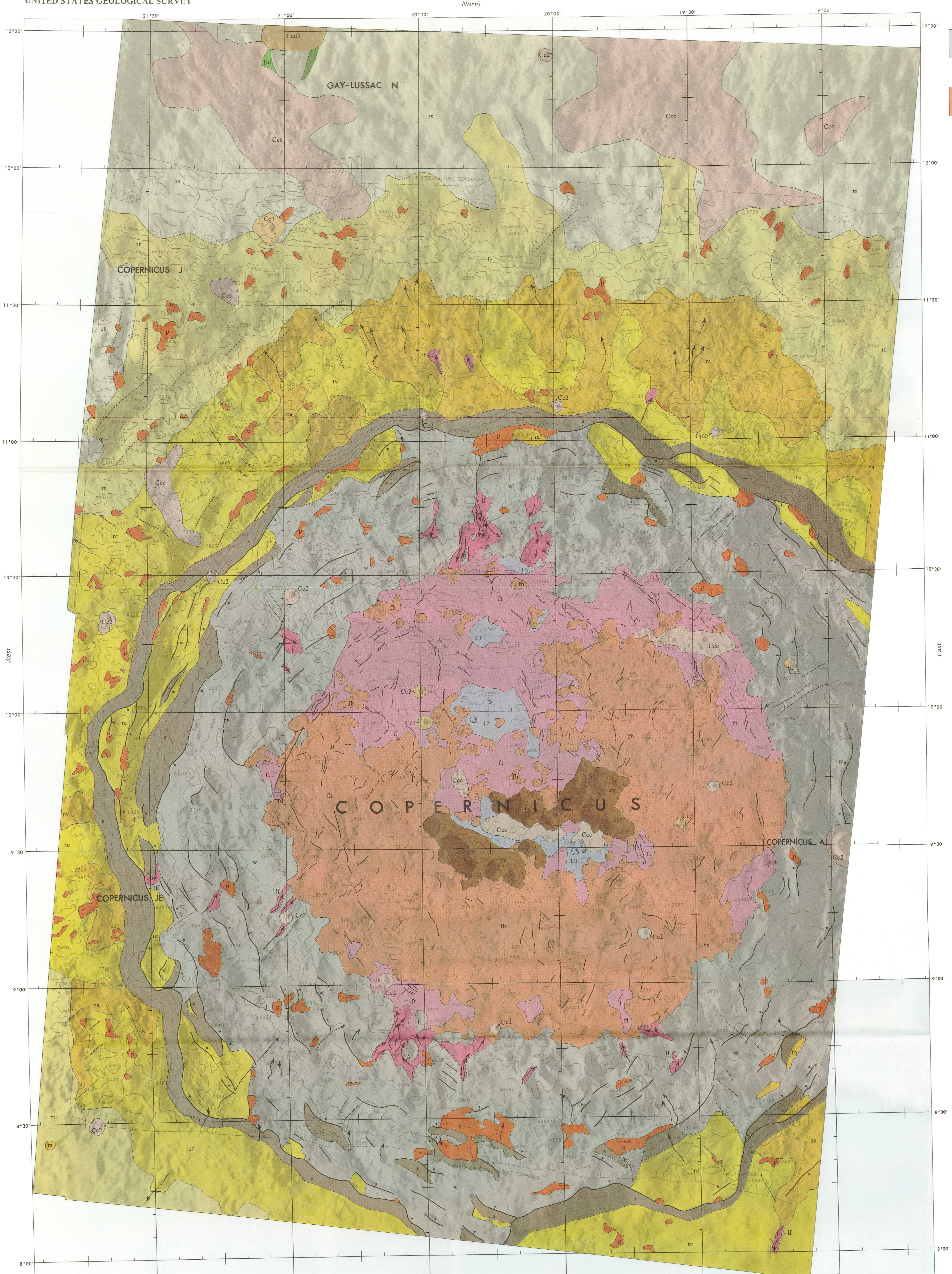
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

Prepared in cooperation with the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION



