UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Emission Spectra in the Thermal Infrared Region

by

Graham R. Hunt[1]
U.S. Geological Survey, Denver, Colorado 80225

Open-File Report 81-787
1981

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

---

[1] Deceased March 26, 1981

Emission Spectra in the Thermal Infrared Region

by

Graham R. Hunt

Spectral measurements in the thermal infrared region are capable of yielding excellent bulk compositional diagnostic information for geologic materials, provided there is control over the choice of sample conditions and environment, technique, and instrumentation to collect the data. This situation has been demonstrated repeatedly in numerous publications, for minerals (e.g., Lyon, 1964) and rocks (e.g., Hunt and Salisbury, 1974), primarily using transmission and reflection techniques. However, the need exists to define the spectral emission characteristics from geologic materials under natural conditions.

The type of information available in transmission spectra for silicates is illustrated in Figure 1, and silicates as a class are readily distinguished from other geologic materials such as carbonates, sulfates, oxides, etc. Unfortunately, the idealized conditions used to produce most of these data are not found in remote-sensing situations, especially when applied to the Earth's surface. The specific vibrations that cause the maxima and minima that occur in silicate spectra are summarized in Figure 2.

Many of the existing data were produced in studies directed at the lunar and planetary surfaces, which exist under unique conditions and environments, and are not directly transferable to studies of the Earth's surface, primarily because of the presence and nature of the terrestrial atmosphere. Not only does the atmosphere obscure specific spectral regions because of absorption and scattering, but it also governs the thermal regime of the surface materials, and its behavior is highly variable with time.

Although the precise locations of the characterizing resonance frequencies for geologic materials are known or can be determined, the manner in which they are expressed in emission spectra is dependent upon many parameters. The fact that so few successful studies have been published attests to the difficulty of acquiring and interpreting meaningful spectral emission data both in the laboratory and under remote-sensing conditions. The accepted position is that the magnitude of spectral effects in broad bandpass experiments is such that the Earth's surface may be regarded as behaving like a black- or gray-body, implying that any genuine spectral information occurs only as a small perturbation of the much greater thermal effects.

The remote-sensing problem of discriminating among different geologic materials consists, first, of determining the form, magnitude, and location of spectral information under natural or simulated terrestrial conditions, and then developing methods to separate these spectral effects from those of thermal differences caused by different irradiance (depending on time of day, solar declination, and topography) and background (atmospheric) conditions, atmospheric heat fluxes, as well as albedo, inertia, and latitude.

Some very preliminary and incomplete laboratory emission data are presented only to illustrate some of the difficulties that exist and must be resolved by further investigations. These data were acquired both from some

