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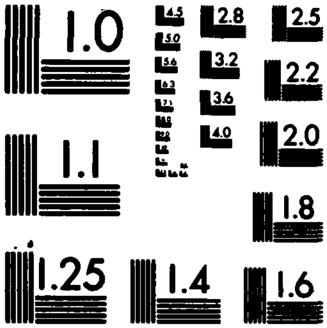

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EFFECTS OF WEATHERING AND LICHEN COVER ON THE MIDDLE INFRARED SPECTRA OF ROCKS

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ABSTRACT

A program to study the spectral characteristics of geologic materials in a near natural condition has been initiated at the Engineer Topographic Laboratories. Much of the present infrared spectral data on rocks and minerals has been determined with samples carefully prepared to maximize certain spectral features and does not reflect the effects of natural processes such as weathering, contamination or lichen growth. Use of such data in the interpretation of remotely sensed imagery could be misleading. This paper reports the results of some initial studies to determine if the spectral effects of rock weathering or lichen cover in the infrared region are important in remote sensing.

INTRODUCTION

Laboratory measurements of middle infrared (3 - 15 microns; 3300 - 667 cm^{-1}) spectra of rocks and minerals show a number of diagnostic features. For terrestrial remote sensing the region between 8 and 14 microns (1250 - 714 cm^{-1}) is the most useful because of high atmospheric transmission and the fact that it is the region of maximum thermal emission at terrestrial surface temperatures. Within this spectral range the most prominent characteristic rock/mineral spectral features are due primarily to stretching modes of silicate groups. The intensity and wavelength position of this silicate absorption peak is related somewhat to the rock type and its position tends to shift toward longer wavelengths as the SiO_2 content decreases, i.e., mafic and ultramafic rocks exhibit absorption peaks at longer wavelengths than do felsic rocks.

The possibility of exploiting these spectral features for remote sensing of rock/mineral type from aircraft or satellite has been suggested by various workers, (Vickers and Lyon, 1967; Lyon, 1972; Vincent, Thomson and Watson, 1972; Vincent, 1975). Lyon (1972) reported distinguishing between basalts, alluvial fans and wind blown sands and also recognizing spectral differences within the basalt flows at Pisgah Crater in California. Vincent, Thomson and Watson (1972) reported distinguishing dacite from basalt and rhyolytic tuff from the surrounding alluvium.

A considerable body of rock/mineral spectral data such as illustrated in Fig. 1 presently exists and is used in rock discrimination. However much of the data was determined using laboratory samples carefully prepared to maximize certain spectral features. Sample preparation often includes crushing or polishing - procedures which destroy potentially diagnostic surficial spectral information. Less data exists concerning the effects on infrared spectra of

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natural processes such as weathering, contamination, varnishing, lichen growth, etc. The use of spectra of samples unrepresentative of field conditions may lead to less precise or even inaccurate interpretation of remotely sensed data.

