COMPOSITIONAL STRATIGRAPHY OF THE LUNAR HIGHLAND CRUST Carle M. Pieters, Dept. Geological Sciences, Brown University, Providence, RI 02912

The global properties of the Moon are still a mystery. This is particularly true concerning the composition of the crust - in both horizontal and vertical dimensions. Nevertheless, fundamental questions about the early evolution of the Moon depend of an accurate assessment of both the bulk composition as well as the abundance and spatial distribution of evolved materials. In order to propose answers to such first order questions, lunar scientists have had to extrapolate using the detailed compositional data on samples collected from only a few localized geologic terrains and on limited low resolution geochemical data (10-20% of the surface) obtained from orbit during Apollo 15 and 16. To discuss the origin and evolution of the Moon necessarily requires the assumption that the Apollo and Luna sample and orbital data provide sufficient and representative information to model the extensive unexplored regions. This is a potential fatal flaw in our understanding of the Moon.

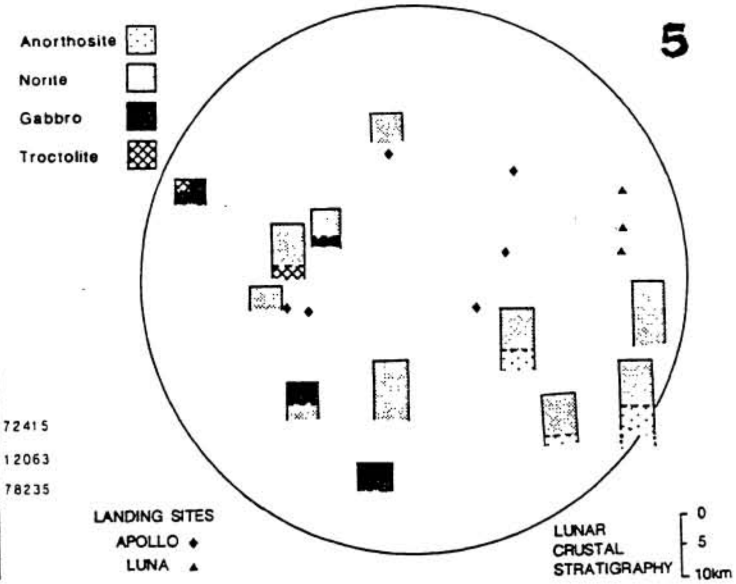
Analyses of "pristine" lunar sample fragments have blossomed during the last decade and have presented the first serious challenge to the early concept of a singular global differentiation event responsible for highland crustal stratigraphy (1,2,3,4). Although spatial information about the source region of these valuable samples has been lost during the subsequent impact record (that also brought them to the sampling site), the growing geochemical statistics argue strongly for extensive plutonic activity (of varying compositions) throughout crustal formation. The Moon, of course, is no longer pristine. The highland surface, even if sampled extensively, consists of materials brecciated and mixed to some degree by more than 4 billion years of impact activity of all scales (5).

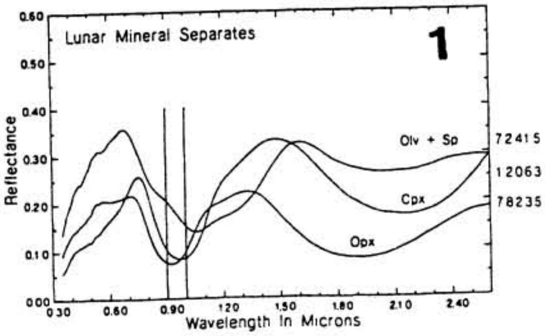
The spectral reflectance data summarized here are meant to remind lunar scientists that the Apollo and Luna data <u>are</u> very biased and should never be assumed to be representative. [In a more positive tone, we are now exceptionally well prepared to return to the job twenty years after Apollo.] The basic mineralogy of lunar material is relatively simple with most lunar rock types composed of different proportions of anhydrous plagioclase, low-Ca pyroxene, high-Ca pyroxene, olivine, and FeTi opaques. The radiogenic and the rare earth elements are additional important discriminants as well as unusual (?) species of other minerals concentrated and/or separated during differentiation events. In spite of the fact that most highland samples are breccias, the primary mineralogy can be determined using near-infrared spectral reflectance measurements (6,7,8). Reflectance spectra of lunar mineral, rock, and soil samples are shown in Figures 1 and 2. Diagnostic spectral features of mafic minerals near 1µm dominate the spectral character of lunar materials. Although significantly subdued, the weak absorption bands observed for mature lunar soils also exhibit features diagnostic of their bulk mineralogy.

