MIDDLE INFRARED REMOTE SENSING FOR GEOLOGY

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Introduction

The middle infrared (MIR) portion of the spectrum available for geologic remote sensing extends from approximately 3 to 25 μm. The source of energy is thermal radiation from surface materials at ambient terrestrial temperatures. The spectral range of usefulness of the region is limited by both the amount of energy available and by transmission of the energy through the atmosphere. At terrestrial temperatures the maximum black body radiation will be somewhere around 10 to 11 μm, dropping off sharply to shorter wavelengths and less sharply to longer wavelengths (see Fig.1). The best atmospheric window lies between about 8 and 14 μm with poorer windows between 3 and 5 μm and between 17-25 μm (see Fig. 2). The region between 3 and 5 μm is further complicated by overlap with the reflected solar radiation which is dropping rapidly in intensity but still has some contribution in this region. Thus the 8-14 region is by far the easiest spectral region to use and has received most of the effort to date. Fortuitously, this is also a spectral region containing diagnostic spectral information on the silicates.

Remote sensing of the earth in the middle infrared is just on the threshold of becoming a valuable new geologic tool. Topics which still need to be studied include 1) the uses and limitations the 8-14 μm region for distinguishing between silicates and non-silicates, for distinguishing among the silicates, and for recognizing other rocks or minerals, 2) a theoretical and experimental understanding of laboratory spectra of rocks and minerals and their relationship to remotely sensed emission spectra, and 3) the possible use of the 3-5 and 17-25 μm portions of the spectrum for remote sensing.

Use of the 8-14 μ region

The recent work at Tintic with multispectral MIR scanner data has demonstrated that there is significant geologic information which can be obtained from surface spectral emissivity data acquired by remote sensors. It was shown that in certain cases even minor differences in rock type could be distinguished, i.e., quartz latite/quartz monzonite could be distinguished from latite/monzonite. At the same time there are numerous excellent collections of laboratory transmission and reflection spectra of minerals and rocks along with explanations of the source mechanisms of the observed spectral features. Fig. 3 through 6, from Hunt are representative. Fig. 3 shows spectra of some silicates and their dependence upon crystal structure. Fig. 4 shows spectra of some non-silicates. Fig. 5 is a diagram summarizing locations of spectral features including Christiansen peaks, transmission minima, and the processes responsible for their origin. In Fig. 6 are shown the spectra of a few common rocks It is clear from these figures that rocks and minerals

possess abundant spectral features under idealized laboratory conditions. The basic problem is to determine exactly what can and cannot be achieved with remote sensing. Because of the difficulties (discussed in the next section) in relating laboratory transmission and reflection data to emission of natural surfaces, it is not possible to accurately predict the specific capabilities for rock type discrimination which can be realized. Field and aircraft data collection programs need to be undertaken along with both theoretical and experimental laboratory work in emission spectroscopy.

Crude spectra have been derived from the six channels of multispectral aircraft data at Tintic, and field spectra have been acquired with the Portable Field Emission Spectrometer (PFES). Both data sets indicate that the spectral differences are at least as much due to variations in the intensity of the spectral feature as to variations in the position of the bands. See Fig. 7. The bands decrease in intensity and shift to higher wavelength with decreasing quartz content of the rocks in a manner similar to laboratory spectra. Further PFES data taken in the Southern California batholith show these same effects.

A new aircraft scanner, the Thermal Infrared Multispectral Scanner (TIMS), is now complete and undergoing testing. This instrument has six mid-infrared channels: 8.2-8.6, 8.6-9.0, 9.0-9.4, 9.4-10.2, 10.2-11.2 and 11.2 to 12.2. The choice of bands was dictated by instrument constraints, atmospheric effects and laboratory and field measurements of spectral signatures of rocks. Data acquisition with the new TIMS aircraft scanner should begin this summer.

