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Remote Sensing in the Mid-Infrared

by

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The 3-5 µm Region

Of the two window regions in the mid-infrared, the 8-14 µm is probably the most useful for geologic remote sensing. However, there is geologic information potentially present in the 3-5 µm region, as illustrated in Figures 1 and 2.

Figure 1 shows transmission spectra of calcite recorded for progressively greater amounts of the mineral embedded in a KBr substrate. The top curve is the usual concentration (1 mg calcite in 300 mg KBr), which results in full scale absorption by the strong fundamental C-O stretching vibration at longer wavelength. The much weaker overtone bands near 3.5 and 4.0 µm are scarcely noticeable at this concentration, but are well-displayed at concentrations of 5 and 10 mg. Weaker overtone at 4.8 µm can only be seen at the two higher concentrations, whereas still weaker overtones near 3.1 µm and 2.6 µm produce only barely preciptible inflections in the 10 mg. curve.

Figure 2 shows reflection spectra of different particle size ranges of the same calcite. What should be noted is that all of the weak overtones are quite prominent at the coasest particle size range and some of them (as at 3.5 and 4.0 µm) become more so as particle size is reduced (Salisbury et al, 1986). Thus, some minerals display spectral features that could be detected in the 3-5 µm window. These include carbonates, sulfates, and some phosphates. However, problems of interpretation raised by the cross-over between reflected and emitted radiation in this region are severe.

The 8-14 µm Region

The 8-14 µm region is the preferred one for geologic remote sensing, both because of the unambiguous detection of emitted radiation and because the fundamental molecular vibration bands of most of the major rock-forming minerals lie in this region.

When the potential of the mid-infrared region for geologic remote sensing was first explored (Lyon, 1964), a rough correlation was found between silica content of igneous rocks and wavelength of the fundamental Si-O stretching vibration. Subsequently, it has become popular to refer to the 8-14 µm region as useful for mapping silica content. This is incorrect for two reasons. First, the correlation of band location and silica content is a poor one. (It would be just as correct to correlate band location with iron/magnesium content or even albedo of igneous rocks.) Second, much of the earth is covered with sedimentary and metamorphic rocks that do not follow the general trend identified for igneous rocks.

In fact, the 8-14 μm region allows us to map mineralogy. This is illustrated in Figures 3 and 4. Figure 3 shows reflection spectra of the minerals quartz, orthoclase and hornblende. When these minerals are mixed to form an artificial rock composed of 35% quartz, 50% orthoclase, and 15% hornblende, they yield the reflection spectrum shown in Figure 4. When spectra of the individual minerals are averaged together (weighted by abundance), a virtually identical spectrum is obtained (Fig. 4). This shows that mineral spectra are additive in this spectral region and that rock spectra are interpretable in terms of mineral abundance. It is noteworthy that quartz will tend to dominate the spectrum of any rock in which it is present because of the relative strength of its reststrahlen band.

In addition to mapping mineralogy, it may be possible to map at least some species of vegetation using the 8-14 μm region of the spectrum. Recent research (Salisbury, in preparation) has shown that the leaves of different species may display distinctly different spectral signatures (Fig. 5). The spectral features are due to a specular reflectance from the leaf cuticle, and differences may to be related to differences in cuticle composition. Reflectance peaks from these leaves are probably no greater than 7%, based on the broad-band measurements of Wong and Blevin (1967). Assuming Kirchoff's Law (E=1-R), this implies emissivities ranging from .93 to 1.0. However, a canopy geometry that maximizes scattering will minimize the spectral information in upwelling 8-14 μm radiance. This is because a reflectance peak implies an emittance trough (E=1-R). Thus, multiple scattering, which involves emission, reflection, absorption and reradiation (transmission is zero), will allow the reflectance peak to fill in the emittance trough. For this reason, relatively little spectral information should be present in the emittance from a fir canopy, for example, while much more would be expected from broad-leafed, planophile canopies. Given noise equivalent temperature changes that will allow detection of emissivity differences of less than 1%, it may indeed be possible to discriminate and even identify many such broad-leafed species.

References

1. Salisbury, J.W., Hapke, Bruce and Eastes, J.W., 1986, Usefulness of weak bands in remote sensing of particulate planetary surfaces: submitted to Journal of Geophysical Research.

2. 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).

3. Wong, C.L. and Blevin, W.R., 1967, Infrared reflectances of plant leaves: Aust. Jour. of Bio. Sci., v. 20, p. 501-508.

