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
RÜMKER QUADRANGLE
I-805 (LAC 23)

NOTES ON BASE

The base was prepared by ACIC with advisory assistance from Dr. Gerard P. Kuiper and his collaborators, D. W. G. Arthur and E. A. Whitaker.

DATUM

The assumed lunar figure is that of a sphere corresponding to the mean lunar radius of 1738 kilometers.

CONTROL

The map area is near the limb of the Moon where positional control is generally poor and extreme rectification of Earth-based telescopic photographs is required in constructing base maps. Significant positional errors in this quadrangle became apparent with the acquisition of Lunar Orbiter IV high resolution (100–200 m), near-vertical photographs. To avoid misleading distortions in the geology, many features have been relocated on the geologic compilation using the Lunar Orbiter data.

Primary Control Positions . . . . ⊕
Supplementary Control Positions . . . . ▲

ELEVATIONS

Radius vector lengths are the distances from the geometrical center of the moon to the plane of the crater rim or the designated position of the feature measured. The lengths of the radius vectors are expressed in kilometers.

The relative elevations of crater rims and other prominences above the surrounding terrain and depths of craters are in meters. They were determined by the shadow measuring techniques as refined by the Department of Astronomy, Manchester University, under the direction of Professor Zdeněk Kopal. The probable error of the localized relative elevations is 100 meters in the vicinity of the center of the moon with the magnitude increasing to 300 meters at 70° from the center due to foreshortening.

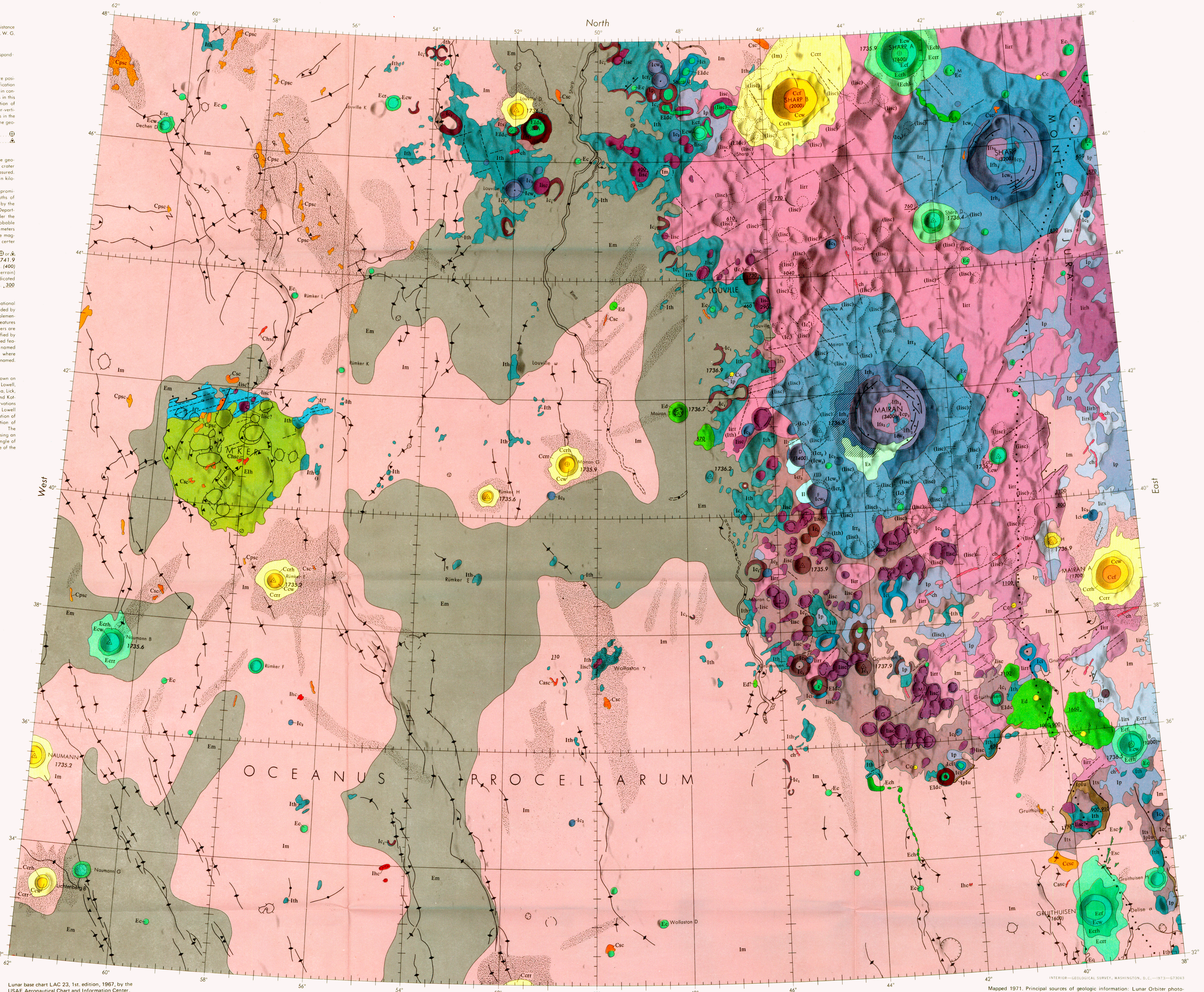
Lengths of Radius Vectors to control points . . . . . ⊕ or ▲ 1741.9
Depth of craters (rim to floor) . . . . (400)
Relative Elevations (referenced to surrounding terrain) with direction and extent of measured slope indicated 300

NAMES

Feature names were adopted from the 1935 International Astronomical Union nomenclature system as amended by Commission 16 of the I.A.U., 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. Names of the supplementary lettered features are deleted when the association with the named feature is apparent. A black dot is included, where necessary, to identify the exact feature or features named.