Laboratory data

The most complete set of laboratory spectra of rocks available for the MIR are the transmission and reflection of spectra of Hunt and Salisbury. Their transmission spectra were obtained using two different sample preparation techniques, the conventional method of the powdered specimens being compressed in KBr pellets, and by deposition of thin layers of fine particles onto a mirror. The principal Christiansen peaks appear in the spectra of the deposited particles (with the particles on the mirror in air), but not in the spectra obtained from the samples in the KBr pellets. However, apart from this difference, most of the absorption features are similar. The reflection spectra measured using polished rock surfaces, which should more closely approximate emission spectra, display significant differences from the transmission spectra. Emission spectra, which would be the most applicable to remote sensing of emitted radiance are more difficult to measure and interpret. In order to be able to measure emissivity, the sample must be at a higher temperature than its surroundings, which creates unnatural temperature gradients. Most of the differences between the spectra obtained in the various modes have been shown both theoretically and experimentally to be dependent upon such variables as particle size, surface roughness, packing density, and the near-surface temperature gradients.

Hunt measured emission spectra in the laboratory of some rock samples collected at Tintic. Although he stated that there were still some problems to be resolved with his experimental procedures, he felt the data were illustrative of the problems involved. His emission spectra are shown in Fig. 8, along with transmission spectra of the same samples run by K. Baird, using the

KBr pellet method. Of this work Hunt wrote, "It is obvious that only general agreement exists between transmission and emission spectra for these particular samples and that the agreement is better at longer wavelengths than in the 10 μm region. These preliminary data are presented to emphasize the need for both experimental and theoretical studies to define the spectral characteristics of emission from geologic materials under natural conditions. Of immediate importance is the need to develop appropriate methods for simulating the natural environment in the laboratory and using the data acquired to develop models to relate the spectral emission behavior to the fundamental properties of geologic materials."

Use of the 3-5 and 17-25 μm regions

Not much work has been reported which attempts to use the 3-5 μm region for spectral remote sensing of the earth's surface. Referring to Fig. 2, one sees that there is good atmospheric transmission between about 3 and 4.2 μm and then again from 4.5 to 5 μm, and data from this wavelength region have been used for determination of the surface temperature. Laboratory spectral data, in this wavelength region, however, show a paucity of diagnostic spectral features of rocks and minerals. There is a very strong molecular water band at 2.94 μm which is present in the spectrum of any mineral with adsorbed water. Hovis claims that there are strong carbonate features near 3.5 and 4.0 μm and that the sulphates and nitrates have a number of strong bands between 3 and 4.5 μm. However, examination of several collections of mineral spectra shows only a relatively weak carbonate band at about 4.02 μm, a few weak chlorite features between 3 and 4.4 μm, and relatively weak gypsum bands at 4.48 and 4.72 μm. Most mineral spectra shown in these collections are completely featureless from 3 to 5 μm. Hydrocarbons and vegetation may have important spectral bands in these wavelengths but little data is available in the literature. Perhaps, therefore, laboratory studies directly explicited toward the feasibility of using this spectral region for geologic remote sensing, are warranted.

This spectral region is further complicated by overlap with the reflected solar radiation which must be taken into consideration at the shorter wavelengths. The exact wavelengths where both sources of radiation must be considered will vary with the amount of incoming solar radiation (dependent primarily on solar angle) and amount of emitted radiation from the surface (dependent primarily on surface temperature).

In the 17-25 μm region, numerous diagnostic spectral features exist. Feldspars have extremely characteristic stretching bands between 15 and 20 μm. Mafic minerals also have stretching bands in this region. Above 20 μm deformation and bending modes for numerous minerals exist. However, the intensity of emitted radiation in these wavelengths is low (see Fig. 1) and the atmospheric transmission is very poor (less than 10%) (Fig. 2). It appears that the 17-25 μm region of the middle infrared does not hold much promise for geologic remote sensing in the immediate future, until and unless more sensitive sensors become available.

ACKNOWLEDGEMENTS

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Figure Captions

1. Black body emission for various temperatures.

2. Atmospheric transmission.

3. Midinfrared transmission spectra of some silicate minerals.

4. Midinfrared transmission spectra of some non-silicate minerals.

5. The location of features and the types of vibrations that produce the spectral signatures of silicates in the midinfrared.