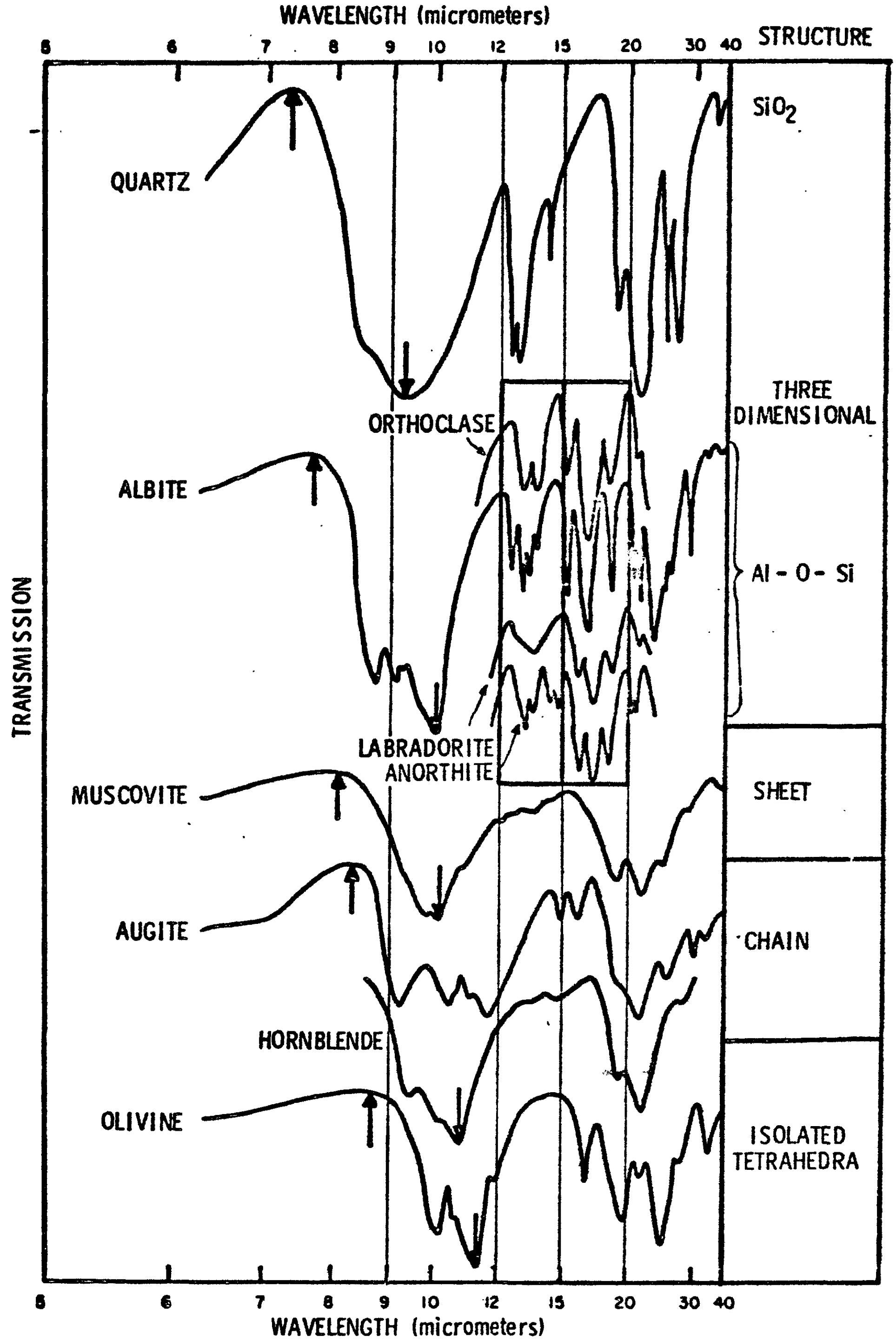

Figure 1.—Transmission spectra of particulate mineral samples recorded in air, arranged to illustrate progressive shifts in major features, such as the principal Christiansen frequency (indicated by ascending arrows) and minimum of the Si-O-stretching fundamentals (indicated by descending arrows), all as a function of changing the bulk structure from three-dimensional to isolated tetrahedra. The presence or absence of specific bands in certain regions (e.g., 12-15 µm) for particular structures is apparent. For more complete discussion, see Hunt, 1980.

