SPECTRAL REFLECTANCE OF HIGHLAND ROCK TYPES AT APOLLO 17: EVIDENCE FROM BOULDER 1, STATION 2

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Abstract. Many of the non-mare rock types at Apollo 17 can be identified uniquely by their spectral reflectance properties. Mineralogical and textural information is present in the spectral curves of samples from Boulder 1, Station 2. It should be possible to determine the regional extent of rocks similar to the boulder using reflectance spectra from a spacecraft in lunar orbit.

1. Introduction

We have measured the spectral reflectance (0.35–2.5 μm) of eight samples from Boulder 1, Station 2 at the Apollo 17 site. In addition, we have measured several other highland rock and soil samples from both North Massif and South Massif. Our objective in this study was to determine whether the various highland lithologies sampled at Apollo 17 could be distinguished from one another using reflectance spectra.

Reflectance spectra are sensitive to the presence of, and relative abundance of, the principal phases in lunar rocks (plagioclase, pyroxene, olivine, ilmenite and glass). Curve shapes also are affected by the textures of the rocks. We will show that it is possible to identify certain Apollo 17 highland rock types using reflectance spectra.

It is not yet clear, however, whether the lithologies that occur on the scale of centimeters in breccias (e.g., in Boulder 1) have recognizable counterpart areas on the scale of kilometers. There is only the most meager information available on the distribution of any highland rock types. Because many of the highland rock types can be uniquely recognized by their spectra, the potential exists for mapping their areal distribution from an orbiting spacecraft (McCord *et al.*, 1975). Boulder fields and bright craters (down to about 1 km across) would be likely targets for such orbital measurements.

2. Boulder 1, Station 2

Diffuse reflectance spectra of samples from Boulder 1 are shown in Figures 1 and 2. Two spectra of soils from Station 2 also are plotted in Figure 2 for comparison with the rock curves. Spectra of samples of the boulder are distinctly different from those of the soils. The soil curves have only faint absorption features near 0.9 μm and 1.9 μm, and have a characteristic steeply sloping continuum. These spectral features are typical of mature lunar soils, and are largely due to the presence of agglutinitic glass (Adams and Charette, 1975). The rock curves, in contrast, exhibit well defined absorption bands and flatter curves, indicating that the boulder incorporates little or no surface soil or material derived from soil. This observation is in agreement with

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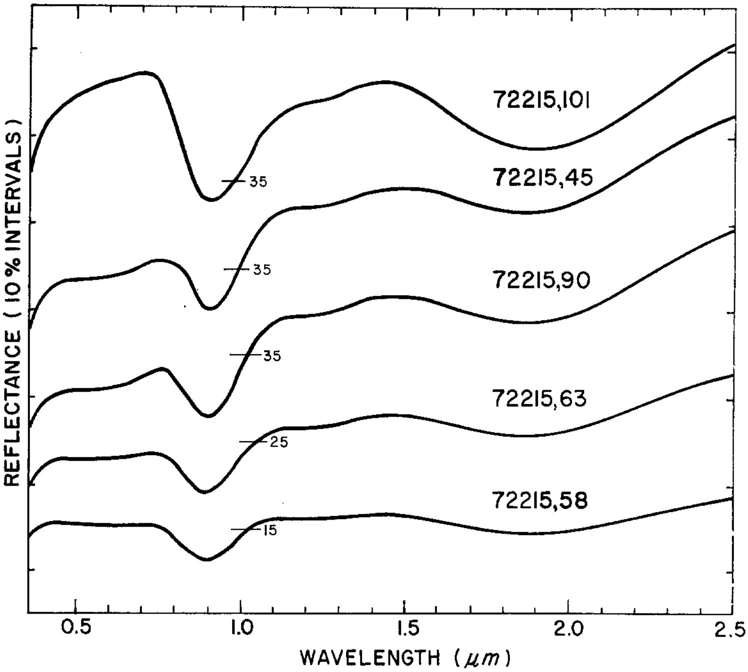

Fig. 1. Diffuse relectance spectra of chips of different lithologies from Boulder 1 sample 72215. Sample 72215,101 is anorthositic gabbro, 72215,45 and 90 are light to medium-gray noritic breccias, 72215,58 is dark-matrix breccia, and 72215,63 is intermediate between these last two lithologies.

the low concentrations of solar wind gases found in the boulder samples by Leich *et al.* (1975).

