NO. 37. COMPARISON OF THE INFRARED SPECTRUM OF MARS WITH THE SPECTRA OF SELECTED TERRESTRIAL ROCKS AND MINERALS

by ALAN B. BINDER* AND DALE P. CRUIKSHANK*

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ABSTRACT

Infrared studies indicate that spectra of certain weathered igneous rocks match the infrared reflection spectrum of Mars.

1. *Introduction*

In recent years attempts have been made to match the albedo, color excess, and polarization of Mars with those characteristics of terrestrial rocks. Kuiper (1952) observed the reflection spectra of a number of rock samples from 0.8–1.8 μ and found that hematite, yellow volcanic ash, and sandstone were a poor match; but that a brownish, felsitic rhyolite matched the spectrum of the bright areas of Mars fairly well. Sharonov (1961) has found that in the visual part of the spectrum, the albedo and color excess of earthly, ochre-colored limonite ($FeO(OH) \cdot nH_2O$) closely approximate the Mars data. Dollfus (1961) also found visually that powdered limonite has polarization properties equivalent to Mars. Using Kuiper's same Mars spectra, Draper, *et al.* (1964) compared spectra of synthetic mixtures of goethite and hematite, but their laboratory data were obtained with a spectrometer and detector different from that used for making the Mars spectra and without a cross calibration of the instruments. Therefore, their data cannot be accurately compared with Kuiper's spectra.

During the past year the problem has been reinvestigated at the Lunar and Planetary Laboratory. Dr. Kuiper observed Mars on August 12, 1963 with the 82-inch telescope of the McDonald Observatory, using the low-dispersion mode of the infrared spectrometer described previously (Kuiper *et al.*, 1962). The laboratory and solar comparisons were obtained by the authors in Tucson with the same equipment and matching resolution. The detector was a 0.1 mm PbS cell used with a rapid scan rate (1.3 μ per minute), giving a resolution ($\lambda/\Delta\lambda$) of about 60 at 1.5 μ. This resolution is sufficient to resolve the CO_2 bands at 2.01 and 2.06 μ. The solar comparisons were made from an illuminated MgO block, which, however, may not have been neutral "white".

2. *Discussion*

The rock and mineral samples were observed using solar illumination in the laboratory in Tucson. A representative spectrum of weathered rhyolite is shown in Figure 1. The deep absorptions at 1.13, 1.39, and 1.87 μ are due to terrestrial water vapor. The four maxima between these absorptions constitute the points measured. For such measures to be consistent the water vapor content of the atmosphere must be reasonably constant. The data were reduced by setting the amplitude of the 1.25 μ maximum equal to 1.00 and then measuring the amplitudes of the 1.05, 1.55, and 2.1 μ maxima on this arbitrary scale. The intensity ratios of Mars and of samples of sun + MgO were taken at each of the four wavelengths and their values plotted in Figures 2, 3, and 4. The spectra are limited on the short-wavelength end by the sensitivity of the PbS cell and on the long-wavelength end by the H_2O absorptions at 2.7 μ and the reduced solar intensity.

The four wavelengths used cover an interval of 1.05 μ, one octave. This portion is not affected by

*Jointly of Department of Geology and Lunar and Planetary Laboratory, University of Arizona.

