DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION AND THE
USAF AERONAUTICAL CHART AND INFORMATION CENTER

GEOLOGIC ATLAS OF THE MOON
COPERNICUS QUADRANGLE
I-515 (LAC-58)

## NOTES ON BASE

The lunar base chart was prepared by the Aeronautical Chart and Information Center, St. Louis, Missouri, with advisory assistance from Dr. Gerard P. Kuiper and his collaborators, D. W. G. Arthur and E. A. Whitaker.

### CONTROL

The position of features on the base chart was determined through the use of selenographic control established primarily from the measures of I. Franz and S. A. Saunder as published by E. A. Whitaker and E. A. Whitaker in the Orthographic Atlas of the Moon, edited by Dr. Gerard P. Kuiper, 1960.

### VERTICAL DATUM

Vertical datum is based on an assumed spherical figure of the Moon and a lunar radius of 1738 km. The datum plane was subsequently adjusted to 2.6 km below the mean radius of 1738 km. This datum is close to the surface of lunar surface of minus elevation value. Gradients of major surface undulations were established by interpolating Schrutka-Rechtenstamm computations of I. Franz's measurements of 150 lunar craters. The probable error of the computed gradients is of the order of about 1000 meters. Vertical datum, as established, is considered interim and will be refined as soon as a more accurate figure of the Moon is determined.

### ELEVATIONS

All elevations are shown in meters. The relative heights of crater rims and other prominences above the mario surface were established principally by the shadow-measuring technique as refined by the Department of Astronomy, University of Manchester, under the direction of Professor Zdenek Kopal. Relative heights, thus established, have been referenced to the assumed vertical datum by means of the control listed in the section on surface undulations. The probable error of the localized relative heights is 100 meters. Inherent with the measuring technique used, relative height determinations in general in mountains are more accurate than in the N-S direction.

| | |
|---|---|
| Height of central peak | 1200 |
| Depth of crater (rim of crater) | 4400 |
| Relative elevations (referenced to surrounding terrain) with direction and extent of slope measured | 3308 |

### CONTOURS

All contours are approximate.
Contour interval is 300 meters.
Intermediate contour ..... or 100 meters .....
Depression contour .....

### NAMES

The feature names were adopted from the 1935 International Astronomical Union nomenclature system as amended by Commission 17 in 1961.

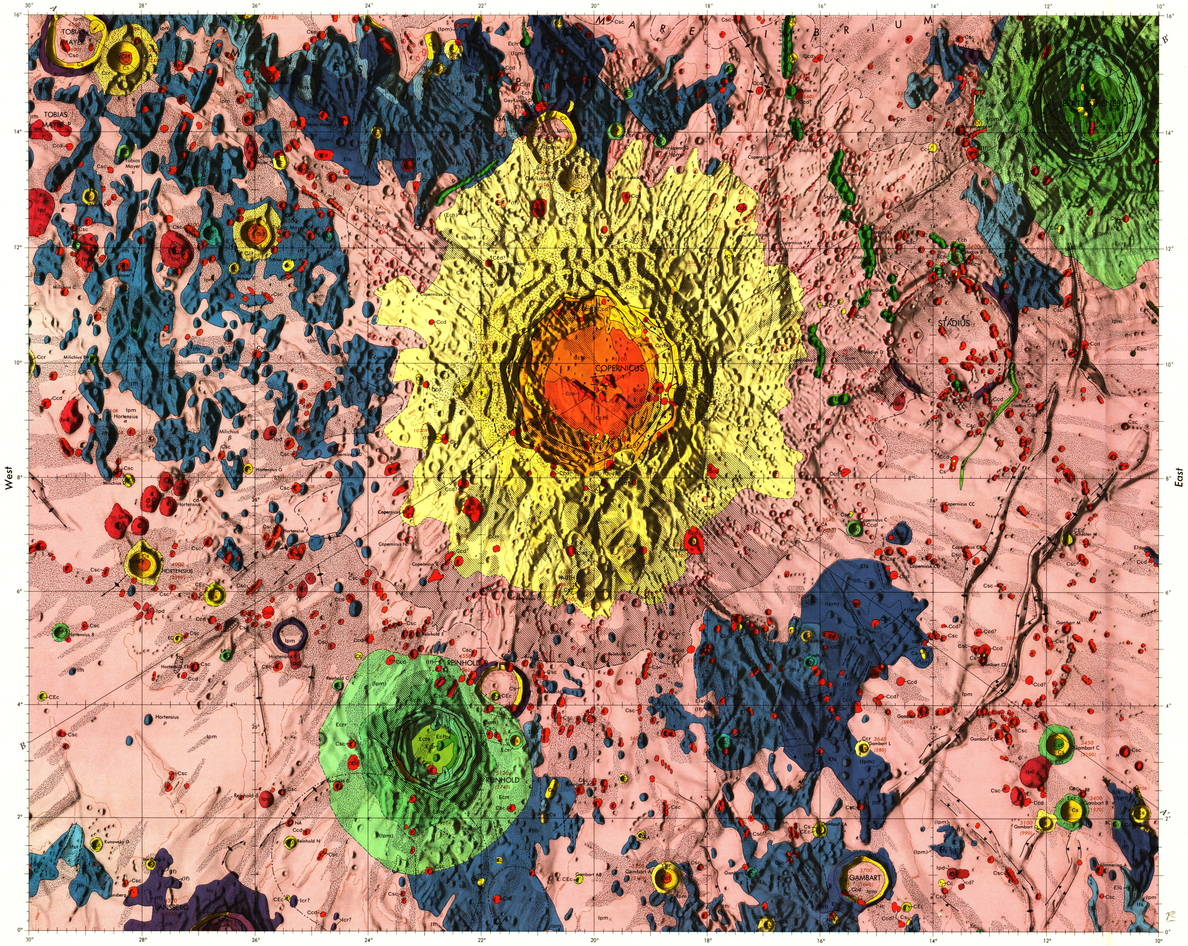
Supplementary lettered features have been added in accordance with the system suggested by Bridget and Muller. Craters are designated by capital letters. Eminences are identified by Greek letters.