6. Midinfrared transmission spectra of a few common rocks.

7. Midinfrared field emission spectra.

8. Quartzite (left) and clay (right) transmission and emission spectra. E-10 is quartzite; E-29 is a quartzite rock with a heavy iron stain; E-38, a silicified rock containing halloysite and quartz; E-55, B-clay altered from latite; E-63, opalized quartz.

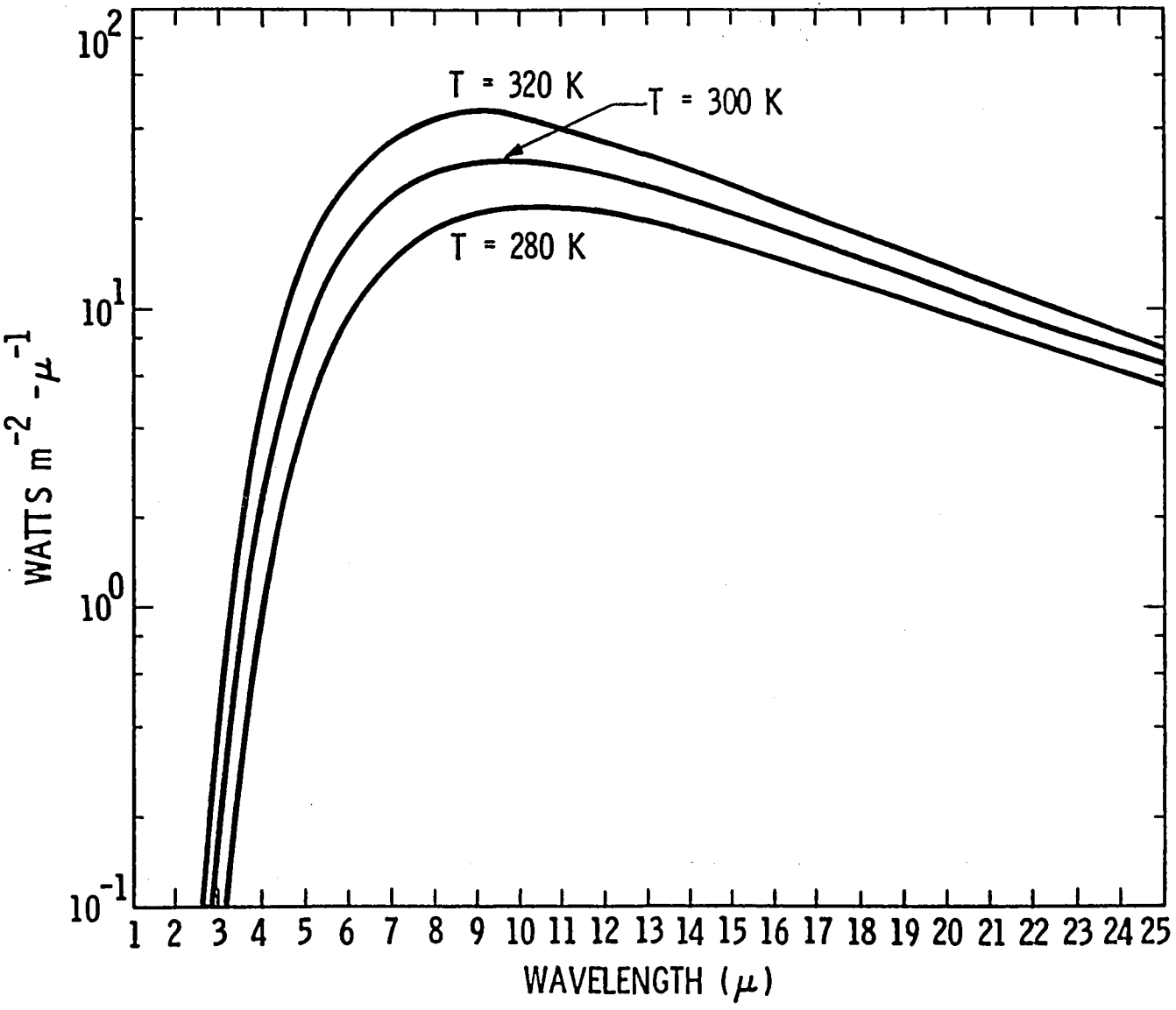
T = 320 K
T = 300 K
T = 280 K
WATTS m^{-2} -μ^{-1}
WAVELENGTH (μ)
10^2
10^1
10^0
10^{-1}
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