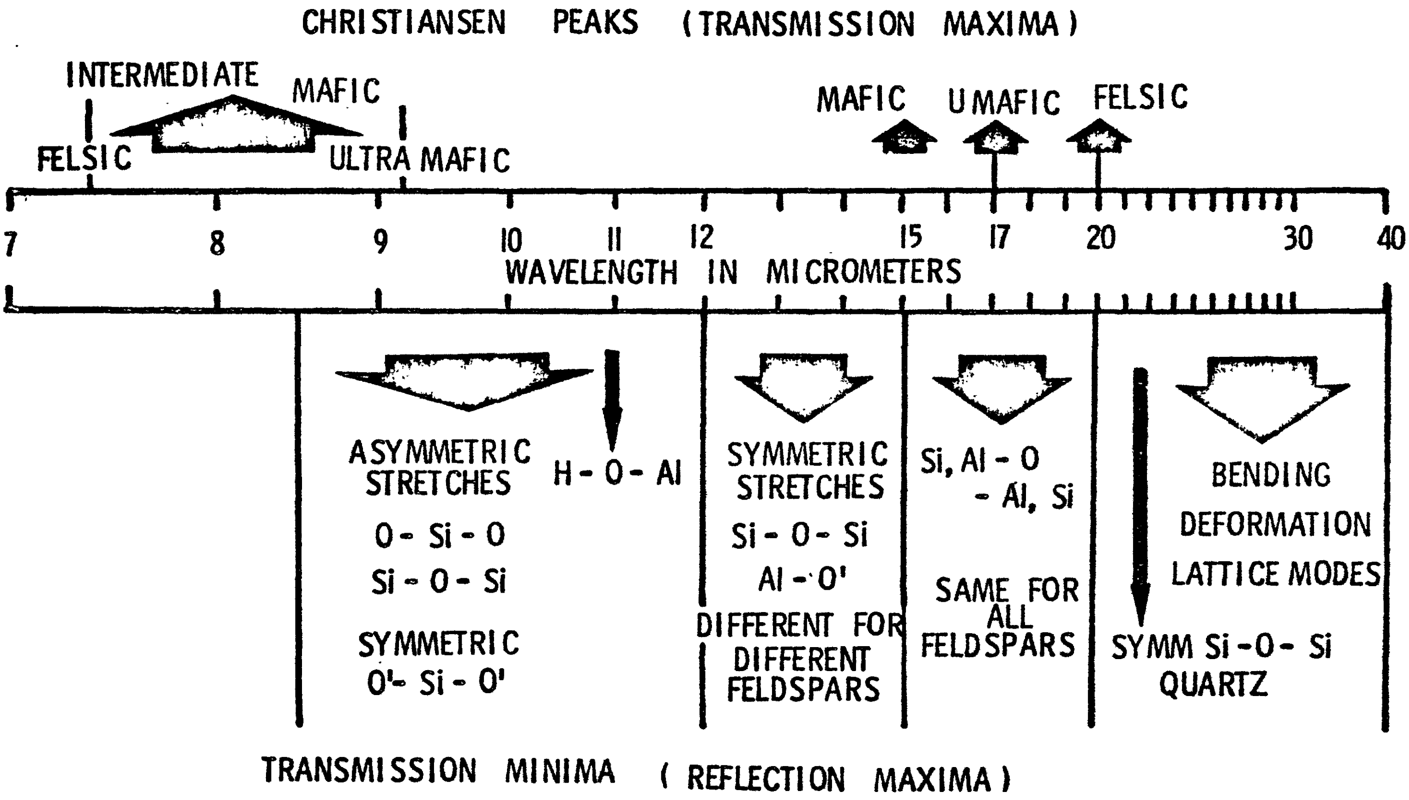

Figure 2.--Diagrammatic illustration indicating the location of features and the types of vibrations that produce the spectral signatures of silicate rocks in the mid-infrared. Christiansen frequencies are indicated above wavelength scale; transmission minima and reflection maxima are indicated below the wavelength scale.

well-characterized samples and from rocks and soils collected[1] from the East Tintic Mountains, Nev., in an area imaged by the airborne NASA 24-channel multispectral scanner.

Emission spectra were recorded using a Fourier Transform Interferometer Spectrometer, which has the advantages of large energy throughput and records all wavelengths simultaneously. The "emission" spectra shown were generated by dividing the emission intensity of the sample by that from a standard blackbody source which matched it in intensity somewhere in the 7 to 25 μm range.

In the laboratory, the initial problem is that of selecting an appropriate method of heating the sample. Several methods were explored including (1) heating the sample in an air furnace, removing it and recording sequential spectra as it cooled, (2) heating the viewed surface with a stream of hot air, (3) heating the viewed surface with unfiltered radiation from a quartz iodide lamp, and (4) heating as in (3) but filtering out the infrared radiation. Methods (1) and (2) are subject to difficulties of controlling and maintaining a steady surface temperature. Using method (3), features due to reststrahlen reflection were apparent in the 10 μm range, even for particulate samples. Even with method (4), some undesirable effects were still observable due to emission from the filter. Typical curves representing the sample emission divided by that of a blackbody at 153°C for a sample of rough-cut quartzite, taken at various temperatures as it cooled after heating in the furnace, are shown in Figure 3.

Spectra were recorded to illustrate the effects of physical condition and to compare transmission and emission spectra of the same sample. Figure 4 shows the emission spectra of some well-characterized 74-250 μm particle-size samples.

