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
THEOPHILUS QUADRANGLE
I-546 (LAC-78)

NOTES ON BASE

The lunar charts RLC 6 (Hypatia) and LAC 78 (Theophilus) were used as the base north and south of 12°S, respectively. Both charts were prepared by the Aeronautical Chart and Information Center (ACIC), United States Air Force, in consultation with Dr. Gerard P. Kuiper and the staff of the Lunar and Planetary Laboratory, University of Arizona. Elevation data were compiled by the University of Manchester.

CONTROL

The lunar features are positioned to conform with the selenographic latitude and longitude coordinates based on selenocentric measurements made by ACIC and published in ACIC Technical Paper 15, "Coordinates of Lunar Features," March 1965. Supplementary positions are developed in the chart areas as an extension of the primary control.

ELEVATIONS

All elevations are shown in meters. The relative heights of crater rims and other prominences above the maria and depths of craters were determined by the shadow-measuring technique, through correlation with data derived from Ranger VIII and earth-based photography. Vertical heights thus established have not been referenced to a vertical datum.

Depth of crater (rim of floor) .... (400)
Relative elevations (referenced to surrounding terrain) 300

Elevations on cross section are adopted from LAC 78. These are 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 surface described by the 1738-km radius to minimize the extent of lunar surface of minus elevation values.

NAMES

Feature names are adopted from the 1935 International Astronomical Union nomenclature system as amended by Commission 16 of the IAU, 1961 and 1964.

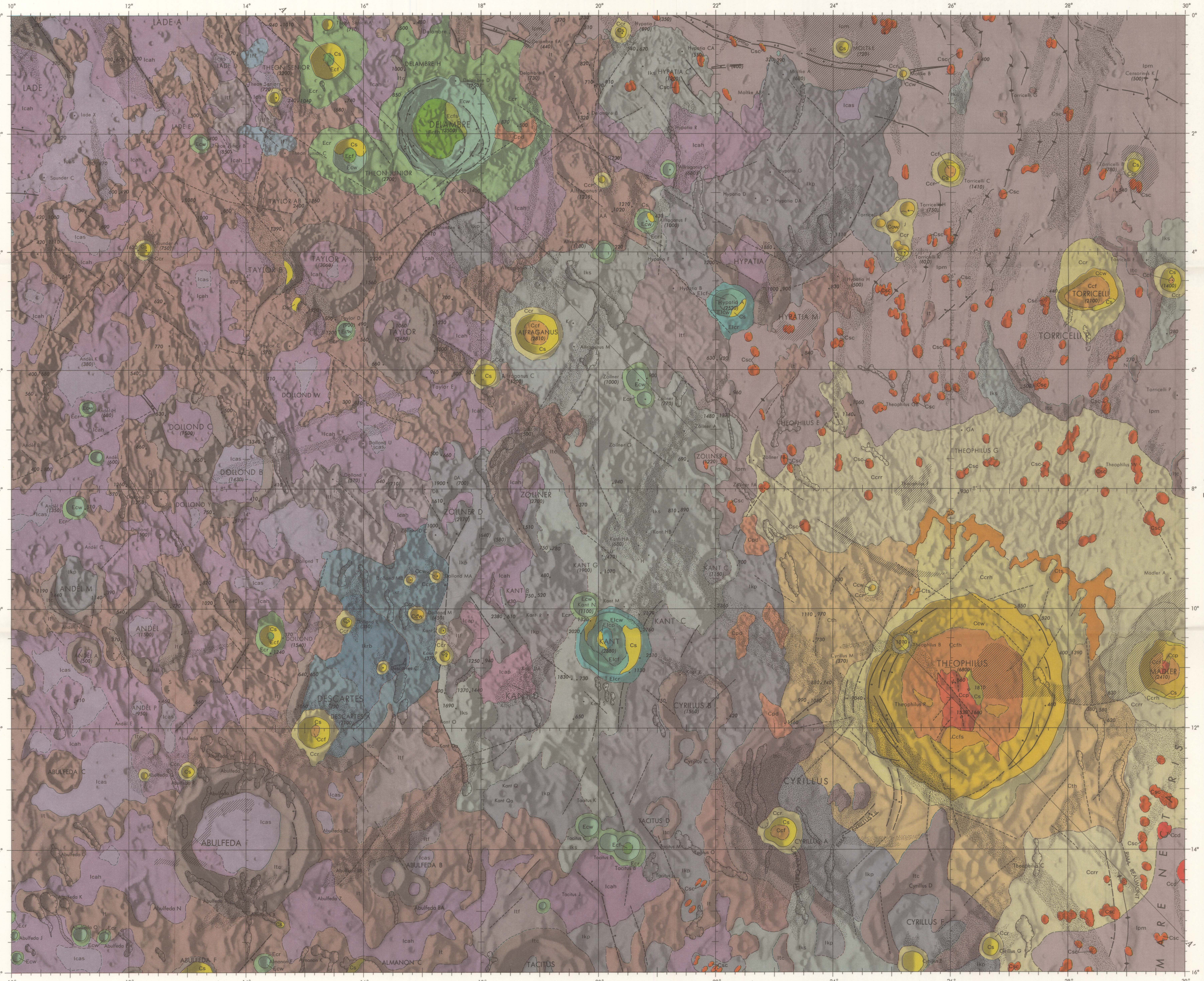
Supplementary features are associated with the named features through the addition of identifying letters. Craters are identified by capital letters. Eminences are identified by Greek letters.