Figure 1

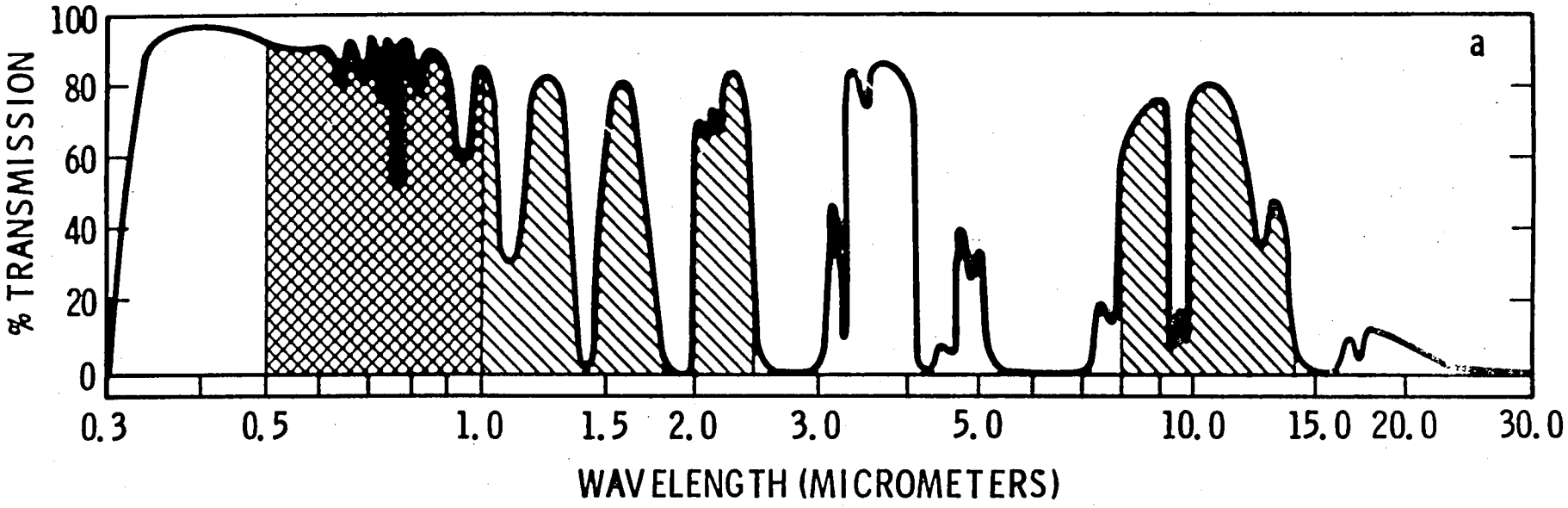
100
80
60
40
20
0
% TRANSMISSION
a
0.3
0.5
1.0
1.5
2.0
3.0
5.0
10.0
15.0
20.0
30.0
WAVELENGTH (MICROMETERS)

Figure 2.

