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

NOTES ON BASE

The base chart was prepared by ACIC 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 this chart was determined through the use of selenographic control established primarily from the measures of J. Franz and S. A. Saunder as compiled by D. W. G. Arthur 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 kilometers. The datum plane was subsequently adjusted to 2.6 kilometers below the surface described by the 1738-kilometer radius to minimize the extent of lunar surface of minus elevation value. Gradients of major surface undulations were established by interpolating Schrutka-Rechtenstamm computations of J. Franz's measurements of 150 moon craters. The probable error of comparative elevation values is evaluated at 1000 meters. Vertical datum, so 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 maria and depths of craters were determined by the shadow measuring techniques as refined by the Department of Astronomy, Manchester University, under the direction of Professor Zdenek Kopal. Relative heights, thus established, have been referenced to the assumed vertical datum and have been integrated with the gradients of the surface undulations. The probable error of the localized relative heights is 100 meters. Inherent with measuring technique used, relative height determinations in general E-W direction are more accurate than in the N-S direction.

Elevation (referenced to datum) 1100
Depth of crater (rim to floor) (900)
Relative Elevations (referenced to surrounding terrain) with direction and extent of slope measured 500R

CONTOURS

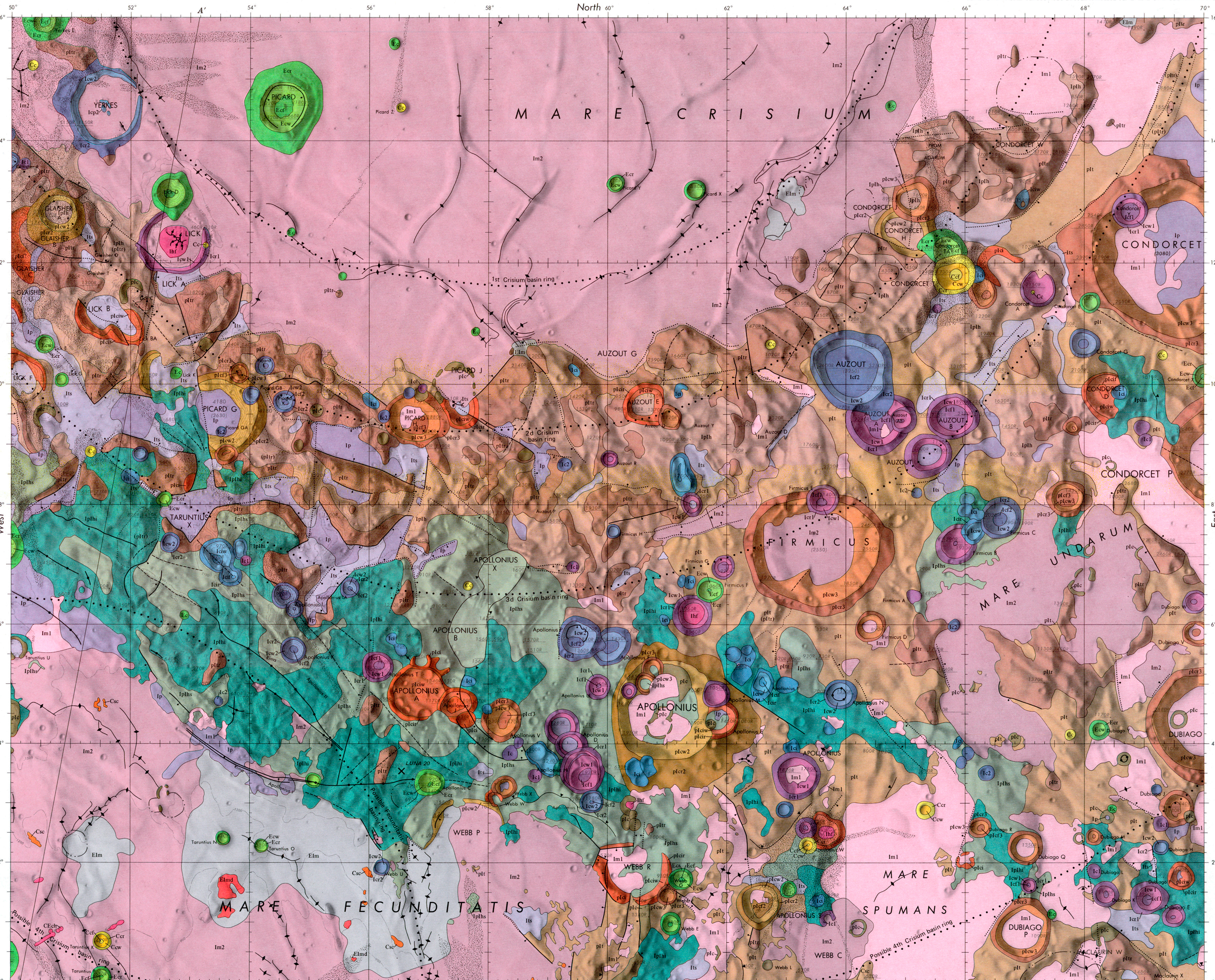
All contours are approximate
Contour interval is 300 meters
Approximate contour —600—
Depression contour
NOTE: Contour information is not currently available beyond 56° East.