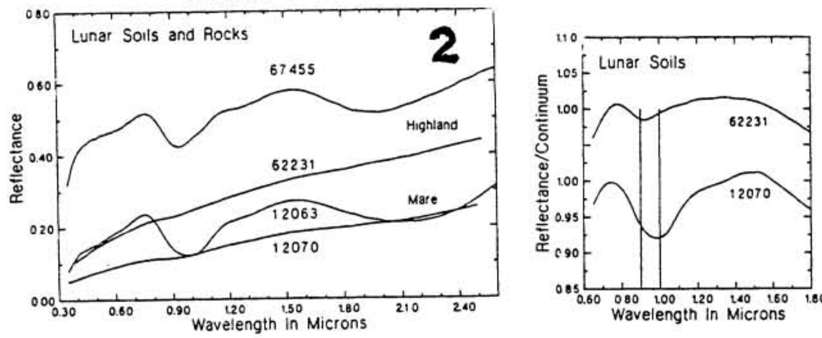
Examples of near-infrared spectra of material exposed by large impact craters 50 -120 km in diameter are shown in Figures 3 and 4. The ejecta and central peaks of such craters probe the stratigraphy of the crust to depths near 15 km (eg. 7). The strength and nature of diagnostic features evident in these spectra demonstrate the compositional diversity of such deep-seated materials: the central peak of Petavius is a mountain of anorthosite (< 5% mafics); that of Arzachel is noritic anorthosite (plagioclase + minor lo-Ca pyroxene); of Copernicus is troctolite (ol + plag); of Tycho is gabbro (high-Ca pyroxene + plag); of Bullialdus is norite (plag + lo-Ca pyroxene). The spatial distribution of material excavated by such large craters provides information about the compositional diversity of the crust with depth. Several craters have been studied extensively: Aristarchus (9), Copernicus (10), Tycho (11), and more recently Bullialdus and Langrenus. The mafic mineral composition of crustal stratigraphy tapped by all near-side craters measured to date is summarized in Figure 5 and the accompanying table (band strength is related to mafic mineral abundance (eg. 8). At Bullialdus an unusual three unit stratigraphy has been recognized for the first time from a concentric pattern of two distinct gabbroic components exposed throughout the rim and the wall (12).