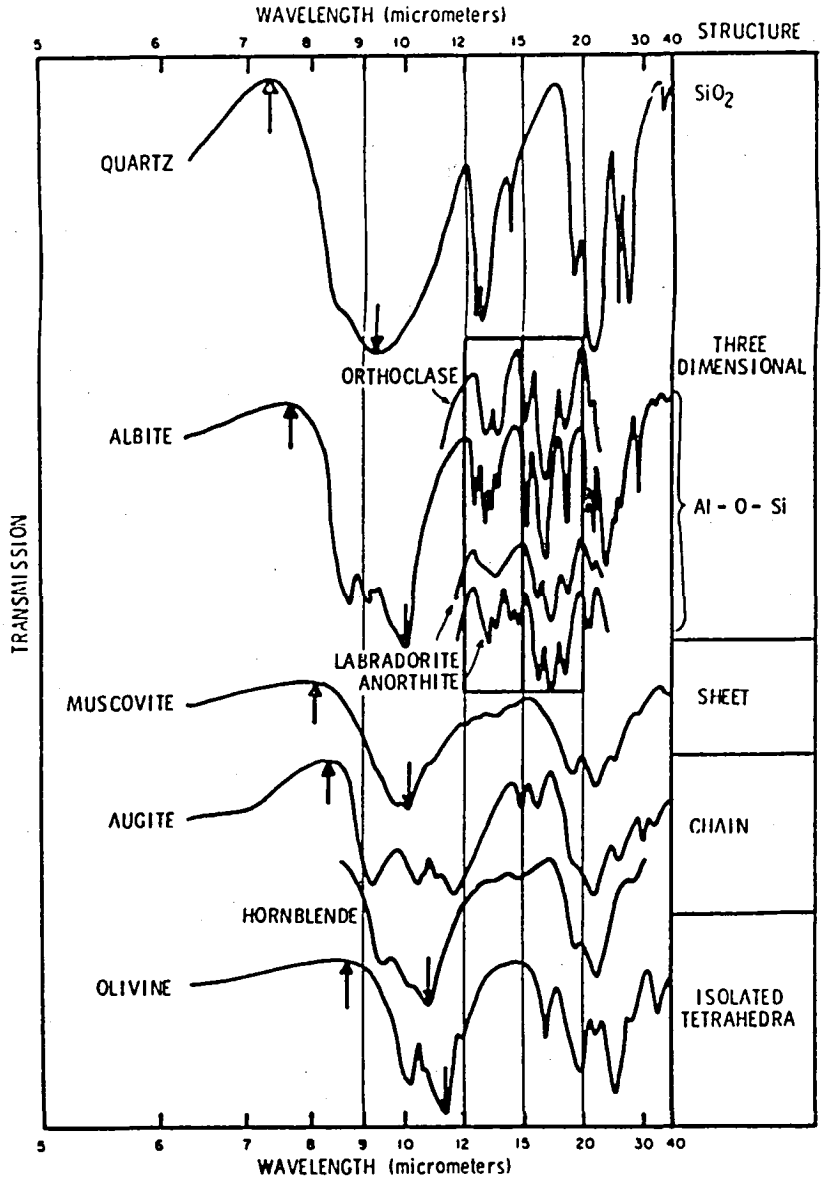
WAVELENGTH (micrometers)
5
6
7
8
9
10
12
15
20
30
40
STRUCTURE
SiO_2
QUARTZ
THREE DIMENSIONAL
ORTHOCLASE
ALBITE
Al - O - Si
LABRADORITE
ANORTHITE
SHEET
MUSCOVITE
CHAIN
AUGITE
HORNBLENDE
ISOLATED TETRAHEDRA
OLIVINE
TRANSMISSION
WAVELENGTH (micrometers)

Figure 3.