NAMES

The feature names were adopted from the 1935 International Astronomical Union nomenclature system as amended by Commission 16 of the IAU. Craters designated by capital letters were selected from the IAU list of Named Lunar Formations. Supplementary lettered formations have been added in accordance with the criterion suggested by Blagg and Müller. They are designated by lowercase letters.

PORTRAYAL

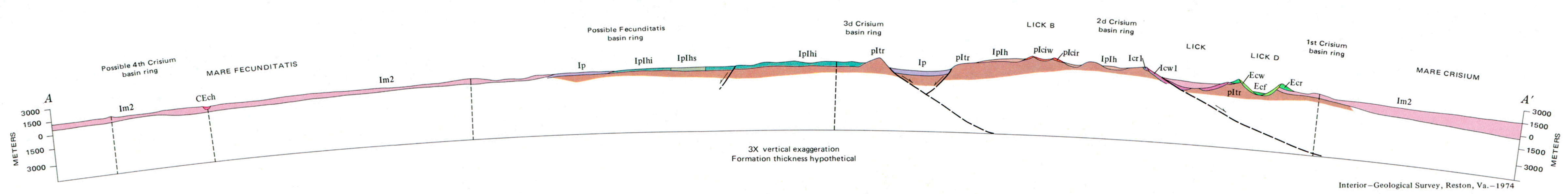
The configuration of the relief features and background coloration shown on this chart were interpreted from photographs taken at Lick, Mc Donald, Mt. Wilson, Yerkes and Pic du Midi Observatories, and published in the 1960 Edition of the USAF Lunar Atlas and unpublished photographs from the Lunar and Planetary Laboratory, University of Arizona and Department of Astronomy, University of Manchester. Visual observations made with the 24 inch Lowell refracting telescope, Flagstaff, Arizona, have also been used to add and clarify details. The pictorial portrayal of 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 eliminated to enable complete interpretation of relief forms.



Lunar base chart LAC 62, 1st edition, 1964, by U.S. Air Force Aeronautical Chart and Information Center, St. Louis, Missouri 63118

Originally compiled 1969-71 by Olson on basis of Lunar Orbiter, Apollo 10, and Apollo 11 photographs; revised 1971-72 by Wilhelms and Olson on basis of Apollo 15 metric (stereoscopic) photographs. Preliminary version based on telescopic photographs and visual observations at Lick Observatory by Masursky (1965).

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



Interior—Geological Survey, Reston, Va.—1974

GEOLOGIC MAP OF THE MARE UNDARUM QUADRANGLE OF THE MOON

By
Annabel B. Olson and Don E. Wilhelms
1974

EXPLANATION

COPERNICAN SYSTEM

CEch — Material of chain craters
Characteristics
Craters closely spaced or overlapping, elliptical or nearly linear
Interpretation
Probably volcanic

Cc Ccr Ccw Ccf — Materials of rayed craters
Characteristics
Topographically sharp; surrounded by bright rays or halos (mapped where extensive)
Cc, *crater material, undivided*
Ccr, *rim material (positive relief outside rim crest)*
Ccw, *wall material (steep slopes inside rim crest)*
Ccf, *floor material (relatively level)*
Interpretation
Young impact craters

Csc — Satellitic-crater material
Characteristics
Small elongate or circular craters occurring in clusters near large rayed craters; in Mare Fecunditatis between 50° and 52° E., satellitic to Taruntius; near 56° and 59° E., to Langrenus
Interpretation
Formed by secondary impact of ejecta from Taruntius and Langrenus