PORTRAYAL

The configuration of the lunar surface features shown on this chart is interpreted from photographs taken at Lowell, U.S. Navy, Catalina Station-University of Arizona, Lick, McDonald, Mount Wilson, Yerkes, Pic du Midi and Kottomia Observatories. Supplementary visual observations with the 20 and 24 inch refracting telescopes at Lowell Observatory provide identification and clarification of indistinct photographic imagery and the addition of minute details not recorded photographically. 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.



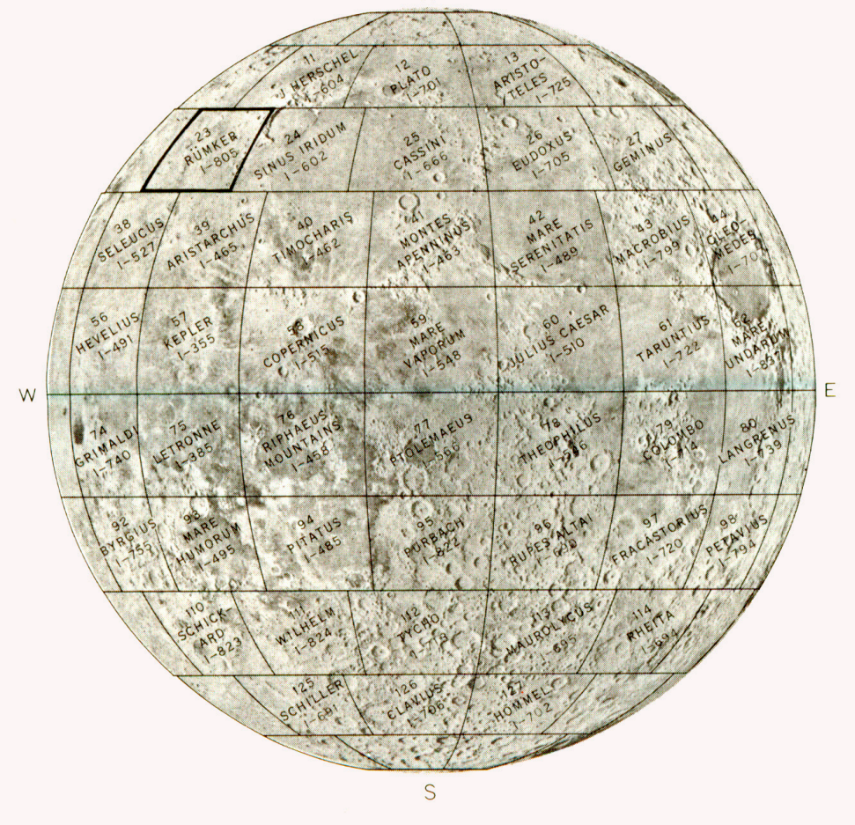
INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1973—G73063

Lunar base chart LAC 23, 1st edition, 1967, by the USAF Aeronautical Chart and Information Center, St. Louis, Missouri 63118

Mapped 1971. Principal sources of geologic information: Lunar Orbiter photographs shown on index map; high-illumination photograph 9991H, U.S. Naval Observatory, Flagstaff, Arizona; thermal data from Shorthill and Saari (1969); albedo data from Pohn, Wildey, and Sutton (1970); color data from Whitaker (1966).

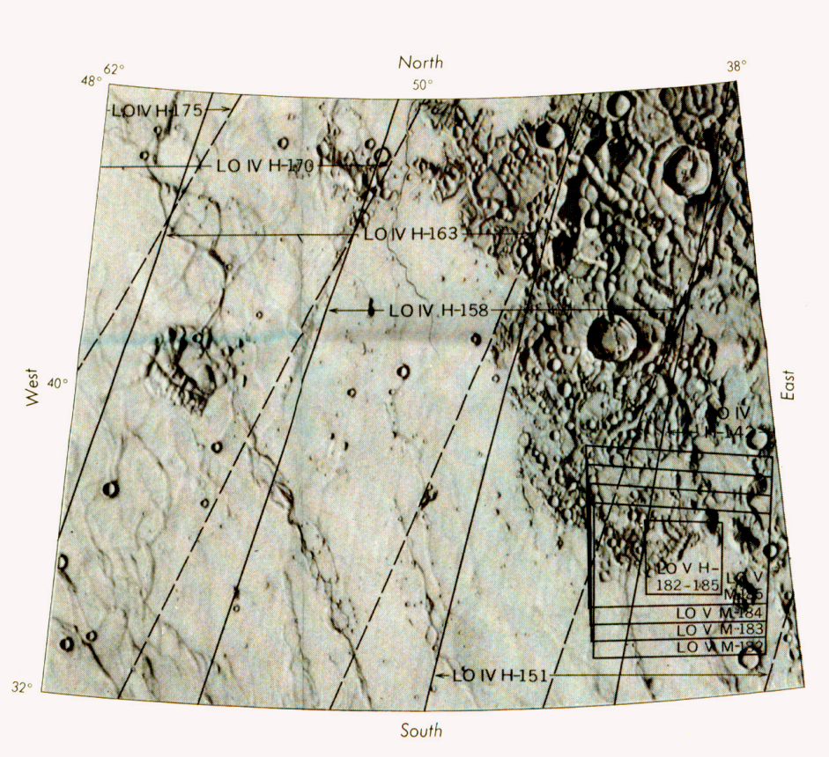
SCALE 1:1,000,000
LAMBERT CONFORMAL PROJECTION
STANDARD PARALLELS 21°20′ AND 42°40′