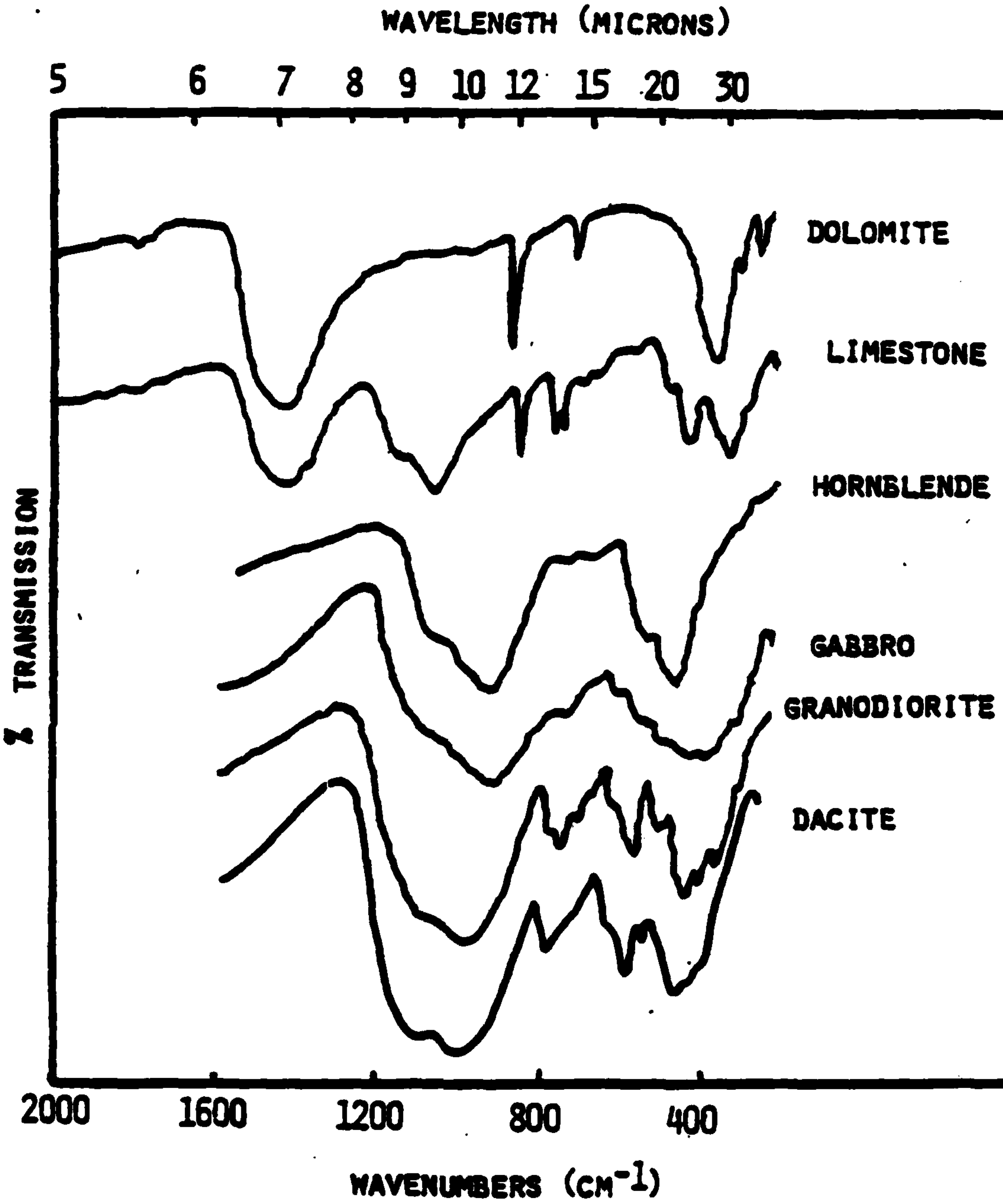

Fig. 1 Composite spectra of several rock/mineral types found in the East Pioneer Mts. Spectra taken from Handbook of Physical Properties of Rocks CRC Press, Inc. Boca Raton, Florida.

Accordingly, a program is underway at the Engineer Topographic Laboratories to study laboratory and field spectral characteristics of geological target materials in as near a natural state as possible. This paper reports some initial studies of the influences of weathering, surface contaminents and lichen growth on the infrared spectral reflectance characteristics of a variety of rock and mineral samples collected in the East Pioneer Mountains, Montana. Rock specimens represent the three major types: igneous, sedimentary and metamorphic. The present data are qualitative as most of the samples were diffuse reflectors and hemispherical collection techniques to measure total reflection were not used. However the spectra do appear to allow rapid screening and diagnostic studies of various surface characteristics using simple techniques. Future more quantitative studies are planned for cases where weathering or other surficial agents seem to significantly alter spectral characteristics of the substrate.