### RELIEF PRESENTATION

The configuration of the relief features shown on the base chart was interpreted from photographs taken at Lick, McDonald, Mt. Wilson, Yerkes, and Pic du Midi Observatories and published in the 1960 edition of the USAF Lunar Atlas and from unpublished photographs from the Lick Observatory 36 inch refractor and the 40 inch reflector and Department of Astronomy, University of Manchester. Visual observations made with the 24 in. Lowell refracting telescope at Flagstaff, Arizona, were also used in certain details. The pictorial pattern and relief forms was developed using an assumed light source from the west with the angle of illumination maintained equal to the angle of slope of the features portrayed. Cast shadows were discriminated to preclude complete interpretation of relief forms.

### EAST-WEST DIRECTION

Orientation of cardinal directions is in accordance with resolution adopted by the IAU General Assembly, 1961.

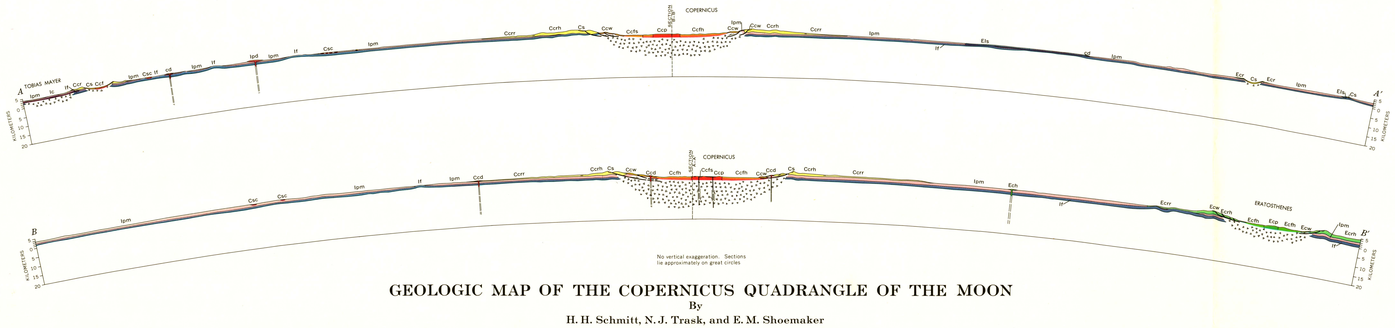



Lunar base chart LAC 58, 2d edition, 1964, by the USAF Aeronautical Chart and Information Center, St. Louis, Missouri 63118

SCALE 1:1 000 000 AT 11°00'45"
MERCATOR PROJECTION

STATUTE MILES 0 50 100
KILOMETERS 0 50 100 150

Sources of geologic information: Published and unpublished photographs from the Lick, Mt. Wilson, and U.S. Naval (Flagstaff, Arizona) Observatories; and visual observations with the 30 inch reflector, U.S.G.S. Observatory, Flagstaff, Arizona (Schmitt and Shoemaker) and with the 36 inch refractor, Lick Observatory (Shoemaker and Trask)