RELIEF PORTRAYAL

Configuration of the relief features is interpreted from telescopic photography, visual observations made with the 24-in. Lowell Observatory refracting telescope, Flagstaff, Ariz., and Ranger VIII television records in the area of effective coverage. The pictorial portrayal of relief forms is 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 are eliminated to enable complete interpretation of relief forms.

EAST-WEST DIRECTION

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



Base from USAF Aeronautical Chart and Information Center lunar charts: Hypatia (RLC 6), 1st edition, 1966, north of 12°S, and Theophilus (LAC 78), 1st edition, 1963, south of 12°S.

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

STATUTE MILES
KILOMETERS

Sources of geologic information: Telescopic photography from the Lick, Mt. Wilson, U.S. Naval (Flagstaff, Ariz.), and Pic du Midi Observatories; Ranger VIII photography; visual observations by the author with the 36-in. refractor, Lick Observatory, 1963–66

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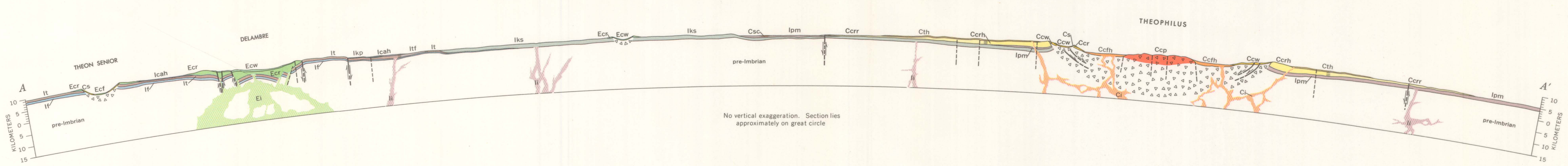


GEOLOGIC MAP OF THE THEOPHILUS QUADRANGLE OF THE MOON

By
Daniel J. Milton
1968

EXPLANATION

Cs — Slope material

Characteristics
Albedo very high. Occurs on or at the base of crater walls and other steep slopes
Interpretation
Talus and bedrock freshly exposed by sliding or slumping on slopes near the angle of repose. Process may be active at present time

Ccd — Dark halo crater material

Characteristics
Material of craters with dark rims; distinguishable where superposed on bright materials
Interpretation
Either material from deeper layers of dark rock ejected from impact craters or dark tephra around volcanic craters

Dark covering material

Characteristics
Albedo low to intermediate. No visible topographic expression. Patches interrupt patterns of rays or other bright units
Interpretation
Patches around Moltke and Torricelli B are thin blankets of dark material ejected from the central crater, similar to Ccd. *Patches not associated with central craters may be rock darkened by sublimates from gaseous emanations or may be thin blankets of dark tephra from unidentified volcanic vents*

Cts, Cth — Theophilus Formation (new name)

Characteristics
Occurrence and type locality on rim of crater Theophilus
Cts, *smooth. Level or uniformly sloping surfaces with no visible relief. Albedo intermediate, slightly lower than that of* Ccrh
Cth, *hummocky. Topography similar to* Ccrh, *but with less abrupt changes of slope and a lower ratio of negative to positive features. Albedo variable but mostly slightly higher than that of* Ccrh
Interpretation
Tephra and possibly lava flows. Volcanism was subsequent to and probably induced by the impact that formed the crater Theophilus
Cts, *occurs as thick fill in basins*
Cth, *occurs as a thinner blanket that does not completely mask Theophilus rim patterns*