Emission spectra of samples of a quartzite and some sandy limestones are shown in Figure 5. The quartzite samples were collected from the same (small) area and the curves are for the samples under different physical conditions, i.e., sand, sand and chips, natural rock surface, and fresh rough-cut rock surface. The appearance of the diagnostic "quartz" feature near 12 μm in the fresh-cut rock is not surprising because of the freshly exposed surface, nor is the decrease in spectral contrast progressing from the fresh-cut (lowest) to the deep sand (top) sample. However, the variation in the appearance of the bands in the 10 μm region (where the extinction coefficients of the fundamental Si-O stretching vibrations have extremely high values) requires further study and explanation. The limestone spectra in the lower half of the figure all display a well-defined band near 11 μm due to the carbonate fundamental mode, diagnostic of carbonates and readily distinguished from silicates.

In Figure 6, transmission spectra[2] of crushed clay and quartzite samples embedded in potassium bromide pellets are compared with emission spectra of the same samples from the Tintic area in their natural form. It is obvious that only general agreement exists between transmission and emission spectra

[1] Samples supplied by A. Kahle and K. Baird of Jet Propulsion Laboratory, Pasadena, California.

[2] Spectra recorded by K. Baird, Jet Propulsion Laboratory, Pasadena, California.

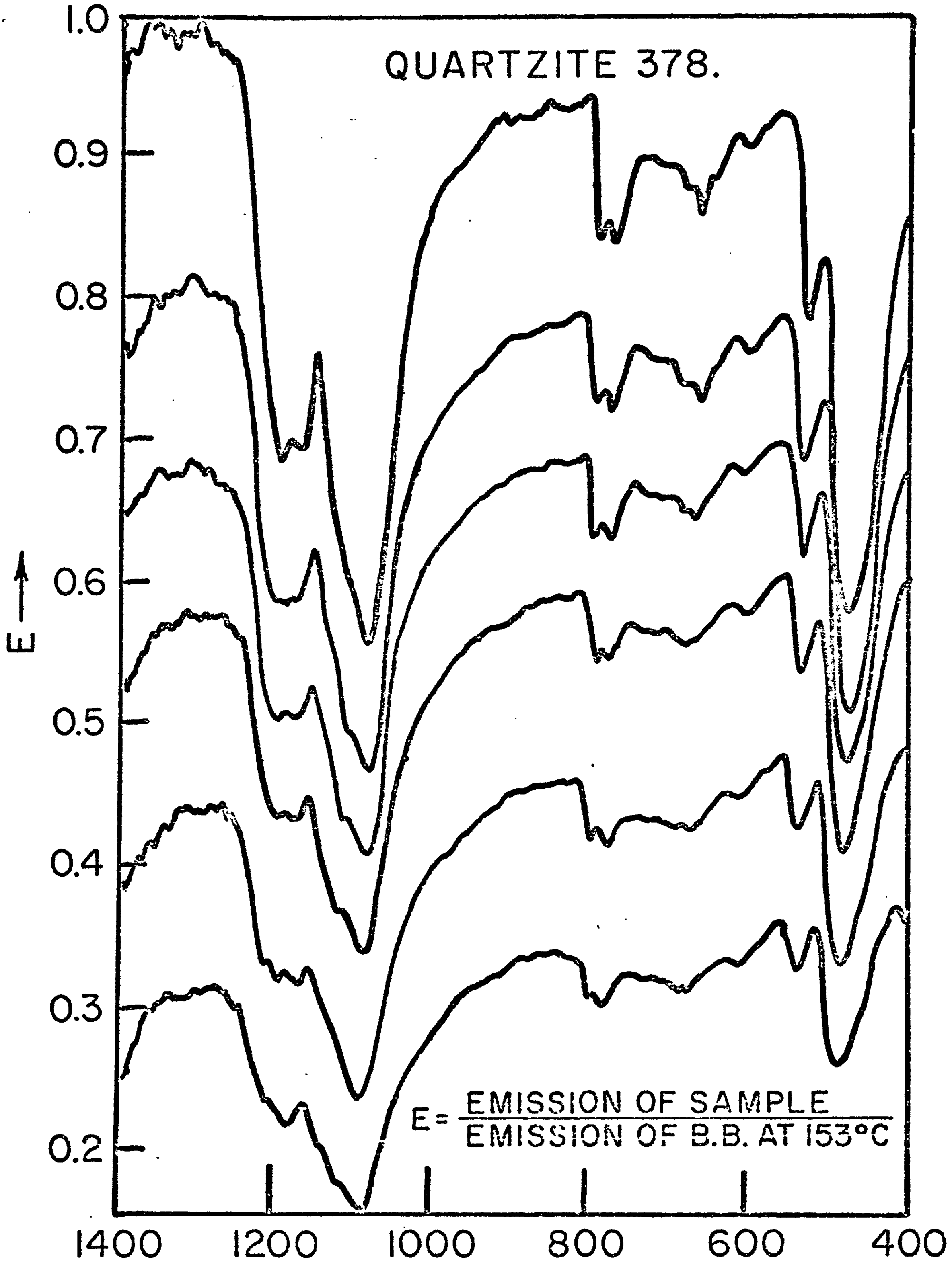

Figure 3.--Curves of the resulting emission values after dividing the emission from a quartzite sample as it cooled (hottest at top, coolest at bottom) by that of a blackbody at 153°C.

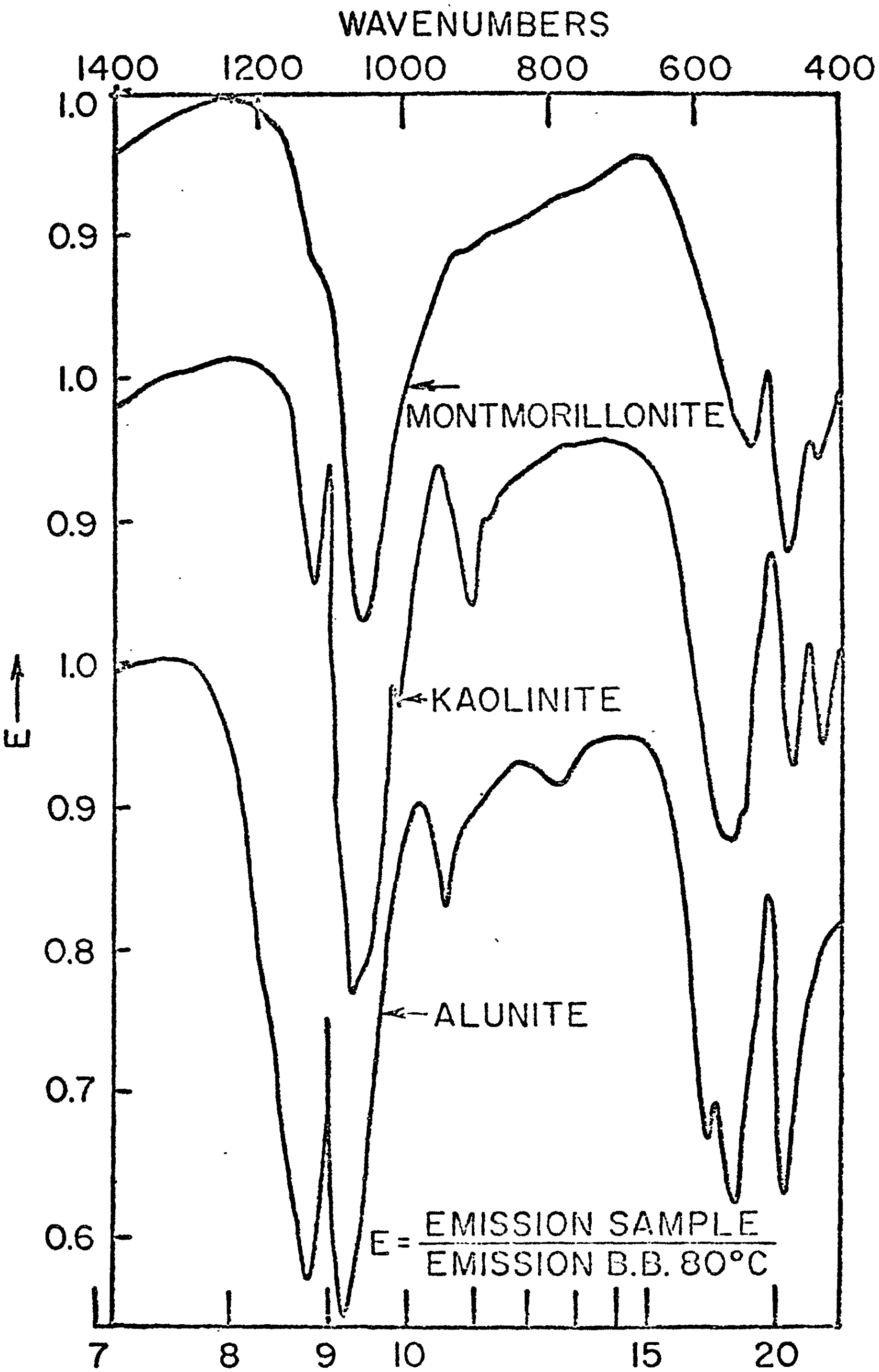

Figure 4.--Emission spectra of well-characterized particulate clay samples.

