THE DETECTION OF FRA MAURO BASALTS IN THE LUNAR HIGHLANDS BY REMOTE SPECTRAL REFLECTANCE TECHNIQUES AND IMPLICATIONS FOR CRUSTAL STRATIGRAPHY

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Because the lunar highland crust down to 60km accounts for about 10% of the lunar volume, a knowledge of the abundance of elements such as Al and the rare earths within the crust is critical for theories of lunar petrogenesis and the bulk composition of the moon (1-3). Evidence available from the lunar orbital x-ray and y-ray experiments (4-5) covers about 10% of the moon's surface. Although these measurements revealed the existence of a high Th component (equated with a KREEP component) primarily in the region of the Imbrium basin and Oceanus Procellarum (5), it was not clear from these data as to the regional distribution of this component across the highlands. The Apollo Soil Survey (6) did detect low-K Fra Mauro basalt compositions at all sites as soil glasses, and breccia components of this composition have been identified at the Apollo 15, 16, and 17 sites as well as the Luna 20 landing site. Additional questions persist, however, regarding the depth distribution of the KREEP component within the crust (7).

We present in this paper an evaluation of telescopic spectral reflectance measurements obtained in previously unsampled areas surrounding the Imbrium basin and in the Southern Highlands using a new technique developed by Charette and Adams (8). This method yields the FeO content of bulk soils, which is a useful parameter in differentiating between anorthosites, anorthositic gabbros and Fra Mauro basalts. We then relate the observed rock-type distribution to a possible pre-Imbrium crustal stratigraphy.

Observational Data. Lunar soils consist of mineral and lithic fragments and, with maturity, of glass that typically welds these particles into agglutinates. The reflectance spectrum of an immature soil is dominated by absorption bands at approximately 0.9-1.0μm and 1.9-2.2μm due to Fe$^{2+}$ crystal-field transitions in pyroxenes (9-10). A mature, agglutinate-rich soil, on the other hand, has a spectrum dominated by the broad Fe$^{2+}$ glass bands near 1.1μm and 2.0μm. The minima positions of the glass bands remain constant in wavelength, but the intensity of the bands does increase linearly with increasing concentration of iron (11).

Charette and Adams (8) have calculated the band depth of the 1μm absorption feature in mature, glass-rich lunar soils and have developed determinative curves for FeO versus band depth for both highland and mare soils based on Bell et al.'s (11) work. To quantitatively determine the band depth of the 1μm feature, metallic iron continua were fitted to laboratory spectra (12) and a Gaussian was fitted to the residual absorption feature. The value of the Gaussian's maximum was taken as the depth of the 1μm composite band for the mature bulk soils. Telescopic data in mature highland regions, the maturity being ascertained by standard spectral reflectance techniques (13-14), were...
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acquired near 0° phase angle in order to minimize the phase effects (15). Band depths were calculated from these spectra and the resultant FeO contents for nine unvisited highland regions were established (Table I).

Geochemical Significance. The data obtained for the FeO abundances are sufficiently precise to enable useful geochemical information to be extracted. The work of the Apollo Soil Survey (6), for example, indicates that high FeO contents (9-11%) are indicative of a substantial Fra Mauro basalt component within a given highland soil. The further significance of the FeO data may be assessed from Figure 1, which shows the correlation between FeO and La for highland breccia samples (data sources from previous Proceedings). Similar correlations would hold for the other elements typical of the KREEP component. Thus Figure 1 shows, in effect, the correlation between the KREEP component and FeO content. Anorthositic samples are low in both FeO and REE, and there is a steady increase in both components until the maximum concentration occurs for both in the Fra Mauro basalts.

Observational Data Interpretation. The telescopic spectral reflectance data show that medium/high-K Fra Mauro basalt compositions dominate the soils in the vicinity of the Imbrium basin at the observed localities, which is consistent with the orbital γ-ray data (5). We infer from the work of Gault et al. (16) that such compositions exist in the deepest region excavated by Imbrium (>40-50km; 17), a conclusion which supports the predictions of Taylor and Jakes (1). It is also noted that the FeO data for Copernicus is similar to analyses of red-brown ropy glasses from the Apollo 12 landing site (FeO=10.6 ±1.7, 28 analyses, (18); FeO=11.6 ±1.4, 41 analyses, (19)). This provides the first direct evidence that these glasses are indeed attributable to a Copernicus ray crossing the landing site.

The other sites ("Moltke Highlands South" and Piccolomini) are far removed from the Imbrium basin and are close to Mare Nectaris. Although these areas may have regoliths dominated by Imbrium ejecta (20), other evidence suggest a substantial Nectaris ejecta component in these areas (21-22). Based upon the FeO content and Figure 1, these surfaces in these regions appear to have compositions equivalent to low-K Fra Mauro basalt, which may have intruded into the anorthosite layer in the vicinity of Nectaris and then been excavated by this relatively shallow event.

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TABLE I

<table>
<thead>
<tr>
<th>Area</th>
<th>Location</th>
<th>FeO (wt%) of Bulk Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Archimedes 3</td>
<td>28°05'N, 4°35'W</td>
<td>10.5 ± 0.3</td>
</tr>
<tr>
<td>Archimedes 4</td>
<td>24°30'N, 3°30'W</td>
<td>10.6 ± 0.3</td>
</tr>
<tr>
<td>Copernicus floor</td>
<td>-</td>
<td>10.6 ± 0.5</td>
</tr>
<tr>
<td>Eratosthenes floor</td>
<td>-</td>
<td>10.3 ± 0.5</td>
</tr>
<tr>
<td>Fra Mauro 8</td>
<td>1°15'S, 17°08'W</td>
<td>10.1 ± 0.3</td>
</tr>
<tr>
<td>Fra Mauro 14</td>
<td>3°55'S, 17°40'W</td>
<td>10.5 ± 0.3</td>
</tr>
<tr>
<td>Plato rim</td>
<td>49°50'N, 7°15'W</td>
<td>10.8 ± 0.3</td>
</tr>
<tr>
<td>Moltke Highlands South</td>
<td>1°55'N, 24°05'E</td>
<td>9.2 ± 0.3</td>
</tr>
<tr>
<td>Piccolommini 1</td>
<td>28°50'S, 30°40'E</td>
<td>8.9 ± 0.3</td>
</tr>
</tbody>
</table>

FIGURE 1

FeO vs La
Highland Breccias

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