All of the rocks and rock-derived fines have curves with absorption bands near 0.9 μm and 1.9 μm (Figures 1 and 2). These bands arise from electronic transitions in Fe^{2+} in orthopyroxene (Burns, 1970). The wavelengths of the band minima indicate that pyroxene is the dominant mafic silicate, and that the average pyroxene composition is approximately $En_{70}Fs_{25}Wo_5$ (Adams, 1974). This spectrally-determined composition agrees well with microprobe analyses of orthopyroxenes in the gray breccia matrix and in the noritic and anorthositic gabbro clasts (Ryder *et al.*, 1975; Stoeser *et al.*, 1974).

Several of the rock curves show an additional shallow band near 0.6 μm that appears to be due to charge transfers involving Fe^{2+} and Ti^{4+} (Loeffler *et al.*, 1975). This band is not unique to any one mineral, but, in lunar samples, it is most often associated with very thin plates of ilmenite (Adams *et al.*, 1974). Ilmenite is a common trace accessory in the pyroxenes of the noritic clasts, where it occurs as platey brown inclusions (Stoeser *et al.*, 1974).

The shallow absorption band near 1.3 μm is contributed by Fe^{2+} in plagioclase (Adams, 1975). The band occurs in all of the spectra of the boulder samples.

Three lithologic types (excluding soils) can be distinguished using the curves in

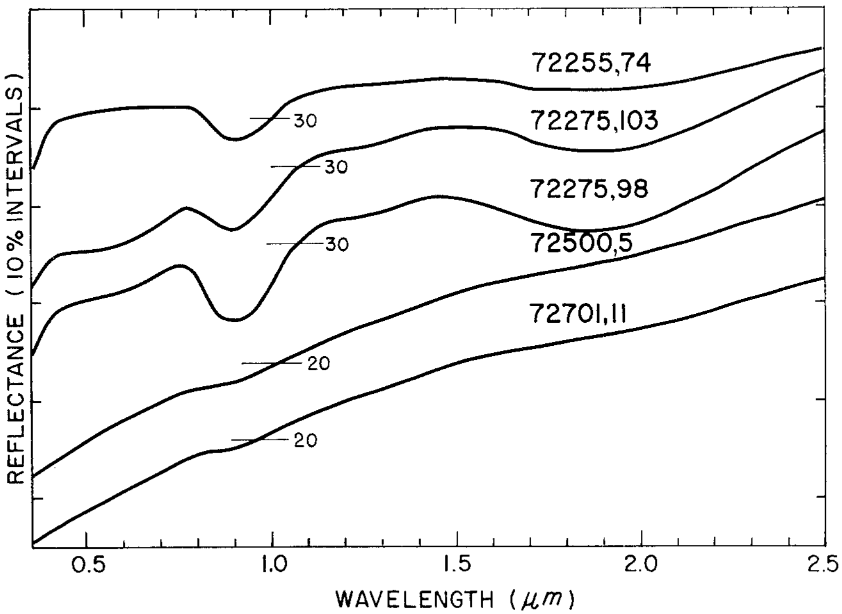

Fig. 2. Diffuse reflectance spectra of samples from Boulder 1: 72255,74 is gray noritic breccia saw cuttings that are heavily contaminated by metal from the saw blade. The spectral curve may be artificially flattened by the presence of the opaque contaminant. 72275,103 is an exterior surface of a chip of light to medium-gray noritic breccia; 72275,98 consists of (clean) saw cuttings from the same lithology; 72500,15 and 72701,11 are two mature soils from South Massif.

Figures 1 and 2. The rock types are: (1) anorthositic gabbro (72215,101), (2) light to medium gray noritic breccia (72215,45; 72215,90; 72275,98; 72275,103), and (3) dark-matrix breccia (72215,58). Sample 72215,63 is intermediate between types 2 and 3.

