in basaltic shergottite meteorites [Mustard and Sunshine, 1995; Mustard *et al.*, 1997]. Subsequently, Bandfield *et al.* [2000] and Christensen *et al.* [2000b]

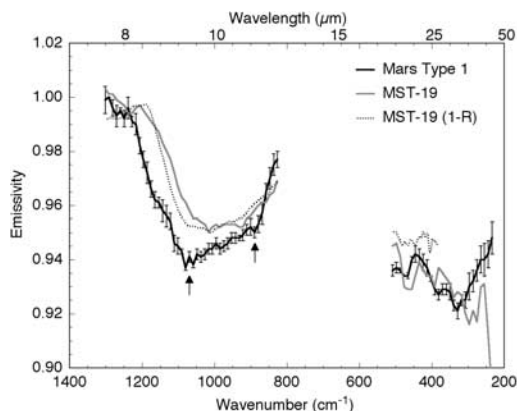
examined thermal infrared (TIR) data of Martian dark surfaces and established that they are characterized primarily by two spectral shapes that do not appear to resemble the TIR spectra of Martian meteorites [Hamilton *et al.*, 1997]. The mineralogies of the Martian TIR spectra were interpreted as representing basalt (type 1) and basaltic andesite to andesite (type 2) [Bandfield *et al.*, 2000].

[3] The interpretation of type 2 surfaces as more silicic than “basalt” has been controversial and recent studies have proposed other interpretations of the TES spectral data [Minitti *et al.*, 2002; Wyatt and McSween, 2002]. In one of these studies, Minitti *et al.* [2002] synthesized Martian meteorite-like basalts to study the effects of various degrees of crystallization and oxidation on their visible to near infrared (0.32–2.55  $\mu\text{m}$ ), and thermal infrared (to 26  $\mu\text{m}$ ) spectra. Minitti and coworkers concluded that biconical reflectance spectra, converted to emissivity spectra, of two of their samples (described below) appeared similar to the two Martian surface spectral types observed by TES, and hypothesized that the Martian surface lithologies might be explained by the presence of oxidized Martian meteorite-like basaltic materials rather than more silicic compositions.

[4] Here we test the hypothesis of Minitti *et al.* [2002] by 1) comparing new, true thermal emission spectra of the oxidized basalts to the TES spectra, and 2) comparing their quantitatively modeled compositions to those of the Martian surface spectra.

## 2. Samples and Approach

[5] Minitti *et al.* [2002] describe synthetic samples of Martian meteorite-like basalts, MST-17 and MST-19. Both samples contain shergottite-like proportions of pyroxene and plagioclase, consistent with crystallization from a Martian meteorite-like (high-FeO, low  $\text{Al}_2\text{O}_3$ ) basalt. MST-17 is a 100% crystallized sample oxidized for 7 days in air at 700°C, and MST-19 is a 65% crystallized sample oxidized for 7 days in air at 700°C. Both samples are particulates with particle sizes ranging from 75–500  $\mu\text{m}$ . In comparing the biconical reflectance spectra of these laboratory samples to the two Martian surface types, MST-17 best matches the type 2 spectrum of Bandfield *et al.* [2000], and MST-19 best matches the type 1 spectrum. Thermal emission spectra of the laboratory samples were acquired in the Thermal Emission Spectroscopy Laboratory at Arizona State University, and calibrated according to the methods described in Ruff *et al.* [1997]. The emission spectra permit direct comparison to TES spectra, and



**Figure 1.** Emission spectra of Mars type 1 surface (from *Bandfield et al.* [2000]) and MST-19 (from *Minitti et al.* [2002]). The error bars on the Martian spectrum indicate the standard deviation calculated by *Bandfield et al.* [2000], and arrows denote the locations of features described in the text. Spectra in this and all subsequent figures shown at full spectral contrast.

represent an improvement over biconical reflectance spectra because the latter measurement technique introduces band broadening on the high wavenumber (short wavelength) side of the silicate stretching fundamental in the vicinity of  $1200\text{ cm}^{-1}$  [*Salisbury et al.*, 1991] (see also Figure 4 of *Christensen et al.* [2000a]).

