THE COMPOSITION AND ORIGIN OF LUNAR CRATER RAYS: IMPLICATIONS FOR THE COPERNICAN-ERATOSTHENIAN BOUNDARY. B.R. Hawke[1], L.R. Gaddis[2], D.T. Blewett[3], J.M. Boyce[1], B.A. Campbell[4], T.A. Giguere[5], J.J. Gillis-Davis[1], P.G. Lucey[1], C.A. Peterson[1], M.S. Robinson[6], and G.A. Smith[1], [1]Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI 96822, [2]U.S. Geological Survey, Astrogeology Program, 2255 N. Gemini Drive, Flagstaff, AZ 86001, [3]NovaSol, 733 Bishop Street, Honolulu, HI 96813, [4]Center for Earth and Planetary Studies, National Air and Space Museum, Washington, D.C. 20560, [5]Intergraph Corporation, P.O. Box 75330, Kapolei, HI 96707, [6]Center for Planetary Sciences, Northwestern University, Evanston, IL 60208.

Introduction: Lunar rays are filamentous high-albedo features that are radial or subradial to impact craters. 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]. In addition, near-IR spectra and 3.8- and 70-cm radar maps were utilized.

The Origin of Selected Lunar Rays:

Messier Crater Complex. Messier (14 km in long dimension) and Messier A (dia.=11 km) are located near 2° S, 47° E in Mare Fecunditatis. Major rays extend north and south from Messier and west from Messier A. Near-IR spectra as well as 3.8-cm radar, FeO, TiO_2, and optical maturity maps indicate that the rays south and west of the Messier complex are dominated by fresh mare material [3]. These rays are prime examples of "immaturity" rays. They are bright because they contain immature basaltic debris. Highlands material is not present in these rays.

Tycho Ray in Mare Nectaris. A major ray from Tycho crater crosses much of Mare Nectaris. We focused our attention on that portion of the ray that extends ~40 km NE of Rosse crater and includes a Tycho secondary crater cluster. Analyses of near-IR spectra, FeO, TiO_2, and OMAT images and a variety of radar data indicate the Tycho ray is dominated by fresh mare material excavated and emplaced by secondary craters [3, 4]. While some highlands material is undoubtedly present in the ray, the major factor that produces the brightness of the ray is the immature mare basalt.

Tycho Ray in Southern Highlands. We also investigated a continuation of the Tycho ray discussed above in the highlands SW of Mare Nectaris. This ray has the same range of FeO values (5.5-7.0 wt.%) as that exhibited by the adjacent highlands terrain. The OMAT map shows that the brighter portions of this ray segment are composed of immature material. The high albedo of this ray is totally due to the immaturity of the highlands debris.

Lichtenberg Crater Rays. The FeO map produced for the Lichtenberg region indicates that the ejecta and rays N and NW of the crater exhibit relatively low FeO abundances. These deposits are dominated by low-FeO highlands debris. The OMAT image demonstrates that these highlands-rich deposits are fully mature. Hence, the Lichtenberg rays exhibit a relatively high albedo because of their composition.

Olbers A Ray. This Copernican-aged impact crater (dia.=43 km) is located in the highlands on the Moon's western limb and exhibits an extensive ray system in Oceanus Procellarum. A number of ray segments are distinct in the OMAT image and are enriched in immature material relative to adjacent terrain. Reduced FeO and TiO_2 values are also associated with these segments. Therefore, both composition and immaturity are important in producing the brightness of these ray segments [3]. These ray segments are good examples of "combination" rays.

In summary, 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.

Implications for the Calibration of the Lunar Stratigraphic Column:

It has long been thought that craters that exhibit rays were formed more recently than 1.1 Ga [e.g., 5]. However, it has now been demonstrated that the rayed crater Lichtenberg is older than 1.68 Ga, perhaps far older [6]. In addition, McEwen *et al*. [7] used counts of craters superposed on large rayed-crater ejecta to determine that Hausen and Pythagoras have ~3.0 Ga or greater ages. The working distinction between the Eratosthenian and Copernican Systems is that Copernican craters larger than a few kilometers in diameter still have visible rays whereas Eratosthenian-aged craters do not [5, 8, 9]. 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 Copernican Period [e.g., 3, 7, 10, 11, 12]. It is clear that a new method is required to distinguish Copernican from Eratosthenian craters. Several workers [3, 11, 12] have suggested that the OMAT parameter be used to define the C-E boundary. The optical maturity values for fresh crater ejecta decrease with age [2]. With increasing age, the OMAT values for ejecta and rays becomes indistinguishable from the background

value, which is the optical maturity index saturation point [2, 12]. 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. The time required for a surface to reach full optical maturity has not been firmly established. However, Grier and co-workers [11, 12] noted that if the ejecta of Copernicus was slightly more mature it would be indistinguishable from the background in an OMAT image. Hence, the saturation of the optical maturity index may occur at about 0.8 Ga which is the commonly accepted age of Copernicus [13, 14, 15].

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 (dia.=55 km) and Autolycus (dia.=39 km) are located NW of the Apollo 15 site in the Imbrium basin. Both have been mapped as Copernican craters based on the presence of rays [5, 16]. The high-albedo rays of Aristillus and Autolycus contain highlands 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 [12, 17]. Hence, Aristillus and Autolycus are older than Copernicus and should be mapped as Eratosthenian-aged craters. Support for an Eratosthenian age for these craters was presented by Ryder *et al*. [9]. They indicated that Aristillus and Autolycus have absolute ages of 1.3 and 2.1 Ga, respectively, based on the results of radiometric dating of Apollo 15 samples. These ages are greater than the age of Copernicus (0.8 Ga).

Taruntius (dia.=56 km) is located at 5.6° N, 46.5° E on the east side of the Moon. Previous workers have mapped Taruntius as a Copernican-aged crater [5, 16]. The high-albedo rays which surround Taruntius are compositional rays. They are optically mature and appear bright only because they contain relatively large amounts of highland debris. Taruntius is older than Copernicus and should be mapped as an Eratosthenian-aged crater. It has beeen suggested that the localized pyroclastic deposits on the interior of Taruntius were very young because of the Copernican age of the host crater. However, it now appears that these pyroclastic deposits are Eratosthenian.

Taruntius H (dia.=8 km) and Taruntius P (dia.=7 km) are located SE of Taruntius in Mare Fecunditatis. Since these craters lack well-defined rays, they are mapped as Eratosthenian craters [18]. The OMAT image of these craters clearly shows that their ejecta deposits are immature. They are younger than Copernicus and should be assigned a Copernican age.

O'Day (dia.=71 km) is located at 30.6° S, 157.5° E on the lunar farside. Previous studies had mapped O'Day as a Copernican crater [5]. However, the ejecta blanket and rays of O'Day are fully mature [12] and the rays in Mare Inginii contain a highlands component. O'Day should be mapped as an Eratosthenian-aged crater.

Finally, Eudoxus (dia.=67 km) is located at 44.3° N, 16.3° E on nearside of the Moon. Several workers have mapped Eudoxus as a Copernican-aged impact structure [5, 16]. Our results demonstrate that Eudoxus exhibits compositional rays. Since both the ejecta and rays of Eudoxus are fully mature [12], this crater should be assigned an Eratosthenian age.

Summary and Conclusions:

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 Copernican Period. The OMAT parameter could be used to define the C-E boundary. The time required for a fresh surface to reach the optical maturity index saturation point could be defined as the Copernican Period. A reevaluation of the ages of Aristillus, Autolycus, Taruntius, O'Day, and Eudoxus indicated that these craters should be assigned an Eratosthenian age.

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