Figure Captions

1. Transmission spectra of calcite recorded using 1, 5, and 10 mg of calcite in 300 mg of KBr. Increasing concentrations of calcite result in greater absorption by weak overtone bands and lower transmission. The broad water band at 2.8 um is an artifact due to the hygroscopic nature of KBr. (Spectra by Jack Salisbury and John Eastes.)

2. Reflection spectra of 250-500 μm (solid line), 74-250 um (dash-dot) and 0.74 μm (dots) particle size ranges of calcite. Arrows mark weak spectral features that are experimental artifacts due to unpurged atmospheric CO_2 and H_2O near 4.3 and 2.7 μm, and a trace contaminent added in griding the finest particle size range near 2.8 μm. (Spectra by Jack Salisbury and John Eastes.)

3. Reflection spectra of the 74-250 μm particle size range of powdered quartz (solid line), orthoclase (dashes), and hornblende (dots). Major reflectance peaks indicate the location of the Si-O stretching fundamental for each mineral - the so-called "reststrahlen" band. Note that quartz has by far the strongest reststrahlen band of any of the major rock-forming minerals. (Spectra by Jack Salisbury and Lou Walter.)

4. Reflection spectrum of a mixture of quartz (35%), orthoclase (50%) and hornblende (15%) and a similarly weighted average of the individual mineral spectra. (Spectra by Jack Salisbury and Lou Walter.)

5. Relative reflectance spectra of green leaves of four different tree species, black oak (*Quercus velutina*), red maple (*Acer rubrum*), beech (*Fagus grandifolia*) and cherry (*Prunus virginiana*). Spectra are displaced vertically for clarity. (Spectra by Jack Salisbury.)

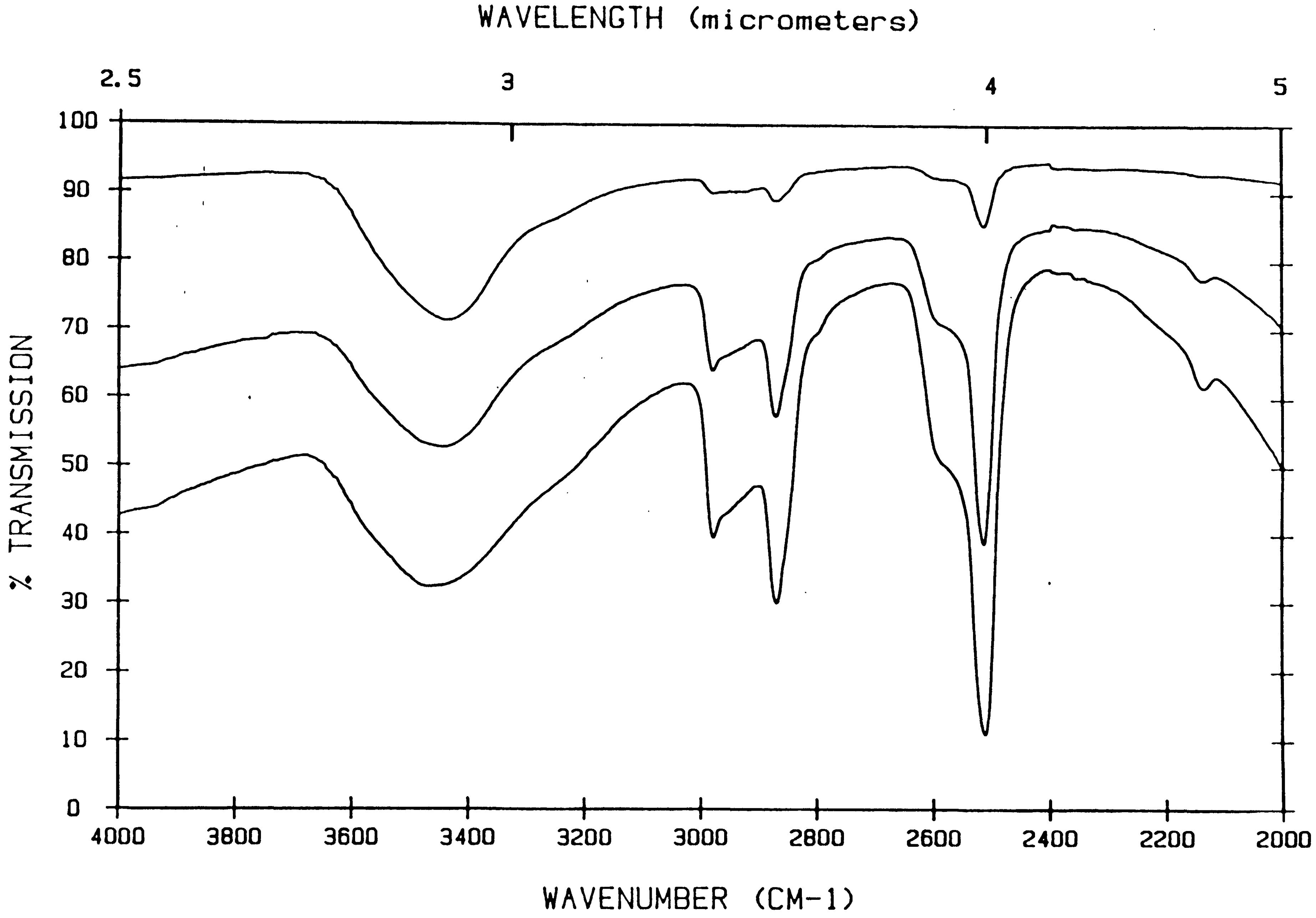
WAVELENGTH (micrometers)
2.5
3
4
5
100
90
80
70
60
50
40
30
20
10
0
% TRANSMISSION
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
WAVENUMBER (CM-1)