Cpd — Densely pitted material

Characteristics
Generally level or gently rolling surface with many closely spaced and coalescing craters, most less than 3 km in diameter. Albedo commonly higher than surrounding areas
Interpretation
Materials produced by explosive, maar type volcanism, involving volatile-rich magma. Superposition on Theophilus rim indicates a Copernican age for some patches, high albedo suggests it for others

Ci — Intrusive rock

Inferred plutons associated with volcanic materials of the same age. Shown only in geologic section

Ccr, Ccrh, Ccrr, Ccw, Ccf, Ccfh, Ccfs, Ccp — Materials of rayed craters

Characteristics
Albedo intermediate to high
Ccr, *rim, undivided. Forms surfaces sloping outward from crater rim crests. Apparently smooth around smaller craters and has hummocks and braided ridges diminishing in size outward from the crest around larger craters. Around Theophilus and Mädler, divided into:*
Ccrh, *hummocky. An inner facies with high local relief*
Ccrr, *radial. An outer facies, with lower relief, dominated by approximately radial ridges*
Ccw, *wall. Mapped on inner wall of craters*
Ccf, *floor, undivided. Forms generally smooth floor in smaller craters. In Theophilus, divided into:*
Ccfh, *hilly. Forms low irregular hills*
Ccfs, *smooth*
Ccp, *central peak. Forms rugged peaks in center of Theophilus and Mädler*
Interpretation
Ccr, *ejecta from impact craters. Divided into:*
Ccrh, *mostly coherent ejecta displaced outward by thrusting*
Ccrr, *mostly fragmental material ejected along ballistic trajectories*
Ccw, *talus and bedrock on slopes which have become stabilized, allowing exposed material to darken*
Ccf, Ccfh, *and* Ccfs, *brecciated bedrock with some cover of ejecta and slumped wall material. Floor of Theophilus and other large craters probably occupied by post-impact volcanic material*
Ccp, *bedrock relatively uplifted by elastic rebound at time of crater-forming impact*

Csc — Satellitic crater material

Characteristics
Material of small (maximum diameter 5 km) shallow craters, mostly elongate with long axis radial to crater Theophilus. Only more conspicuous craters are mapped
Interpretation
Craters formed by the impact of rock ejected by the primary impact that formed the crater Theophilus

Ray material

Characteristics
Albedo high. No visible topographic expression. Occurs as irregular plumose streaks, most of which are radial to larger craters, and as halos around smaller craters
Interpretation
Ejecta from primary and secondary craters. Surface is probably densely populated by craters below the limit of telescopic resolution. Principal systems originate at Theophilus, Tycho (NE-trending rays in center of quadrangle), Stevinus (NW-trending system), and Godin (in NW corner). Minor rays not clearly associated with any primary crater may be streaks of light-colored volcanic ejecta or rock stained by light-colored sublimates from gaseous emanations

COPERNICAN SYSTEM

Ecr, Ecw, Ecf, Ecfh, Ecfs — Materials of fresh nonrayed craters

Characteristics
Materials of craters without rays or bright halos. Units correspond to units of Copernican rayed crater materials. Fine-scale topographic features on the outer rim of larger craters different from that of surrounding terrain, either rougher or smoother. Smaller craters, for which rim texture cannot be resolved, are included where they appear unrelated to regional patterns
Interpretation
Most craters are probably of impact origin. Some, particularly those with smoother rims, may be volcanic. Smoothness suggests that the surface materials of Delambre are volcanic rather than impact ejecta. Interpretation as a caldera (as in geologic section) rather than as an impact crater overlain by volcanic rocks is less secure but is suggested by the lesser local relief than usual for a crater of its diameter and by the absence of an observable satellitic crater field

Ei — Intrusive rock

Inferred plutons associated with volcanic materials of the same age. Shown only in geologic section

Elcr, Elcw, Elcf, Elcp — Crater materials

Characteristics
Materials of craters with raised rims and sharply defined crests, but fine texture on outer rim is indistinguishable from that of adjacent Kant Plateau materials. Units correspond to units of Eratosthenian and Copernican crater materials. Crater boundary drawn at base of raised rim
Interpretation
Either calderas, contemporaneous with youngest beds of surrounding volcanic rocks, or subsequent impact craters

ERATOSTHENIAN SYSTEM

Icas, Icah, Icap — Cayley Formation

Characteristics
Material of level plains. Albedo intermediate, lower than that of most terra units
Icas, *smooth. Hills or small craters absent or very sparse at the resolution of the best available photography*
Icah, *hilly. Much of surface occupied by low hills, craters, and irregular depressions*
Icap, *pitted. Level surface with many small craters*
Interpretation
Tephra and probably subordinate lava flows, forming deep fill in basins
Icas, *subjacent topography is concealed and constructional volcanic features are absent*
Icah, *generally represents areas where volcanic material is thinner and subjacent features are not completely masked, but also includes areas where constructional features are present*
Icap, *maar fields*