Base is lunar topographic photomap Copernicus, Orbiter-V-site 37, 1st edition January 1971 by U.S. Army Topographic Command
The horizontal and vertical control was established by photogrammetric triangulation using orbit constraints and is based on Lunar Orbiter V ephemeris data dated 15 Oct. 1968
Relative horizontal accuracy is ±1184 metres expressed at 90 percent probability

Contours and spot elevations are expressed as radius vectors in metres with the first three digits omitted. For example, a radius vector of 1,735,200 metres is expressed as 5200 metres
Vertical accuracy ranges from ±97 metres in center to ±585 metres at north and south ends of map, expressed at 90 percent probability

SCALE 1:250 000
TRANSVERSE MERCATOR PROJECTION

5 0 5 10 NAUTICAL MILES
5 0 5 10 STATUTE MILES
5 0 5 10 KILOMETRES

CONTOUR INTERVAL 400 METRES
SUPPLEMENTARY CONTOURS (DASHED) AT 200 METRE INTERVAL

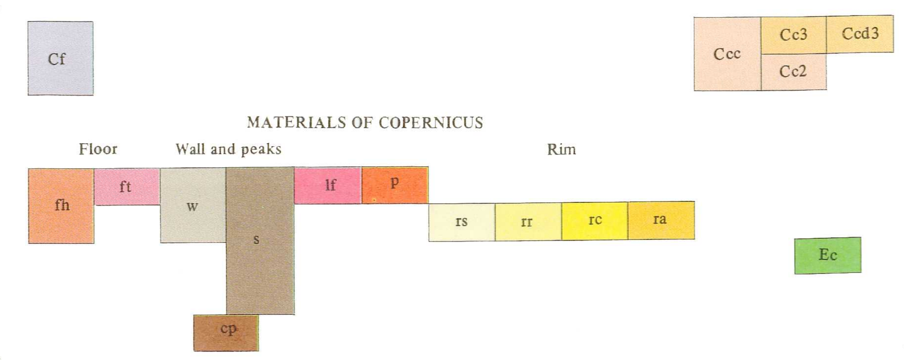
Interior — Geological Survey, Reston, Va. —1975

Mapped 1969-72. Principal sources of geologic information: Lunar Orbiter high-resolution photographs II-162 (oblique); IV 121, 126; V 150 to V 157; Lunar Orbiter medium-resolution photographs V 150 to V 157
Prepared on behalf of the National Aeronautics and Space Administration under contract No. W13, 130
Dedicated to the astronomer Nicolaus Copernicus 500 years after his birth in 1473

GEOLOGIC MAP OF THE CRATER COPERNICUS

By
K. A. Howard
1975

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Cf FILL MATERIAL – Flat part of Copernicus floor in which cracks and prominent texture are either lacking or greatly subdued; boundaries gradational with textured floor material; crater counts indicate an age younger than other Copernicus units (Greeley and Gault, 1971). *Interpreted* as thin mantle of mass-wasted detritus or ejecta that collected in lows; alternatively may be young volcanic materials

CRATER MATERIALS

Cc3 Craters moderately sharp crested, blocky; one 1-km crater has distinctive rays. *Interpreted* as material of impact craters

Ccd3 Dark halo around crater; belongs to a set of dark-halo craters (beyond map area) at distances > 1 crater radius from Copernicus. *Interpreted* as impact ejecta consisting mainly of mare basalt or other dark material excavated from beneath brighter Copernicus ejecta

Cc2 Craters are slightly blocky; rim crests moderately subdued. *Interpreted* as material of degraded impact craters

Ccc CRATER-CLUSTER MATERIAL – Round clustered craters; diameter range 100-800 m; generally not blocky; shapes correspond to Cc2 and Cc3 craters in Trask's (1970) scheme. *Interpreted* as probably secondary impact craters; some may be from high-angle late-falling Copernicus ejecta

Ec CRATER MATERIAL – Walls of nearly obliterated 7-km-wide crater. *Interpreted* as a crater partly swamped by Copernicus smooth rim material