EXPERIMENTAL PROCEDURE

For each sample investigated, a spectrum was recorded on a weathered surface, a fresh surface, and if present, a lichen covered surface. Spectral measurements were made using a Perkin-Elmer Model 983 infrared spectrophotometer* fitted with a diffuse reflectance attachment, Fig. 2. Use of this device allows spectral measurements to be made directly on the surfaces of small samples. In the optical arrangement radiation from the source (a heated ceramic tube) is divided into reference and sample beams. The sample is placed 22 millimeters below and between the two ellipsoidal mirrors. These are used at a x6 demagnification so that a small (about 2x2 mm) area of the sample is measured. Radiation reflected from the sample is ratioed to the reference beam and this ratio is reported as % reflectance. The source

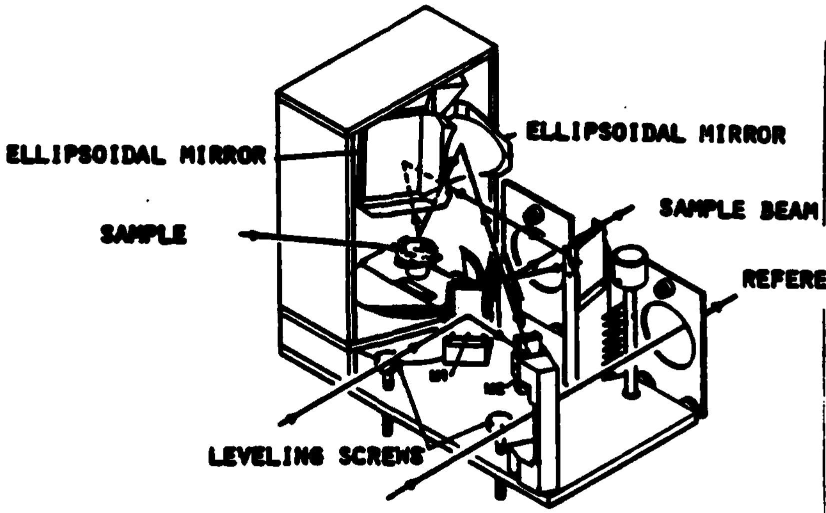

Fig. 2 Optical paths, diffuse reflectance accessory.

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radiation was chopped to minimize the effects of stray background radiation or emission of the sample itself. Most samples were chips of irregular dimensions ranging from 2 to 4 cm in diameter and were used without preparation of any sort. A sample was placed in position in the sample area and, depending on the thickness of the sample and the degree of roughness of its surface, was lowered or raised and tilted slightly until the sample beam was focused on its surface. Relatively fine-grained smooth-surfaced samples could be examined easily and spectra of high signal-to-noise ratio could be recorded. There was some uncertainity about relative band intensities as the latter can vary with sample orientation. However significant changes in band position were not observed. To compensate for intensity changes with sample orientation, spectra were recorded at five separate positions on each sample and the results averaged. With coarse-grained composite specimens such as granites, relative large changes in spectral structure as well as in intensity were observed when the sample position was changed. The surfaces of such specimens were irregular and the mineral particles constituting the rock were randomly orientated and consequently reflected in random directions. With the small diameter of the probing beam it was impossible to align the samples so that the incident beam struck a representative area of the rock surface. Spectra recorded at five different locations on these samples were also averaged in order to obtain a more nearly representative reflectance from the sample, however it is expected that in the case of large-grained granites, data are less accurate than for fine-grained specimens. The spectra were recorded at approximately 7 cm^{-1} resolution.

RESULTS

Effects of Weathering

Shown in Figs. 3 to 6 are spectral data determined from the various rock/mineral surfaces investigated. Weathered surfaces varied from thin layers of discoloration or contamination to layers several millimeters thick.

Fig. 3(a) illustrates the spectra of fresh and weathered surfaces of a rhyodacite sample. The weathered surface of this specimen consisted of a reddish-brown layer about 4 mm thick having a distinctly different visual appearance from that of the substrate. The spectra of the two surfaces are very similar except for a peak near 1025 cm^{-1} (9.8 microns) for the weathered face. Chemical analysis of the weathered layer was not performed, however it was softer than the fresh substrate and probably consists of iron oxides plus an increased clay content relative to the fresh rock. Such would account for the visual difference between substrate and weathered layer as well for the peak near 1025 cm^{-1} (9.8 microns) as two common clay minerals, montmorillonite and kaolinite, have spectral maxima in this region. Effects of ferric oxide were not observed; this material is spectrally rather featureless in the 8- to 14- micron wavelength region and thin layers do not exert significant spectral features.