Ipm — Mare material of Procellarum Group

Characteristics
Albedo low to intermediate. Forms low plains abruptly terminating against higher terra units. Surface smooth and generally level but long low irregular ridges and some rilles and scarps occur
Interpretation
Volcanic materials: flows, tephra beds, or both

Iks, Ikp, Ikr, Ikrb — Materials of Kant Plateau

Characteristics
Albedo high; albedo of Ikrb *very high. Forms plateaus with generally smooth surfaces that are broadly rolling rather than level*
Iks, *smooth. Minor part of surface is occupied by small craters, sharp-rimmed irregular elongate depressions and positive features (including some domes with summit pits)*
Ikp, *pitted. Major part of surface occupied by irregular depressions*
Ikr, *rugged. Has many twisting elongate depressions and hummocks and almost no level ground; one of the roughest textured units in the quadrangle*
Ikrb, *rugged, bright. Has the same topographic expression as* Ikr, *but a very high albedo*
Interpretation
Volcanic materials that had less tendency to flow to low places than those of Cayley Formation. Probably a high ratio of lava flows to tephra. Possibly similar to plateau basalts of Earth. Only broad features of subjacent topography preserved, much subdued. Ikp, Ikr, *and* Ikrb *are composed of lavas more viscous than those of* Iks, *with less tendency to flow to low places, perhaps erupted with more accompanying volcano-tectonic deformation. Very high albedo of* Ikrb *suggests that at least the surface beds may be Copernican rather than Imbrian in age*

Ii — Intrusive rock

Inferred plutons associated with volcanic materials of the same age. Shown only in geologic section

It, Itc, Itf — Irregular terra units

Characteristics
It, *rugged terra. Rugged topography with no dominant regular patterns. Positive and negative features a few kilometers across with moderate to steep slopes occupy almost all the surface; level or smooth expanses are nearly absent. Albedo intermediate*
Itc, *rugged terra of crater rims. Rugged topography, in detail similar to* It, *but with the gross topographic form of a large crater rim (or central peak). Albedo intermediate to high, generally higher than that of* It
Itf, *furrowed terra. Rolling plains with many shallow depressions elongate in the NW-SE direction, telescopically resolvable only under best seeing conditions*
Interpretation
Surface layer of these units generally consists of volcanic materials of varying thickness, for the most part thin, but sufficient to conceal patterns produced by material ejected from the Imbrium basin. Subjacent rocks may be exposed locally. Topography is primarily controlled by subjacent relief (pre-Imbrian terrain modified by Imbrian sculpture), but has been affected by volcano-tectonic deformation of Imbrian age
Itc, *volcanic materials were deposited on crater rims, most or all of pre-Imbrian age and probable impact origin. Higher albedo suggests the presence of freshly exposed material, that is, unresolved patches of slope material* (Cs)
Itf, *shows elongate depressions belonging to the Imbrian sculpture system, formed by faulting and collapse either during the Imbrian event and incompletely masked by volcanic materials or during deposition of the volcanic materials by reactivation of faulting of the Imbrian sculpture system in the subjacent rock*

If — Fra Mauro Formation

Characteristics
Surface nearly saturated with shallow subcircular craters about 1 km in diameter. Albedo intermediate
Interpretation
A remnant of the outer facies of ejecta from the Imbrium impact event, with many secondary impact craters. Although the area of probable outcrop is small, Fra Mauro is believed to exist in the subsurface over much of the northwest part of the Theophilus quadrangle

IMBRIAN SYSTEM

GENERAL INFORMATION

The surface of the Moon is heterogeneous. The differences from area to area of characteristic topographic forms and of physical properties such as albedo (reflectivity under full-Moon illumination) indicate that the materials underlying the surface vary from one area to another and that different processes have operated in the development of the surface. In lunar geologic mapping, areas are delineated that, as far as possible, are analogous in terrestrial mapping to the areas of outcrop of stratigraphic units—bodies of rock whose limited range of lithology and age and relatively simple geologic form indicate formation under a common set of conditions. For the Moon, at the present time, physical properties that are believed dependent on lithology rather than lithology itself must characterize units. Age relations between units can be established from their boundary relations if certain simple assumptions are made about processes on the Moon—for example that most younger units were deposited at the surface.