MATERIALS OF COPERNICUS

fh HUMMOCKY FLOOR MATERIAL – Isolated to coalesced hummocks, ½-4 km across, partly separated by small patches of textured floor material; hills generally blocky; fissures numerous but less abundant than in textured floor unit; hummocks merge with some of larger hummocks of wall material; largest hummocks, just southeast of central peaks, are gradational in size with central peaks but are darker and distinctly fissured. *Interpreted* as fractured bedrock, partly displaced by inward movement of slumps off the wall; mostly coated by a cracked veneer of impact melt

ft TEXTURED FLOOR MATERIAL – Level to rolling ground that on a fine scale consists of intervening irregular subparallel ridges or hummocks and troughs a few metres in relief and 50-100 m across; contains a few pit craters; cut by numerous irregular winding and branching fissures that have rounded lips; fissures narrow downward so that outcrop walls are a few metres apart in the bottom; cracks and ridge-trough texture both show patterns related (for example, concentric) to edge of crater floor or to local hills; floor material on west side is apparently lowered from similar material on crater walls; some blocks on surface or in pit craters; most superposed craters are very blocky. *Interpreted* as pooled impact melt (probably only partly molten) derived partly from drainage down crater walls; ridge-trough texture may be flow pressure ridges and partly fissures; fissures were caused by shrinkage (possibly enlarged by degassing), which indicates considerable contraction due to solidification and degassing of rock melt; surface subsided considerably owing to this contraction and possibly by drainage into subsurface breccia; blocks and small hummocks may represent unmelted blocks in impact melt, or possibly rootless spatter mounds

w WALL MATERIAL. Irregular terraces and hillocks forming wall of Copernicus; many of the terraces stepped down toward the crater floor by fault scarps; many radial valleys or canyons; terraces and some slopes show draped veneer of hard rock (Howard, 1972b) that commonly is cracked parallel to the slope contours (crack edges are blocky); valleys commonly subdued or show leveed channels and other evidence of flowage. *Interpreted* as chaotically jumbled slumps, veneered and locally flooded by partly molten impact fallback

s SCARP MATERIAL – Steep bright inward-facing scarps at top of crater wall; outcrop ledges abundant, especially at the very top as seen in Orbiter II oblique view; large talus blocks commonly at base of scarp. *Interpreted* as fault scarps in which the truncated edge of Copernicus ejecta is exposed and so are the successively underlying regolith, Imbrian mare basalts, breccia of the Fra Mauro Formation, and pre-Imbrian rocks; outcrop ledge at top may be welded or glassy impact melt similar to that which has partly drained off the rim material to form pond material; talus coats much of the scarp

cp CENTRAL-PEAK MATERIAL – Bright massive central peaks; outcrops abundant, some in steeply sloping ledges; large blocks in talus at base. *Interpreted* as deep-seated bedrock with impact-breccia intrusions, uplifted from beneath the crater floor as much as 10 km in a steep domal uplift; highest strata exposed are stratigraphically under the Fra Mauro Formation; uplift formed during excavation of Copernicus

p POND MATERIAL – Flat or nearly flat plains or ponds in closed depressions; where thin, blocks or hillocks of older material locally protrude; high-resolution pictures show a few small troughs and cracks in the larger, thicker ponds; flow channels appear to drain into or out of some ponds; albedo generally lower than adjacent ground. *Interpreted* as ponded impact melt drained by gravity from adjacent slopes; possibly some impact melt extruded from fissures; thicker ponds cracked upon cooling and shrinking

lf LOBATE FLOW OR CHANNEL MATERIAL – Lobes and deposits of leveed channels that indicate flow of material downhill (smaller or indistinct channels shown by arrow only); appears gradational with thin hard-rock veneer on crater walls, and with pond material and textured floor material; near crater floor, some cracks and textures similar to textured floor unit (ft). *Interpreted* as mobilized, partly molten ejecta that flowed downhill; more viscous than pond material and textured floor material

