MINERALOGY OF MARTIAN ATMOSPHERIC DUST INFERRED FROM SPECTRAL DECONVOLUTION OF MGS TES AND MARINER 9 IRIS DATA. Harry Y. McSween Jr.[1], Victoria E. Hamilton[2], and Bruce W. Hapke[3], [1]Department of Geological Sciences, University of Tennessee, Knoxville, TN 37996, mcsween@utk.edu, [2]Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI 96822, hamilton@higp.hawaii.edu, [3]Department of Geology and Planetary Sciences, University of Pittsburgh, Pittsburgh, PA 15260, hapke+@pitt.edu.

Introduction: Although numerous inferences have been made about the mineralogy of martian dust from visible and near-infrared spectral observations [summarized by 1], direct determination has been hampered by spectral masking due to fine-grained ferric oxides. The failure to identify the minerals that constitute the dust and surficial soils, aside from some oxide pigments, hampers our understanding of martian weathering processes and conditions. Therefore, we are attempting to directly determine the silicate mineralogy of the global dust by deconvolving thermal infrared spectra of atmospheric dust acquired during seasonal dust storms by the Mars Global Surveyor Thermal Emission Spectrometer (MGS TES) and Mariner 9 Infrared Interferometer Spectrometer (IRIS). Thermal infrared spectra of atmospheric dust are dominated by absorptions in the 8 – 12 µm region. Such features are consistent with the presence of significant amounts of silicate materials. Although montmorillonite has been suggested to be a significant component of the dust, this composition is not consistent with visible to near-infrared and thermal infrared observations of dust on the surface [2]. We hope to place new constraints on the composition of the atmospheric dust by performing new analyses of the TES and IRIS data.

Methods: The infrared spectrum measured at an orbiting sensor is typically a combination of the spectral properties of the atmosphere and surface components. If data acquired during global dust storms are used for analysis, the contribution of the surface materials is effectively minimized. However, the signal from the atmosphere alone is a complicated combination of signatures that include not only scattering from suspended aerosols, but also the transmission and absorption of both the incident light and light scattered by the surface, as well as light multiply scattered between the surface and atmosphere. This is a formidable problem whose components can only be separated rigorously by viewing a given area on the Martian surface at different angles, and thus through different thicknesses of atmospheric dust. This separation has been performed for a few areas on Mars using the IRIS and TES infrared spectroscopic data. [3] analyzed and inverted IRIS infrared data using a radiative transfer program that solved for several parameters, including the spectral complex refractive indices of the aerosol dust, and these are used in our analyses.

These optical constants need to be converted to infrared spectra so that they may be compared to available spectral libraries. One well-documented library [4] contains transmittance spectra of KBr pellets containing minerals ground to finer than 2 µm. We converted the martian refractive indices to equivalent transmittances using a Maxwell-Garnett effective medium model [5]. This model calculates the spectral absorption coefficient and transmittance of a KBr pellet containing martian dust. These spectra were then linearly deconvolved [6] using ~30 minerals including: feldspars, olivines, pyroxenes, zeolites, phyllosilicates, quartz, amphibole, goethite, gypsum, and calcite. The deconvolution was limited to the 1300-850 cm^{-1} region to avoid regions containing atmospheric H_2O and CO_2 absorptions. The optical constants at wavelengths longer than the CO_2 absorption are less reliable and therefore are not included.

Results and Discussion: Deconvolution model fits to the synthetic TES and IRIS transmission spectra are shown in Figure 1.

Model Fits to Dust Spectra: The model fit to the MGS TES dust spectrum is of good quality, with some minor regions of misfit. The modeled mineralogy of this spectrum is dominated by (~70 vol.%) framework silicates (plagioclase and zeolite), with gypsum and pyroxenes identified near, but below, generalized detection limits of ~15 vol.%. The model fits to the Mariner 9 IRIS spectra are generally poor and indicate that the mineralogical information derived from the fit is not valid so it is not reported here.

The quality of the fit to the TES dust spectrum suggests that the major mineralogy of the spectrum is retrieved relatively accurately. The implications of these results are discussed further below. The fits to the IRIS spectra indicate a problem with either the end member set used in the deconvolution or the spectra themselves. Because apparent emissivity spectra acquired by TES and IRIS during martian dust storms appear similar (whereas the synthetic transmission spectra shown here are dissimilar), and the TES spectrum is modeled relatively well with the provided end member minerals, we favor a problem with the synthesized IRIS spectra derived from optical constants. Furthermore, the spiky character of the IRIS M2b spectrum near 900 cm^{-1} is not characteristic of silicate mineral spectra. The calculations of [32] make certain assumptions that affect the derived values of the optical constants. We believe that the derivation of the optical constants from the IRIS data, and the subsequent generation of new spectra from the optical constants has introduced inaccuracies that confound the deconvolution. The TES transmission spectrum is not a perfect fit either, but that spectrum appears more like the initial TES spectrum, and yields a generally reasonable model fit and mineralogical result.

