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CRUSTAL HETEROGENEITY OF THE MOON VIEWED FROM THE GALILEO SSI CAMERA: LUNAR SAMPLE CALIBRATIONS AND COMPOSITIONAL IMPLICATIONS.

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The Galileo fly-by of the Earth-Moon system on December 8, 1990 provided an extraordinary opportunity to test an array of sophisticated remote sensing instruments using "ground truth" information (returned samples) about the lunar surface. The synoptic view from the spacecraft also provided an exceptional scientific opportunity to assess the character of unexplored portions of the western limb and farside of the Moon. The SSI multi-spectral camera uses a CCD array detector with a series of seven filters that span the spectral range from 0.4 to 1.0 µm. Several sets of multispectral images of the Moon were obtained over a wide range of viewing and lighting conditions: from over 100° phase angle for the first images of the nearside to 20° phase when viewing the Orientale basin. The variety of mare and highland compositions discerned from these data and their calibration linked with the lunar samples are summarized here. Companion abstracts in these volumes highlight the SSI camera and Earth-Moon encounters, Orientale and South-Pole-Aitken basins, and lunar maria (1, 2, 3).

SUMMARY OF SPECTRAL CALIBRATION. Shown in Figure 1 are bidirectional reflectance spectra of mature soils and rock powders from the Apollo collection. Superimposed are five SSI effective filter bandpasses (two methane filters were not used in this analysis initially). Since the color of the Moon is known to vary with viewing geometry (4), detailed bidirectional reflectance measurements of mature lunar soils were undertaken to provide the calibration data necessary for the specific geometry encountered by Galileo and are discussed elsewhere (see 5). Because the surface calibration site preferred by astronomers was beyond the terminator (Apollo 16), secondary standards were selected on the western nearside that have been well studied using earthbased telescopes (and calibrated to Apollo 16). The chosen sites include several mare and highland areas in and around Mare Humorum and the Surveyor I site (in Flamsteed P) (6). Earth-based spectra of these standard areas were convolved with the effective Galileo filters and calibrated with the bidirectional measurements of Apollo 16 soil obtained at the appropriate geometry. Preliminary calibration procedures to the raw data included standard dark current removal and flatfield correction (initially using preflight data), "dust blemish" removal, and ghost image and scattered light removal (the latter are thought to be due to a dust cover over the aperture of SSI that could not be removed before the encounter).

The spectral properties of the lunar surface measured with SSI filters using pre-flight calibration shows systematic color deviations up to 40% when compared to the "ground truth" spectrum of the surface derived from appropriate bidirectional spectra of lunar samples. This apparent error in absolute color is presumed to be related to the dust cover and will be checked before and after the dust cover is removed later this year. Relative color can be checked independent of absolute color, but is sensitive to the accuracy of the gain and offset corrections mentioned above. Shown in Figure 2a,b is a comparison of telescopic and SSI relative reflectance spectra for four areas on the western nearside. All spectra are relative to the standard area MH0 in Mare Humorum and are scaled to unity at 0.76µm. MH0, Flamsteed and MH203 represent a range of mare compositions, MH40 is typical highland, and MH45 is a fresh mare crater. These SSI relative reflectance spectra are in qualitative agreement with the telescopic spectra and thus confirm that the data are reliable. Precise quantitative analyses await inflight calibration and refinement of the ghost image and scattered light removal techniques.

COMPOSITIONAL PARAMETERS. The spectra in Figures 1 and 2 demonstrate the primary spectral properties of lunar materials in the spectral range covered by the SSI camera. There is a generally smoothly varying continuum from 0.4 to about 0.76 µm and an absorption band between 0.9 and 1.1 µm which is due to a variety of mafic minerals (largely, different types of pyroxenes). Highland soils are relatively red through the visible range and normally exhibit a weaker feature at 1 µm (less mafics) than the mare. The visible continuum slope of mature mare soils varies significantly and is linked to TiO_2 content (e.g. 7). For our initial science analyses we have chosen the 0.40, 0.76 and 1.0 µm filters to evaluate spatial variations across the Moon: the 0.40/0.76 µm ratio is sensitive to variations in continuum slope and the 0.76/1.0 µm ratio provides a good indication of the strength of absorption bands due to the presence of mafic minerals.

SUMMARY OF NEARSIDE COLOR. Familiar color variations on the lunar nearside (7,8) are apparent in the SSI multispectral images providing additional confidence in data quality. Most feldspathic highlands are relatively red (low 0.40/0.76 µm) with only minor mafic components (low 0.76/1.0 µm). The basaltic mare are distinguished by a stronger mafic mineral signature (higher 0.76/1.0 µm) and the great variety of high and low-Ti basalts in Oceanus Procellarum are readily recognized (through variations in 0.40/0.76 µm). Fresh craters are easily distinguished from mature soils: mare craters exhibit a much stronger mafic mineral absorption (very high 0.76/1.0 µm) and highland craters exhibit a flat continuum (very blue, or high 0.40/0.76 µm) with a variably weak mafic mineral absorption. There are several intriguing exceptions for familiar areas. For example, southwest of Humorum in the highlands surrounding Schickard is a large region several hundred kilometers in extent that exhibits a distinctly enhanced mafic signature (high 0.76/1.0 µm) suggestive of a regionally extensive mare component in the soils (2).