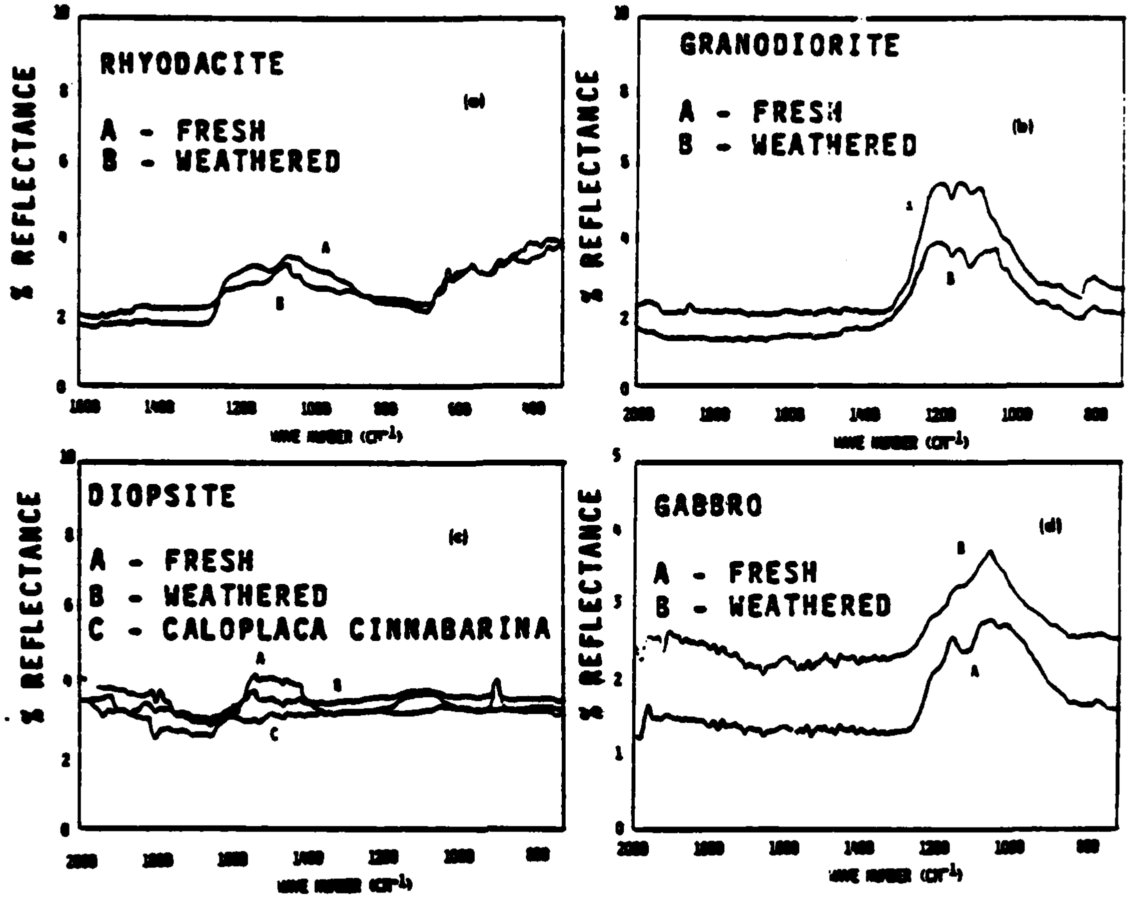

Fig. 3 Infrared spectral characteristics of fresh, weathered and lichen covered rock and mineral surfaces.

The two traces for the fresh and weathered surfaces of the granodiorite sample depicted in Fig. 3(b) differ somewhat in amplitude, but otherwise appear very similiar with no significant shifts in wavelength for the maxima. The appearance of the fresh and weathered surfaces of this specimen were visualy similar except for a very thin layer of reddish discoloration on the weathered surface due to ferric oxides.