Ray material
Characteristics
Bright streaks radiating from Copernican craters; large occurrences in northwest radial to Proclus; in south, to Langrenus
Interpretation
Impact ejecta and small secondary impact craters

ERATOSTHENIAN SYSTEM

Ec Ecr Ecw Ecf — Circular-crater materials
Characteristics
Rayless; topography slightly subdued relative to Copernican materials
Ec, *crater material, undivided*
Ecr, *rim material*
Ecw, *wall material*
Ecf, *floor material*
Interpretation
Mostly impact craters; some alined along mare ridges could be volcanic

IMBRIAN SYSTEM

Im2 / Im1 — Mare materials
Characteristics
Dark plains. Unit Im2 *darker and less cratered than* Im1. *Some marginal parts of* Im1 *conform to underlying relief; most surfaces of both units otherwise flat except for mapped ridges and scarps*
Interpretation
Basalt flows, possibly including some pyroclastics. Im2 *probably younger and thicker than* Im1. *Higher albedo of* Im1 *possibly caused by greater admixture of terra materials*

EIm — Mare or mantling material
Characteristics
Darkest and least cratered unit in area. Floods rims of craters Taruntius N and Taruntius O. Occurrences in Mare Crisium thinly mantle subjacent terrain
Interpretation
Young basalt flows or pyroclastic material

EImd — Mare dome material
Characteristics
Broad, low; tops flat or rough. Albedo same as surrounding mare
Interpretation
Extrusive volcanic material

Upper Imbrian

Ic2 Icr2 Icw2 Icf2 Icp2 — Circular-crater materials
Characteristics
Sharp to moderately sharp topographic detail; walls mostly bright
Ic2, *crater material, undivided*
Icr2, *rim material*
Icw2, *wall material*
Icf2, *floor material*
Icp2, *peak material*
Interpretation
Mostly of impact origin; Yerkes could be caldera (smooth-rimmed-crater class of Wilhelms and McCauley, 1971)

Lower Imbrian

Ic1 Icr1 Icw1 Icf1 — Circular-crater materials
Characteristics
Moderately subdued topographic detail; many small superposed craters; many dark streaks on walls
Ic1, *crater material, undivided*
Icr1, *rim material*
Icw1, *wall material*
Icf1, *floor material*
Interpretation
Mostly of impact origin; Lick could be caldera (smooth-rimmed-crater class of Wilhelms and McCauley, 1971). Topographic subdual and dark wall material due to degradation by mass wasting and meteorite bombardment

Ihf — Hilly and furrowed material
Characteristics
Moundlike crater floors transected by linear furrows
Interpretation
Volcanic, or fractured, strongly uplifted crater floor material

Ip — Plains material
Characteristics
Terra plains of intermediate albedo; smoother, flatter, and darker than other terra units; brighter rougher, more cratered than mare units. Mostly in topographic lows
Interpretation
Thick deposits of mass-wasted debris, or possibly volcanic

Its — Material of smooth terra
Characteristics
Moderately subdued nondistinctive surface texture. Generally in topographic depressions with weakly expressed pre-Imbrian subsurface
Interpretation
Debris derived from adjacent slopes by mass wasting

Ici Icir Iciw Icif — Irregular-crater materials
Characteristics
Outline noncircular; moderately subdued.
Ici, *irregular-crater material, undivided*
Icir, *rim material*
Iciw, *wall material*
Icif, *floor material*
Interpretation
Volcanic craters or Imbrium basin secondary impact craters

Ic — Crater material, undivided
Characteristics
Moderately subdued crater, mostly small, complete or incomplete
Interpretation
Origin unknown

PRE-IMBRIAN AND IMBRIAN SYSTEM

IpIhi IpIhs — Hilly and pitted materials
Characteristics
Aggregates of closely spaced, moderately fresh-looking, irregular to subcircular craters, pits, and furrows and minor hills mostly 1 to 5 km across; larger, similar craters mapped as irregular-crater material
IpIhi, *relatively irregular photographic macro- and microrelief and large, numerous craters and pits; west of crater Apollonius A pits and furrows quite irregular, grading to fissures*
IpIhs, *smoother, more uniform macro- and microrelief, smaller pits, and somewhat lower albedo than unit* IpIhi
Interpretation
Crisium basin ejecta (pre-Imbrian) modified in Imbrian Period by volcanism, fracturing, or impact of ejecta from distant craters or basins. Volcanism or fracturing most probable for unit IpIhi *west of Apollonius A*