Fig. 1

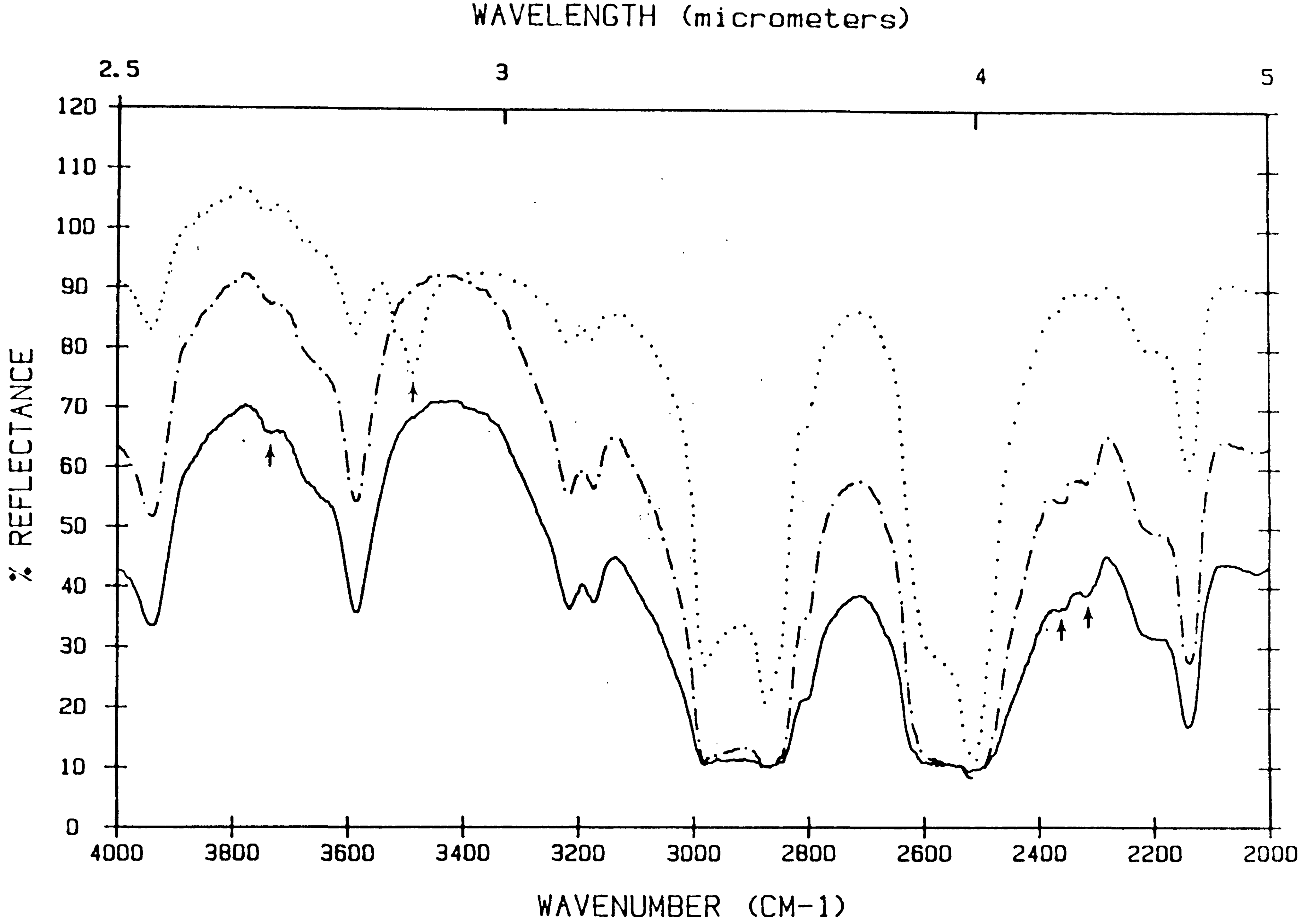
WAVELENGTH (micrometers)
2.5
3
4
5
120
110
100
90
80
70
60
50
40
30
20
10
0
% REFLECTANCE
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
WAVENUMBER (CM-1)