[6] To compare the MST-17 and MST-19 spectra quantitatively to the Martian surface spectra, their mineralogies were modeled using the same linear deconvolution approach employed by *Bandfield et al.* [2000]. A linear deconvolution algorithm uses a library of pure mineral spectra (“end members”) to perform a linear least-squares fit to the spectrum of the unknown mixture [*Ramsey and Christensen*, 1998]. The algorithm supplies the user with a model-derived spectrum and the specific end members used in the fit along with the percentage of the model spectrum represented by each end member. To ensure that the deconvolution of the laboratory spectra is performed under conditions identical to those applied to the Martian data, the laboratory spectra (acquired at  $2\text{ cm}^{-1}$  sampling) were resampled to match TES data ( $10\text{ cm}^{-1}$  sampling). *Bandfield et al.* [2000] deconvolved the Martian spectra from  $1300\text{--}400\text{ cm}^{-1}$ , with the region of atmospheric  $\text{CO}_2$  absorption ( $\sim 825\text{--}508\text{ cm}^{-1}$ ) excluded. The same spectral range constraints and the exact end member library of *Bandfield et al.* [2000] were applied to the deconvolution of the laboratory sample spectra in this study.

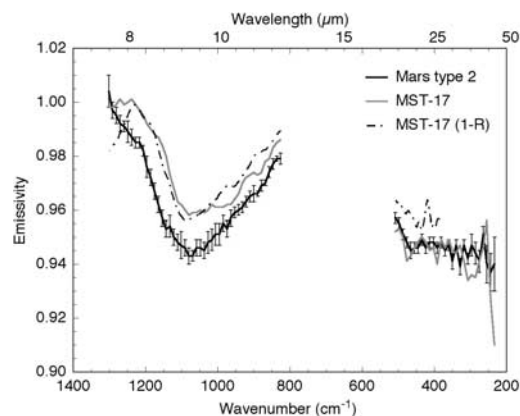
### 3. Results and Discussion

[7] Figures 1 and 2 show thermal emission spectra of the oxidized laboratory samples as compared to the spectra of the type 1 and type 2 Martian surfaces measured by TES. Comparison of the Martian spectra and the oxidized basalt spectra demonstrate that the Martian spectra have equal or greater spectral contrast indicating that the Martian surface samples are of similar (or greater) particle size as the oxidized basalt samples ( $\sim$ hundreds of microns [*Hamilton*, 1999]). This result is consistent with the observation of

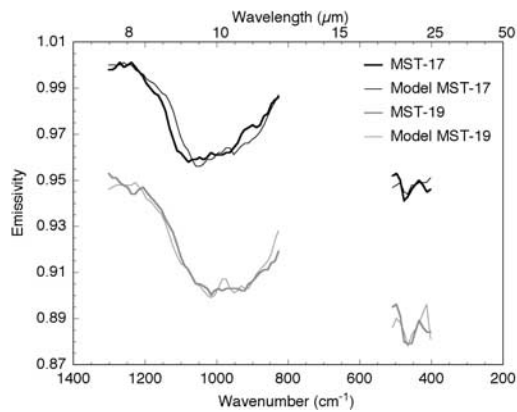
*Bandfield et al.* [2000] that the spectra of type 1 and 2 surfaces are best matched by spectra of sand-sized materials.