RIM MATERIALS

rs Smooth. Outer rim. Generally smooth swells and vales > 1 km across; approximately coincident with "radial rim material" mapped at 1:1,000,000 scale (Schmitt and others, 1967); locally surface shows faint radial striations; gradational toward rim crest with unit rr; relief of swells decreases outward. *Interpreted* as fragmental ejecta deposited by outward-weakening radial flows; swells may be thickened zones or may overlie fault slices in bedrock

rr Radial. Closer to the crater than unit rs. Long rounded ridges and troughs, 200-400 m across, radial to Copernicus; generally not blocky. *Interpreted* as mainly nonmolten ejecta deposited in streamlined dunes by radial flow; absence of blocks but association with pond material suggests that molten material is largely drained off

rc Concentric. Near the rim crest. Moderately blocky; fine striations and scarps concentric to Copernicus and spaced ~ 100 m apart are superposed on broad low swells; fine-scale topography sharp and detailed; numerous radial troughs with finely jagged sides; hard surface cracked locally, commonly forms thin outcrop ledge at top of crater wall scarp. *Interpreted* as thick welded ejecta deposited by radial flow; upper surface eroded by last part of radial flow, causing crisp topography; ejecta partly melted and the most mobile parts drained off to form pond material and left blocky residue; concentric pattern partly erosional or depositional from radial flow but partly reflects close-spaced fractures and faults that formed mainly in response to slumping of the nearby crater wall; radial troughs are early formed fractures and channels eroded by radial flow; broad swells concentric to crater may be thrust slices in bedrock beneath ejecta

ra Angular. Near the rim crest. Rugged angular hills and ridges ~ 1 km across; ridges subradial; amphitheaterlike valleys; sharp topography; somewhat blocky; numerous leveed flow channels indicate downhill flow in valleys. *Interpreted* as partly molten ejecta; rugged surface may partly reflect underlying faults; much of relief caused by gravitational collapse of hill slopes and consequent downhill flowage of moderately fluidized debris (more viscous than pond material or floor materials)

Contact

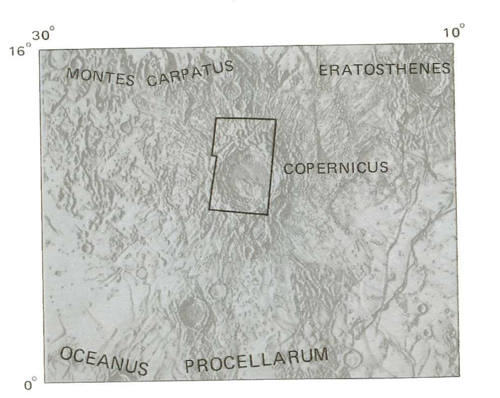
Fault – Dashed where approximate; dotted lines indicate lineament interpreted as buried fault. Bar and ball on downthrown side

Flow channel – Dashed where inferred; arrow shows downhill flow direction. Leveed channels, some with lobate protrusions at the downhill end; amphitheaters at heads of some. *Interpreted* as flow features formed by downhill flowage of fluid, partly molten ejecta

Radial trough – Linear and radial to Copernicus; some pass over or cut through topographic obstacles. *Interpreted* as fractures or flow channels; some on Copernicus rim may be scoured by radial flow

Pit crater – In floor material; rimless pits; interiors are deep, bowl shaped, and rocky. *Interpreted* as collapse craters formed by foundering of hard crust into cavities from which gas or still-molten fallback has been evacuated

Fissures – Lips rounded, outcrop ledges are common in narrow lower parts. *Interpreted* as shrinkage cracks caused by cooling and degassing of molten rock; loose surficial material has drained into the cracks



INDEX MAP OF THE COPERNICUS QUADRANGLE

INTRODUCTION

The brightly rayed crater Copernicus, one of the most familiar features of the Moon, served as the type example of an impact crrater in Shoemaker's (1962) classic analysis. This map shows the geology of the crater as interpreted in photographs taken by Lunar Orbiter V. A geologic map at 1:1,000,000 scale showing the regional setting of Copernicus and the extent of rim deposits and satellite craters was prepared from telescopic observations by Schmitt, Trask, and Shoemaker (1967).

