after crustal formation (plutonic intrusions and late stage accretion), or (3) subsequent to crustal formation (big basin global redistribution of surface material). Alternatively, (4) the data discussed here may be grossly incomplete (probably) and unrepresentative (possibly) of the lunar crust, or (5) further laboratory and theoretical analysis of lunar materials and (mega)regolith formation may be able to show that what is observed here are noritic breccias can in fact be made from the anorthosites, gabbros, and troctolites if the are battered and put together in the right manner. The biggest difficulty is the observed pyroxene compositions: there does not appear to be sufficient low-Ca pyroxene in lower crustal stratigraphy to account for that observed in breccias on the surface. All of these hypotheses probably play a partial role in accounting for the observations (except perhaps late stage accretion, which would be inconsistent with the ages of the known suite of lunar samples). Which hypothesis is the dominant explanation for the difference between the upper megaregolith and the rest of the lunar crust has yet to be determined and will certainly require more complete global geochemical data.

6. SUMMARY AND CONCLUSIONS

Remotely sensed spectral reflectance data used to infer the mineralogical composition of the near-side lunar highland crust have been synthesized and discussed in the previous sections. New compositional information is derived that supplements and expands the knowledge obtained from returned lunar samples. A few highlights are worth reiterating.

1. Characteristic absorption features for spatially extensive surface compositions can be identified in spectra for both soils and freshly exposed material. The most readily detected minerals include orthopyroxene (lo-Ca), clinopyroxene (hi-Ca), olivines, plagioclase, and Fe-bearing glass. The strength of absorption bands, an essential measurement for mineral abundance estimates, is most prominent for freshly exposed material. For mature soils the strength of absorption features is greatly reduced because of the presence of absorbing agglutinates created during regolith formation.

2. For unsampled areas of exposed immature crustal material, largely craters, the average mineral compositions observed are generally comparable to rock types that can be identified in the lunar sample collections. A variety of noritic, gabbroic, anorthositic, and troctolitic compositions, some of which are only found as minor fragments in the lunar sample collection, are all found as distinct near-surface rock types occurring as compositional units that are spatially at least as extensive as the scale of the observations (5–15 km).

3. The mineral assemblages observed for three quarters of the areas studied that sample the upper 1–2 km of the near-side lunar highland crust (the megaregolith) are noritic in composition, the major mafic mineral being low-Ca pyroxene. Three subgroups are identified that are distinguished from each other by pyroxene abundance or characteristics that are commonly dependent on physical properties (such as degree of brecciation, amount and type of matrix, and effective particle size). All three noritic subgroups are intermixed spatially across the near-side highland crust.

4. The composition observed for the noritic upper few kilometers of crust (megaregolith) is distinctly different from the stratigraphically deeper (5–10 km) crustal material. Less than a quarter of the areas measured that sample deep-seated material are noritic in composition. The dominant mineral assemblages of these deeper, less disrupted, and perhaps more pristine, crustal materials are (listed in decreasing number of areas observed) gabbroic, anorthosite, noritic, and troctolitic compositions.

5. Noritic compositions occur across the entire lunar near-side crust with no apparent clustering associated with any of the major basins. The spatial distribution of gabbroic compositions, however, exhibits a concentration in the western hemisphere.

6. If the statistics of these studies are not misleading, the noritic megaregolith cannot have been derived directly from the average lunar crustal rock types found at 5–10 km depth.

7. The lunar near-side crust is thus both laterally and vertically distinctly heterogeneous in composition. Although the composition of the uppermost portion of the highland crust, the megaregolith, is dominated by one mineralogical rock type, the lunar crust is not well mixed below 1–2 km in spite of the extensive impact record.

As new information for the lunar crust has become available, lunar scientists have relearned a familiar truth concerning exploration of the unknown: the complexity of answers to a geological, geochemical, or geophysical question is dependent on the amount of information about the subject. The simple magma ocean models originally proposed for the origin and composition of the lunar crust are clearly inadequate to describe the diversity of lunar materials observed across the lunar near side. The more complex models invoking layered plutons within an anorthositic crust [e.g., *James*, 1980; *Warren and Wasson*, 1980] are probably more realistic. To be consistent with the mineralogical information discussed above, the scale of the plutons would have to be at least several kilometers, and an origin for the plutons that accounts for the range of compositions observed would need to be developed. Similarly, the relation of the megaregolith to the complex underlying crust and the early impact record needs to be clarified. Resolution of these unknown relationships are dependent on a global assessment of lunar materials. They underline some of the fundamental unanswered questions about the formation and early evolution of the moon. As the moon is explored in more detail over the next decade by spacecraft with sophisticated sensors, a more complete and thorough understanding of earth's nearest neighbor will emerge. When the unknown becomes familiar and commonplace, the current questions will have been answered or found to be unimportant and will certainly be replaced by new questions that may then be directed more toward utilization than exploration.

APPENDIX: DATA ACQUISITION TECHNIQUES

An ongoing data acquisition program has been underway for the last several years to obtain near-infrared reflectance spectra from 0.65 to 2.5 μm for small (3 to 10 km diameter) areas on the lunar surface. About 350 independent reflectance spectra have been acquired and processed for about 210 areas (some areas were measured on different nights or different lunations). All data were acquired using telescopes at Mauna Kea Observatory (MKO) on Hawaii, which is located at an elevation of almost 14,000 feet (4200 m). This is one of the few earth-based observatories that provides two essential conditions for this type of data: (1) sufficiently low atmospheric absorption, especially in near-infrared water bands, to allow an adequate signal for a continuous spectral measurement to 2.5 μm (see, for example, *McCord and Clark* [1979]) and (2) good to excellent "seeing" (a term in astronomy used to describe the general turbulence of the earth's atmosphere that limits the clarity and resolution of an image).

Most of the lunar reflectance data were taken with the Uni-