The anorthositic gabbro curve is characterized by (1) deep pyroxene and plagioclase Fe^{2+} bands; (2) a high left shoulder (near 0.7 μm) relative to the right shoulder (near 1.1 μm) on either side of the pyroxene band at 0.90 μm; and (3) the absence of any absorption feature near 0.6 μm.

The light to medium-gray noritic breccias are characterized by (1) pyroxene bands of intermediate depth; (2) left shoulder at 0.8 μm and lower than the right shoulder at 1.1 μm; (3) a broad absorption near 0.6 μm, and (4) a positive slope to the overall curve.

The dark breccias are distinguished by (1) weak pyroxene and plagioclase bands; (2) shoulders of nearly equal height on either side of the 0.90 μm absorption band; (3) no absorption band near 0.6 μm, and (4) a flat slope of the continuum.

3. Apollo 17 Highland Rocks

Reflectance spectra of several highland rock samples from Apollo 17 and Apollo 16 are shown in Figures 3–5. The spectra are grouped according to the three lithologic

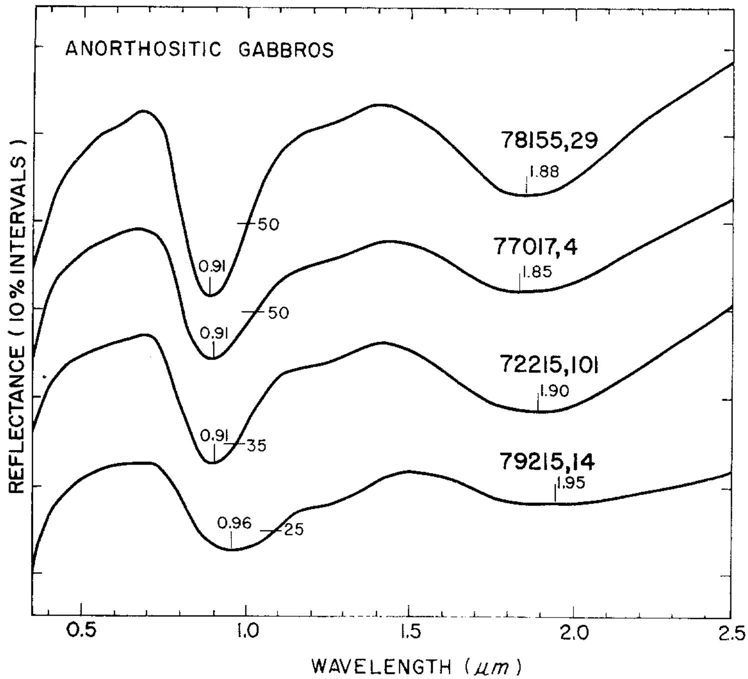

Fig. 3. Characteristic diffuse reflectance spectra of lunar anorthositic gabbros.

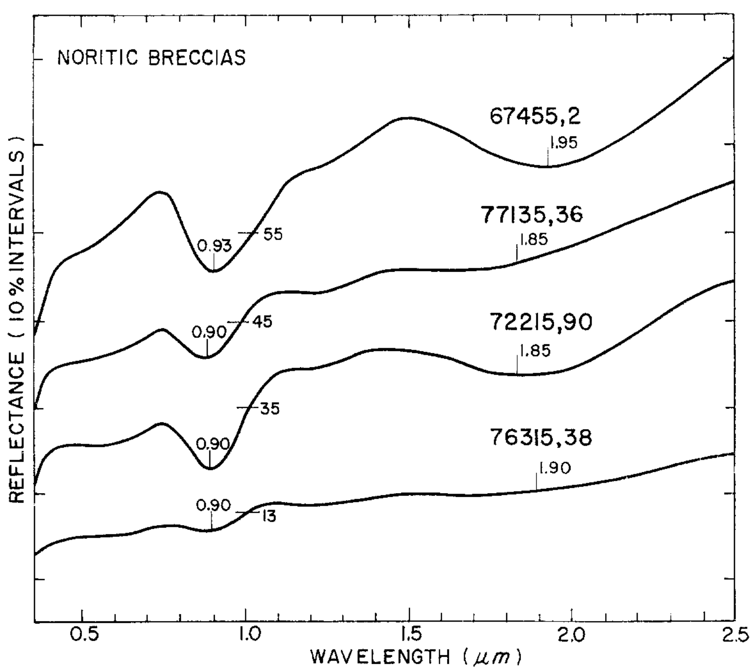

Fig. 4. Characteristic diffuse reflectance spectra of lunar noritic breccias.