STATUTE MILES
KILOMETERS



INDEX MAP OF THE NEAR SIDE OF THE MOON

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



LUNAR ORBITER PHOTOGRAPHIC COVERAGE OF RÜMKER QUADRANGLE

Numbers refer to high-resolution frames of Orbiter IV and high- and medium-resolution frames of Orbiter V.

(Em)

Contact
Dotted where buried. Buried unit indicated by symbol in parenthesis

Fault
Bar and ball on downthrown side

Rille
Long depression, straight to sinuous. Ball on single line where narrow; dashed where indistinct
Interpretation: Graben; sinuous parts may be collapsed or partly collapsed (dashed) lava tubes interconnecting evacuated subsurface magma chambers into which lava has withdrawn

Mare ridge
Line along crest
Interpretation: volcanic extrusion

Mare scarp
Barb at base of scarp indicates slope direction

Lineament
Narrow ridge and trough in terra, mostly radial to large craters
Interpretation: Fault, fracture and (or) depositional and scour pattern of impact ejecta

Terra ridge
Interpretation: Faulted and titled block around craters Iridum, Mairan, or Sharp. In Sharp B may be dike

Buried crater rim
Line marks topographically expressed crest

Rimless depression
Collapse caldera or volcanic vent into which lava has withdrawn

ch

Chain-crater material
Alined, rimless to low-rimmed overlapping craters
Interpretation: *Structurally controlled volcanic craters or collapse depressions*

Dome in Rümker Hills and mare material
Interpretation: Igneous intrusion

Iridum satellitic crater rim crest

Dark mantling material

Major ring of Imbrium basin

GEOLOGIC MAP OF THE RÜMKER QUADRANGLE OF THE MOON

By

David H. Scott and R. E. Eggleton

1973

E X P L A N A T I O N

COPERNICAN SYSTEM

Crater Materials

Cc	Ccr	Ccrh	Ccrr	Ccw	Ccf

Materials of craters with bright rays or halos

Characteristics
Materials of sharp-rimmed nearly circular craters surrounded by bright rays or halos. High thermal response at eclipse associated with craters > 7 km rim crest diameter except largest (23 km) crater, Sharp B; north rim and wall of this crater are transected by prominent ridge (best seen on L.O. IV 157-M)
Cc, *crater material, undivided. Craters too small (< 3 km) for subdivision of units*
Ccr, *rim material, undivided. Grades from hummocky to smooth outward from rim crest. Subdivided (Ccrh, Ccrr) in craters > 6 km as follows:*
Ccrh, *rim material, hummocky. Steep concave collar outside rim crest; sharp break in slope at base*
Ccrr, *rim material, radial. Texturally gradational with hummocky rim material; becomes smoother and finer outward; has ridges and grooves radial to crater or in herringbone pattern with apices toward crater*
Ccw, *wall material. Contact with rim material arbitrarily mapped at rim crest; steep smooth bright slopes extending from rim crest to floor*
Ccf, *floor material. Hummocky to relatively smooth surface at base of crater wall. Not mapped in craters < 10 km*
Interpretation
Crater morphology indicates impact origin; high thermal anomalies associated with exposures of fresh bedrock (Shorthill and Saari, 1969). Prominent ridge transecting rim and wall of Sharp B may be dike
Ccr, Ccrh, *unsorted ejecta; abundant large blocks intermixed with small fragments overlying thrust sheets of fractured bedrock*
Ccrr, *base surge and ballistically deposited ejecta; becomes finer grained and probably better sorted with semblance of bedding farther from crater*
Ccw, *fractured bedrock and shock-produced breccia on upper part of wall; contact with thrust slices and ejecta blocks not discernible. Slump and talus deposits near base of wall*
Ccf, *shock brecciated and partly melted materials; may include finer fractions of fallback and blocks of bedrock faulted and uplifted by adjustment to stresses produced by impact; possibly some volcanic material included*

▨

Bright ray and halo material

Characteristics
Forms bright diffuse streaks and halos on maria. Streaks coincide approximately with satellitic crater material and trend toward large primary craters, mostly outside quadrangle. Halos around craters < 10 km diameter
Interpretation
Highly dispersed, finely divided fragmental ejecta of large Copernican primary impact craters and associated secondary craters