Fig. 2

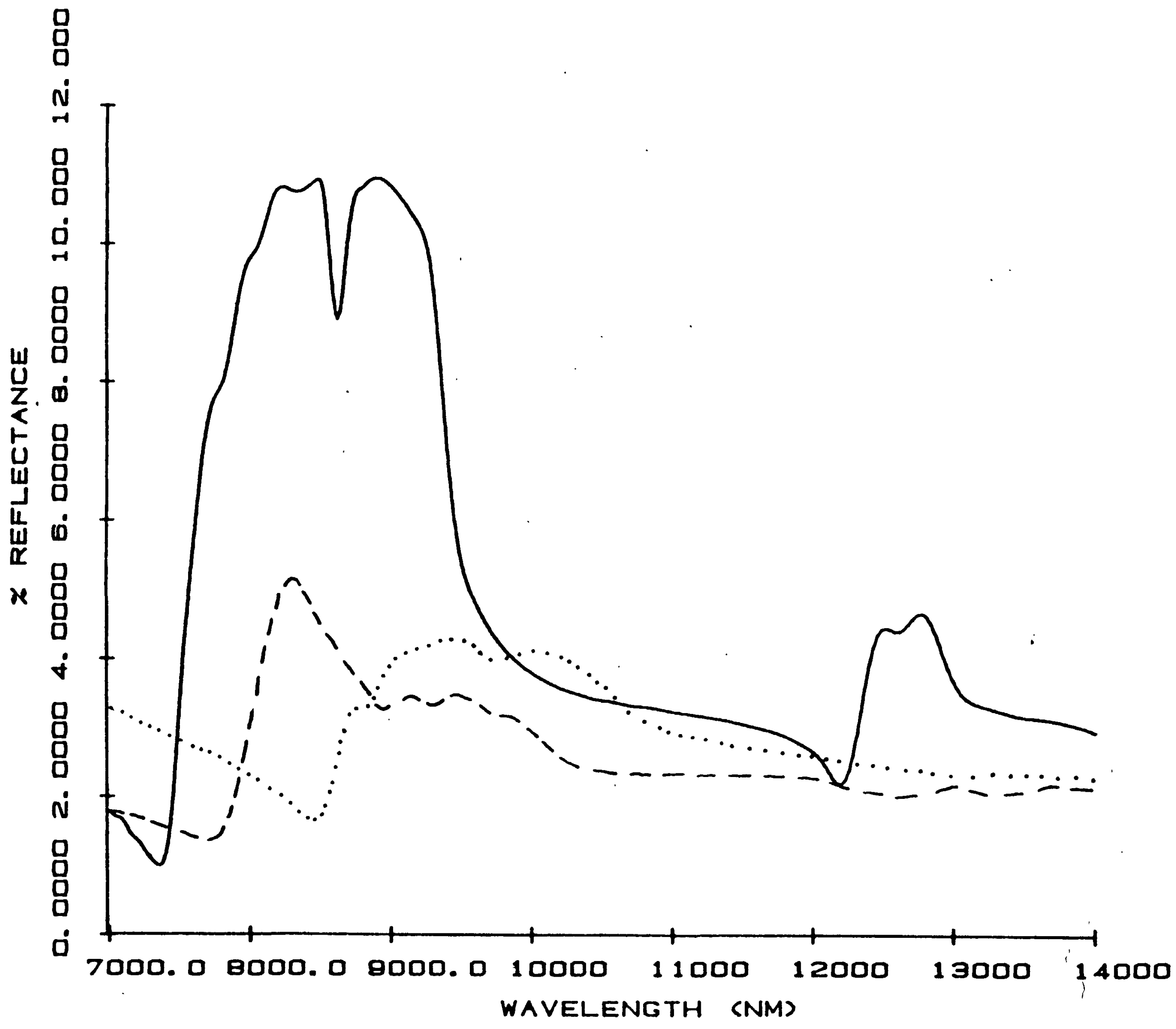
% REFLECTANCE
0.0000
2.0000
4.0000
6.0000
8.0000
10.000
12.000
7000.0
8000.0
9000.0
10000
11000
12000
13000
14000
WAVELENGTH (NM)