GEOLOGIC SUMMARY

Copernicus lies northwest of the center of the nearside, at 10° north latitude, 20° west longitude. The crater is in Oceanus Procellarum 100 km south of the Carpathian Mountains, which form the southern rim of the Imbrium basin. Regional relations show that the material on which Copernicus is superposed is mainly mare of Imbrian age. Protruding through the mare are numerous small massifs and island hummocks of the Alpes and Fra Mauro Formations (Schmitt and others, 1967; Wilhelms and McCauley, 1971), premare rocks believed to represent Imbrium-basin ejecta and pre-Imbrian rocks that were structurally displaced by the Imbrium event. The formation of Copernicus obliterated any vestige of landforms associated with the Imbrian and pre-Imbrian units in the map area, but the truncated edges of these units probably are exposed in the walls and central peaks of the crater. A single Eratosthenian postmare crater in the northwest part of the map area barely shows through the Copernicus rim deposits.

Copernicus is 95 km wide and 3-4 km deep. Its rim stands a kilometre above the surrounding mare plain. In form, Copernicus is typical of large fresh-appearing lunar craters. Hummocky ground beyond the rim crests breaks off sharply at the inward-facing scarp of the crater wall, below which a series of terraces descend to the crater floor. In the center of the crudely level floor a cluster of peaks rises to a height of 1 km. Fluid material that ponded or flowed downhill occurs on the rim, wall, and floor. These features could have been formed by an impact event in which ejecta were deposited on the rim of the growing crater, and the walls of the crater slumped inward as the center was uplifted. Afterward, parts of the ejecta that were molten or partly molten drained downhill and ponded in the crater floor and other depressions.

RIM MATERIALS

As recognized in 1:1,000,000-scale mapping, the rim of Copernicus is characterized by large concentric or branching hummocks out to ½-1 crater radius, and beyond that by radial ridges (Schmitt and others, 1967). Finer surface textures are used here to distinguish four facies of rim deposits within the map area. These fine textures may represent only the upper part of the rim deposit and not the full thickness. Smooth rim material (unit rs) forms the outermost of these and very roughly coincides with the radially ridged terrane recognized at 1:1,000,000 scale. This unit consists of large, irregular, smooth-surfaced, subdued hills, which grade toward the crater into material that is prominently textured with dunes or ridges radial to Copernicus, mapped as radial rim material (unit rr). Both of these facies contain few blocks. They are interpreted as mainly fine-grained fragmental debris that was deposited by radial flowage from the crater. Disappearance of the radial dunes outward suggests dissipation of the flow.

The radial facies overlies or locally merges inward with blocky materials with sharp relief next to the crater. Most of this inner zone is mapped as concentric rim material (unit rc), in which numerous striations concentric to Copernicus are superposed on broad, low swells. These striations probably include dunes, but some show fault offset and are evidently close-spaced faults and fractures. On parts of the rim that have slumped into the crater, these close-spaced concentric fractures commonly show offset parallel to the slumps; some both inside and outside the rim crest may have been caused by relaxation toward the slump faces. A facies of angular rim material (unit ra) locally forms rugged hills and valleys close to the crater. The sharp relief and blocky surface of both this and the concentric rim unit suggest that their upper surface was swept clean of fine material. The width of the rim zone that appears eroded is approximately one-third of a crater radius.

STRUCTURE OF THE CRATER

The walls of Copernicus descend in a series of slump terraces that become progressively more irregular and jumbled closer to the crater floor. With the exception of a large slump in the southeast, most terraces are tilted away from the crater. This backward tilting is analogous to "reverse drag," and indicated that the underlying slip surfaces are concave upward (Hamblin, 1965). Therefore the slumps are probably not the result of undermining as in caldera collapse, where inward tilting is the rule (Howard, 1972a). Slumped walls are found in nearly all large, fresh-appearing craters that have central peaks. Dence (1968) suggested that slumping causes the central uplift in terrestrial craters.