No vertical exaggeration. Sections lie approximately on great circles

# GEOLOGIC MAP OF THE COPERNICUS QUADRANGLE OF THE MOON

By
H. H. Schmitt, N. J. Trask, and E. M. Shoemaker

1967

## EXPLANATION

**Cs** — Slope material

Characteristics
*Normal albedo 0.12–0.17, mean 0.14. Occurs mostly on the interior walls of craters where it is brighter than the material of the exterior rim. Details of topography not discernible. Many exposures show fine-scale terracing into rotes during eclipse (Shorthill and Swann, 1966)*
Interpretation
*Freshly exposed bedrock and freshly generated talus. Isolated patches on small hummocks or in dark halo craters may be sublimate*

**Ccd** — Dark-halo crater material

Characteristics
*Material in and around small craters that has lower albedo than the surroundings. All exposures small. Superposed on rays or rim material of Copernicus. Topography appears smooth. Normal albedo mostly 0.10–0.11 but ranges to 0.14 in craters on the wall and floor of Copernicus*
Interpretation
*Pyroclastic materials in and around volcanic craters. Some may be ejecta from impact craters that have penetrated a layer with albedo lower than that of the surface material*

**Cc** — Crater material, undivided

Characteristics
*Sharp-rimmed rayed craters too small to permit identification of individual crater units*
Interpretation
*Material of impact craters*

**Ccr Ccm1 Ccr2 Ccw Ccf Ccfs Ccfh Cco** — Material of rayed craters

Characteristics
*Ccw, wall material. Hummocky topography locally crossed by narrow benches roughly concentric to rim of Copernicus. Normal albedo 0.11–0.16; material with a normal albedo <0.13 shown by ruled pattern*
*Ccf, rim, terraced, radial. Discontinuous ridges and valleys with albedo higher than rim-crest region. Ridges and valleys commonly 100–200 meters high. Normal albedo 0.108–0.124; material with normal albedo >0.118 shown by dashed pattern; material with albedo <0.114 shown by ruled pattern; material shown by a ruled pattern has a high density of dark halo craters*
*Ccm, rim material, radial. Surface of moderate local relief with low ridges subradial to Copernicus; has few satellitic craters. Normal albedo 0.103–0.124; dashed and ruled patterns have same meaning as for hummocky rim material. This unit consists of radial ridges that are continuous around the rim of Copernicus. A third facies of the rim surrounds radial rim material and consists of discontinuous radial ridges, seen best under low illuminations, interspersed with satellitic craters and with albedo slightly lower than that of radial rim material. Outer limit of third facies marked by special contact symbol. Underlying geology shown where third facies occurs because this facies is patchy*
*Ccr, floor material, undivided. Smooth-appearing material on the floors of rayed craters. Normal albedo 0.14–0.16. In Copernicus, divided into*
*Ccr1, floor material, smooth. Smooth-appearing material on level to gently rolling northwest floor of Copernicus. Normal albedo 0.13–0.16; ruled pattern has some meaning as for wall material (Ccw)*
*Ccr2, floor material, hummocky. Surface of low irregular hummocks. Normal albedo 0.14–0.16; ruled pattern has some meaning as for wall material (Ccw)*
*Cco, peak material. Forms high ground within Copernicus. Normal albedo 0.17*
Interpretation
*Ccw, shattered talus and slumped rim materials*
*Ccr, ejecta from craters probably of impact origin*
*Ccr1, ejecta from Copernicus and from a subsequent size, probably with abundant large blocks. May include thrust slices of underlying bedrock*
*Ccr2, impact-produced ejecta, finer-grained than Ccr1. Unit grades outward to third facies with abundant satellitic craters*
*Third facies is mixture of ejecta from Copernicus and from secondary impact craters formed by fragments ejected from Copernicus*
*Radial streaks of relatively high and relatively low albedo in ray material may reflect differences in texture of material deposited, for example, Fra Mauro Group or Fra Mauro Formation. Some areas of relatively low albedo may consist of a later covering of volcanic ash. Rim material probably consists of rays*
*Ccf, areas too small to interpret*
*Ccfs, either a smoothed and eroded part of an impact-produced breccia lens or a later volcanic cover; development may have been localized by presence of buried and pulverized Fra Mauro Formation in contrast to more cohesive Procellarum Group*
*Ccfh, top, top of block-covered terraces*
*Cco, lens of intensely brecciated bedrock uplifted just subsequent to impact*

**Cs** — Crater material

*Small rayless craters not in contact with rays of Copernicus. Stratigraphic position indeterminate*