IpIh — Hill and mantle material
Characteristics
Small bright hills and intervening darker, smoother material on slopes and in depressions. Rugged macro- and microrelief
Interpretation
Pre-Imbrian bedrock and ejecta of Crisium basin (bright hills) and debris derived therefrom by mass wasting partly in Imbrian Period (dark material). Dark material could be partly pyroclastic and related to mare material. Occurrence centered at 9½° N., 59° E., consisting of dark mound and adjacent dark mantle, most likely to be volcanic

PRE-IMBRIAN

Upper pre-Imbrian

pIcr3 pIcw3 pIcf3 — Circular-crater materials
Characteristics
Topographically subdued; wall terraces visible in large craters but partly coalesced by smoothing
pIcr3, *rim material*
pIcw3, *wall material*
pIcf3, *floor material*
Interpretation
Origin unknown. Younger than Crisium basin

Lower or middle pre-Imbrian

pIcr2 pIcw2 pIcf2 — Circular-crater materials
Characteristics
Heavily subdued and cratered; textural detail lacking; crater commonly incomplete
pIcr2, *rim material*
pIcw2, *wall material*
pIcf2, *floor material*
Interpretation
Origin unknown. Age relative to Crisium basin unknown

pIt — Terra material, undivided
Characteristics
Moderate to low macro- and microrelief. Nondistinctive surface, ranging from smooth to finely or coarsely hummocky
Interpretation
Probably Crisium basin ejecta overlain by mixed impact ejecta and erosional debris

pIci pIcir pIciw pIcif — Irregular-crater materials
Characteristics
Outline noncircular; commonly an incompletely closed ridge; topographically subdued
pIci, *irregular-crater material, undivided*
pIcir, *rim material*
pIciw, *wall material*
pIcif, *floor material*
Interpretation
Origin unknown; possibly volcanic, or originally circular impact crater modified by faulting, erosion, or burial; queried where of possible structural origin

pIc — Crater material, undivided
Characteristics
Topographically subdued ring, mostly small, commonly incomplete
Interpretation
Origin unknown

pItr — Material of rugged terra
Characteristics
Rugged blocks, generally with rectilinear outlines. Forms highest and most rugged parts of Crisium basin rim. Slopes steep, smooth, and generally brighter than adjacent materials
Interpretation
Pre-basin rock uplifted during formation of Crisum basin by impact. Brightness maintained by exposure of fresh material through mass wasting

(pItr) ?
Contact
Dotted where buried (contact evident from surface topography); buried unit shown in parentheses; queried where doubtful

Fault
Solid line at base of scarp; dotted where inferred and buried. Bar and ball on apparent downthrown side

Narrow groove
Probable fault or fracture. On cross section also represents interpreted volcanic feeder

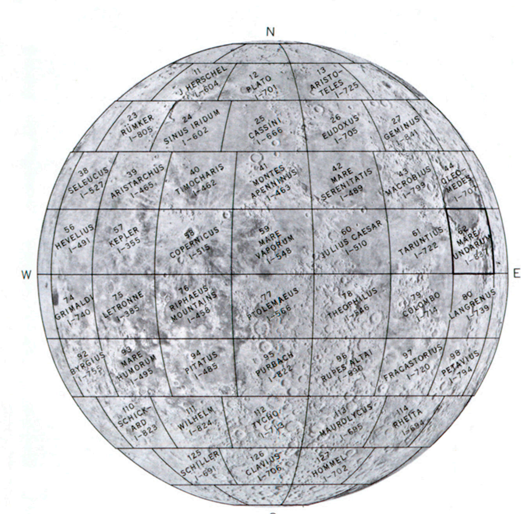
Sharp rille
Probable graben. Also indicates concentric structure of unknown origin within crater

Mare ridge
Barbs point downslope

Scarp
Sharp break in slope within geologic unit. Barb points downslope

Concealed crater rim crest

Mare basin raised ring
Expressed topographically or inferred



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

GEOLOGIC SUMMARY

The map area contains two mare provinces, one terra province, and one province of mixed mare and terra. The maria are the semicircular southern half of Mare Crisium and the northeast sector of Mare Fecunditatis. The massive belt of terra that arcs across the quadrangle between these maria is the south rim of the Crisium multiringed basin; its southwest part is probably superposed on an older, originally similar, arcuate rim of the Fecunditatis basin. The fourth province, in the southeast corner, includes small irregular maria such as Mare Undarum and Mare Spumans and intervening peninsulas and islands of terra.