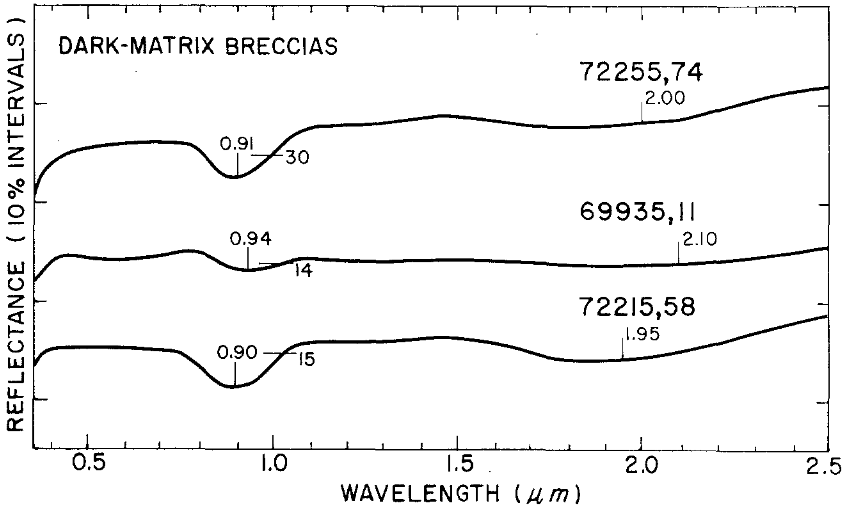

Fig. 5. Characteristic diffuse reflectance spectra of lunar dark-matrix breccias. (Note that 72255,74 may not be a valid sample – see Figure 2).

types already discussed at Boulder 1, Station 2. The anorthositic gabbros (Figure 3) have granulitic to poiklitic textures, and typically have matrix feldspar that is coarse grained (25–400 μm) relative to that in the noritic breccias (5–25 μm) (Figure 4) (Simonds *et al.*, 1974). The noritic rocks are fragmented breccias that contain a widely diverse clast population. The anorthositic rocks at the Apollo 17 site typically contain 70–80% feldspar whereas the noritic breccias have 50–60% feldspar (Simonds *et al.*, 1974).

The shoulder heights on either side of the 0.9 μm absorption band are a function of (1) the amount of plagioclase in the rock and (2) the grain size of plagioclase. The effect of grain size can be shown by the curves in Figure 6. The lower solid curve in Figure 6 is for a rock chip of 15065,58, a gabbro from Station 1 at Apollo 15. Note that the shoulders (at 0.8 μm and 1.4 μm) on either side of the pyroxene/olivine band near 1.0 μm are approximately equal in height. The upper solid curve is for a powdered sample of the same rock chip. The spectral contrast of pyroxene has been increased as a result of the reduced grain size (Adams and Filice, 1967), therefore the pyroxene absorption bands are deeper. The plagioclase absorption band at 1.3 μm, however, has been diminished in intensity because the plagioclase grains have been reduced below the size for maximum absorption. Plagioclase, having a low extinction coefficient, has the deepest bands when coarse grained. The dashed curve in Figure 6 shows the deep band at 1.3 μm in a coarse-grained plagioclase-separate from 12063,79. It is now possible to see that as the broad absorption near 1.3 μm diminishes with decreasing plagioclase grain size the shoulder of the pyroxene band near 1.3 μm will increase in height. In addition, for rocks of comparable grain size, the one with less plagioclase will have a higher shoulder near 1.3 μm.