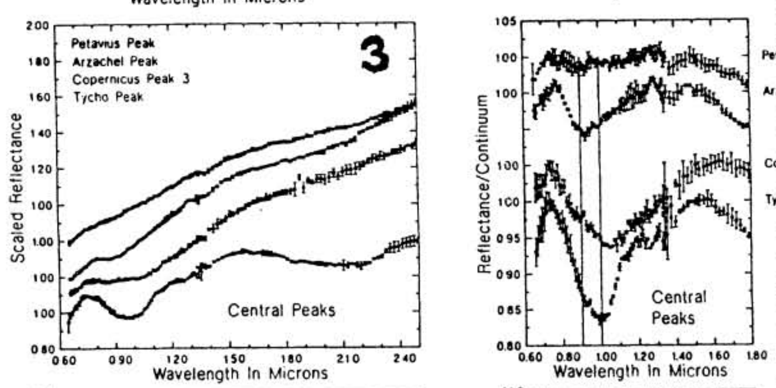
<u>Observations and Conclusions.</u> The range of geochemical data for the *eastern* highland crust (sample analyses as well as remote measurements of elemental and mineral composition) consistently describe the highland crust as very feldspathic with low-Ca pyroxene being the most common mafic mineral. These internally consistent data for the eastern crust are thus normally used as constraints for crustal evolution. The preponderance of gabbroic lithologies in the western hemisphere noted above (7,13), however, is in stark contrast to these traditional observations. Recognition first of the gabbronorite subdivision of pristine samples(14) then of the additional range of pristine compositions sampled at Apollo 14, which clearly distinguish them from the eastern groups (15), add to the growing evidence indicating the evolution of the western nearside crust *must have been distinctly different* from that of the relatively well-studied east. Although we are all still perhaps like the blind men studying the elephant, it is reassuring that the remote observations and sample analyses seem to eventually converge, albeit with increasing complexity. A new era of detailed exploration of the Moon will inevitably provide the planetary science community a wealth of answers, questions, and important surprises about the Earth's nearest neighbor. We may learn that the largest (Procellarum) or the most recent (Orientale) basin forming event (5) dominates lunar evolution well beyond expectations. During the next decade it is anticipated advanced remote sensors will give us the first fully global assessment of this beloved ancient beast and should thus bring lunar science from uncertain adolescence to the first stages of mature activity.

Region	Crust: upper	lower---band strength %	
W Aristarchus	gabbro	gabbro/troctolite	8
I Copernicus	norite	troctolite	12
I Bullialdus	gabbros	norite	17
I Eratosthenes	norite	gabbro	7
I Tycho	gabbro	gabbro	17
I Alphonsus	(norite)	anorthosite	<1
I Arzachel	norite	norite	6
I Aristillus	(norite)	norite	14
I Theophilius	norite	anorthosite	<1
I Piccolomini	(norite)	anorthosite	<1
I Petavius	(norite)	anorthosite	<1
E Langrenus	norite	norite	5









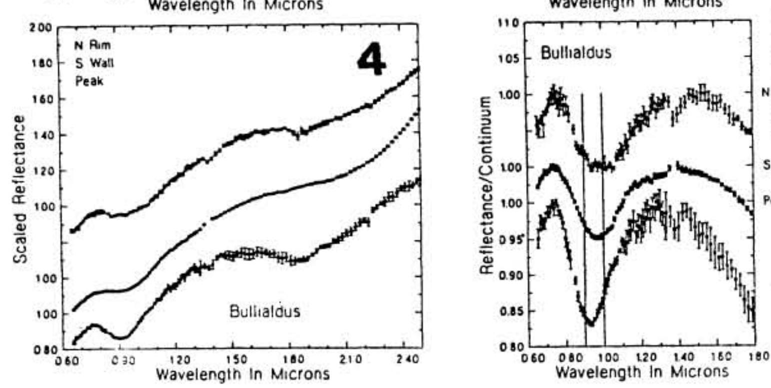


Figure 1. Reflectance spectra of mafic mineral separates. Hi-Ca pyroxenes have band centers at longer wavelengths than Lo-Ca. **Figure 2.** Reflectance spectra of lunar samples. Absorption features indicate the composition of mafic minerals present, even in soils (R). **Figure 3.** Scaled reflectance spectra (telescopic; of central peaks in large impact craters. Diagnostic absorption features are easily identified when the continuum is removed (right). See text for composition of these mountains. **Figure 4.** Representative spectra for areas in Bullialdus (61 km). The central peaks are clearly noritic, but the upper crustal units contain two types of gabbroic material deposited symmetrically around the crater. **Figure 5.** Summary of lunar crustal stratigraphy using large impact craters as probes into the upper 15 km of lunar crust.

Acknol: NAGW-28, NAG9-184.

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