Spectral traces A and B in Fig. 3(c) are of fresh and weathered surfaces of a sample of diopside. The spectrum of the fresh surface exhibits bands centered near 1100 cm^{-1} (9.1 microns) and 1470 cm^{-1} (6.8 microns). Diopside formed as a result of metamorphosis of limestone in contact with magma, and the 9.1 micron band is due to silicates derived from the magma and the 6.8 micron band to the presence of unmetamorphosed limestone. Visual differences between the fresh and weathered faces were small, and the weathering appeared to consist of a very thin layer of discoloration. Spectral differences in the infrared are also small with no significant shifts in peak shape or position.

Fig. 3(d) shows spectral data for fresh and weathered faces of a gabbro sample. The weathered face appeared quite silty and for this sample there is a difference in shape of the peaks as well as in intensity. The peak near 9.7 microns (1075 cm^{-1}) for the weathered surface resembles that for the weathered surface of the rhyodacite in Fig. 3(a).

Fig. 4 includes spectra for the fresh and weathered surfaces of samples of marble, tonalite, aplite and dolostone. The weathered faces of these rocks showed thin films of faint discoloration of undetermined composition through which the features of the substrate rocks could be seen. No differences other than slight differences in amplitude of the peaks is evident and the weathering products do not appear to exert significant effect.

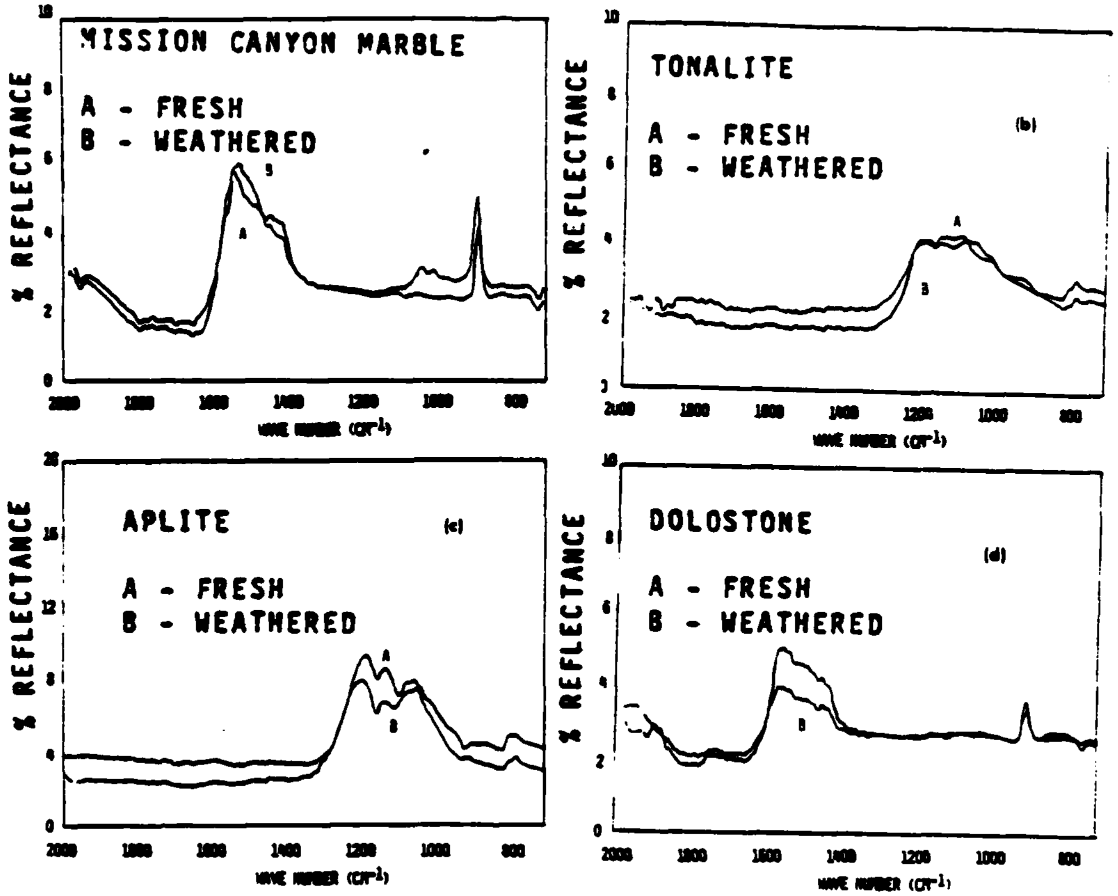

Fig. 4 Infrared spectral characteristics of fresh and weathered rock surfaces.