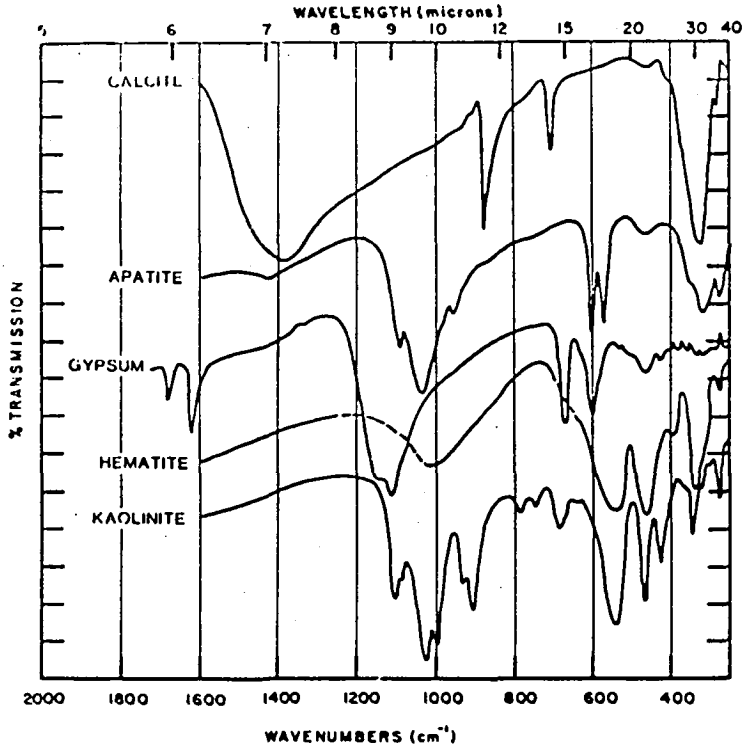

Figure 4.

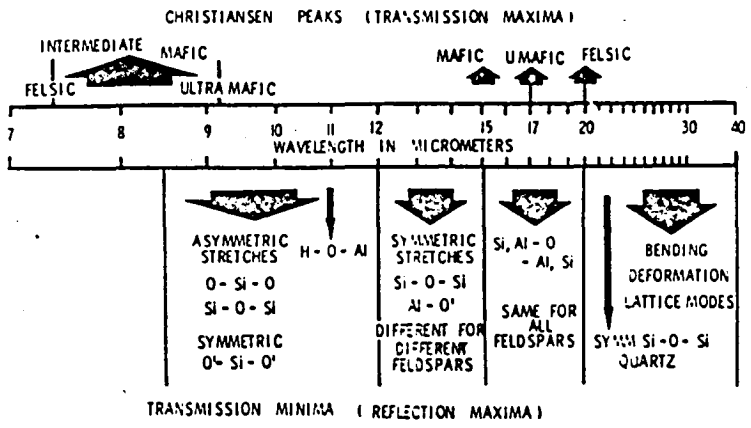

Figure 5.

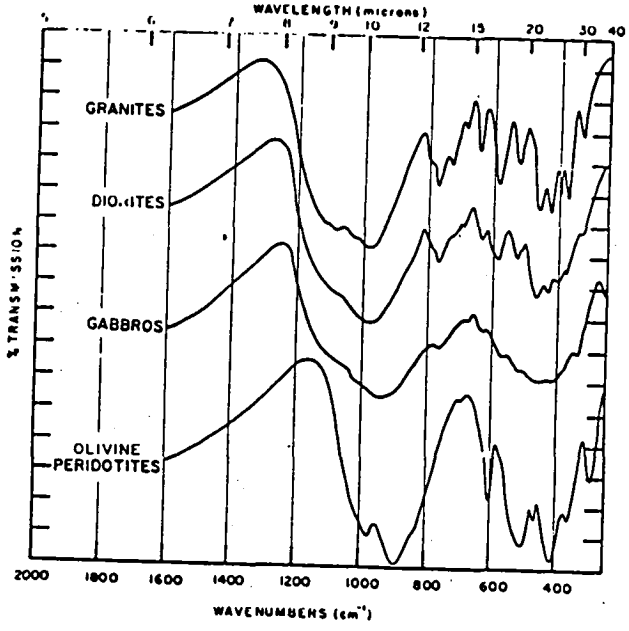

Figure 6.