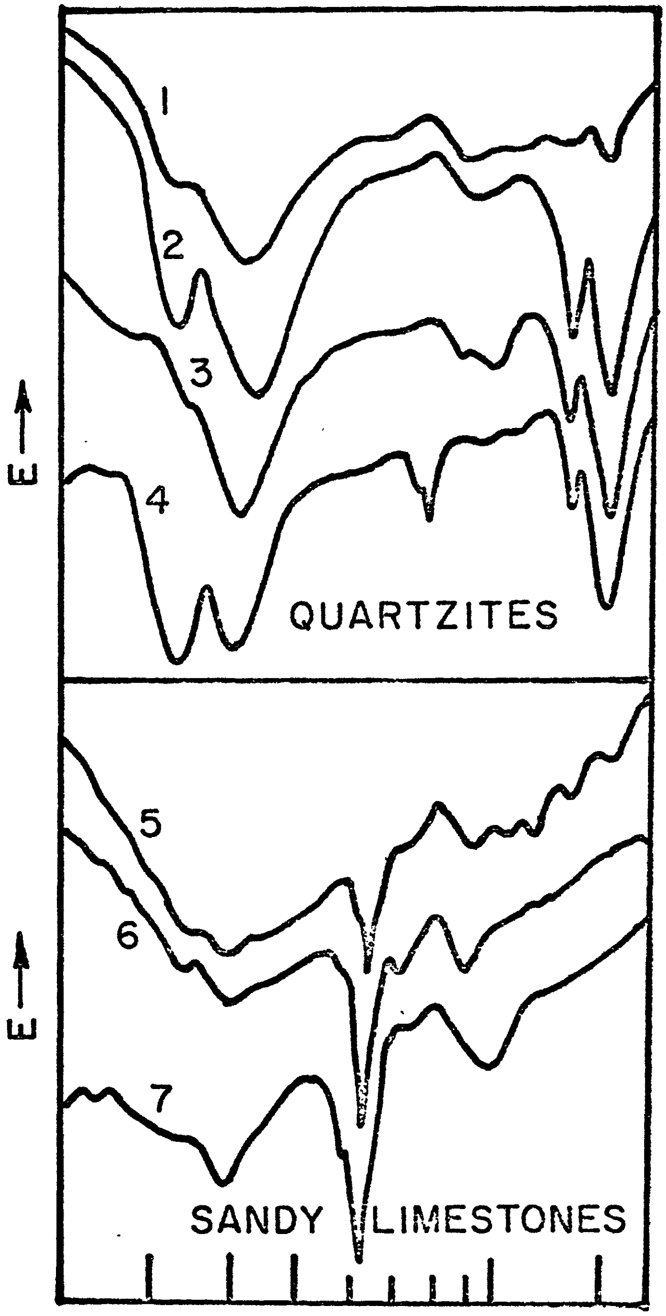

Figure 5.--Emission spectra of a quartzite sample (top) and some limestone samples (bottom). The conditions of the quartzite samples are for curve (1) thick layer of sand; (2) thin layer of sand covering rock chips; (3) natural rock surface; and (4) a rough-cut rock surface. The curves in the bottom half are (5) limey alluvium sand; (6) dolomite sand; and (7) limestone rock.