[8] One of the reasons *Minitti et al.* [2002] suggested that the Martian lithologies might be oxidized Martian meteorite material was the a compelling similarity of the biconical reflectance spectra of the synthetic basalts (converted to emissivity spectra) and the Martian spectra (see Figure 14 of *Minitti et al.* [2002]). However, when actual emission spectra of the synthetic basalts and Martian surfaces are compared, some features differ (Figures 1 and 2). In the  $1200\text{--}800\text{ cm}^{-1}$  region, the absorptions in the MST-19 reflectance spectra begin at slightly higher wavenumbers (shorter wavelengths) than in surface type 1. Two of the distinctive spectral traits of the Martian type 1 spectrum are the emissivity minimum at  $\sim 1060\text{ cm}^{-1}$  and the distinct shoulder at  $\sim 875\text{ cm}^{-1}$ , which form a somewhat “boxy” shape. Neither of these features is apparent in either the reflectance or emission the spectrum of MST-19. The Martian type 2 spectrum is characterized by a more “V-shaped” absorption than type 1 and a band minimum at  $\sim 1070\text{ cm}^{-1}$ . MST-17 shares the general shape and band minimum of the type 2 spectrum in this region, with slightly different spectral structure on the low wavenumber side of the broad emission feature. In the  $525\text{--}250\text{ cm}^{-1}$  region, MST-19 generally exhibits greater spectral variation than MST-17, which is consistent with a similar characteristic in the two Martian spectra [*Bandfield et al.*, 2000]. The low wavenumber ( $<525\text{ cm}^{-1}$ ) portion of the MST-17 spectrum generally does not deviate significantly from the type 2 Mars spectrum (Figure 2), but a comparison of MST-19 and the type 1 Mars spectrum shows that MST-19 exhibits features that are either offset from features in the type 1 spectrum ( $\sim 500\text{--}425\text{ cm}^{-1}$ ), not apparent in the type 1 spectrum ( $\sim 325\text{--}250\text{ cm}^{-1}$ ), or appear as emission maxima rather than minima ( $\sim 375\text{ cm}^{-1}$ ). These differences are somewhat less apparent than the differences at higher wavenumbers. Some of the discrepancies between the *Minitti et al.* [2002] comparisons and those shown here may be due to differences in the spectral measurement approaches.

[9] Biconical reflectance spectra converted to emissivity spectra are known to differ from true thermal emission



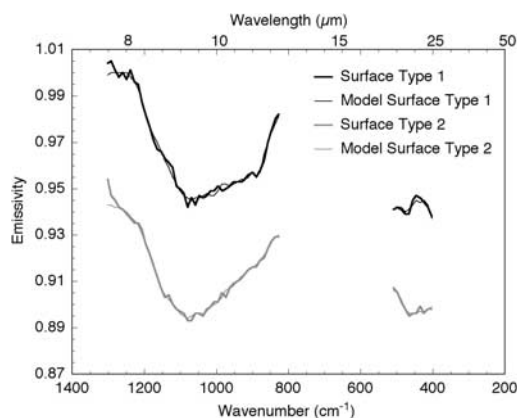
**Figure 2.** Emission spectra of Mars type 2 surface (from *Bandfield et al.* [2000]) and MST-17 (from *Minitti et al.* [2002]). The error bars on the Martian spectrum indicate the standard deviation calculated by *Bandfield et al.* [2000].



**Figure 3.** Comparison of measured spectra and modeled spectra for samples MST-17 and MST-19. The MST-19 spectra are offset by  $-0.05$  for clarity. Models were run from  $1300\text{--}400\text{ cm}^{-1}$ , and only these wavelengths are shown (with the region of atmospheric  $\text{CO}_2$  excluded).

spectra because of spectral artifacts introduced by the biconical measurement geometry [Salisbury *et al.*, 1991]. Measurement geometry effects can be avoided by hardware modifications [Salisbury *et al.*, 1991] or by using an integrating sphere to make hemispherical reflectance measurements, but such modifications were not implemented by Minitti *et al.* [2002] in the RELAB facility at Brown Univ. Although Minitti *et al.* [2002] used a sample preparation technique devised to minimize the biconical measurement geometry effects [Mustard and Hays, 1997], some of the differences between the emission spectra of the synthetic basalts and the Martian spectra indicate that the effects of the biconical measurement geometry were partially, but not fully, mitigated (primarily in the case of MST-19).

[10] Qualitative differences between the emissivity spectra of the oxidized synthetic basalts and the Martian surface (aside from spectral contrast) must result from compositional differences. The positions of the reststrahlen features in the  $1200\text{--}800\text{ cm}^{-1}$  region of the synthetic basalt spectra are consistent with relatively mafic mineralogies [Walter and Salisbury, 1989], and this in turn is consistent with



**Figure 4.** Thermal Emission Spectrometer and modeled spectra of Martian type 1 and type 2 surfaces from Bandfield *et al.* [2000]. The type 2 spectra are offset by  $-0.05$  for clarity.