PFES FIELD SPECTRA
TINTIC, UTAH

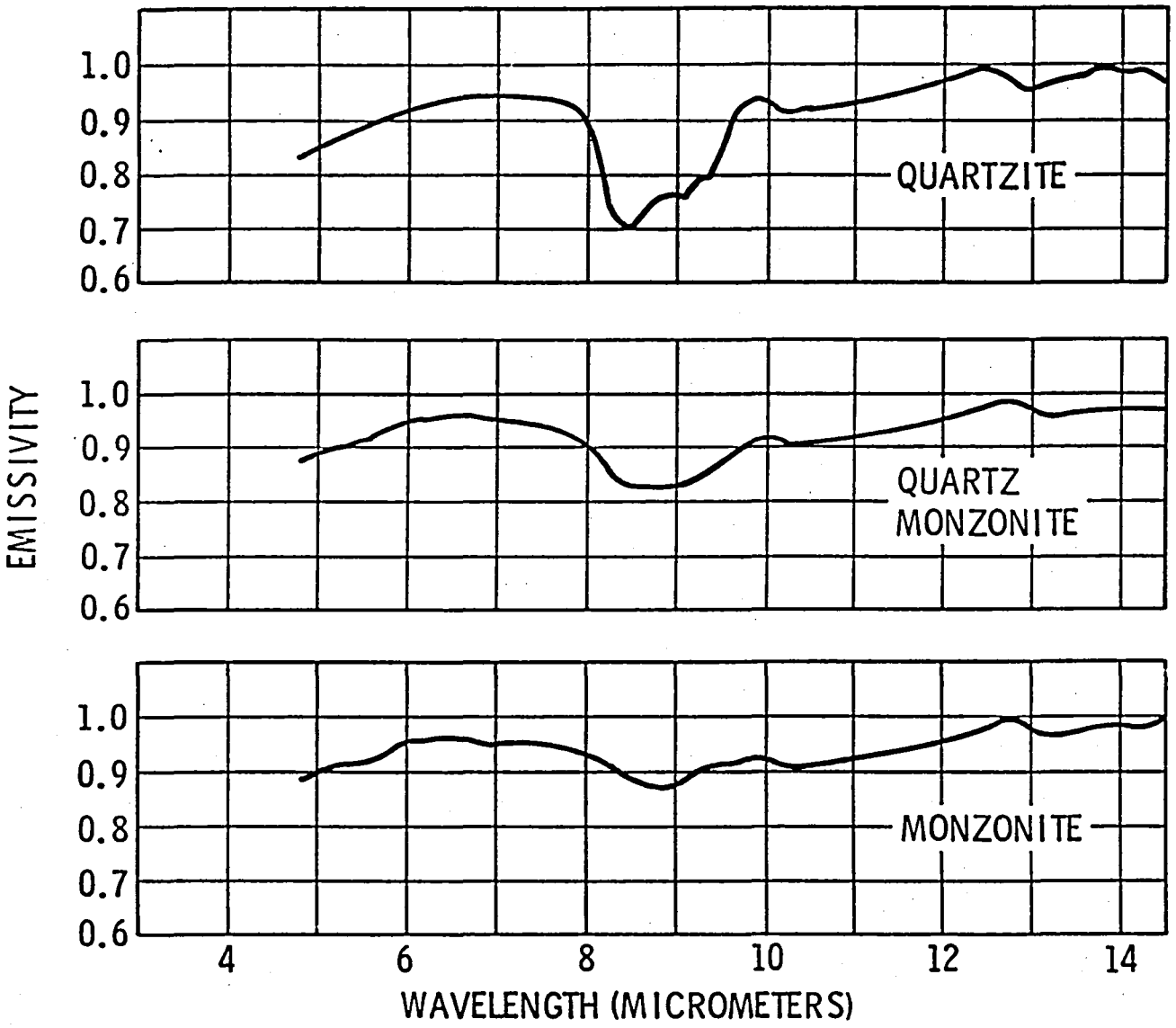

Figure 7.

