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GALILEO SSI LUNAR OBSERVATIONS: COPERNICAN CRATERS AND SOILS;
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The Galileo spacecraft completed its first Earth-Moon flyby (EM1) in December 1990 [1] and its second flyby (EM2) in December 1992. Copernican-age craters are among the most prominent features seen in the SSI (Solid-State Imaging) multispectral images of the Moon. The interiors, rays, and continuous ejecta deposits of these youngest craters stand out as the brightest features in images of albedo and visible/1-micron color ratios (except where impact melts are abundant). Crater colors and albedos (away from impact melts) are correlated with their geologic emplacement ages as determined from counts of superposed craters [2-4]; these age-color relations can be used to estimate the emplacement age (time since impact event) for many Copernican-age craters on the near and far sides of the Moon.

Unlike Earth, where erosion and other processes obscure the impact record, the Moon exhibits a complete record of the impact flux over the Earth-Moon region during the past few billion years. Deciphering that record (or just its most recent portion) could resolve current controversies over the magnitude and the periodicity or episodicity of the asteroid and comet flux in the neighborhood of Earth and its effects on the evolution of life and on mass extinctions. In principle, this deciphering could be done through remote sensing combined with radiometric dates for key units, such as impact melts of large Copernican craters with extensive ray systems.

Understanding the stratigraphy of crater deposits is essential for determining the geologic history of the Moon. Preferably, geologic ages are assigned from direct stratigraphic observations, such as superposition of a unit on the rays of Copernicus (or vice versa), but for post-Imbrian units this is possible only over a small percentage of the Moon's surface. The next-best method (in the absence of radiometric dates) is use of the size-frequency counts of superposed craters, but sufficiently high-resolution images are not yet available for much of the Moon, especially on the farside. Thus, the presence or prominence of rays and ejecta deposits, as well as crater morphology, have been the key factors for distinguishing between the Copernican and Eratosthenian time-stratigraphic systems. However, ray visibility depends not only on age, but also on crater size (and ejecta volume), compositional differences between ejecta and substrate, and phase angle. Furthermore, crater morphology can be difficult to interpret, especially where images are poor, and Neukum and Konig [3] have documented a tendency for photogeologists to assign younger relative ages to the larger craters than are indicated by crater counts.

The spectral reflectivities of lunar soils are controlled primarily by (1) soil maturity, resulting from the soil's cumulative age of exposure to the space environment; (2) steady-state horizontal and vertical mixing of fresh crystalline materials [e.g., ref. 5]; and (3) the mineralogy of the underlying bedrock or megaregolith. Improved understanding of items (1) and (2) above will improve our ability to interpret item (3), especially for the use of crater compositions as probes of crustal stratigraphy [6]. We have examined the multispectral and superposed crater frequencies of large isolated craters, mostly of Eratosthenian and Copernican ages, to avoid complications due to (i) secondaries (as they affect superposed crater counts) and (ii) spatially and temporally nonuniform regolith mixing from younger, large, and nearby impacts. Crater counts are available for 11 mare craters and 9 highlands craters within the region of the Moon imaged during EM1. The EM2 coverage provides multispectral data for 10 additional craters with superposed crater counts. Also, the EM2 data provide improved spatial resolution and signal-to-noise ratios [7] over the western nearside.

Correlations between log N (cumulative crater frequency per km^2 reduced to diameter = 1 km) and both the 0.56/0.99 micron color ratios and 0.56-micron normal albedos of the crater materials are clearly significant for craters younger than Copernicus. These results are used to estimate the emplacement ages of many other nearside and farside Copernican craters and to map their distributions. The apparent deficiency of Copernican craters on the farside compared with those on the nearside on published geologic maps is not present in our Copernican-unit map, confirming the suspicion that this apparent deficiency was due to a paucity of low-phase images of the farside. Our Copernican-unit map provides the first age estimates for hundreds of craters in the diameter range of 1 to 10 km.

The linear trends between N and the 0.56/0.99 micron ratio differ between the maria and the highlands and between the interiors and the continuous ejecta of the craters. Similar trends are established for color and albedo versus soil-maturity indices for the returned lunar samples, again with distinct trends for mare and highlands soils. However, the mare versus highland offsets are reversed in the two comparisons: any particular 0.56/0.99 micron ratio value corresponds to a smaller N (younger emplacement age) but to a larger maturity index (older exposure age) for highland relative to mare trends. These trend offsets may be explained by variations in regolith thicknesses, which influences the rates of mixing with relatively fresh ejecta [5,7]. The maria have thinner regoliths than do most highland areas, so mare soils undergo a higher rate of mixing with fresh ejecta from nearby impacts. A similar explanation may apply to the different trends seen in continuous ejecta blankets and in crater interiors: the interiors undergo a higher rate of mixing with fresh ejecta due to (i) greater near-surface abundances of blocky or massive crystalline rock in the crater interior and in the blocky ejecta concentrated near the crater rim, and (ii) relatively steep slopes on crater walls and central peaks, where regoliths are kept thin by downslope mass movements and preferential downslope movement of ejecta from impacts that are small relative to the slope [8]. Therefore, soil maturity parameters, which are related to a soil's cumulative exposure age, correspond to a range of emplacement ages for the underlying geologic unit, depending on the geology of the surrounding area. Understanding these relations will allow us to make better use of multispectral imaging for relative age dating and reconstruction of the geologic history of the Moon.

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