Spectral curves for a specimen of hornblendite are illustrated in Fig. 5(a). For this sample fresh and weathered faces were distinctly different in appearance. The fresh surface was dark colored whereas the weathered layer was distinctly reddish-brown and about 6 mm thick. The differences apparent in the visible are also evident in

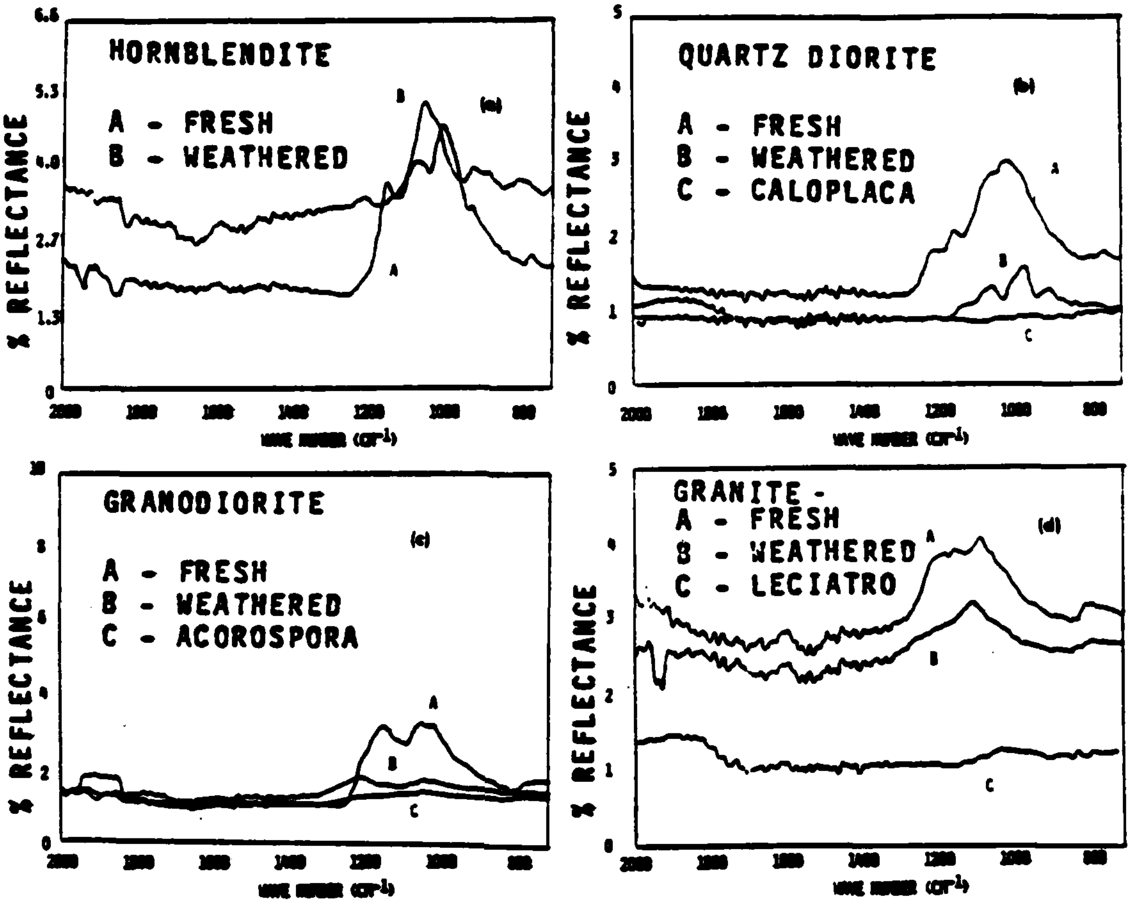

Fig. 5 Infrared spectral characteristics of fresh, weathered and lichen covered rock surfaces.