**Ec** — Crater material, undivided

*Small rayless craters overlapped by rays of Copernicus*

**Ecr Ecrh Ecrr Ecw Ecf Ecfh Ecfm Eco** — Material of rayless craters

Characteristics
*Topography of units similar to that of Ec but with lower albedo. Normal albedo 0.097–0.11, rarely, observed by rays of Copernicus; ruled pattern indicates areas that have normal albedo <0.108 and fewer rays from Copernicus than the immediate surroundings*
Interpretation
*Units of impact craters similar in origin to material of rayed craters. Areas shown by ruled pattern are probably ejecta Procellarum Group materials that have been strongly darkened by solar proton bombardment*

**Ech** — Crater material

*Similar to Eratosthenian crater material but stratigraphic position indeterminate*

**Es** — Sulpician Gallus Formation

Characteristics
*Normal albedo 0.075–0.096. Topography varies from smooth and flat to gently rolling; positive relief elements consist of low domes and irregular hillocks similar to the hillocks of the Fra Mauro Formation but with lower slopes. Unit has a high density of dark halo craters*
Interpretation
*Volcanic materials. Variable thickness of pyroclastic materials erupted from vents mostly below the identifying resolution of available photographs. Some of the surface flows on the flanks of domes. Irregular hillocks may reflect subjacent topography*

**Ecd** — Satellitic crater material

Characteristics
*Small (<2 km diameter) relatively shallow craters occurring in clusters near the outer limit of Copernicus and in the ray system and not large enough to show rim elements. Difficult to distinguish from small Ec in the area between Copernicus and Eratosthenes*
Interpretation
*Craters formed by impact of fragments ejected from Eratosthenes*

**Ecm** — Chain crater material

Characteristics
*Small (4 km maximum diameter) craters commonly merging with one another. Distinguished from large Copernican satellitic craters (Csc) by sharper, higher rims and greater depths*
Interpretation
*Volcanic craters aligned along structural lines, mostly fissures, but some elongated volcanoes or flows. Control undetermined. Material is Eratosthenian and therefore older. Relative freshness suggests Erathosthenian age*

**Esr** — Sinuous rille material

Characteristics
*Shallow, narrow, curving depression with crateriike enlargements at one end. Crossed by rays from Copernicus*
Interpretation
*Lava drainage channel, channel eroded by an ash flow, or a curved graben with volcanic craters at one end*

**Csc** — Satellitic crater material

Characteristics
*Small (<4 km maximum diameter) craters occurring in large, lines, and clusters outside the rim material of Copernicus. Craters are especially common on ray elements at the ends closest to Copernicus. Low rims and irregular outlines. Many of the smaller circular craters are a composite of two or more circular craters*
Interpretation
*Craters on rays are secondary impact craters formed by fragments ejected from Copernicus at the time of formation of the crater that formed the satellitic craters within the rim material and for which the rim crest only is shown (Shoemaker, 1962). Interpretation of craters mapped as Csc not on rays is less certain; most are probably secondary impact craters formed by the Copernicus event but some may be older or younger impact or volcanic craters*

**Crr** — Ray material

Characteristics
*Irregular, planose streaks of higher albedo than the surroundings that are radial or subradial to the centers of craters and have no visible relief. Rays of Copernicus cover much of the quadrangle; many individual rays can be traced to the rim crest of the crater of the ends closest to Copernicus. Also includes narrow bands of material with albedo higher than the surroundings around some small craters. Normal albedo mostly 0.10–0.12, 0.12–0.16 in halos and rays on western rim of Copernicus*
Interpretation
*Freshly exposed crushed rock derived in part from primary rayed craters and in part from satellitic craters which occur on the rays. Halos around some very small craters may consist of unresolved small rays*

**Ccd** — Dark-halo crater material

Characteristics
*Material in and around small craters that have lower albedo than the surroundings. All exposures small. Superposed on rays or rim material of Copernicus. Topography appears smooth. Normal albedo mostly 0.10–0.11 in craters on the wall and floor of Copernicus*
Interpretation
*Pyroclastic materials in and around volcanic craters. Some may be ejecta from impact craters that have penetrated a layer with albedo lower than that of the surface material*

**Cc** — Crater material, undivided

Characteristics
*Sharp-rimmed rayed craters too small to permit identification of individual crater units*
Interpretation
*Material of impact craters*