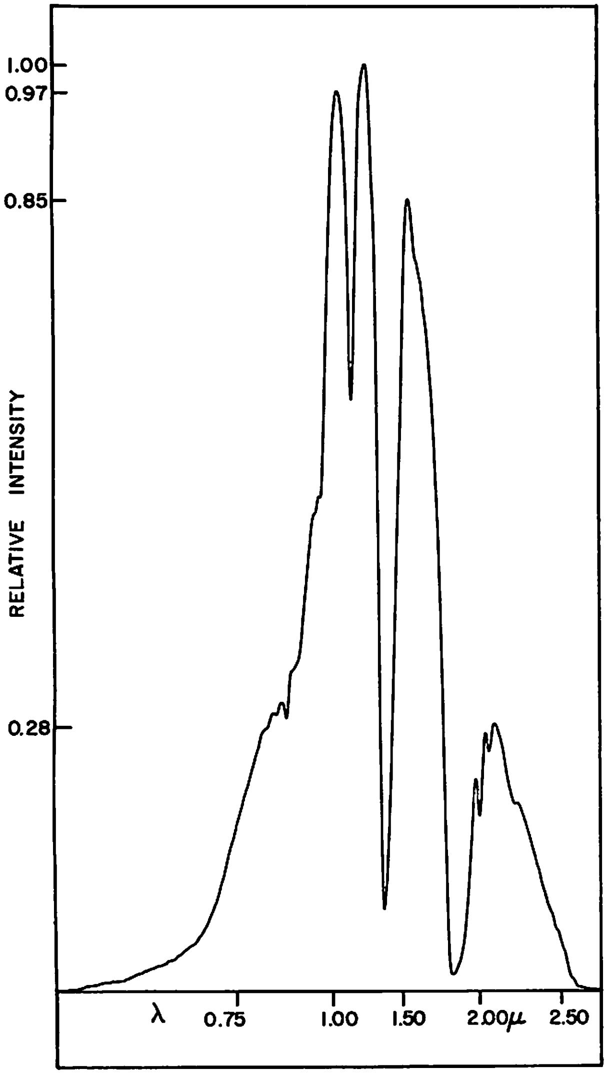

Fig. 1. Representative tracing of the reflection spectrum of rhyolite with limonite stain.

the strong scattering in the atmosphere of Mars in blue light, though the 1.55 and 2.1 μ maxima will be somewhat affected by terrestrial and Martian CO_2. To circumvent the terrestrial CO_2 correction, one may observe the comparison samples with the sun at approximately the same zenith distance as for the Mars observations, as was done. Corrections for the Martian CO_2 were not made, but these should cause an uncertainty in the 2.1 μ maximum of no more than 1–2 percent.

Because of various tentative identifications for the Martian surface made before, samples of fresh and weathered igneous rocks were selected for these comparisons. In an arid desert environment, the iron-bearing minerals (biotite, hornblende, augite, etc.) in igneous rocks may have limonite as a weathering product. Red sandstone, red mudstones, red soils, and pure hematite (Fe_2O_4) and limonite were also examined.

Out of 50 samples, only five had reflection curves that matched the Mars curve within the estimated errors of the Mars data at each of the four points. The estimated errors of the Mars data are indicated by verticle lines in Figures 2, 3, and 4. The data are inherently less accurate at the longest wavelength, but it is there that deviations of the various samples from the Mars data are the smallest. The most important point distinguishing the curves is the 1.05 μ point, at which the estimated error of the Mars data is small and the samples show the greatest deviations.

Figure 2 shows that pure hematite and pure limonite do not match the 1.05 μ point if 1.25 μ is used as reference, whereas, the 1.55 and 2.1 μ points are reasonably well represented. Figure 3 shows the results of three representative rock samples which do not completely match the Mars data. Red sandstone is a poorest match; pink granite is less discordant; and the rhyolite sample used is discordant at 1.05 μ but agrees well at 1.55 and 2.1 μ. It was noted that the various samples of a given rock type, as expected, showed some spread in their curves. The samples in Figure 4 are rocks with weathered surfaces. The weathering has produced a thin surface coating of limonite, varying in thickness. It is seen that these weathered surfaces (of the igneous rocks rhyolite, granite, andesite, and basalt) well represent the Mars reflectivities in this region. The red *sedimentary* rock and soils examined, whose coloring agent is hematite, have reflective characteristics similar to hematite. Although this result suggests that reddish sedimentary rocks do not make up large portions of the Martian deserts, more detailed comparisons with Mars are needed. Other much less common coloring agents of sedimentary rocks are goethite, $HFeO_2$, and lepidocrocite, FeO(OH); goethite is the major constitutent of limonite. However, these two minerals color a rock yellow.

3. *Concluding Remarks*

The limonite coating on igneous rocks described above may be either a powdery coating or a surface stain, both of which are formed and preserved in arid desert environments. A powdery surface would be suggested by the polarization measurements. All samples having the heavy limonite stain or limonite powder surface matched the Mars spectra, but no