the infrared spectra; significant intensity and structual differences between the two curves are seen. The curve (trace B) for the weathered surface consists of a single intense peak near 9.7. microns (1025 cm-^{1}) accompanied by several minor peaks on either side, whereas the curve (trace A) for the fresh surface consists of three relatively strong peaks. The 1025 cm-^{1} (9.7 microns) peak is also similar to those of the silty weathered faces of the rhyodacite and gabbro samples.

Fig. 5(b) shows spectra for a quartz diorite. A fresh face of this sample was relatively coarse grained and dark toned. A non-fresh surface (which may be a contamination rather than a weathering product) consisted of a thin greenish colored film. Under the microscope the film appeared grainy and may be olivine. Trace A in Fig. 5(b) is for the fresh surface and trace B represents the non-fresh or weathered green-colored surface. The shape of the two spectra differ considerably, however the green surficial film has not been analyzed to determine its specific spectral characteristics.

Data for a granodiorite are illustrated in Fig. 5(c). For this sample the spectrum of the weathered face is depressed and a shift of one of the peaks to shorter wavelength has occurred.

Spectra for a granite are illustrated in Fig. 5(d). These traces are for a relatively large grained sample and are less accurate due to the small area examined on the sample. The spectrum of the weathered face with a maximum near 1100 cm-^{1} (9.1 microns) does however resemble those of other weathered surfaces and this fact may allow spectral distinction between fresh and weathered surfaces.

Effect of Lichen Cover

Approximately 38 species of lichen were identified in the East Poineer Mountains and in some undisturbed areas large surface areas of the terrain were extensively covered. The species distribution appears somewhat dependent on rock type, Spectra of various lichen covered surfaces are indicated in Fig. 6 as well as in Fig. 5(b), (c),(d) and Fig. 3(c).

Spectra of four lichen species on several substrate rocks are presented in Fig. 6(d). The similarity of these spectra as well as others suggests that the spectral characteristics of lichen growth would be much the same on diverse rock types. Comparison of spectral curves for substrate rocks