**Ccr Ccm1 Ccr2 Ccw Ccf Ccfs Ccfh Cco** — Material of rayed craters

Characteristics
*Ccw, wall material. Hummocky topography locally crossed by narrow benches roughly concentric to rim of Copernicus. Normal albedo 0.11–0.16; material with a normal albedo <0.13 shown by ruled pattern*
*Ccf, rim, terraced, radial. Discontinuous ridges and valleys with albedo higher than rim-crest region. Ridges and valleys commonly 100–200 meters high. Normal albedo 0.108–0.124; material with normal albedo >0.118 shown by dashed pattern; material with albedo <0.114 shown by ruled pattern; material shown by a ruled pattern has a high density of dark halo craters*
*Ccm, rim material, radial. Surface of moderate local relief with low ridges subradial to Copernicus; has few satellitic craters. Normal albedo 0.103–0.124; dashed and ruled patterns have same meaning as for hummocky rim material. This unit consists of radial ridges that are continuous around the rim of Copernicus. A third facies of the rim surrounds radial rim material and consists of discontinuous radial ridges, seen best under low illuminations, interspersed with satellitic craters and with albedo slightly lower than that of radial rim material. Outer limit of third facies marked by special contact symbol. Underlying geology shown where third facies occurs because this facies is patchy*
*Ccr, floor material, undivided. Smooth-appearing material on the floors of rayed craters. Normal albedo 0.14–0.16. In Copernicus, divided into*
*Ccr1, floor material, smooth. Smooth-appearing material on level to gently rolling northwest floor of Copernicus. Normal albedo 0.13–0.16; ruled pattern has some meaning as for wall material (Ccw)*
*Ccr2, floor material, hummocky. Surface of low irregular hummocks. Normal albedo 0.14–0.16; ruled pattern has some meaning as for wall material (Ccw)*
*Cco, peak material. Forms high ground within Copernicus. Normal albedo 0.17*
Interpretation
*Ccw, shattered talus and slumped rim materials*
*Ccr, ejects from craters probably of impact origin*
*Ccr1, ejecta from Copernicus and from a subsequent size, probably with abundant large blocks. May include thrust slices of underlying bedrock*
*Ccr2, impact-produced ejecta, finer-grained than Ccm. Unit grades outward to third facies with abundant satellitic craters*
*Third facies is mixture of ejecta from Copernicus and from secondary impact craters formed by fragments ejected from Copernicus*
*Radial streaks of relatively high and relatively low albedo in ray material may reflect differences in texture of material deposited, for example, Procellarum Group or Fra Mauro Formation. Some areas of relatively low albedo may consist of a later covering of volcanic ash. Rim material probably consists of rays*
*Ccf, areas too small to interpret*
*Ccfs, either a smoothed and eroded part of an impact-produced breccia lens or a later volcanic cover; development may have been localized by presence of buried and pulverized Fra Mauro Formation in contrast to more cohesive Procellarum Group*
*Ccfh, top, top of block-covered terraces*
*Cco, lens of intensely brecciated bedrock uplifted just subsequent to impact*

**Ipm** — Procellarum Group

Characteristics
*Ipm, mare material. Normal albedo 0.098–0.102 where not covered by rays. Surface generally smooth but has local relief of as much as 10 m. Ipd, mare dome. Normal albedo same as surrounding Ipm. Forms smooth circular to elliptical domes as much as 11 km across and from 100 to 300 meters high. Many domes have summit craters*
Interpretation
*Ipm, volcanic materials; pyroclastic materials, flows and ash*
*Ipd, low shield volcanos or the surface expression of shallow intrusives*

**If Ifh Ifs** — Fra Mauro Formation

Characteristics
*If, Fra Mauro Formation, undifferentiated. Shown on cross sections and where covered*
*Ifh, hummocky member. Hummocks ranging from 1 to 3 km in diameter on broadly level to gently rolling topography; terrain crossed by narrow troughs and swarps trending NNW and NNE (Imbrian sculpture). Normal albedo 0.10–0.12*
*Ifs, smooth member. Relatively large (70 km maximum dimension) hills, ridges and plateaus; smooth appearing to slightly hummocky in detail. Ridges alongside NW and NNE-trending troughs typical of the Imbrian sculpture system. Normal albedo 0.10–0.12*
Interpretation
*Ifh, ejecta from the Imbrian basin, probably generated by impact; hummocks are mounds of ejecta*
*Ifs, ejecta from the Imbrian basin resting on uplifted blocks of pre-impact materials; hummocks absent because of downslope movement of debris*
*The topography of the formation may be largely the product of structural movement at the time of formation of the Imbrian basin and consist of uplifted and downdropped blocks of pre-basin materials covered with a veneer of debris*

**Ipm** — Mare ridge

*Line marks crest. Arrows mark tapered end. Interpretation: Anticline or site of igneous intrusion*

**Ipm** — Mare scarp

*Line marks foot of scarp. Barb points downslope. Dotted where concealed. Interpretation: Fault or flow front*