Csc	Casc
	Chsc
	Ccsc
	Cpsc

Materials of satellitic craters

Characteristics
Materials of sharp, bright, shallow, circular to elongate to V-shaped craters occurring singly and in clusters and chains mostly within rays. Long axes of chains and apices of V's generally directed toward large primary craters (outside quadrangle) designated by first lower case letter. Superposition relations not determinable, but stratigraphic sequence shown based on physical characteristics of primary craters such as morphology, brightness of rays, and thermal anomaly
Csc, *primary crater unidentified*
Casc, *radial to Aristarchus*
Chsc, *radial to Harpalus*
Ccsc, *radial to Copernicus*
Cpsc, *radial to Pythagoras*
Interpretation
Secondary impact craters formed by ejecta from designated primary crater or from unidentified crater

ERATOSTHENIAN SYSTEM

Mare and Light Plains Materials

Em

Mare material

Characteristics
Flat, smooth; low density of small craters; darker (albedo < 0.080 to about 0.085) and bluer than Imbrian mare material. Embays Eratosthenian crater Naumann G and upper Imbrian craters, but other Eratosthenian craters and rays of Copernican craters superposed
Interpretation
Basalt flows mostly of Eratosthenian age

Ec	Ecr	Ecrh	Ecrr	Ecw	Ecf

Materials of sharp-rimmed rayless craters

Characteristics
Morphologically similar to corresponding units of rayed craters but rim crests more subdued and texture of radial rim material (Ecrr) *less distinct. Materials of craters < 5 km are undivided. Thermal anomalies moderate to absent, but high at crater Gruithuisen; albedo high to intermediate on terrae, intermediate to low on maria*
Interpretation
Same as corresponding units of rayed craters. Subdual of rim crests and radial rim texture attributed to erosion by small impacts and mass wasting. Decrease in albedo and thermal registry due to partial covering of bedrock by fine mass-wasted debris; rays have darkened with time and are not discernible

Esc

Material of craters satellitic to crater Gruithuisen

Characteristics
Similar to Copernican satellitic crater materials but less bright, more subdued, and radial to Gruithuisen; occurs within 50 km of Gruithuisen
Interpretation
Secondary craters formed by ejecta from Gruithuisen

Volcanic(?) Landform Materials

Ech

Material of chain craters

Characteristics
Material of alined, low-rimmed and rimless craters located in northeast and southeast parts of quadrangle. Southern chain consists of small (2 km), elongate, bowl-shaped craters and flat-bottomed depressions and narrow, gash-like clefts, lying along a somewhat sinuous mare ridge; chain trends NNW, parallel to major ridges in Oceanus Procellarum and the Rima Sharp rille system to the northwest; craters in chain appear as fresh as small nearby Eratosthenian craters. Craters in the northern chain, between craters Sharp and Sharp A, are mostly coalesced and form a nearly continuous arcuate trough about 3 km wide; superposed on rim material (Irr_2) *of Sharp but covered by rim material* (Ecrr) *of Sharp A*
Interpretation
Volcanic fissures and collapse depressions of Eratosthenian age. Southern chain, like some terrestrial analogs, controlled by regional structure (Scott and Trask, 1971)

Ed

Dome material

Characteristics
Material of large, high (> 1600 m) domes (Gruithuisen γ and δ) in southeast part of map area, and smaller domes mostly near east margin of Oceanus Procellarum. Albedo high. Gruithuisen domes have smooth to hummocky, gently rounded crests and steep hackly sides which apparently overlap mare basalts and structures in the mare (rille, depression, and ridge). Mairan T, a nearly circular dome with group of summit craters, possibly embayed by mare basalt (Em). *Queried where may be hill of unit* Ith
Interpretation
Volcanic cumulo-domes composed of viscous felsic lava. Eratosthenian age suggested by superposition on Imbrian mare and possible embayment by Eratosthenian mare

Es

Smooth material on crater Mairan

Characteristics
Smooth, bulbous material, forms level surfaces in low areas. Subdues southern rim crest and hummocky rim member (Irh_2) *of Mairan. Albedo intermediate; may be partly covered by dark mantling material (line pattern)*
Interpretation
Volcanic material extruded from fractures along south rim and wall of Mairan; younger than Mairan, probably Eratosthenian in age

EIdc

Material of clustered domes

Characteristics
Material forming clusters of small (about 1 km) subcircular to elongate bulbous domes. Occurs in craters having ringed floors (Icfr) *and some irregular craters* (Ici), *lower Imbrian* (Ic_1), *and Iridum satellitic* (Iisc) *craters. Appears fresh except where subdued by rim material of Copernican crater Sharp B*
Interpretation
Volcanic domes made up of viscous extrusive rocks of intermediate or felsic composition. Younger than early Imbrian, older than Copernican; thus may range from Eratosthenian to middle Imbrian in age

EIh

Material of Rümker Hills

Characteristics
Plateau-forming material; topographically expressed by broadly terraced, smooth, undulating plains surmounted by domical hills. Albedo low; small craters abundant to sparse, as on adjacent mare; axes of superposed crater chains directed toward large craters Harpalus and Pythagoras outside quadrangle. Individual hills circular to irregular in outline, with nearly flat-topped to gently convex profiles. Unit embayed by mare basalts except on southwest margin where it apparently overlaps a mare ridge and scarp
Interpretation
Volcanic flows, pyroclastics, and intrusive and extrusive igneous plugs (see text)

