

VARIATIONS IN THE Fe MINERALOGY OF BRIGHT MARTIAN SOIL

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Introduction. Bright regions on Mars are interpreted as "soil" derived by chemical alteration of crustal rocks, whose main pigmentary component is ferric oxide or oxyhydroxide [1-3]. The mineralogy and mineralogic variability of ferric iron are important evidence for the evolution of Martian soil: mineralogy of ferric phases is sensitive to chemical conditions in their genetic environments, and the spatial distributions of different ferric phases would record a history of both chemical environments and physical mixing. Reflectance spectroscopic studies provide several types of evidence that discriminate possible pigmentary phases, including the position of a crystal field absorption near 0.9 μm and position and strengths of absorptions in the UV-visible wavelength region [4-6]. Recent telescopic spectra and laboratory measurements of Mars soil analogs [7-9] suggest that spectral features of bright soil can be explained based on a single pigmentary phase, hematite ($\alpha\text{-Fe}_2\text{O}_3$), occurring in both "nanophase" and more crystalline forms. Here we report a systematic investigation of Martian bright regions using ISM imaging spectrometer data, in which we examined spatial variations in the position and shape of the $\sim 0.9\text{-}\mu\text{m}$ absorption. We found both local and regional heterogeneities that indicate differences in Fe mineralogy. These results demonstrate that bright soils do not represent a single lithology that has been homogenized by eolian mixing, and suggest that weathering of soils in different geologic settings has followed different physical and chemical pathways.

Data Characteristics and Analysis. ISM data are ideally suited to this analysis because of their high spectral and spatial resolution, broad geographic coverage, and high signal-to-noise ratio. ISM returned 9 images or "windows" covering $\sim 20\%$ of the equatorial region, with a pixel size of 22 km and 128 channels spanning a wavelength range of 0.76-3.16 μm [10]. Data processing has been described by Erard *et al.* [11] and Mustard *et al.* [12]. Spatially averaged ISM spectra for a number of regions have been compared to corresponding telescopic spectra, and found to have a high degree of correlation [13]. Since the signal-to-noise ratio of ISM spectra in the 0.9- μm wavelength region ranges between 600:1 and 1300:1, small variations in shape and position of the 0.9- μm absorption can be recognized and mapped at high spatial resolution over much of the equatorial belt.

A systematic analysis of the shape and position of the $\sim 0.9\text{-}\mu\text{m}$ ferric absorption in bright regions was conducted by surveying bright soils observed by ISM, defining regions with distinctive 0.9- μm absorptions, and measuring representative spectra of these regions. Regions exhibiting evidence for absorptions due to crystalline mafic minerals were avoided, because Fe^{2+} in these minerals would modify the shape and position of the 0.9- μm absorption. Absorption centers were estimated after fitting the spectra with cubic splines, and absorption depths were estimated by dividing reflectances at the absorption centers by reflectances at shorter and longer wavelengths.

Related Studies. We have previously used ISM data to determine the presence, strength, and variability of absorptions related to H_2O and OH in bright Martian soils [14,15]. Bright soils may be loosely grouped into two major classes. "Normal bright soils" represent the majority of bright soils observed by ISM. These have a strong absorption at 3.0 μm due to H_2O , plus a narrow absorption $\leq 1\%$ in depth centered at 2.20-2.25 μm . The latter is attributed to poorly crystalline phyllosilicate. "Hydrated bright soils" exhibit a consistently stronger 3.0- μm absorption, probably due to greater H_2O content. In most cases the 2.2- μm absorption is weaker or absent, and in some cases the presence of pyroxene is suggested by a broad, shallow absorption centered at 2.0-2.3 μm .

Results. Among "normal bright soils," there are three geographic regions which exhibit distinct absorptions near 0.9 μm (Figure 1). Previous studies have provided some evidence for these differences, but did not fully resolve the distinct absorptions. Bright soils throughout the Tharsis plateau plains and westward into Amazonis exhibit a ferric iron absorption 2-4% deep and centered at 0.84-0.86 μm . Soils at high elevations on the Tharsis Montes volcanoes, particularly Ascraeus Mons, exhibit an absorption shifted longward to 0.88 μm . In earlier analysis of ISM data, Bibring *et al.* [16] recognized that spectral properties near 1 μm distinguish Ascraeus Mons from the surrounding region, though they did not specifically identify position of the ferric absorption as responsible for this difference. The absorption exhibited by bright soils in Arabia is radically different, 5-7% deep and centered near 0.92 μm . The distinctiveness of Arabia had been recognized by McCord *et al.* [17] and attributed to mafic minerals, but ISM spectra do not exhibit evidence for crystalline olivine or pyroxene in this region.