**Ipm** — Trough

*Lines mark center line. Barbs point downslope. Interpretation: Center of buried graben*

**Ipm** — Landslide (slump) block

*Arrows show direction of movement. Interpretation: Large blocks which have slumped inward on the walls of craters but appear to have remained mostly intact*

Concealed crater rim
*Symbol marks crest*

Rimless crater or depression
*Occurs on summits of mare domes. Interpretation: Caldera*

Irregular depression
*Interpretation: Collapse depression*

Breccia lens
*Shown on cross sections beneath crater floors. Interpretation: Impact-produced breccia lens*

**Cse** — Crater material

*Small rayless craters not in contact with rays of Copernicus. Stratigraphic position indeterminate*

**Csc** — Satellitic crater material

Characteristics
*Small (<4 km maximum diameter) craters occurring in large, lines, and clusters outside the rim material of Copernicus. Craters are especially common on ray elements at the ends closest to Copernicus. Low rims and irregular outlines. Many of the smaller circular craters are a composite of two or more circular craters*
Interpretation
*Craters on rays are secondary impact craters formed by fragments ejected from Copernicus at the time of formation of the crater that formed the satellitic craters within the rim material and for which the rim crest only is shown (Shoemaker, 1962). Interpretation of craters mapped as Csc not on rays is less certain; most are probably secondary impact craters formed by the Copernicus event but some may be older or younger impact or volcanic craters*

**Crr** — Ray material

Characteristics
*Irregular, planose streaks of higher albedo than the surroundings that are radial or subradial to the centers of craters and have no visible relief. Rays of Copernicus cover much of the quadrangle; many individual rays can be traced to the rim crest of the crater of the ends closest to Copernicus. Also includes narrow bands of material with albedo higher than the surroundings around some small craters. Normal albedo mostly 0.10–0.12, 0.12–0.16 in halos and rays on western rim of Copernicus*
Interpretation
*Freshly exposed crushed rock derived in part from primary rayed craters and in part from satellitic craters which occur on the rays. Halos around some very small craters may consist of unresolved small rays*

## INTRODUCTION

The surface of the Moon is heterogeneous both on a regional and a fine scale. The geologic mapping of this surface is similar in principle to the geologic mapping of the Earth's surface and depends on the discrimination of similarities and differences between materials and features at different points on the surface. Materials and features that are similar in appearance and that are similar in their physical properties as albedo indicate that the areas are underlain by materials of different nature and have formed under different processes. The units shown on the map are analogous to stratigraphic units adopted for mapping terrestrial geology in that they are bodies of rock with a limited range of properties and age and are of relatively simple geometric form. It is inferred that the material of the individual rock units mapped has formed under a limited set of conditions. The relative age of each unit is determined where they overlie one another. For example, the rays around Copernicus overlap the craters Eratosthenes and Reinhold and the rim materials of Copernicus, Eratosthenes, and Reinhold overlap the smooth materials of the maria.

The relative age of each unit determines its position in the stratigraphic column that has been worked out for the region around Mare Imbrium and that is based on events that affected much of the surface of the Moon (Shoemaker and Hackman, 1962). The major divisions of the stratigraphic column are called systems; each system corresponds to a period of time whose salient events in the area around Mare Imbrium are listed in the table below, the most recent at the top.

| PERIOD | EVENTS |
|---|---|
| *Copernican* | Formation of ray craters |
| *Eratosthenian* | Formation of large craters whose rays are no longer visible |
| *Imbrian* | Deposition of extensive mare material of the Procellarum Group<br>Crater formation<br>Events related to the formation of Imbrium basin |
| *pre-Imbrian time (not yet formally divided)* | Crater formation; formation of other mare basins |

The symbol for each map unit consists of two letters (an abbreviation of its age assignment (capital) and an abbreviation of its name (lower case). The units are described in order of decreasing age under each period. The characteristics and interpretation of each are followed by an interpretation of its origin or composition. The values of normal albedo were derived from microdensitometer measurements of full Moon photographs calibrated with photoelectrically derived albedos of selected points (unpublished data by Pohn and Wilhey, U.S. Geological Survey).