It was previously noted that the spectral curves of the gray (noritic) breccias in

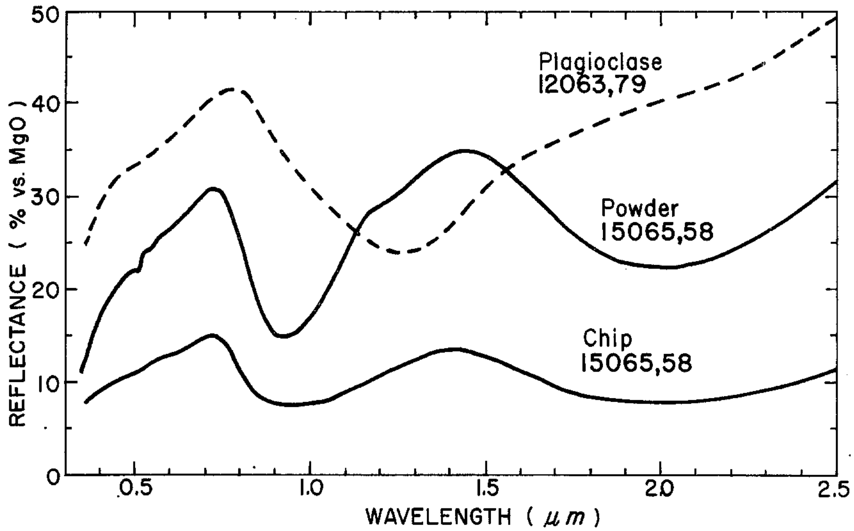

Fig. 6. Diffuse reflectance spectra of gabbro 15065 and of a plagioclase separate from basalt 12063. The bottom solid curve is of an interior surface of a rock chip; the upper solid curve is of a powder of the same chip. Note change of the height of the shoulder at 0.7 μm with pulverization of the sample. The high shoulder at 1.4 μm is attributed to decreased absorption at that wavelength by Fe^{2+} in plagioclase (dashed curve).

Boulder 1 (Figures 1 and 2) have a broad absorption feature near 0.6 μm. Figures 3–5 show that the 0.6 μm band is typical for other breccias of this type. The absorption near 0.6 μm further reduces the height of the left shoulder of the 0.9 μm pyroxene band, adding to the plagioclase effect described above.

The dark-matrix breccias have very little spectral contrast, owing to the presence of dark glass and/or opaque minerals. There is also a gradation from the anorthositic and noritic rocks to the dark matrix breccias. Sample 76315,38 (Figure 4), for example, is intermediate between the noritic and the dark breccias in spectral properties. The opaque material in these breccias contributes little or nothing to the spectrum, but serves mainly to mask other absorption bands, and to move the spectral curve toward a flat, straight line.

Although we have been concerned primarily with the shapes of the reflectance curves as functions of rock type, the band positions provide additional information on the constituent mineralogy. For example, the bottom curve in Figure 3 (79215,14) clearly shows the presence of olivine in addition to pyroxene and plagioclase. The asymmetric band at 0.96 μm in combination with the band at 1.02 μm provides this evidence, as is discussed in detail by Adams (1975).

4. Conclusions

Wood (1975) has drawn attention to the dark-breccia component of Boulder 1. The dark-breccia occurs as rounded inclusions of finely-comminuted clastic material and probably is the dominant lithology of the boulder. If it were possible to obtain a reflectance spectrum of the boulder as a whole it is likely that the curve would be similar to that of 72215,58 (Figure 1).

Based on the reflectance properites of approximately 30 samples of highland rocks from various sites we find that the dark breccias of the kind shown in Figure 5 are rare at the Apollo 17 site, although they are more common at the Apollo 14, 15, 16 sites. We tentatively conclude, therefore, that it may be possible in the future to identify the source-crop of Boulder 1 (presumably higher up on South Massif) and to map the extent of the ejecta that produced the boulder. Identification of the dark-breccia lithology will require higher spatial resolution than is now available from earth-based telescopes (10–20 km) in order to eliminate the spectral contribution of soils. It will be necessary to obtain reflectance spectra of bright ('fresh') craters and of boulder fields on a scale of at least a kilometer, a task that is within the capability of a spacecraft in lunar orbit.

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