Comparison to Other Work: Results from the Mariner 6/7 IRS, Mariner 9 IRIS, and Phobos ISM spectrometers suggest that minerals containing molecular H_2O [7, 8], such as clays, palagonite (also suggested by [9], and hydrous carbonates may be components of the surface dust. Features due to Fe^{3+} provide evidence for hematite [1]. Features due to crystalline silicates have not been clearly identified in visible and near-infrared observations, leading to the suggestion that the soils are composed largely of chemically weathered, amorphous or poorly crystalline materials.

[10] produced refined models of the shapes of martian surface and atmospheric spectra using multiple emission angle data from MGS TES. They found that the spectra of high-albedo surfaces have features consistent with fine particulate (<~40 µm) materials dominated by silicates. No single material matches the surface dust spectrum, but features consistent with intermediate to calcic plagioclase and bound water (in unidentified phases) dominate these spectra. Features consistent with mafic minerals, such as pyroxene and olivine, are lacking. The low abundance of Fe^{3+}-bearing minerals precludes their detection in the thermal infrared. [10] therefore infer that martian dust is composed of both primary and secondary minerals, with either a significant mechanical weathering explaining the prevalence of feldspar over alteration minerals (favored), or a physical mixture of chemically altered and unaltered materials.

[11] has suggested that the martian surface dust may contain zeolite, a hypothesis that is consistent with our results and supported by a variety of indirect observations [12]. Zeolites may be described loosely as "hydrated feldspars" and are also framework silicates. Because of their chemical and structural similarities, the spectra of fine particulate zeolites and feldspars are quite similar. Our results can be interpreted as indicating that both zeolite and feldspar are present. However, if these minerals cannot be distinguished based on spectral character alone, the distinction between feldspar and zeolite is ambiguous, and a more conservative interpretation is that large quantities of "framework silicate" are present. The presence of alteration minerals commonly associated with either feldspar or zeolite would be evidence for one or the other. Our end member set included alteration phases commonly found in the presence of both minerals, but they were not identified in the deconvolution model. Because of possible spectral ambiguity, [10] considered the possibility of zeolites as a component of the surface dust, but do not favor them because they have not been identified in martian meteorites and because of the lack of observed phyllosilicates and K-feldspar (minerals that are commonly present in the environments where zeolites form) in remote sensing data sets.

Our data indicate the possible presence of gypsum, which is consistent with the presence of S measured in the martian soil at the Viking and Pathfinder sites. However, this detection is near general detection limits and we cannot say confidently that it is present.

Chemical analyses of martian soils have been used to derive the chemistry of the global dust [13]. The dust composition cannot be rationalized only as mixtures of zeolites and plagioclase with ferric oxides, so other spectrally neutral (presumably poorly crystalline) phase(s) must be present. Because transmission spectra of volcanic glass and palagonite are not available, we cannot determine whether or not they could improve the model fits to the spectra. Future analyses converting the data to true emissivity will allow us to explore these options.

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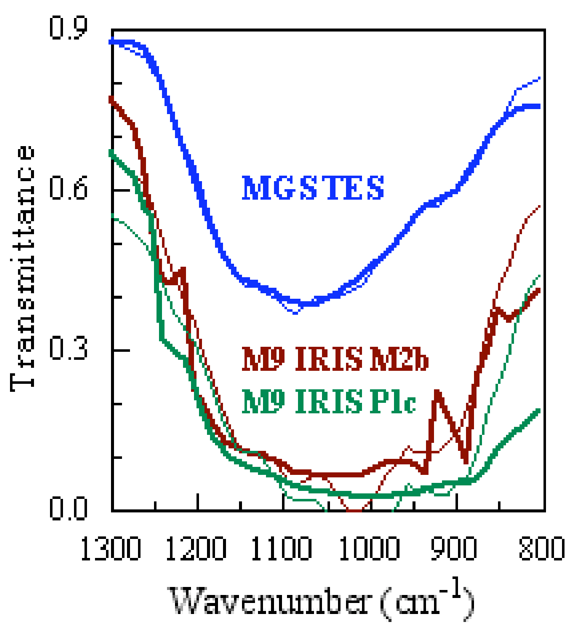

Figure 1. Synthetic transmission spectra (thick lines) and model spectra (thin lines).