Fig. 3

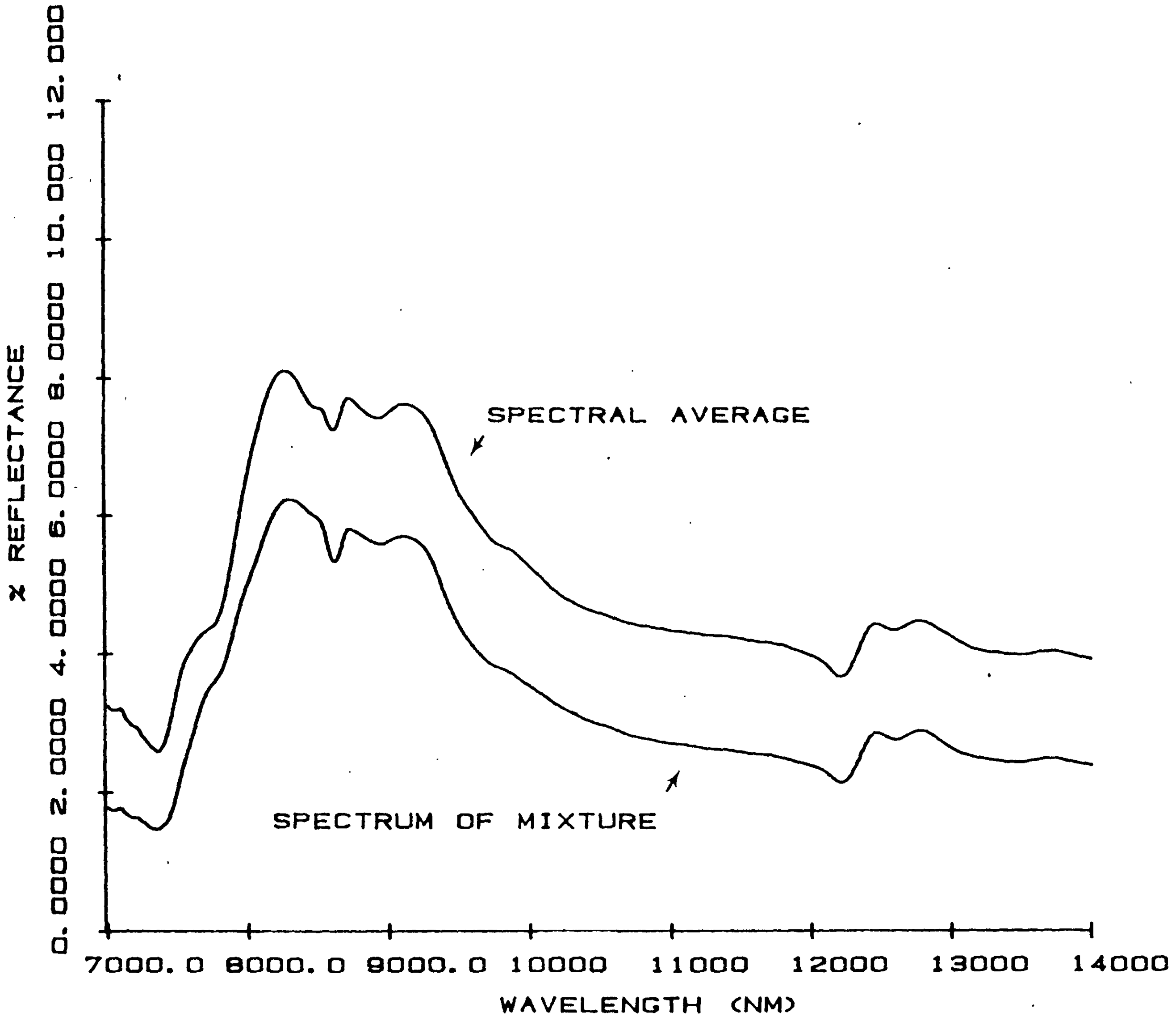
% REFLECTANCE
0.0000
2.0000
4.0000
6.0000
8.0000
10.000
12.000
7000.0
8000.0
9000.0
10000
11000
12000
13000
14000
WAVELENGTH (NM)
SPECTRAL AVERAGE
SPECTRUM OF MIXTURE