IMBRIAN SYSTEM

Im

Mare material

Characteristics
Similar to and gradational with Eratosthenian mare material but not as dark (albedo about 0.085-0.097), redder, and higher density of small craters. Embays upper Imbrian craters but Eratosthenian craters superposed
Interpretation
Basalt flows mostly of late Imbrian age. Decrease in albedo and redness from Imbrian to Eratosthenian mare materials suggests compositional change of flows with time

Ip

Light plains material

Characteristics
Flat, smooth material having higher albedo and higher density of small craters than mare materials. Fills depressions in terra; overlapped in places by Imbrian mare units but is superposed on Iridum rim materials
Interpretation
Probably mostly volcanic flows of late Imbrian age; possibly similar to mare basalts, but higher albedo suggests more felsic minerals or more thorough brecciation by impact and a thicker and more complete regolith than for the mare. Some patches may consist of local mass-wasting products derived from adjacent topographic highs. Imbrium and Iridum ejecta may be present locally

Ic_2	Icr_2	Irh_2	Irr_2	Icw_2	Ifs_2	Ifh_2	Icp_2

Materials of moderately subdued craters

Characteristics
Wall and rim materials (Icw_2, Icr_2) *of craters < 12 km similar to corresponding units of younger craters but rims more subdued, walls less steep, albedo low, no thermal anomalies except Mairan (moderate) and Sharp (high). Craters < 8 km undivided. Superposed on Iridum crater rim units. Materials of craters Mairan (40 km) and Sharp (40 km) subdivided as follows:*
Irh_2, *rim material, hummocky. More subdued counterpart of similar unit in younger craters but in places extends inside rim crest. Has low albedo on west side of Mairan, shown by ruled symbol*
Irr_2, *rim material, radial. Same as around younger craters but more subdued. Eratosthenian craters superposed. Albedo intermediate*
Icw_2, *wall material. Terraced; smooth on steep scarps, hummocky and ridged at base of scarps*
Ifs_2, *floor material, smooth*
Ifh_2, *floor material, hummocky*
Icp_2, *peak material. Resembles hummocky floor material but has slightly more positive relief*
Interpretation
Impact crater materials of late Imbrian age; compared with younger craters, morphologic characteristics progressively subdued with time. Thermal anomalies at Mairan and Sharp attributed to fresh bedrock exposed on fault scarps; faulting has widened craters, produced terraces, and caused slumping of rim material (Irh_2) *into crater interiors. Peak material* (Icp_2), *like hummocky floor material* (Ifh_2), *consists of faulted brecciated bedrock but more highly uplifted near crater centers*

Ihc

Material of cratered hills

Characteristics
Material of small (2-6 km) circular to elongate hills with summit craters whose floors are higher than adjacent terrain. Hills convex upward; summit craters commonly breach sides of hills. Albedo about same as mare materials which embay hills. Mostly occur southeast of Rümker Hills and closely resemble similar-sized hills of the Marius Hills (McCauley, 1968)
Interpretation
Composite volcanic constructional forms; probably made up of interbedded lava flows and pyroclastic materials of basaltic composition

Il

Lobate material

Characteristics
Smooth to hummocky material having lobate margins and extending outward from rim crests of craters Mairan D and F. Modifies morphology of crater rim material (Icr_2) *and subdues or obscures sharp break in slope between rim material and adjacent terrain. Radial rim material* (Irr_2) *of Mairan superposed in places. Albedo intermediate*
Interpretation
Volcanic material extruded from fissures on flanks of craters Mairan D and F and partly burying their rim materials

Iridum Crater Materials

Iirh	Iirs	Iirr

Rim materials of Iridum crater

Characteristics
Intergradational units around rim of Iridum crater (Sinus Iridum, east of quadrangle)
Iirh, *rim material, hummocky. Mountainous terrain (Montes Jura) formed by ridges and valleys roughly concentric with Iridum crater; local relief may exceed 500 m. Ridges coarsely lineated radial to crater. Transitional with radial rim material* (Iirr) *and transitional or partly subdued by smooth rim material* (Iirs). *Embayed by plains material* (Ip)
Iirs, *rim material, smooth. Undulating, moderate to low relief without lineations or Iridum satellitic craters* (Iisc). *Embayed by plains unit and Imbrian mare materials but in places appears intergradational with plains*
Iirr, *rim material, radial. Smooth to hummocky, low to high relief; lineated by ridges and troughs (1 km to several km wide) radial to Iridum crater. Subdues ridges of Montes Jura and Iridum satellitic craters. In places, outer limit of radial rim unit mapped where appearance of satellitic craters changes from subdued to sharp. Unit buries or partly buries lower Imbrian craters, but upper Imbrian craters superposed*
Interpretation
Materials produced by the impact that formed Iridum crater during an instant of middle Imbrian time
Iirh, *large ridges of fractured bedrock and blocky ejecta uplifted by major faults concentric with Iridum crater; radially lineated by smaller normal faults and by troughs sculptured by ejecta having high-velocity, low-angle trajectories*
Iirs, *a blanket of relatively fine ejecta deposited as fallback having low lateral velocity component*
Iirr, *ejecta blanket deposited by turbulent, mobile, ground-hugging cloud of debris (base surge) having moderate lateral velocity; entrained fragments deposited as outward-thinning wedge that buried and partly buried secondary impact craters* (Iisc) *formed by earlier arrivals of higher velocity ejecta. Radial ridges and troughs produced by particle fallout and gouging along outwardly directed vectors having variable velocity within debris cloud; other lineaments of structural origin developed during and after impact*