The central peaks of Copernicus formed early in the cratering event. They are lapped by floor materials, and two small peaks just southeast of the mapped central peaks are coated by the cracked floor material. These two peaks are therefore mapped as hummocky floor material. The central peaks are believed to be analogous to central uplifts in terrestrial impact structures and certain experimental craters. If so, they expose rock uplifted from beneath the crater floor on the order of one-tenth the crater diameter (Howard and others, 1972), and they formed during the cratering event (Milton and others, 1972; Roddy, 1968) by inward movement of country rock (Wilshire and Howard, 1968). This motion would appear to balance the downward and inward gliding of the wall slumps. The rising central uplift may have withdrawn material from beneath the walls to cause slumping or the slumped crater walls may have forced up the central uplift.

Hummocks on the crater floor merge outward with the wall slumps and inward with the central peaks, suggesting a continuity between the slumps and the peaks. Some of the hummocks and central peaks are compared to cinder cones by Hartmann (1968), Lowman (1969), Kosofsky and El-Baz (1970), and Green (1971). The resemblances seem superficial and may be explained by random impact pits on a few of the hummocks and by an oblique foreshortened view in one photograph of the central peaks. The hummocks may be partly the upthrust toes of the slumps. In some terrestrial astroblemes, the structural zone analogous to that occupied by the hummocks in Copernicus is characterized by thrust slivers displaced toward the center of the crater (Offield and others, 1970) or by complex steep basins and domes (Wilshire and others, 1972).

FLOW DEPOSITS

Fluid materials ponded or flowed downhill on the major units so far described. These materials solidified or welded and are now cracked and are blocky where cratered or exposed as ledges. Similar flow features are seen with even greater clarity at the younger craters Tycho, Aristarchus, and King (Shoemaker and others, 1968; Gault and others, 1968; Crittenden, 1968; Lowman, 1969; Strom and Fielder, 1970; Moore, 1968, 1971; Cruikshank and Wood, 1972; Howard, 1971, 1972b; Strom and Whitaker, 1971; El-Baz, 1969, 1972; Young and others, 1972). The fluid materials can be explained as impact melts. The thickest accumulation forms the textured material (unit ft) in the northern part of the crater floor. Irregular tension cracks in this material show that it contracted as it solidified. This same fissured material coats most or all the hummocks (unit fh) in the floor and forms isolated terraces along the west edge of the floor. Together these indicate that the level of the fluid was originally much higher and has subsided. The amount of subsidence is on the order of 200 m, the height of the biggest coated hummocks. Yet the present thickness of textured floor material is no greater than 100-200 m, even where it is deepest, for isolated hummocks indicate that the underlying hummocky ground is only thinly covered. Rimless pit craters in the floor material (Hartmann, 1968) may imply that some of the fluid drained downward, possibly into underlying breccia. The cracks in the floor material indicate that in addition the fluid compressed and contracted, so that it originally may have been full of voids, as in a welded tuff.

Numerous small depressions on the crater wall and rim are filled to a level surface by material (unit p) that has ponded. Greeley and Gault (1971) interpret crater counts to mean that small collapse pits are present in these ponds on the wall. Most ponds have no apparent source other than local slopes, and it appears as if the runoff from local drainage basins ponded in low places. This can be explained if partly molten ejecta had coated the walls and rim of the crater, and the most mobile fractions drained downhill. Solidified melt, or at least welded material, coats nearly all the slumped walls and the near part of the rim (in units rc and ra), as indicated by cracked, blocky, hard-rock veneers that are exposed in the walls and the top of the wall scarp. Thick accumulations of cracked material coat the lower parts of the walls and appear gradational with the crater floor. Patches of pond material extend to the outer limits of the radial rim facies, implying that the ejecta had a substantial content of melt out to a distance slightly greater than half a crater radius beyond the rim crest. The suevite at the Ries structure in Germany (Hörz, 1965; Dennis, 1971) has a comparable distribution.