SUMMARY OF LIMB AND FARSIDE COLOR. Most distinctions between mare and highlands are also evident on the farside and the general spectral properties of broad regions of the northern highlands indicate a predominance of feldspathic soil approximately comparable to that returned by Apollo 16. The basalts of Orientale are heterogeneous, with the eastern basalts perhaps being more Ti-rich (slightly higher 0.40/0.76 µm) (see discussion in 3). Strong spectral variations are associated with immature highland surfaces, many of which are relatively blue (low mafic) highland craters and their ray systems (several of which are notably asymmetric). On a more spectrally subtle scale, the limb and farside soils appear very heterogeneous. There are distinct 0.40/0.76 µm variations of a few percent that define areally extensive units and imply variations in iron (or glass) content. One of the largest and "reddest" regions is the interior of the South Pole-Aitken basin (see discussion in 2).

Perhaps most interesting are large and small farside areas that are enriched with mafic minerals. The largest region is in the southern portion of South Pole-Aitken basin and appears to extend eastward, a tantalizing suggestion that the basin excavated compositions of the lower crust/upper mantle or cryptomare. Furthermore, while many highland craters exhibit classic feldspathic characteristics (bright blue, low mafic), several distinctive craters are also identified as mafic-rich from their enhanced 0.76/1.0 µm [Lowell, Wright, Guthilick].

OVERVIEW. The farside of the Moon has held its secrets well since initial Zond and Apollo exploration. This large area of lunar crust is dominated by heavily cratered terrain and basin deposits that represent the products of the first half billion years of crustal evolution. Continuing analysis of the returned lunar samples suggest a "magma ocean" and/or "serial magmatism" model for evolution of the primordial lunar crust (e.g. 9). Testing either hypothesis, however, requires compositional information about crustal stratigraphy and lateral heterogeneity, and resolution of this important planetary science issue is dependent on additional data. These new Galileo multispectral images indicate previously unknown local and regional compositional diversity of the farside crust. Future analyses will focus on individual features and a more detailed assessment of crustal stratigraphy and heterogeneity.

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Figure 1

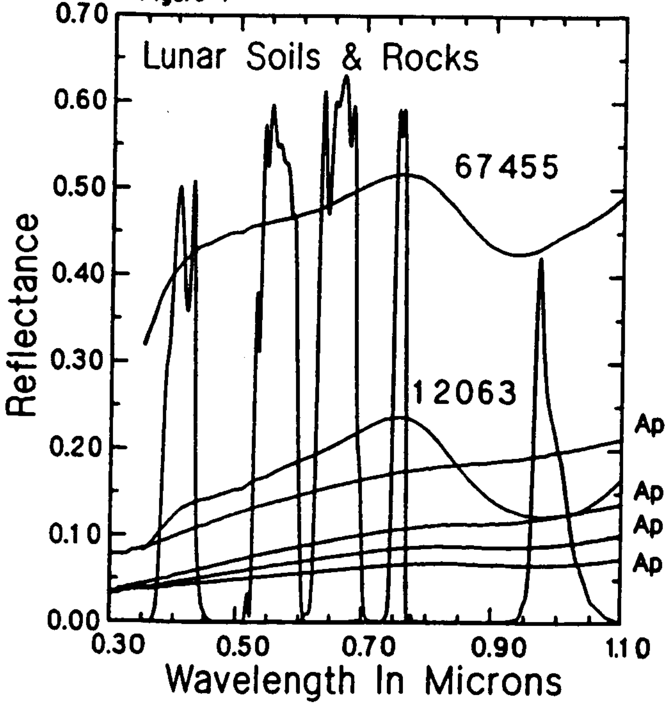

Figure 2a

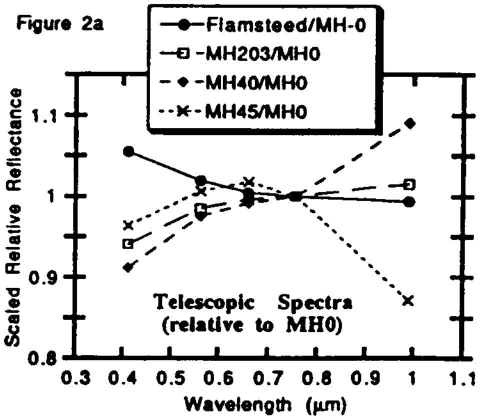

Figure 2b