The Crisium basin is relatively degraded and undoubtedly formed in pre-Imbrian time. It consists of an inner basin, four concentric mountainous rings, and deep or shallow shelves or troughs between the rings. The general positions of the rings are shown by dots, and their highest peaks are mapped as material of rugged terra (pItr). The inner ring is now marked by isolated islands and mare ridges in the mare fill. The next two rings are high and rugged and form the present main basin rim. The outer, vaguer, fourth ring is marked by the terra in the southeast; the irregular maria there fill depressions adjacent to this vague high. The raised rings and their intervening depressions are bounded by linear structures, many of which, especially along the second and third rings, are here interpreted as faults. In general these structures are concentric or radial to the basin, but in detail they may follow other trends ("lunar grid"; Casella and Binder, 1972). Judging from young basins such as Orientale (Mutch, 1970, p. 147-156) and Imbrium (Wilhelms and McCauley, 1971), abundant Crisium basin ejecta was probably deposited when the basin formed. Radially lineated ejecta presumably blanketed the terrain outside the third basin ring, and hummocky material--ejecta or highly fractured bedrock--formed closer to the basin. The ejecta is not now definitely identified but probably forms much of units pIt and IpIh, which are in the proper position and which have a predominantly hilly or hummocky texture that could be primary or modified ejecta.

The raised rings, the depressions between them, and the presumed ejecta were considerably modified in the long interval after they formed in pre-Imbrian time and before the mare material was deposited in late Imbrian time. Mass wasting removed material from high terrain and deposited it in adjacent depressions. The character of at least five map units is determined partly or entirely by this process. The steepest slopes on high peaks and scarps have a high albedo, probably because fresh bedrock and debris have been exposed there by downslope movement (unit pItr and small steep hills of other units). Hill and mantle material (unit IpIh) has a coarse patchy appearance on telescopic and Apollo photographs taken at high sun-illumination angle; the steep hills are bright and the intervening depressions and slopes are dark or exhibit a streaked appearance clearly resulting from downslope movement of material (probably largely in Imbrian time). The dark material is probably debris that is relatively stable and has become dark because of relatively long exposure. In the deepest depressions of the Crisium rim, thicker deposits accumulated during Imbrian time, so that most or all of the underlying relief is covered (units Its and Ip respectively); the surfaces of those units are relatively dark for terra and exhibit only Imbrian or younger craters. Mass wasting has probably affected another unit, undivided terra material (pIt), but the effects of this and other modifying processes are difficult to distinguish from primary depositional characteristics.

Other modifications were produced by cratering. Impact craters (most or all circular craters) produced seismic energy that aided in the degradation process. Volcanic craters (perhaps many of the irregular craters) could also be present and might have superposed a blanket of ejecta on the terrain.

The extent to which volcanism shaped the terra of the Crisium rim is unknown. Patches in unit IpIh, which occurs among the high peaks of the Crisium rim near Mare Crisium, are almost mare like in their low albedo. Perhaps these are not merely stabilized eroded debris but basaltic pyroclastic deposits like those believed present at the Apollo 17 site (Scott and others, 1972). The plains material (unit Ip), if not mass-wasted debris, may be volcanic flows like those of the maria but older; some very flat surfaces with sharp-appearing craters and abrupt contacts suggest this origin. The morphology of the hills and pitted units (IpIhi and IpIhs) can also be well explained by volcanism, especially west of the crater Apollonius A where furrows and pits of unit IpIhi are alined along fractures or parallel with them. However, rock samples returned from this unit south of Apollonius A in February 1972 by the Soviet spacecraft Luna 20 (3°32′ N., 56°33′ E.) are probably impact breccias (Wilshire and others, 1974). They are similar to rocks sampled by Apollo 16 in similar-appearing terrain that generally had been interpreted as volcanic. At the Apollo 16 site, the plains unit is also probably of impact origin. Thus the role of the volcanism in shaping at least the high-albedo units of the terra is probably minor. Part or all of units IpIhi and IpIhs may consist of Crisium basin ejecta peppered in Imbrian time by secondary impacts of craters and basins. The concentration of the units in NW-SE belts suggests that a major source of impacting fragments is the Imbrium basin, which lies about 1400 km to the northwest.