Leveed flow channels and lobes demonstrate that fluids flowed downhill on parts of the crater rim and on the walls (Crittenden, 1967; Lowman, 1969; Kosofsky and El-Baz, 1970). Some of these drained into or out of patches of pond material (Lowman, 1969) or into the crater floor. Many head in amphitheaters and can be accounted for if parts of hills collapsed by gravity. These are common on the angular rim material; and amphitheaters and channels account for some of the rugged topography of this unit. In comparison to the ponded material, the leveed channels and flow lobes represent fluid that was generally more viscous, possibly because it contained a higher proportion of unmelted xenoliths.

The fluid materials thus flowed downhill after radial flow had passed across the crater rim and after the walls had slumped. They may be parts of the ejecta blanket that remained fluid, or may be fallback that settled back on the ground after radial flowage ceased. Possibly the ejecta were partly molten and partly volatilized, so that gasses as well as melts contributed to their fluidity.

THE COPERNICUS IMPACT

The features described can be explained if Copernicus was formed by a catastrophic impact. The impact excavated a crater and uplifted the rim. As the thick ejecta blanket was deposited, continued radial outward flow of cratered material swept clean the surface of part of the blanket. Farther out where the flow dissipated, streamlined radial dunes were deposited, and beyond that, a smooth blanket. The crater walls slid inward, and the center of the crater was uplifted. Parts of the ejecta or late fallback remained fluid — probably molten — and ran downhill to pond in depressions. A thick accumulation of impact melt in the crater floor shrank by compression of voids and may have drained into underlying breccia.

FEATURES YOUNGER THAN COPERNICUS

Patches of smooth, sparsely cratered fill material (unit Cf) occupy some low parts of the floor of Copernicus. This unit may be mass-wasted detritus or post-Copernicus volcanic materials. Small craters also postdate the formation of Copernicus. Some of them form clusters and probably are secondary-impact features. At the north edge of the map area is one of a family of dark-halo craters (unit Ccd3) that pock the outer part of the Copernicus ejecta blanket; these may be impact craters that excavated dark mare basalt from beneath the ejecta. Schmitt, Trask, and Shoemaker (1967) recognize a buried peninsula of pre-mare rocks extending toward Copernicus from the northwest. If the dark-halo crater is correctly interpreted here, then this peninsula stops short of the map area, and mare basalt is present beneath most or all the Copernicus ejecta in the map area.

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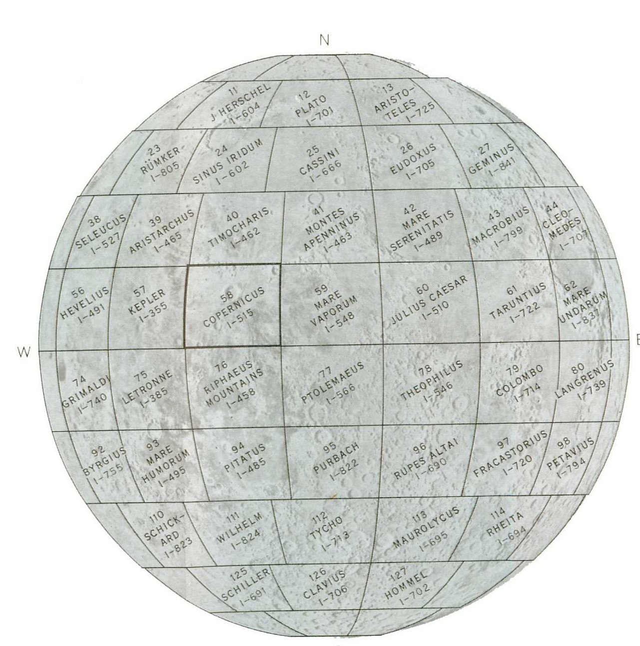

INDEX MAP OF THE EARTHSIDE HEMISPHERE OF THE MOON
Number above quadrangle name refers to lunar base chart (LAC series); number below refers to published geologic map

Information from Pohn and Wildey, 1970; high-illumination photograph 5818, 61-inch reflector, U.S. Naval Observatory, Flagstaff, Arizona

ALBEDO

High ~16–17 percent
Medium
Low ~11–12 percent

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