Fig. 4

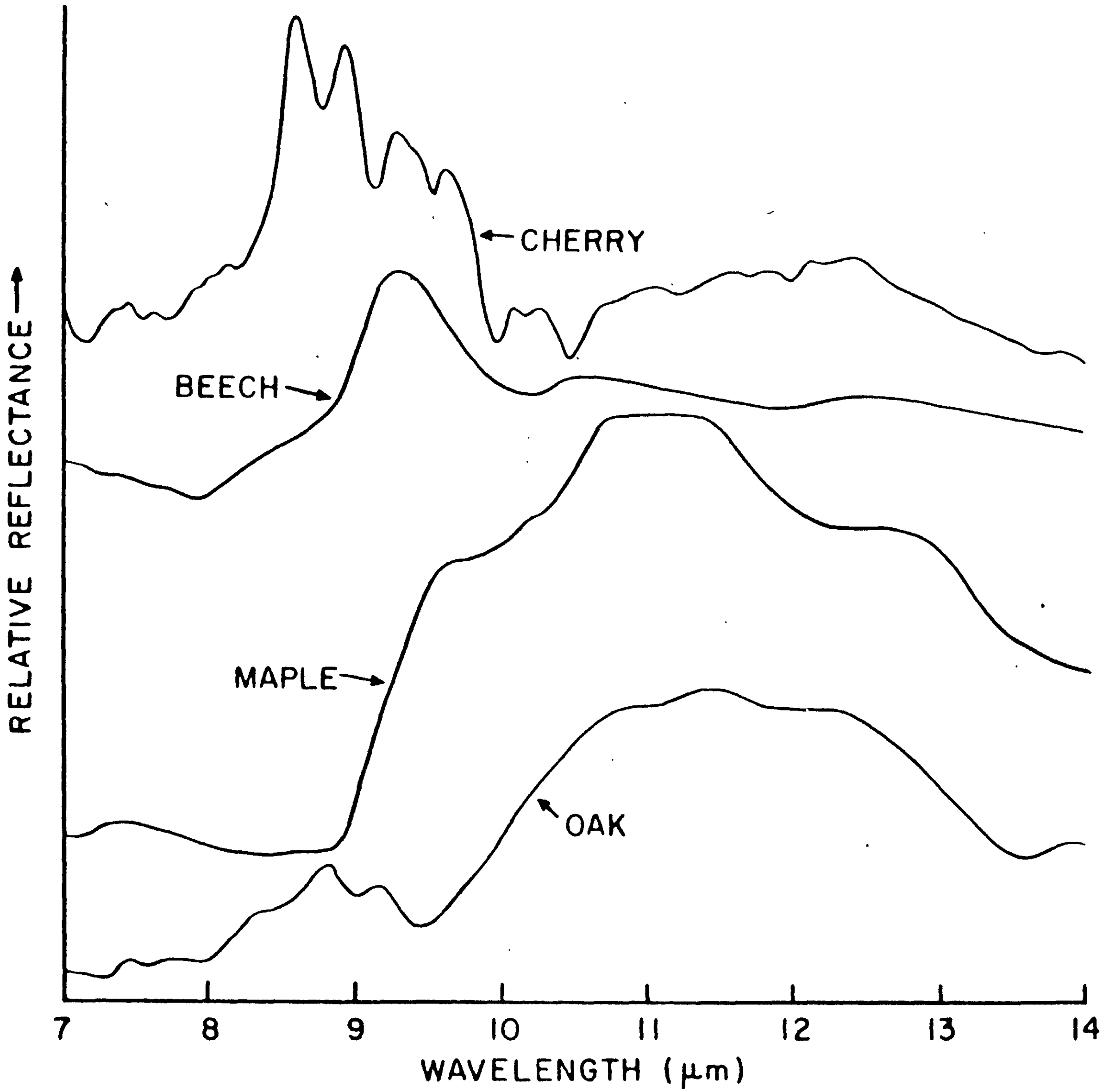
CHERRY
BEECH
MAPLE
OAK
RELATIVE REFLECTANCE
7
8
9
10
11
12
13
14
WAVELENGTH (μm)

Fig. 5