After most of this terra-modifying activity ceased, except probably for some mass wasting, the maria were emplaced in the Crisium basin and other remaining deep depressions. Three mare units that may be different in age are mapped (Im1, Im2, EIm), as are some fresh, flat-topped mare domes (unit EImd). Sampling by Apollo and Luna missions, including Luna 16 that landed in Mare Fecunditatis just south of the quadrangle (0°42′S., 56°18′E.), has shown that mare rocks are basaltic.

After the maria formed, impact cratering continued (units Ec and Cc). The sparsity of post-mare crater materials shows that activity slowed considerably during this time, although radiometric dates on mare material elsewhere indicate that post-mare time accounts for about two-thirds of lunar history. Some small patches of very dark material (included in unit EIm) and a few post-mare crater chains and clusters of probable volcanic origin (unit CEch) also date from this later time.

REFERENCES

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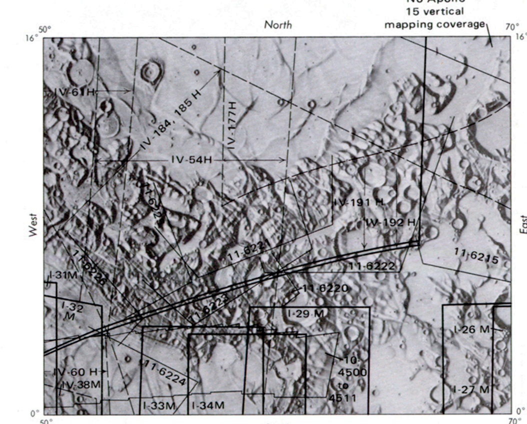

PHOTOGRAPHIC COVERAGE OF MARE UNDARUM QUADRANGLE

Roman numeral indicates Lunar Orbiter mission; Arabic numeral indicates frame number; letter indicates high (H) or medium (M) resolution; heavy lines indicate best low-sun-illumination Orbiter coverage: Orbiter IV frame 192H (or 191H), resolution 200-300 m, and seven Orbiter I M-frames, resolution about 40 m; dashed lines indicate supplementary Orbiter coverage; additional Orbiter IV H-frames 39, 40, 46, 47, and 53 partly cover area but are badly washed out.

Light solid lines indicate best Apollo 10 and 11 orbital coverage; Apollo 10 stereoscopic coverage (jagged boundary) is continuous between end-frames 4500 (east) and 4511 (west boundary of map); partial outlines show most useful parts of eight Apollo 11 oblique frames that (except 6224) include horizon; additional Apollo 8, 10, and 11 frames partly cover area but sun angle too high, obliquity too extreme, or resolution too low to be useful.

Strips of Apollo 15 mapping (metric) frames cover entire quadrangle except northeast corner; each frame covers area about 180 km square; 60-85 percent side overlap, 70-85 percent forward overlap; strips inclined about N 70° W; high sun-illumination angle (56° to 83°) so stereoscopic viewing necessary for most purposes; the following frame numbers, listed north to south, cover area; stars indicate five strips of vertical photographs that are sufficient to cover area once with some side overlap:

0358 - 0378* (includes Condorcet)
0530 - 0550
0802 - 0823 (west-looking oblique)
0937 - 0957* (includes Auzout and Firmicus)
1078 - 1099
1371 - 1391 (east-looking oblique)
1487 - 1504 (north-looking oblique)
1620 - 1640* (includes Apollonius)
1762 - 1780
1900 - 1918* (includes Webb R)
1998 - 2009 (mostly dark)
2144 - 2122* (SW map corner)
2258 - 2266

Apollo 16 vertical mapping frames 2909-2928 and many redundant vertical and oblique frames cover southern part of quadrangle below 4° N. at east border to below ½° N. at west border; they were not used in compiling map and are not significantly better than the Apollo 15 photos that were used.

Apollo 17 mapping frames cover entire quadrangle; frames 274-293 cover northern part of quadrangle above 12° N. at east border to above 14° N. at west border, including the small triangular area in northwest corner not covered by Apollo 15 photos; these Apollo 17 frames were taken at low sun angle and are superior to the Apollo 15 photos used in compiling the map; other Apollo 17 frames are not significantly better than the Apollo 15 photos.

Apollo 15, 16, and 17 panoramic high-resolution photographs also cover the quadrangle but were not used in mapping; all except some of Apollo 17 were taken at a high sun angle unsatisfactory for mapping at this scale.

For sale by U.S. Geological Survey, Reston, Va. 22092, price $1.00