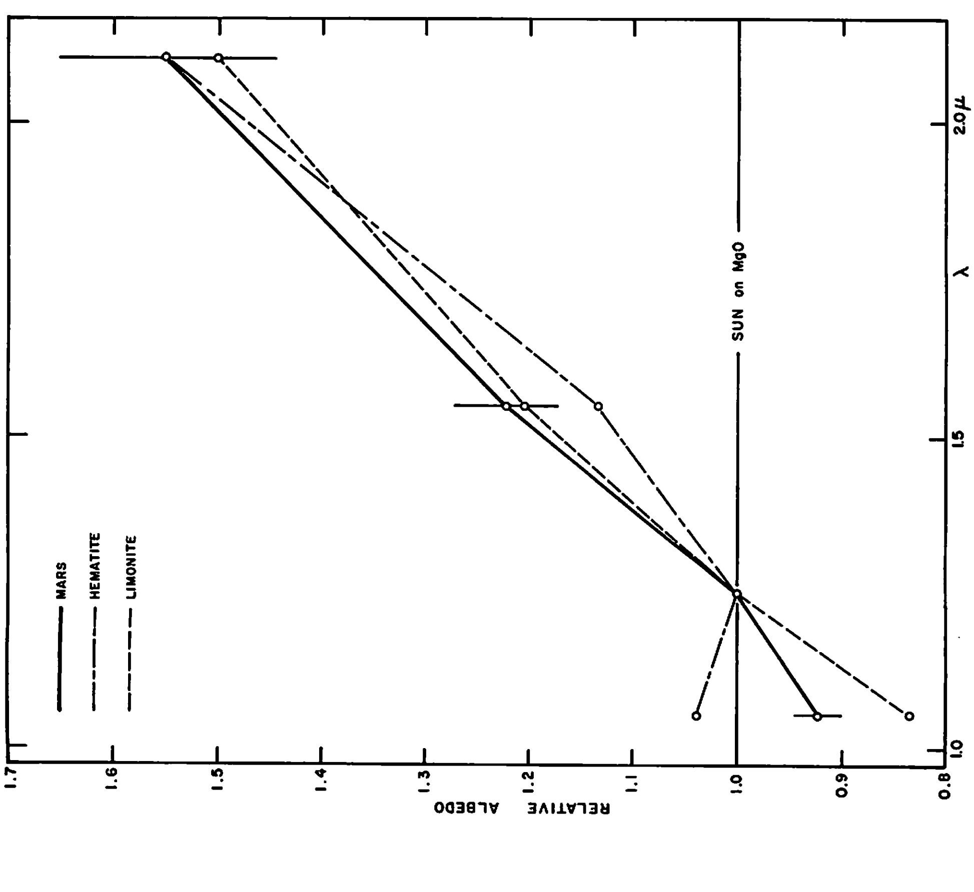

Fig. 2. Relative albedos of pure hematite and pure limonite compared to Mars. The divergence at the 1.05 μ point is the most significant characteristic of these samples.

