spectrum (usually near 0.73 and 1.6 μm); the ratio of the spectrum/continuum allows the superimposed features to be studied separately.

Each crater and soil in Figure 5 was chosen to be from the same geologic region to represent freshly exposed material and mature soil from the Apollo 16 area, the Apollo 14 area, and central Mare Serenitatis. The Apollo 16 spectrum of mature soil was measured in the laboratory by J. B. Adams; the spectrum has been smoothed and sampled at the same wavelengths as the other spectra obtained with an earth-based telescope. The Apollo 16 mature soil is an essential part of calibration for the telescopic spectra (see the appendix).

The spectra of Figure 5 demonstrate some of the common systematics observed for lunar reflectance spectra (both laboratory and telescopic): (1) Absorption bands are stronger for rocks and fresh craters than for mature soils. (2) Mature soils generally exhibit a steeper continuum than rocks or fresh material exposed by craters. (3) Although the continuum slope and band strengths are different for soils and their nearby craters, the band centers (and shape) are essentially the same for the two areas from the same geologic unit, since it is the same bulk mineralogy contributing absorption features. (4) The nature of a pyroxene absorption band near 1 μm is distinctly different for the mare than for the highland areas. The band center near 0.90–0.93 μm for these two highland examples (Apollo 14 and 16) is indicative of low-Ca orthopyroxenes as the dominant mafic component, while the band center near 0.98 μm for the mare in Serenitatis is indicative of the high-Ca clinopyroxene mineralogy of the basalts. (The slightly longer band center for Apollo 14 in relation to Apollo 16 indicates an additional clinopyroxene component in typical Apollo 14 material.) (5) The highland spectra exhibit a change of continuum slope between 1.40 and 1.60 μm. (A less steep slope should be used for analysis of the long-wavelength pyroxene band; this was not done in Figure 5). This change of slope is associated with the feldspathic nature of highland material (see sections 4 and 5 concerning rock type A). On the other hand, the inherently steeper continuum slope around the 1-μm as well as the 2-μm pyroxene absorption bands of the mare regions appears to be associated with the large abundance of high-Ca clinopyroxenes in the basaltic mare.

For both the highlands and the maria the greatest spectral contrast occurs for spectra of freshly exposed surfaces. Since mature lunar soils are dominated by the dark agglutinitic alteration products, the absorption bands of soils are substantially weaker and thus more difficult to accurately measure. Although distinct differences in band strength and band center can be noted between the soil spectra of Apollo 14 and Apollo 16, these characteristics (which are controlled by differences in mineralogy) are more reliably measured and compared from the crater spectra. With data derived from earth-based instruments the most readily detectable mineralogical information applicable to the study of crustal composition thus comes from areas where rocks or rock powders are exposed or abundant. Examples include fresh craters, since they are areas where mature soils have not had time to develop [McCord et al., 1972b; Pieters, 1977], and mountains or massifs, since they also have not accumulated mature soils because of their steep topography. The remaining sections of this review will concentrate on the analysis of such telescopic data accumulated over the last several years.

An important cautionary note concerning the difference of scale between laboratory and telescopic measurements was made by Adams and Charette [1975] and should be carefully considered when comparing the remote measurements with laboratory materials. The remote measurements are derived from at least a few kilometers of surface area, integrating the properties of all components into one measurement. The laboratory measurements concentrate on a single lithology or chip on the centimeter scale. The only way the two can be comparable is if one lithology strongly dominates the region measured by the remote observations and the physical form of material for the two measurements is similar. There has been no problem comparing laboratory and telescope lunar soil spectra, since the soil formation process is itself a homogenization process. The returned samples of soil are representative of large regions observed remotely. The multicomponent breccias from the highlands, such as 60019 shown in Figure 2, present additional complexities, since it is not only difficult to describe the bulk mineralogy of the whole rock, but it is equally difficult to obtain a representative spectrum of the sample. The use of laboratory spectra of highland rock types as ground truth for the spectra of fresh highland craters will require a more systematic measurement of highland rock type end-member components, an estimation of the effects of physical properties for surface materials, and the development of appropriate mixing models to be used with remote reflectance measurements. The importance of such detailed studies has been recognized over the last several years, and specific topics are being pursued by research groups involved in geological applications of spectral reflectance measurements.

4. NEAR-INFRARED SPECTRA OF EXPOSED CRUSTAL MATERIAL

Discussion of near-infrared spectra for craters and mountains of the lunar highland crust is divided into two parts. This section includes a summary of the data available, a description of the spectral characteristics of distinct highland near-surface rock types, and the mineralogical interpretation of these observed rock types. The following section contains a discussion of the implications of these data and an analysis of the vertical and lateral distribution of crustal rock types represented by these data.

The areas examined in this survey, grouped according to compositional properties (see below), are listed in Tables 1 and 2 and include small fresh craters in the highlands, steeply sloped highland mountains or massifs, and central peaks and walls of large craters. Many of these areas have been discussed in earlier publications (references in section 3). All areas have a higher albedo than surrounding material and are thus inferred to contain immature soils and/or freshly exposed rocks and lithic fragments. The largest class of immature surfaces studied are fresh craters 5 to 15 km in diameter (indicated as "cr" in the seventh column of Table 1). Since the telescopic measurements cover an area 4–10 km in diameter, usually only the rim of craters 15 to 40 km in diameter was measured (indicated as "rm"). Mountains or massifs are a separate class of surfaces and are indicated as "mt" in Table 1. The central peaks of large craters expose material from a deeper stratigraphic layer than do the small craters and mountains (see below) and are thus analyzed separately (Table 2). Interior walls associated with these large craters (which could be a mix of upper and lower stratigraphic units) are indicated as "w" in Table 1.

Near-surface rock types identified from these telescopic spectra are discussed using some of the same mineralogical descriptions as those used for the returned lunar samples (section 2), although the proportion of mineral constituents are currently only roughly constrained. Identification of specific