## SUMMARY OF GEOLOGIC HISTORY

The complex topography of the terrae reflects the earliest decipherable history of the quadrangle. Remnants of a ring structure, the Inner Rook ring of the Imbrium basin. The terrae are traversed by scarps, grabens, and ridges, the arrangement of which are oriented north-northeast and north-northwest. These lineament features are part of the system of Imbrian sculpture which is approximately radial to the center of the basin and extends outward from the basin around its entire periphery (Hackman, 1962). The extent and regularity of this system of fractures suggest that the Imbrian basin was formed by a single catastrophic event. The ejecta blanket of the Imbrian basin, the Fra Mauro of the Imbrian sculpture has been mapped as the Fra Mauro Formation. The exposures of the Fra Mauro are continuous with the type locality in the Riphaeus Mountains region directly to the south (Eggleton, 1965). The Fra Mauro Formation occurs in a pattern concentric with the Imbrian basin; in general, the hills diminish in size outward from the edge of the basin and grade outward to a gently rolling topography with low ridges radial to the basin. Two members of the formation are recognized: (1) the hummocky member, consisting of hummocks up to 3 km in diameter, consisting of closely-spaced, relatively steep-sided hummocks and (2) the smooth member, consisting of larger, smooth-appearing ridges, hills, and plateaus without numerous hummocks. The Fra Mauro Formation appears to be an ejecta blanket excavated by an impact that formed the Imbrian basin, although in the Copernicus quadrangle limited exposures of the formation make it difficult to distinguish hills that are part of such a blanket from hills that are uplifted fault blocks of pre-Imbrian material. The ridges, hills, and plateaus of the smooth member have been mapped as expressions of pre-Imbrian topography buried by ejecta.

Between the time of formation of the Imbrian basin and the flooding of the basin by mare material, a number of craters formed in the quadrangle. Lansberg, Stadius, Julius Mayer, Reinhold B, Gambart, and Gay-Lussac are the chief examples of this class (Ic) they are not intersected by Imbrian sculpture and are not buried by the Procellarum Group. The age of the Sulpicius Gallus Formation is uncertain. The narrow, sharp rim crests and lack of subdued crater rim deposits on some of these craters (for example, Gambart and Reinhold B) raise the possibility that they are calderas although similar characteristics might result from isostatic rebound and erosion of impact craters. Lansberg closely resembles Eratosthenes and Copernicus and is probably of impact origin.

Materials of the Procellarum Group (Ipm) make up the widespread flat, dark areas of the Moon. They underlie much upper surface of this unit follows closely the curvature of the Moon, and the material appears to have filled most pre-existing depressions to approximately the same level. The mare material probably consists of a mixture of volcanic lava and ash flows.

Very dark, apparently thin deposits of the Sulpicius Gallus Formation (Es), which overlap both terra and mare material, were first mapped in the Mare Serenitatis region by Carr (1966) and occur in other isolated patches to the east of the Copernicus quadrangle. The formation is mapped in the Copernicus quadrangle on the basis of its similar characteristics and stratigraphic position. In a few places, as in the crater Sulpicius Gallus, the upper surface of the deposits of the formation includes some low domes; elsewhere it is flat or appears to reflect in a smoother form the hummocky topography of the underlying Fra Mauro Formation. Within all areas of exposure of the formation, abundant small dark spots may be observed on recent high-quality full-Moon photographs; some of the dark areas surround small craters and others have no resolvable crater within them. The materials of the Sulpicius Gallus Formation are probably volcanic in origin and may have resulted from a continuation of the activity that gave rise to the mare materials. The formation may be the same age as the Procellarum Group; however, the Sulpicius Gallus may be superposed on and therefore younger than some parts of the Procellarum.

The post-mare craters in the Copernicus region include the large, well-defined craters Copernicus, Eratosthenes, and Reinhold as well as many smaller craters. Of these, Copernicus is the largest and lies at the focus of one of the most prominent ray systems on the near side of the Moon. A profusion of elongate depressions and small craters (maximum diameter 5 km) occurs around the periphery of Copernicus. Many of these are radial to Copernicus and are aligned with rays of the crater. The depressions and small craters are evidently related to Copernicus and are mapped as satellitic craters (Csc). Of special interest are several loops of satellitic craters with the concave side toward the crater. The best example of such a loop is in the southeast quadrant of the map area north of Gambart C. Many of the satellitic craters in this loop lie at the heads of ray elements that are approximately radial to the center of Copernicus. Shoemaker (1962) showed that the satellitic craters are secondary impact craters formed by fragments ejected from Copernicus and in the rays; these gradually diminish in number outward from the crater. The depressions and small craters are evidently related to Copernicus and are mapped as satellitic craters (Csc). Of special interest are several loops of satellitic craters with the concave side toward the crater. The best example of such a loop is in the southeast quadrant of the map area north of Gambart C. Many of the satellitic craters in this loop lie at the heads of ray elements that are approximately radial to the center of Copernicus. Shoemaker (1962) showed that the satellitic craters are secondary impact craters formed by fragments ejected from Copernicus and in the rays; these gradually diminish in number outward from the crater. The depressions and small craters are evidently related to Copernicus and are mapped as satellitic craters (Csc). Of special interest are several loops of satellitic craters with the concave side toward the crater. The best example of such a loop is in the southeast quadrant of the map area north of Gambart C. Many of the satellitic craters in this loop lie at the heads of ray elements that are approximately radial to the center of Copernicus. Shoemaker (1962) showed that the satellitic craters are secondary impact craters formed by fragments ejected along ballistic trajectories from a northeast-southwest trending line about 8 km from a shock epicenter at the center of Copernicus. The fragments were evidently part of a pre-existing elongate structural block that maintained its identity momentarily as it was engulfed by a shock such as would be generated by the impact of a meteorite. There are additional loops of ray elements around Copernicus; some of the ray elements in these loops have resolvable satellitic craters and some do not. The presence of loops of ray elements, some with and some without satellitic craters to the rays constitutes strong evidence that Copernicus is an impact crater, that the satellitic craters are secondary impact craters,and that the rays are formed mostly by ejecta from the primary and secondary craters.