Iisc

Material of craters satellitic to Iridum crater

Characteristics
Material of shallow bowl-shaped craters occurring individually and in clusters and chains peripheral and radial to Iridum crater; rim-crest outlines nearly circular to elongate, asymmetrical and roughly V-shaped, widening away from Iridum and commonly breached or poorly developed in this direction. Larger craters, as much as 10 km across, may have well-developed rim or partial rims. Most satellitic craters within the clearly recognizable radial rim member (Iirr) *of Iridum craters are subdued. Queried where origin or age uncertain*
Interpretation
Secondary crater material formed by impact of coherent blocks and clustered fragments of ejecta from Iridum crater. Material deposited along ballistic trajectories preceding arrival of slower moving finer debris of unit Iirr; *range of secondary impact material exceeds that of unit* Iirr

Ic_1

Material of subdued craters

Characteristics
Crater material undivided. Outlines are nearly circular, rim crests raised but rounded, floors bowl-shaped to flat and partly filled by plains (Ip), *smooth terra* (Its), *or clustered dome* (EIdc) *materials. Craters adjacent to Oceanus Procellarum deeply embayed by mare basalts. In places covered or partly covered by Iridum crater ejecta* (Iirr)
Interpretation
Most craters formed by impact; those having floors of clustered dome material may be volcanic. Younger than Imbrium basin, older than Iridum crater

Ici

Material of irregularly shaped craters

Characteristics
Materials of craters whose asymmetric outlines apparently are not composed of overlapping, coalescing rims of circular craters. Rim crests very low to moderate relief. Some floors contain unit EIdc. *Iridum satellitic craters* (Iisc) *superposed in places*
Interpretation
Volcanic origin suggested by irregular shape and association with unit EIdc. *Age probably early Imbrian*

Icfr

Material of craters with ringed floors

Characteristics
Undivided material of craters Gruithuisen K (6 km) and Louville DA (12 km) having annular ring or rings centered within main rim crest. Similar-appearing craters common elsewhere on Moon. Gross morphology resembles that of small (1 km) cinder cone near Mount Lassen, Calif. (Chapman and others, 1969, fig. 31-6). Floors of Louville DA and Gruithuisen K covered by unit EIdc *between inner ring and crater wall. Rim crests moderately subdued, and rims partly embayed by Imbrian mare basalt. Central part of inner ring of Gruithuisen K appears very smooth on high-resolution photographs (L.O. V 182-H)*
Interpretation
Volcanic craters of Imbrian age; central part of Gruithuisen K may be younger. Annular rings may be dikes, cone sheets, or ejecta rims produced by subsequent eruptions from central vent

Imbrium Basin Materials

Ith	Its

Materials of hilly and smooth terra

Characteristics
Intergradational units; appear beyond outer margin of Iridum radial rim material (Iirr), *which generally seems to be superposed on both units. Embayed by plains units* (Ip), *but contact relations with lower Imbrian crater material* (Ic_1) *indistinct. Albedo intermediate*
Ith, *hilly to hummocky. Small patches resemble Alpes Formation, part of the ejecta blanket of the Imbrium basin (Page, 1970), but hills generally more variable in size and shape and more subdued. Iridum satellitic craters* (Iisc) *superposed but rim crests subdued*
Its, *smooth, undulatory. Rim crests of Iridum satellitic craters mostly sharp. More lineaments than unit* Ith, *less than* Iirr
Interpretation
Accumulations of mass-wasted debris, impact-crater ejecta, and volcanic materials covering Imbrium basin ejecta blanket (Alpes and Fra Mauro Formations)
Ith, *relatively thin cover which masks subjacent topography but does not obliterate it. Iridum satellitic craters more subdued than on unit* Its *because of higher rate of crater degradation on sloping surfaces*
Its, *relatively thick cover concealing older landforms*

If

Fra Mauro(?) Formation

Characteristics
Smooth, lineated, slightly hummocky material in north part of Rümker Hills; embayed by mare material. Texturally resembles Fra Mauro Formation in other places around Imbrium basin at similar distances from outer ring (450 km). Identity queried because albedo and density of small craters generally lower than typical Fra Mauro and lineations trend east-northeast (not radial to Imbrium basin). Hills characteristic of material of Rümker Hills present but more subdued
Interpretation
Fra Mauro(?) Formation intruded by igneous plugs and partly blanketed by younger material of Rümker Hills. Lineament trend controlled by lunar grid systems

PRE-IMBRIAN OR IMBRIAN

Iplu

Undivided material

Characteristics
Material forming smooth scarps in southeast part of map area. Overlain by hilly (Ith) *and smooth* (Its) *terra units. Abrupt break in slope with adjacent terra or mare materials at base of scarps. Relief decreases toward southwest*
Interpretation
Material uplifted and tilted by faulting during and after Imbrium basin impact. Probably includes pre-Imbrian rocks overlain by Imbrium basin ejecta