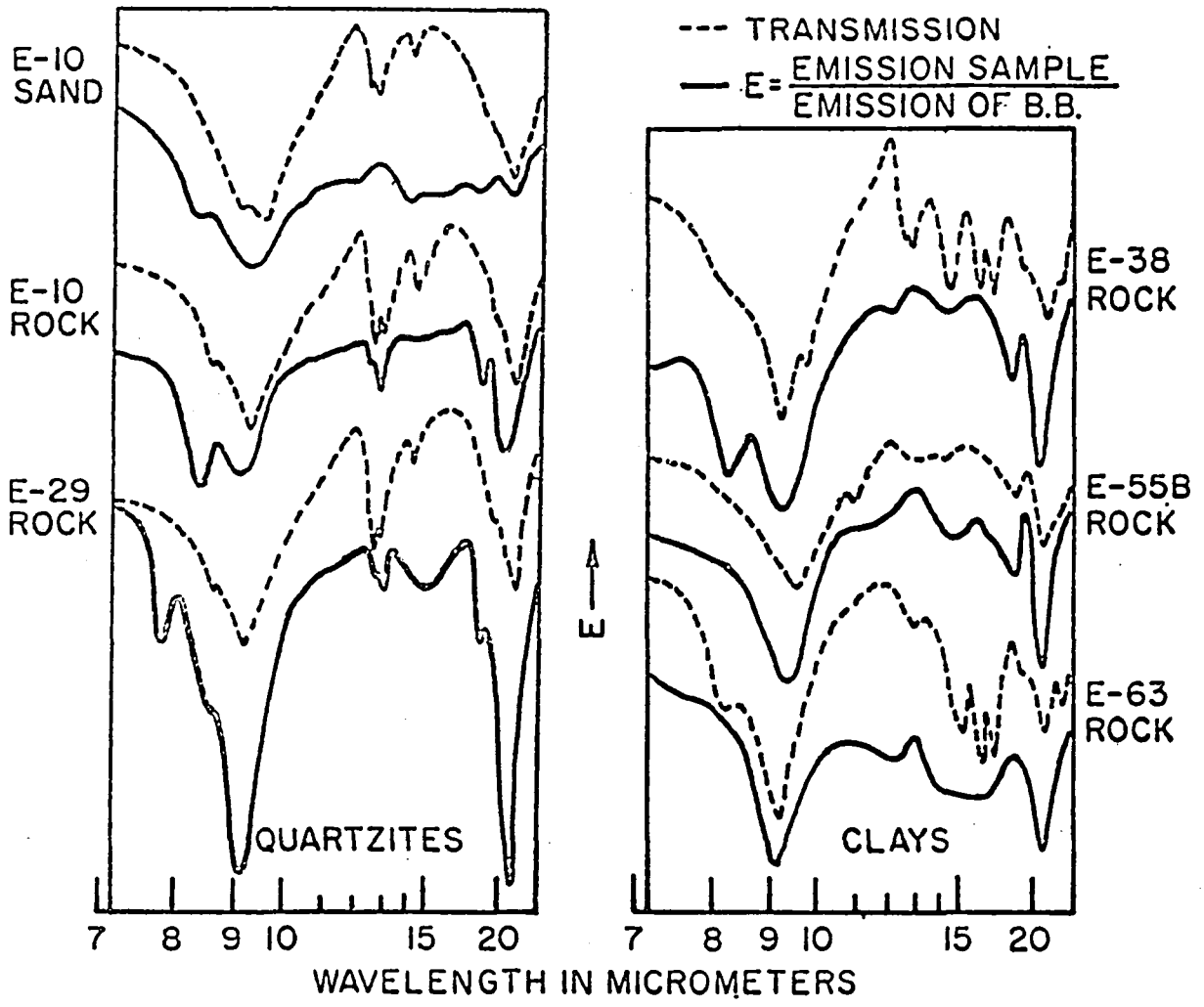
--- TRANSMISSION
— E= EMISSION SAMPLE / EMISSION OF B.B.
E-10 SAND
E-10 ROCK
E-29 ROCK
E-38 ROCK
E-55B ROCK
E-63 ROCK
E
QUARTZITES
CLAYS
7 8 9 10 15 20
7 8 9 10 15 20
WAVELENGTH IN MICROMETERS

Figure 8.