A sequence of time-stratigraphic units based on events that affected much of the surface of the Moon has been established in the vicinity of Mare Imbrium, and may serve as a general framework for lunar stratigraphy. The systems and salient events of each are as follows (Shoemaker, 1962; Shoemaker and Hackman, 1962):

PERIOD	EVENTS
Copernican	Formation of rayed craters.
Eratosthenian	Formation of craters whose rays are no longer visible.
Imbrian	Extensive volcanism in mare basins.
	Formation of Mare Imbrium basin.
pre-Imbrian	

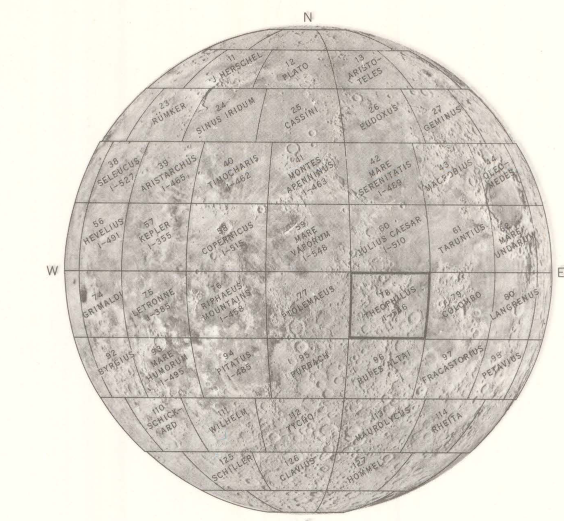
Each unit is given either a descriptive designation or a formal stratigraphic name, and the letter symbol for each unit is composed of an abbreviation of its age assignment (capital) and name (lower case). The observed criteria by which units are discriminated are given as "characteristics"; the genesis that seems most consistent with those characteristics is given under "interpretation."

Lunar topographic forms that have been observed range in lateral dimension from hundreds of kilometers down to millimeters (the latter seen by lunar soft-landing missions). Discrimination of geologic units in mapping at a scale of 1:1,000,000 is based primarily on topographic forms which have lateral dimensions from several kilometers down to the limit of telescopic resolution, about one-half kilometer. In the Theophilus quadrangle, most features in this size range are believed to be of volcanic and volcano-tectonic origin. Consequently, the more widespread units are interpreted as volcanic. Toward either end of the size range, the role of impact in the production of topographic form increases in importance. For example, the largest craters are probably of impact origin. In most places, however, the small-scale features characteristic of fresh impact craters are modified, suggesting a cover of volcanic materials. The presence of the underlying crater forms may serve as a secondary criterion to subdivide the volcanic units. Toward the small end of the size range, impact-produced features again predominate over endogenetic features. The size range at which this happens is, however, beyond telescopic resolution, and does not affect mapping at this scale.

The virtual absence at the surface of features that can be attributed to the Imbrium impact event indicates that the earliest Imbrian surface has been covered by younger materials. A maximum age of Imbrian is thus established for most of the exposed units. Assignments of most of the regional units on the terra to the Imbrian rather than to a younger period is based on a tentative correlation of the extensive terra volcanics with the Procellarum mare volcanism, although some younger materials may well be present. Between the various Imbrian units there is virtually no way of establishing relative age. The order in which they are listed in the explanation indicates the degree to which they make subjacent topography.

REFERENCES

Shoemaker, E. M., 1962, Interpretation of lunar craters, in Kopal, Z., 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, Z., and Mikhailov, Z. K., eds., The Moon—Internat. Astron. Union Symposium 14: London, Academic Press, p. 289–300.



INDEX MAP OF THE SUBTERRESTRIAL HEMISPHERE OF THE MOON
Number above quadrangle name refers to lunar base chart (LAC series); number below refers to published geologic map

Contact
Long dashed where indefinite; short dashed where gradational

Fault
Solid where surface material is apparently displaced, dashed where surface material is apparently draped over fault in subjacent rock. Bar and ball indicated downthrown side; hachured where younger unit was deposited against fault scarp

Lineament
Interpretation: Fault, but sense of movement undetermined

Mare ridge
Interpretation: Line marks crest of an anticline

Irregular, rimless or low-rimmed depression
Interpretation: Volcanic collapse feature

Sinuous rille
Interpretation: Volcanic flow channel

Breccia lens
Shown in geologic section beneath crater floors. Interpretation: Impact-produced breccia

Laterally gradational contact
Shown only in geologic section. Corresponds to short-dashed contact on map

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