OBSERVATIONS OF SILICATE RESTSTRAHLEN BANDS IN LUNAR INFRARED SPECTRA.
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Background. The mid-infrared region, where thermal emission dominates the lunar spectrum, is potentially useful for mineralogical remote sensing, because the molecular vibration spectra in this region (reststrahlen) are directly interpretable in terms of molecular composition.

Progress in utilization of this spectral region has been slow relative to the reflective region. Atmospheric effects make this region difficult to observe with ground-based telescopes, and a further difficulty lies in the low spectral contrast of emission features in the lunar spectrum which leads to a requirement for exceptionally high signal-to-noise ratios in the spectra.

Observations of lunar infrared spectra using ground-based telescopes (e.g. Goetz (1)), or balloon-borne telescopes (e.g. Murcray (2)) revealed no significant spectral features other than the Christansen peak near 8 microns. However, recent laboratory work by Aronson et al. (3) on lunar samples has shown that weak spectral features at the 1-3% contrast level do exist in the mid-infrared region, and they can be related to sample composition.

The objective of this work was to obtain lunar thermal infrared spectra at a sufficiently high signal-to-noise ratio to permit observations of the lunar silicate bands, which must exist, as shown from the laboratory measurements on lunar samples.

Data Acquisition. Lunar infrared spectra at a 2 cm⁻¹ resolution were measured at the Cassegrain focus of the 2.3m telescope of the Wyoming Infrared Observatory (WIRO), using a Michelson interferometer spectrometer having an optical design similar to that reported by Treffers (4). Liquid helium-cooled germanium bolometer detectors were used. The field of view of the instrument was about 3 arc sec. The WIRO site is very dry, particularly in the winter when most of our observations were made. Unfortunately, infrared spectroscopy requires photometric nights (few during winter months) and this, coupled with difficult working conditions and the complexity of the instrument, gave a low yield of useful data. However, about a half-dozen reliable spectra have been obtained. Two of the best of these are discussed in this report.

Calibration of the instrument in terms of spectral radiance was done by measuring difference spectra from black body sources at two different temperatures.

Since the spectral contrast of the reststrahlen bands was expected to be only a few percent, achievement of a satisfactory signal-to-noise in detection of the bands requires very high signal-to-noise in the spectrum. Achieving a 10:1 signal-to-noise ratio in a 1% spectral band requires a signal-to-noise ratio of 1000:1 in the spectrum.

Tests of signal-to-noise and repeatability of successive lunar spectra indicated that the required levels could be reached under photometric sky conditions. Traces of cirrus clouds in the field of view altered the spectral baseline significantly. Seeing was less important, having only the effect of increasing the effective spot size observed on the lunar surface.

Data Analysis. The major problem in analysis of mid-infrared spectral data is accounting for atmospheric and telescope transmission. Of several approaches tried, the most useful was to use a standard lunar site as a reference, and ratio the spectra from test sites to a spectrum of the standard site, measured at nearly the same time. In this way, atmospheric and telescopic factors are cancelled. The Apollo 11 landing site was chosen as the initial standard site, since something is known about the surface.
composition, and the emissivity of the glassy mare surface was expected to show little or no spectral character. The ratio of test site spectrum to standard site spectrum is influenced not only by spectral features, but also by temperature differences between the two sites. A baseline which accounts approximately for temperature difference between the sites was drawn by calculating the ratio of spectral emissivities for two black bodies at the computed surface temperature of the two sites. Temperatures were computed assuming equilibrium between solar insolation and thermal emission, and an absorptivity-emissivity ratio of unity. Deviations of the observed spectra from the computed baseline ratio indicate spectral features in the data.

Results and Conclusion. Spectral ratio measurements for the bright Descartes formation (-10.66 lat, +15.95 long) near the Apollo landing site are shown in Figure 1a. The straight line plotted in this figure is the computed black body ratio. Significant spectral features are seen at 950 cm\(^{-1}\), 1070 cm\(^{-1}\), and 1220 cm\(^{-1}\). The first two correspond approximately to pyroxene bands, as shown in Figure 1b, where calculated emissivities for 5 micron pyroxene spheres are shown (Aronson's model (3) was used for the calculation). In addition, the general character of the two curves, observed and calculated, is similar. Pieters (5) has remarked that preliminary study of reflectance spectra of this region indicates the probable presence of pyroxene, which supports this interpretation. The third feature at 1220 cm\(^{-1}\) is probably the result of a significant difference between the Christiansen peaks from the two lunar sites. Differences in spectral contrast and position of the Christiansen peaks can result from differences of particle size distribution and silicate acidity at the two sites.

Spectral ratio measurements for the central peak of Tycho are shown in Figure 2a. Strong spectral features are evident in this plot. A broad feature from 800 to 960 cm\(^{-1}\) having small secondary minima near 850 and 940 cm\(^{-1}\) is prominent. Another feature centered near 1050 cm\(^{-1}\) is partly obscured by interference from the ozone band. A deep band is found centered near 1160 cm\(^{-1}\). Laboratory measurements of the emission spectra of polycrystalline olivine and microcline feldspar are shown in Figure 2b. Band minima in these spectra correspond roughly to the observed lunar spectral features, except for the secondary minima near 850 cm\(^{-1}\). This might correspond to the band near 820 cm\(^{-1}\) noted by Aronson (3) in finely powdered samples of feldspar. This band does not appear in spectra of bulk samples.

These data demonstrate that spectral features can be observed in lunar infrared emission spectra, and that these features correspond approximately to those expected from crystalline feldspar, pyroxene, and olivine. It appears likely that with further work, thermal infrared measurements can be a useful tool for analysing and mapping lunar surface composition.

LUNAR SILICATE BANDS

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FIGURE 1A. RATIO DESCARTES FORMATION TO APOLLO 11 SITE

FIGURE 2A. RATIO TYCHO CENTRAL PEAK TO APOLLO 11 SITE.

FIGURE 1B. CALC. EMISSIVITY PYROXENE (5 micron spheres, augite)

FIGURE 2B. OBSERVED RADIANCE SPECTRA OF BULK OLIVINE & FELDSPAR

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