REMOTE SENSING STUDIES OF COPERNICUS RAYS: IMPLICATIONS FOR THE COPERNICAN-ERATOSTHENIAN BOUNDARY.

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Introduction: The nature and origin of lunar rays have long been the subjects of major controversies. We have been investigating the origin of lunar crater rays in support of the new Lunar Geologic Mapping Program. In an effort to better understand the processes responsible for the formation of lunar rays, we have utilized a variety of remote sensing data to study selected rays. Clementine UV-VIS images were used to produce high-resolution FeO, TiO_2, and optical maturity (OMAT) maps for the various rays utilizing the methods presented by Lucey et al. [1, 2]. Near-IR spectra and 3.8- and 70-cm radar maps were also utilized [3, 4]. Our preliminary finding resulted in a model for lunar ray formation [5, 6]. It was found that lunar rays are bright because of compositional contrast with the surrounding terrain, the presence of immature debris, or some combination of the two. The purpose of this report is to present the results of studies of Copernicus rays and to assess the implications for the calibration of the lunar stratigraphic column.

The Origin of Copernicus Rays in Mare Imbrium: Copernicus is a large bright-rayed crater, 93 km in diameter, located at 9.5º N, 20.0º W on the lunar nearside, and has long been used as a stratigraphic marker for lunar geology [7, 8, 9]. Continuous ejecta deposits occur up to a crater diameter away from the rim crest of Copernicus, while the ray system extends radially for more than 500 km [9]. We have investigated the Copernicus rays that extend north across the surface of Mare Imbrium with particular emphasis on four major rays. Two of these rays (Rays 1 and 2) extend north of Copernicus, and two (Rays 3 and 4) extend to the northeast. The albedo of the rays varies from moderate to high, and all exhibit numerous secondary craters which range in diameter from 200 m to 7.0 km. Many of the secondaries occur in chains on clusters that exhibit characteristic V structures or herringbone patterns. It has been demonstrated that herringbone patterns are formed by the interference of ejected materials during the near-simultaneous impact of secondary-forming projectiles [9, 10]. In the secondary crater clusters, the downrange members of the clusters are commonly mantled by ejecta or debris surges generated by the uprange secondaries.

The rays north of Copernicus (Rays 1 and 2) exhibit moderate to strong returns in the 3.8-cm depolarized radar image mosaic. The highest values are associated with secondary crater clusters. These areas have greater abundances of 1- to 40-cm-sized fragments in the upper 0.5 m of the regolith. Portions of Rays 1 and 2 exhibit slightly enhanced backscatter in the depolarized 70-cm radar image. The strongest enhancements are associated with secondary crater clusters. These enhancements have an excess of meter-sized blocks within 5-10 m of the surface.

The Copernicus rays in Mare Imbrium exhibit lower FeO and TiO_2 values than do the adjacent mare deposits. The background mare flows have FeO values that range between 17 and 19 wt.% and TiO_2 concentrations that range between 4 and 6 wt.%. The rays north of Copernicus have FeO abundances that vary from 12 to 16 wt.% and TiO_2 values that range from 2 to 4 wt.%. The FeO and TiO_2 concentrations generally show a positive correlation with the albedo values exhibited by the ray surfaces. FeO abundances generally decrease along a given ray as a function of distance from Copernicus. The measured FeO value (8.0 wt.%) for the Copernicus ejecta blanket can be used to calculate the amount of highland-rich primary ejecta in the rays north of Copernicus. The calculated abundances of primary ejecta range from 20% to 60%.

The optical maturity (OMAT) images of the Copernicus rays indicate that relatively high OMAT values are associated with secondary crater chains and clusters. The highest values are exhibited by steep slopes on the crater interiors. Apparently, downslope movement on the interior crater walls constantly adds fresh material to the regolith. Ray surfaces away from the interiors of secondary craters display much lower OMAT values. These OMAT values are slightly higher than those exhibited by fully mature background mare surfaces near the rays. The rays of Copernicus in Mare Imbrium have not reached full optical maturity.

Several faint rays from the crater Eratosthenes were identified in Mare Imbrium. These rays exhibit lower FeO and TiO_2 values than do the adjacent mare units and are fully mature.

In summary, the Copernicus rays in Mare Imbrium display relatively low FeO and TiO_2 values because of the presence of variable amounts of highland-rich primary ejecta. The rays exhibit relatively low OMAT values except for areas with secondary crater clusters. Still, the rays are not fully mature. The Copernicus rays are bright largely due to contrast in albedo between the ray material containing highland-rich primary ejecta and the adjacent dark mare surfaces. Only in the vicinity of secondary crater clusters and chains does the presence of immature, high-albedo material make a significant contribution to the brightness of the rays.

Implications for the Copernican-Eratosthenian Boundary: The working distinction between the Eratosthenian (E) and Copernican (C) Systems is that Copernican craters have visible rays whereas Eratosthenian-aged craters do not [7, 11, 12]. Since compositional rays can persist for 3 Ga or more, the mere presence of bright rays is not a reliable indicator that a crater was formed during the C Period [6, 9, 13, 14, 15]. It is clear that a new method is required to distinguish C from E-aged craters. It has been suggested that the OMAT parameter be used to define the C-E boundary [6, 14, 15]. With increasing age, the OMAT values for ejecta and rays decrease and eventually become indistinguishable from the background value, which is the optical maturity index saturation point [2, 15]. The time required for a fresh surface to reach the optical maturity index saturation point could be defined as the Copernican Period. Surfaces that have reached full optical maturity would then be of Eratosthenian (or greater) age. Grier and co-workers [14, 15] noted that if the ejecta of Copernicus were slightly more mature, it would be indistinguishable from the background in an OMAT image. Our results for the Copernicus rays in Mare Imbrium are consistent with these findings. Hence, the saturation of the optical maturity index may occur at about 0.8 Ga which is the commonly accepted age of Copernicus [16, 17, 18].

A Reevaluation of Lunar Crater Ages: Because of the new definition of the C-E boundary, we have investigated the rays associated with a number of lunar craters. Our purposes were to determine the compositions and maturity states of the rays and to assess the ages of the parent craters in light of the new criteria.

Aristillus and Autolycus are located NW of the Apollo 15 site. Both have been mapped as Copernican craters based on the presence of rays [8, 12]. The high-albedo rays of Aristillus and Autolycus contain highland material and are bright because of compositional contrast with the surrounding mare terrain. The rays and ejecta of both craters have reached full optical maturity. Hence, Aristillus and Autolycus are older than Copernicus and should be mapped as Eratosthenian-aged craters.

Taruntius, O'Day, and Eudoxus have been mapped as Copernican-aged craters [8, 12]. Our results indicate that the rays associated with these craters are compositional rays. They are optically mature and appear bright only because they contain highland debris. These craters are older than Copernicus and should be mapped as Eratosthenian-aged craters.

Taruntius H and P are located SE of Taruntius. Since these small craters lack well-defined rays, they are mapped as Eratosthenian craters [19]. The OMAT image of these craters shows that their ejecta deposits are immature. They are younger than Copernicus and should be assigned a Copernican age.

Pytheas has been mapped as a Copernican-aged crater [8, 12]. Some portions of the Pytheas ejecta deposit exhibit low OMAT values and appear to be fully mature. Other portions of the ejecta blanket have higher OMAT values. The cause of this difference is the subject of a continuing investigation.

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