GEOLOGIC SUMMARY

SETTING

The Rümker quadrangle, in the northwest quadrant of the Moon, is adjacent to the western rim of the multi-ring Imbrium basin and to Sinus Iridum, a large (220 km diameter) mare-filled crater. Both of these great depressions were probably formed by impact, as indicated here and elsewhere on the Moon by the characteristic form, distribution, and texture of surrounding materials and structures. The Imbrium basin and Iridum crater were filled by mare materials during the Imbrian and Eratosthenian Periods. In this quadrangle, the widespread ejecta blanket of the Imbrium basin, as well as the basin's concentric ridges and mountain rings, has largely been buried by terra materials of mixed origin and by ejecta from Iridum and numerous smaller impact craters. These materials, together with some terra units of probable volcanic origin, make up the highland terrain. Mare materials of Oceanus Procellarum cover part of this westward-sloping highland shelf and separate it from the Rümker Hills, an isolated plateau surrounded by the mare. No visible discontinuity distinguishes mare materials of Oceanus Procellarum from those in the Imbrium basin, both of which contain several units having similar albedo and color. Parts of the mare are very dark and smooth and appear relatively young, and parts of the terra contain many diverse landforms of Imbrian and younger age that appear to be volcanic. This region may therefore have been more active internally during the late stages of lunar history than many others on the near side.

GEOLOGIC UNITS

The relative ages of units are determined by superposition and transection relations and, less definitively, by morphologic and other criteria such as topographic sharpness, crater density, albedo, and thermal response at eclipse. Where possible, all units are assigned to the lunar stratigraphic column, as proposed by Shoemaker (1962), Shoemaker and Hackman (1962), and Wilhelms (1970). Materials are grouped into five categories according to their physical characteristics, probable mode of origin, or association with a major feature or event.

Imbrium basin materials

Imbrium basin materials comprise those units which by their age and distribution appear to be more closely associated with the formation of the Imbrium basin than with later volcanic, tectonic, or impact events. Materials exposed in fault scarps bounding tilted blocks marginal to the basin in the southeast highlands probably consist of Imbrium ejecta and pre-basin bedrock. The units are indistinguishable on the photographs and are mapped as one (Iplu). The Fra Mauro Formation is questionably identified in the Rümker Hills, but elsewhere the characteristic swirly texture of this Imbrium basin ejecta blanket as well as its hilly counterpart, the Alpes Formation, is not recognized. Instead, two terra units (Ith, Its) make up most of the highland terrain around the Imbrium basin. These units resemble subdued versions of both the Alpes and Fra Mauro Formations; thus they are interpreted as mantling units of unknown composition, origin, and thickness.

Iridum crater materials

The ejecta blanket of the Iridum crater extends about 250 km from the rim of Sinus Iridum just east of the quadrangle and provides a good marker horizon for this region of the Moon. It covers Imbrium basin materials and crater materials of early Imbrian age; superposition relations of younger units indicate that it is of middle Imbrian age. As with other large craters of impact origin, the rim materials of Iridum are subdivided into members by their texture, depositional patterns, and relief--characteristics which also reflect the size, mode of transport, and velocity of the ejected or displaced materials. Within and beyond the continuous ejecta blanket are numerous craters and clusters of overlapping craters having elongate asymmetric outlines whose orientation and disposition indicate secondary impacts generated by the Iridum event. The largest individual members of the Iridum secondary crater population are about 10 km in diameter. The ratio of maximum secondary crater diameter to that of the primary crater is thus about 1:22, about the same as that around large craters like Copernicus or the Orientale basin.

Mare and light plains materials

Two mare units of Eratosthenian and Imbrian age are distinguished in Oceanus Procellarum by their albedo, color, and density of small craters. Imbrian mare and plains materials fill small isolated depressions within the terra. Albedo and crater density apparently increase progressively with increasing age: the youngest mare unit (Em) is dark and smooth, whereas plains material (Ip) is light and highly pitted with small craters. Spectral reflectance (Whitaker, 1966) has also been useful for subdividing mare materials as color seems to be generally constant within individual units. Older units appear redder than younger ones, and the younger reflect more blue light. Although color may be related both to composition and to age, this concordance between color and relative age may indicate a progressive change in composition of the materials with time.

Imbrian craters more than 3 km across are much more numerous on terrae than on maria, whereas Eratosthenian and Copernican craters are about equally abundant on both types of terrain. The Imbrian craters are embayed by both mare units but, with one possible exception (Naumann G), Eratosthenian and younger craters are superposed on the mare. These relations are in accord with a latest Imbrian age for the oldest mare unit and a Copernican or late Eratosthenian age for the mare embaying the Eratosthenian crater. The paucity of partly buried craters or their outlines indicates that the mare materials (probably basalts) are thick enough to have completely covered most Imbrian craters and probably some pre-Imbrian craters as well.