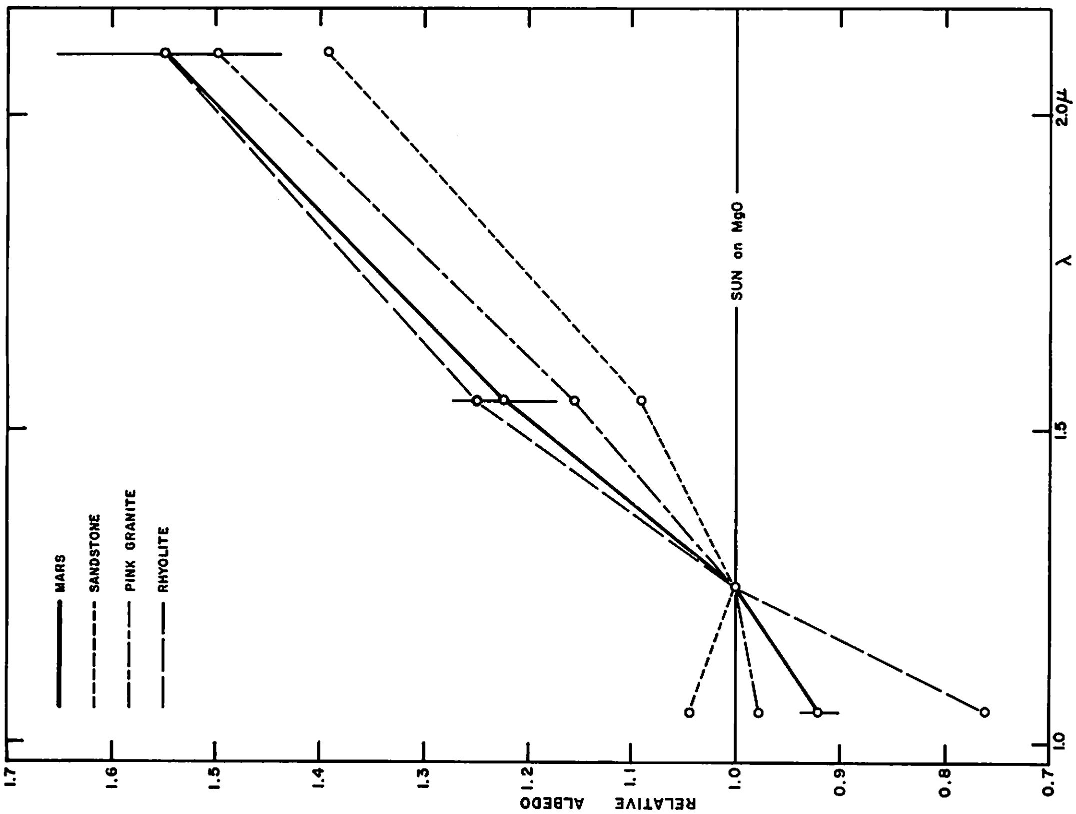

Fig. 3. Diverse albedos of various fresh reddish rock samples compared to Mars.

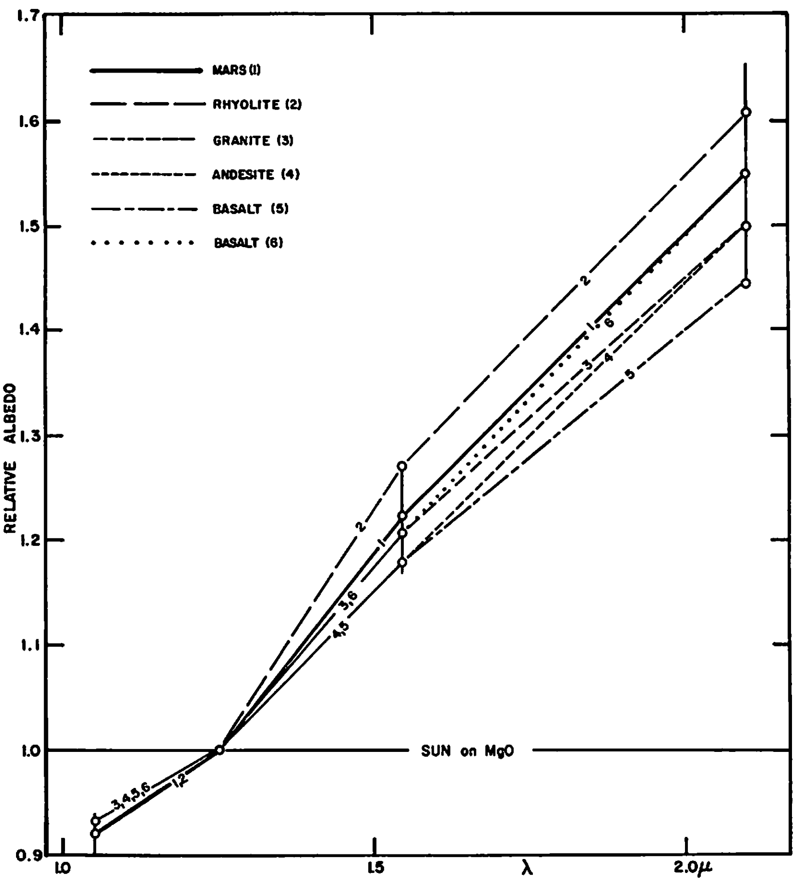

Fig. 4. Albedos of five types of rock stained with limonite measured relative to the 1.25 μ peak are compared with the spectrum of Mars (solid line) relative to sunlight on a reflecting surface of MgO. Vertical lines indicate the accuracy of the respective points on the Mars spectrum. The five samples in this figure are those found to approximate the Mars spectra most closely.

other samples agreed. Field observations indicate that in terrestrial deserts the stained surface is more common than the powdery surface; if a Martian analogy can be drawn with terrestrial deserts, it may be assumed that the Mars surface is composed partly of stained outcrops, rock fragments, and finer material.

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Postscript. I am indebted to Mr. Binder for pointing out to me that the spectrophotometric comparison made in 1952 was with slightly weathered rhyolite, not a fresh rhyolite surface. The new observations reported above and my 1952 observation are therefore consistent, although this is not proof, as is apparent from the above paper, that the Martian rock is rhyolite. The identification made above encompasses a broad class of igneous rocks.

G.P.K.