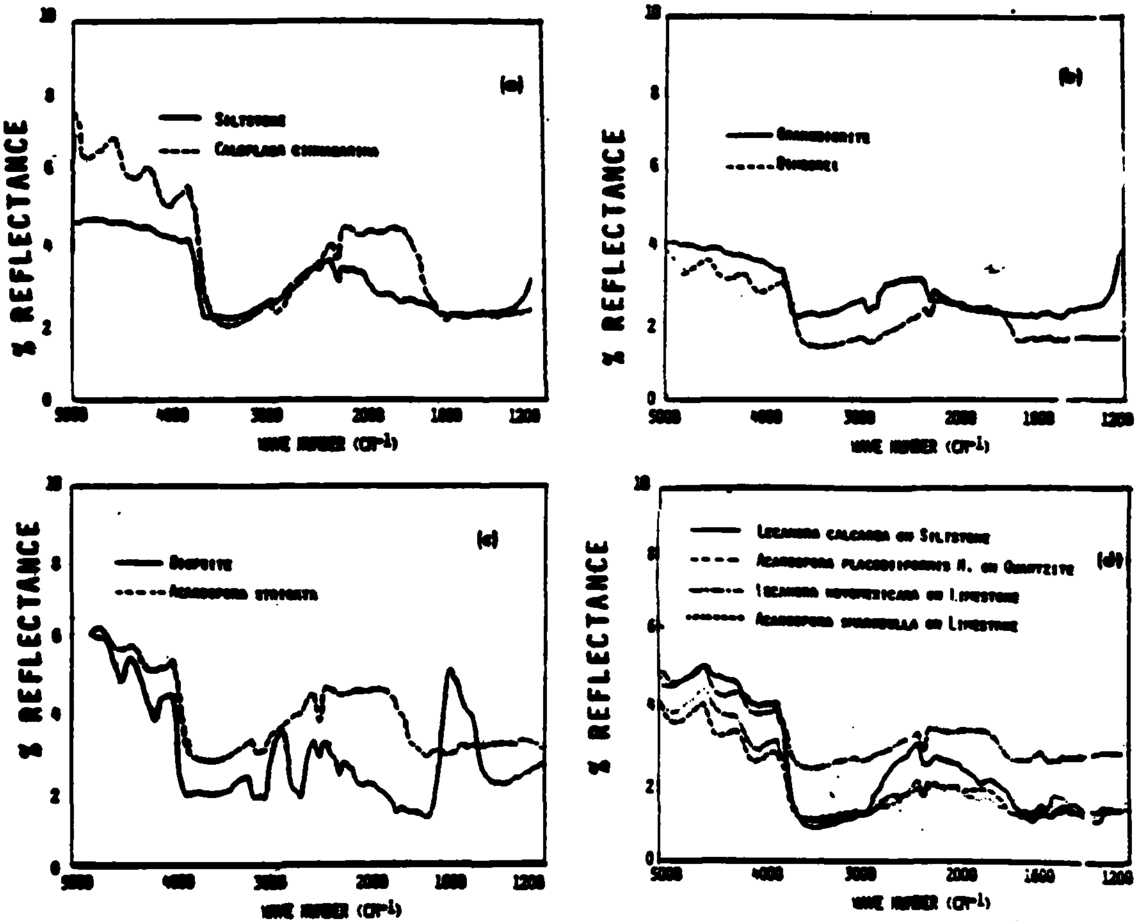

Fig. 6 Infrared spectral characteristics of various licten species and substrate rocks.

and their lichen covered surfaces in Fig. 6(a), (b) and (c) indicates that the fresh rock samples can be differentiated, but can no longer be differentiated when lichen covered. The silicate bands observed for fresh surfaces of the siltstone and granodiorite samples of Fig. 6(a) and (b) and both the carbonate and silicate features of the fresh diopside surface in Fig. 6(c) are absent in the corresponding spectra for lichen covered surfaces.

For the spectral region between about 1600 cm^{-1} (6.2 microns) and 700 cm^{-1} (14.3 microns) each of the lichen covered surfaces has taken on spectral characteristics similar to those of a gray body. Similar results are noted for the quartz diorite, granodiorite and granite samples in Fig. 5(b), (c) and (d) respectively.

CONCLUSION

Qualitative infrared reflectance spectra have been used to observe some of the effects of weathering and lichen cover on the spectral characteristics of a variety of rocks and minerals. These effects were found to be variable and appeared to depend on the thickness of the weathered layer as well as its chemical composition and physical state. Ferric oxide has no significant spectral features in the region 2000 - 7000 cm^{-1} (5 - 14.3 microns) and thin films of this material as a weathering product on rock surfaces do not alter their spectral features. One effect observed in the present study was the presence of distinct peaks between 1025 and 1100 cm^{-1} (9.7 - 9.1 microns) on the spectra of a number of weathered surfaces. These peaks were absent in the spectra of corresponding fresh surfaces. Two clay minerals, montmorillonite and kaolinite, are common weathering products exhibiting spectral maxima near these wavelengths, and the spectral differences between fresh and weathered surfaces of those specimens are likely due to the presence of these materials.

The spectra of a number of weathered surfaces were similar enough to those of corresponding fresh faces that distinguishing between the two is considered unlikely. The latter spectra were usually of samples with weathered surfaces consisting of very thin layers of faint discoloration through which the surface characteristics of the substrate were visible. More complete studies including chemical analyses of the weathering products are considered necessary to quantitatively determine the spectral effects of weathering processes.

The presence of extensive lichen growth serves to obliterate spectral characteristics of the underlying rocks. Since the presence of lichens contitutes a form of vegetative cover, the spectral effect of an increase in lichen growth should be to make distinction between vegetated areas and areas often considered unvegetated more difficult. This makes topographic clues about rock types of increased value in imagery of areas of extensive lichen cover.

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