**Table 1.** Deconvolution Results

Phase*	<i>Bandfield</i>	<i>Minitti</i>	<i>Bandfield</i>	<i>Minitti</i>
	<i>et al.</i> [2000] Type 1 (Basaltic)	<i>et al.</i> [2002] MST-19	<i>et al.</i> [2000] Type 2 (Andesitic)	<i>et al.</i> [2002] MST-17
Feldspar	50	35	35	20
Clinopyroxene	25	20	(10)	20
Glass (obsidian)	–	–	25	(5)
Phyllosilicate	(15)	50	(15)	40
RMS Error (emissivity)	0.179	0.384	0.089	0.242

\*Values reported to the nearest 5% as in Bandfield *et al.* [2000]; values in parenthesis are at or below the detection limit; end member list available in Bandfield *et al.* [2000].

shergottite meteorites, which are dominated modally by pyroxene [McSween, 1994]. The compositions derived from the Martian spectra, however, are dominated by plagioclase feldspar [Bandfield *et al.*, 2000], consistent with the slightly higher wavenumber absorptions observed.

[11] A means of quantifying the broad visual similarity of the laboratory sample spectra and the Martian spectra is to model the oxidized basalt compositions using the same approach that was applied to the Martian data. Figure 3 shows the spectra of the oxidized synthetic basalts and their modeled spectra from the linear deconvolution. The model spectra exhibit significant deviations from the measured spectra, particularly in the  $1200\text{--}800\text{ cm}^{-1}$  region. The model of MST-17 does not match either the negative slope between  $1200$  and  $1050\text{ cm}^{-1}$ , the positive slope in the  $950\text{--}850\text{ cm}^{-1}$  region, or the band minimum at  $\sim 1070\text{ cm}^{-1}$ . There is an emission maximum in the model of MST-19 (at  $\sim 975\text{ cm}^{-1}$ ) that is not present in the measured spectrum. At lower wavenumbers, the amplitudes of the features between  $525\text{--}400\text{ cm}^{-1}$  are not well matched in either the MST-17 or MST-19 model. These poor fits indicate that the end member set used for the deconvolution does not include one or more major phases present in the oxidized basalts [Ramsey and Christensen, 1998]. (Identifying an end member set that would correctly model these samples is beyond the scope of this work, but is being undertaken by co-author Minitti and coworkers in a separate study.) By comparison, the model fits to the Martian spectra obtained by Bandfield *et al.* [2000] (Figure 4) are substantially better, indicating that the end member set adequately represents the major components of the Martian surface materials and does not require the phases that are necessary for successful modeling of the oxidized basalt spectra [Ramsey and Christensen, 1998].

[12] Table 1 shows the modeled modal abundances of major phases in the laboratory samples as compared to the results of Bandfield *et al.* [2000] for the Martian surface spectra. Bandfield *et al.* [2000] grouped their deconvolution results by major mineral class and showed only those classes at or near the detection limit of 15 vol%; uncertainties associated with the derived abundances were stated to be  $\sim 10\text{--}15\text{ vol}\%$ . To be consistent with the Martian surface types, the oxidized basalt deconvolution abundances should fall within these uncertainties, but in many cases do not (Table 1). The low quality of the spectral fits to the synthetic basalt samples indicates that the modes derived for these samples do not accurately represent the mineralogies of the samples; this is confirmed by the sample mineralogies

reported by *Minitti et al.* [2002]. Despite the visual similarities between the synthetic and Martian spectra, the high phyllosilicate (and low feldspar) contents in the models of the synthetic samples point toward a more mafic spectral character in the oxidized basalt than in the Martian spectra. The fact that the oxidized basalt spectra cannot be modeled as well as the Martian spectra using the same end member set is evidence that materials present in oxidized shergottite-like basalts are not significant components of the Martian surface.

[13] Phases that are needed to adequately deconvolve the oxidized basalt spectra are missing from the end member set and may be oxidation products, minerals associated with the primary igneous mineralogy of the shergottite-like samples (e. g., pigeonite), or both. Oxidation is almost certainly occurring on the Martian surface, but the dark regions represented by the TES spectra are dominated by coarse particulates that may abrade away oxidative coatings at a rate faster than that at which they are produced, or make the coatings optically thin at thermal wavelengths. If so, such materials may not be sufficiently abundant to be observed in TES data. Alternatively, *Hamilton et al.* [2003] demonstrated that spectra of shergottite meteorites do not match TES spectra of Mars in any spatially significant (10's of km) portions of dark regions. Therefore, the differences between the modeled synthetic basalt and TES compositions may represent differences in primary mineralogy rather than secondary mineralogy.

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