Crater materials

The age of the craters mapped here ranges from early Imbrian to Copernican. A progressive decrease in the abundance of older to younger craters on the terra probably reflects a declining flux of impacting meteorites with time. Except for numerous secondary craters from Iridum, most craters have nearly circular outlines, rough rims, and deep, flat to bowl-shaped floors characteristic of an impact origin. Other craters have morphologies and material associations suggestive of an internal origin and are discussed below.

Volcanic(?) landform materials

Aside from the extensive basalt flows in Oceanus Procellarum, many other features in themselves or by association with others reflect the operation of volcanic processes in this region. The Gruithuisen domes (Ed) and some smaller similar domes mapped as the same unit resemble terrestrial cumulo-domes formed by extrusions of highly viscous lava (Holmes, 1965, fig. 229). In the Rümker Hills, plug-like forms which have arched and possibly penetrated to the surface are bordered in places by lobate scarps resembling lava-flow fronts. Unlike most upland areas, the Rümker Hills have a low albedo, comparable with that of the adjacent mare, and, like the mare, they are probably basaltic in composition or are mantled by basalt.

Within the mare in the southeast part of the quadrangle a series of small craters (Ech) separated by mesa-like hills form a long, somewhat sinuous chain resembling a string of beads. Most of these craters are rimless, or nearly so (unlike impact craters) and resemble depressions formed by caving along parts of a lava tube or by subsurface drainage of magma into fissures and subsequent collapse. In this respect, the crater chain probably represents an early and incomplete stage in the process of rille formation; individual depressions did not coalesce and develop into the winding, continuous, flat-floored valleys illustrated by Rima Sharp to the northwest.

Crater chains as well as several hills with summit craters or breached ramparts (Ihc) in the western mare have morphologic analogs in terrestrial volcanic fields (Scott and Trask, 1971). Craters with ringed floors (Icfr) are like those mapped elsewhere on the Moon (Trask and Titley, 1966). An outstanding terrestrial example of this type of crater occurs in the Mount Lassen volcanic province (Chapman and others, 1969, fig. 31-6). The floors of ringed craters as well as some other craters in the Rümker quadrangle are filled with clusters of small domes (EIdc). This association of clustered domes with craters resembling terrestrial volcanoes suggests that the domes may be tholoids consisting of viscous lava like those that form steep-sided domes in the vents of some strato-volcanoes on Earth. Other features, such as chain craters (ch), lobate material (Il), and a smooth unit (Es) on the rim of the crater Mairan, are also interpreted as volcanic and suggest that magmatic differentiation progressed farther here than elsewhere on the Moon.

STRUCTURE

The main rim of the Imbrium multi-ring basin is poorly defined here. It originally formed high mountains like those of the Carpathian, Apennine, and Caucasus around other parts of the basin. These have subsided and been buried by mare basalts, Iridum crater ejecta, and other materials. The large ridges of the Montes Jura are more nearly concentric with the Iridum crater than with the Imbrium basin. Some of the high but subdued areas north of the Gruithuisen domes, however, may be remnants of an Imbrium rim. Major mare ridges and rilles (such as those of Rima Sharp) within Oceanus Procellarum strike northwest to about latitude 40°-45° N., where their trends swing rather abruptly to the northeast into Sinus Roris. This change in direction roughly reflects the curvature of the Imbrium basin and suggests that the ridges and rilles owe their existence (at least in part) to faults and fractures concentric with the basin. The ridges may represent upwelling and solidification of basaltic material along fractures during late stages of mare extrusion, whereas the rilles, like some of the chain craters (Ech) previously discussed, are probably collapsed lava drainage channels.

Troughs and ridges radial to Sinus Iridum occur in the rim materials of the Iridum crater and within terra units. Some of these lineaments probably resulted from sculpturing of the terrain by missiles within the ejecta cloud. However, many crater chains (ch) parallel lineament directions and, as they occur on plains deposits, must have formed after the Iridum impact. It seems likely, therefore, that many lineaments, as well as crater chains, have structural roots.

GEOLOGIC HISTORY

The extensive ejecta blanket produced by the large impact which formed the Iridum crater eradicated much of the geologic record in the Rümker quadrangle prior to middle Imbrian time. The Fra Mauro (?) and Alpes Formations, which are characteristic of the earlier more widespread ejecta blanket around the Imbrium basin, were mostly buried by the Iridum crater materials as well as other younger units such as hilly and smooth terra and the mare materials of Oceanus Procellarum.

Evidence for early Imbrian to Eratosthenian volcanism in the highlands is present (units Icfr, Ici, EIh, EIdc, Ed). (The more extensive terra materials (Ith, Its) also may be partly of volcanic origin.) The Rümker Hills were formed by faulting, uplift, and the intrusion of large plug-like forms which may have locally arched the surface and penetrated it during the Imbrian and Eratosthenian Periods. During the latter part of the Imbrian Period, lava flows filled crater floors and depressions within the terra, forming the level plains (Ip) in this area. These initial flows were succeeded by larger volumes of darker materials, probably basalts, which filled great depressions and formed the maria of Oceanus Procellarum, the Imbrium basin, and Iridum crater. A change in composition of the basalt flows with time is indicated by albedo and color variations. The later flows that probably formed in Eratosthenian time are darker and bluer.

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Prepared on behalf of the National Aeronautics and Space Administration under contract No. W-13, 130

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