Some "hydrated bright soils" exhibit a broad, shallow absorption at 2.0-2.3 μm , suggesting that their 0.9- μm absorptions are modified by ferrous iron in pyroxene. However at least two regions lack evidence for crystalline mafic minerals but exhibit strong, distinctive features near 0.9 μm (Figure 2). These may be attributable to ferric phases. One region corresponds to a visible-color anomaly within a topographic depression in layered deposits of western Candor Chasma [18]. Here, an absorption 5-6% deep is centered at 0.91 μm . The other region is in eastern Lunae Planum, within the "dark red" visible color unit [2,3]. Here an absorption $\sim 4\%$ deep is centered near 0.89 μm .

Compositional Implications. Variations in the 0.9- μm absorption may be attributable to several factors. Most "normal" bright soils have an absorption centered near 0.85 μm , consistent with hematite ($\alpha\text{-Fe}_2\text{O}_3$) being the

dominant ferric phase. Variations in hematite particle size can shift the absorption by as much as $0.03 \mu\text{m}$ [5], plausibly accounting for small variations such as between the Tharsis plains and Tharsis Montes. However the longer-wavelength absorption centers in "normal bright soil" in Arabia, and in "hydrated bright soil" in Lunae Planum and Candor Chasma, cannot be reconciled with a dominantly hematitic ferric mineralogy. We suggest the presence in these regions of one or more different phases, possibly maghemite ($\gamma\text{-Fe}_2\text{O}_3$), goethite ($\alpha\text{-FeOOH}$), ferrihydrite ($\text{Fe}_{10}\text{O}_{24}\text{H}_{18}$), jarosite ($(\text{K,Na,H}_3\text{O})\text{Fe}_3(\text{SO}_4)_2(\text{OH})_6$), or Fe-containing glass. This heterogeneity in the Fe absorption demonstrates that bright soils are not a single lithology that has been homogenized by eolian mixing [e.g. 2]. These results also suggest that weathering of the bright soils in different settings has followed different pathways, possibly including sorting by particle size and differing contributions of weathering of basaltic glass, precipitation from aqueous solutions, and alteration of the precipitates by heating and desiccation [cf. 4,18,19].

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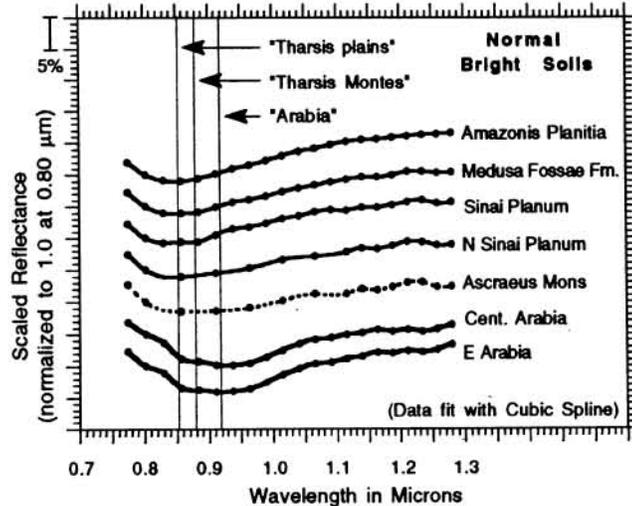


Figure 1. Representative spectra of "normal bright materials" lacking evidence for mafic minerals. Circles indicate ISM channels used in the spectra. Thin solid lines represent bright soils in the Tharsis plains and Amazonis; dashed lines soils at high elevations on the flanks of Tharsis Montes; and heavy solid lines soils in Arabia. Vertical lines are approximate absorption centers in each region.

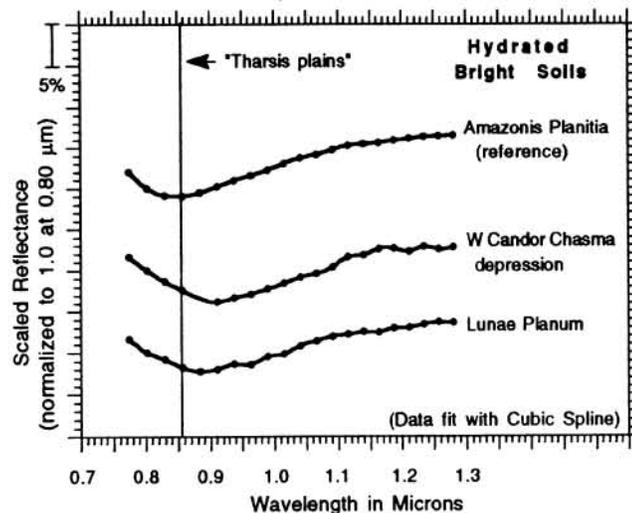


Figure 2. Representative spectra of "hydrated bright materials" lacking evidence for mafic minerals. Circles indicate ISM channels used in the spectra. Amazonis Planitia is included for comparison to "normal bright materials" in the same geographic region from which these spectra were obtained.