Visible and near infrared diffuse reflection spectra are sensitive indicators of the average pyroxene composition of lunar rocks and soils (1). Wavelength positions of absorption bands arising from Fe$^{2+}$ change in a regular way from orthopyroxene to pigeonite to augite in response to changes in octahedral site symmetry. Orthopyroxenites and low-Ca pigeonites have two main bands, one near 0.90 $\mu$m and one near 1.90 $\mu$m. Augites show bands near 0.96 $\mu$m and 2.10 $\mu$m. Where several kinds of pyroxenes are present only an average spectrum is obtained because the individual bands are not resolved. Using mineral separates it has been shown that band positions in the lunar samples are governed by pyroxene only and are essentially unaffected by the presence of other minerals and of glass. Band depths, however, are strongly masked by the presence of dark glass (2).

Pyroxene bands in the Apollo 11 and 12 mare soils at 0.95 $\mu$m and 2.06 $\mu$m are at slightly shorter wavelengths than the bands for the mare breccias and crystalline rocks, suggesting that a foreign component of low-Ca pyroxene in the soil is shifting the average pyroxene composition. The foreign component is accounted for chemically and optically by the anorthositic and KREEP fragments, both of which contain low-Ca pyroxene.

Pyroxene bands for the Apollo 14 soils fall near 0.93 $\mu$m and 2.03 $\mu$m. These band positions indicate an average pyroxene composition in the soil that is less calcic than at the mare sites, in agreement with the chemical and modal data (3). In the Fra Mauro soils, however, the average pyroxene composition is significantly more calcic than the "parent" Apollo 14 breccias and basalts. It thus appears that the Fra Mauro soil has a foreign component of high-Ca pyroxene. The only known source of abundant high-Ca pyroxene is the mare regions, and it is suggested that mare material, including pyroxene, has been added as a contaminant, presumably by an impact-transport mechanism. Laboratory experiments show that addition of a few (<10) percent of mare material to the Fra Mauro breccias shifts the optical spectra to that of the Apollo 14 soil. The light-toned soil from Cone Crater has an average pyroxene composition intermediate between that of the breccias and the bulk Apollo 14 soil, suggesting that
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Cone Crater is young enough to be only slightly contaminated by mare material. The increase in band depths in the reflection spectra with increasing crystal/glass ratio that was noted at the Apollo 11 and 12 sites (2,4) is further evidenced at Fra Mauro. On the basis of weak band structure in the telescopic spectrum it was predicted that the Apollo 14 soil would have a higher glass content than the Apollo 11 and 12 soils. The Fra Mauro soil samples confirm this prediction. In the laboratory, deep band structure in the spectral curve of the Cone Crater soil correlates with a very low (<10%) glass content.

The unusually low glass content of the Cone Crater soil provides further evidence that the degree of vitrification of a soil is an index of its maturity. If lunar soils are ranked in order of increasing glass content -- Cone Crater (<10%), Apollo 12 (20%), Apollo 11 (50%), and Apollo 14 (40-75%) -- it is seen that this ranking also correlates with increasing thickness of the regolith, and geologic evidence for increasing maturity of the surfaces.

Vitrification also affects the albedo of the soil, especially if opaque minerals are present. Regolith material consisting of lighter-toned silicates (plagioclase, pyroxene) and of opaques (ilmenite, metallic iron) has a "salt and pepper" appearance when crystalline, but turns uniformly dark when made into glass. A given material on the lunar surface thus becomes progressively darker with age through impact vitrification. The extent of darkening is determined primarily by the iron and titanium content of the glass and, therefore, by the amount of ilmenite, metallic iron, etc. in the parent rocks. The Fra Mauro soils, although more mature (glassy) than the mare soils, are not as dark because the parent Fra Mauro materials contain fewer opaques and have lower overall iron and titanium contents.

If the Cone Crater soil is representative of immature regolith at the Fra Mauro site it is of interest to consider whether vitrification alone would produce soil comparable in albedo to that in the surrounding area. The Cone Crater soil contains <5% opaques (including those in the lithic fragments). Laboratory experiments imply that even when completely vitrified the Cone Crater soil remains anomalously bright.

An outside source of dark glass and/or opaques appears to be required to darken the Fra Mauro regolith to the albedo of the typical surface soil. It is suggested that the source is the mare regions, and that contamination by mare material accounts for both a change in the average pyroxene composition and in the amount of dark glass in the highland soil. The presence of 11% mare glass in the Apollo 14 soil is reported by other investigators (3). Telescopic observations imply that a glassy soil is well developed throughout the uplands, as it is at Fra Mauro, and that
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Bright craters and rays are, on average, more crystalline than the "background" areas (4). Cone Crater is too small to be measured spectrally by earth-based telescope (at present the area sensed telescopically is 18 km in diameter), but the laboratory spectral curve indicates a high crystal/glass ratio and the presence of low-Ca pyroxene. The large bright highland craters that have been observed telescopically are not as crystalline as Cone Crater, and are therefore probably older; furthermore highland craters give band positions that imply average pyroxene compositions comparable to mare material or to Fra Mauro soil. No evidence has been found for large exposures of fresh KREEP or anorthosite having dominant low-Ca pyroxene. If such rocks are exposed over large areas of the highlands their optical properties may have been obscured by a thin surface admixture of mare material.

Laboratory spectral reflectivity curves of soil samples from Apollo 11, 12, 14 and 15 sites were ratioed to each other, and the resulting curves were compared with telescopic ratio curves. McCord et al. (5) have shown that the highly accurate (~1%) telescopic ratio curves can be grouped into distinct types that are characteristic of maria and highlands and the young and old craters of each terrain. The Apollo laboratory ratio curves reproduce all of the spectral types observed telescopically, providing further evidence that the Apollo samples represent the lunar surface on a regional basis. The telescopic ratio curve for the Apollo 14 site is typical for the uplands in general. It is likely, therefore, that the contamination by mare material seen at the Fra Mauro site is regional in extent.

REFERENCES

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