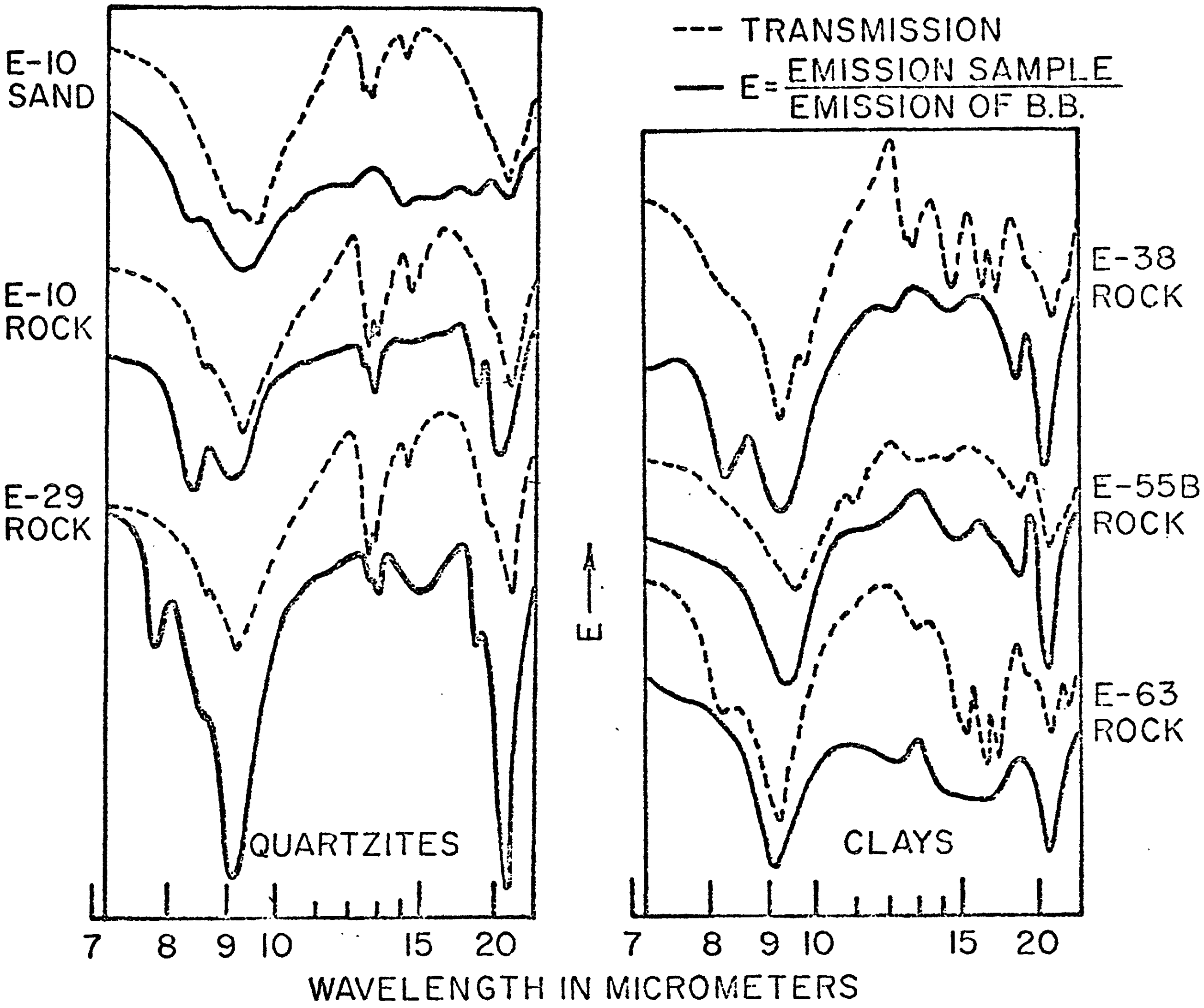

Figure 6.--Quartzite (left) and clay (right) transmission and emission spectra. E-10 is quartzite; E-29 is a quartzite rock with a heavy iron stain; E-38, a silicified rock containing halloysite and quartz; E-55, B-clay altered from latite; E-63, opalized quartz.

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 which relate the spectral emission behavior to the fundamental properties of geologic materials.

References

Hunt, G. R., 1980, Electromagnetic radiation--The communication link in remote sensing, in Siegel, B. S., and Gillespie, A. R., eds., Chapter 2, Remote Sensing in Geology: New York, John Wiley & Sons, p. 5-45.

Hunt, G. R., and Salisbury, J. W., 1974, Mid-infrared spectral behavior of igneous rocks: AFCRL-TR-74-0625, 144 p.

Lyon, R. J. P., 1964, Evaluation of infrared spectrophotometry for compositional analysis of lunar and planetary soils--Rough and powdered surfaces: Stanford Research Institute Final Report Part II, Contract NaSr 49(04), 176 p.