The similarity of the morphology of other large post-mare craters in the Copernicus quadrangle to the morphology of Copernicus strongly suggests that they also formed by impact. Around Copernicus, three facies of the rim material have been mapped: (1) an inner facies consisting of discontinuous radial hummocky ridges, (2) an intermediate radial facies with low ridges approximately radial to the center of the crater, and (3) an outer cratered facies with very low radial ridges and many interspersed, low-rimmed, partly covered satellitic craters. The low ridges of the outer facies extend to as much as 150 km from the rim crest. The outer limit of this facies is shown by a special contact symbol and the underlying geology is shown as though exposed at the surface because of the patchiness of the facies. Albedo of the rim material is generally higher than the surroundings is generally high but has a wide variation. Streaks of material with albedo both higher and lower than the mean albedo of the rim are present and probably reflect differences in the lithology of the rim material.

Superposed on the wall and rim materials and on the rays of Copernicus are many small craters with halos of material that is darker than the surroundings. These dark halo craters are the youngest features in the quadrangle. Many of the craters have formed since the time of the Apollo 11 mission. Similar dark halo craters on the floor of Alphonsus photographed by the Ranger IX mission. Material newly exposed at the surface of the Moon appears to darken gradually with time (Shoemaker, 1962). The dark rim material around Eratosthenes and Reinhold is probably near the final stage of such darkening. Material of the dark halo craters on the rim of Copernicus is very young, however, and its low albedo probably is a consequence of differences in composition between it and the surrounding material.

## LUNAR ORBITER II PHOTOGRAPHS

The striking oblique photographs of the crater Copernicus taken by the Lunar Orbiter II spacecraft (November 23, 1966) show the surface details of several of the units shown on this map. The Sulpicius Gallus Formation, as seen, is foreshortened, from approximately 50 km south of Copernicus to the crater's southern horizon. Especially noteworthy are angular blocks up to 30 meters in diameter at the surface of the hummocky crater rim material, evidence for tilted ledges of bedrock in the material of the central peak, and curving grooves and ridges in the crater wall material that suggest downslope movement of debris. Craters with diameters as small as 30 meters can be seen scattered over the rim material south of the crater.

## REFERENCES

Carr, M. H., 1966, Geologic map of the Mare Serenitatis region of the Moon: U.S. Geol. Survey Map I-489.
Eggleton, R. E., 1965, Geologic map of the Riphaeus Mountains region of the Moon: U.S. Geol. Survey Map I-458.
Hartmann, W. K., 1965, Radial structures surrounding lunar basins, I: The Imbrium System: Univ. Arizona Lunar and Planetary Lab. Commun., v. 2, no. 34, p. 1.
Shoemaker, E. M., 1962, Interpretation of lunar craters, in Kopal, Zdenek, ed, Physics and astronomy of the Moon: London, Academic Press, p. 283–359.
Shoemaker, E. M., and Hackman, R. J., 1962, Stratigraphic basis for a lunar time scale, in Kopal, Zdenek, and Mikhailov, Z. K., eds., The Moon—Symposium 14 of the International Astronomical Union: London, Academic Press, p. 289–300.
Shorthill, R. W., and Saari, J. M., 1966, Recent discovery of hot spots on the lunar surface, in Kopal, Z. N., Mezzal, J. R., and O'Keefe, J. A., eds., The Nature of the Lunar Surface, Proceedings of the 1965 IAU-NASA Symposium: Baltimore, The Johns Hopkins Press, p. 215–228.

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Number above quadrangle name refers to lunar base chart (LAC series); number below refers to published geologic map

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