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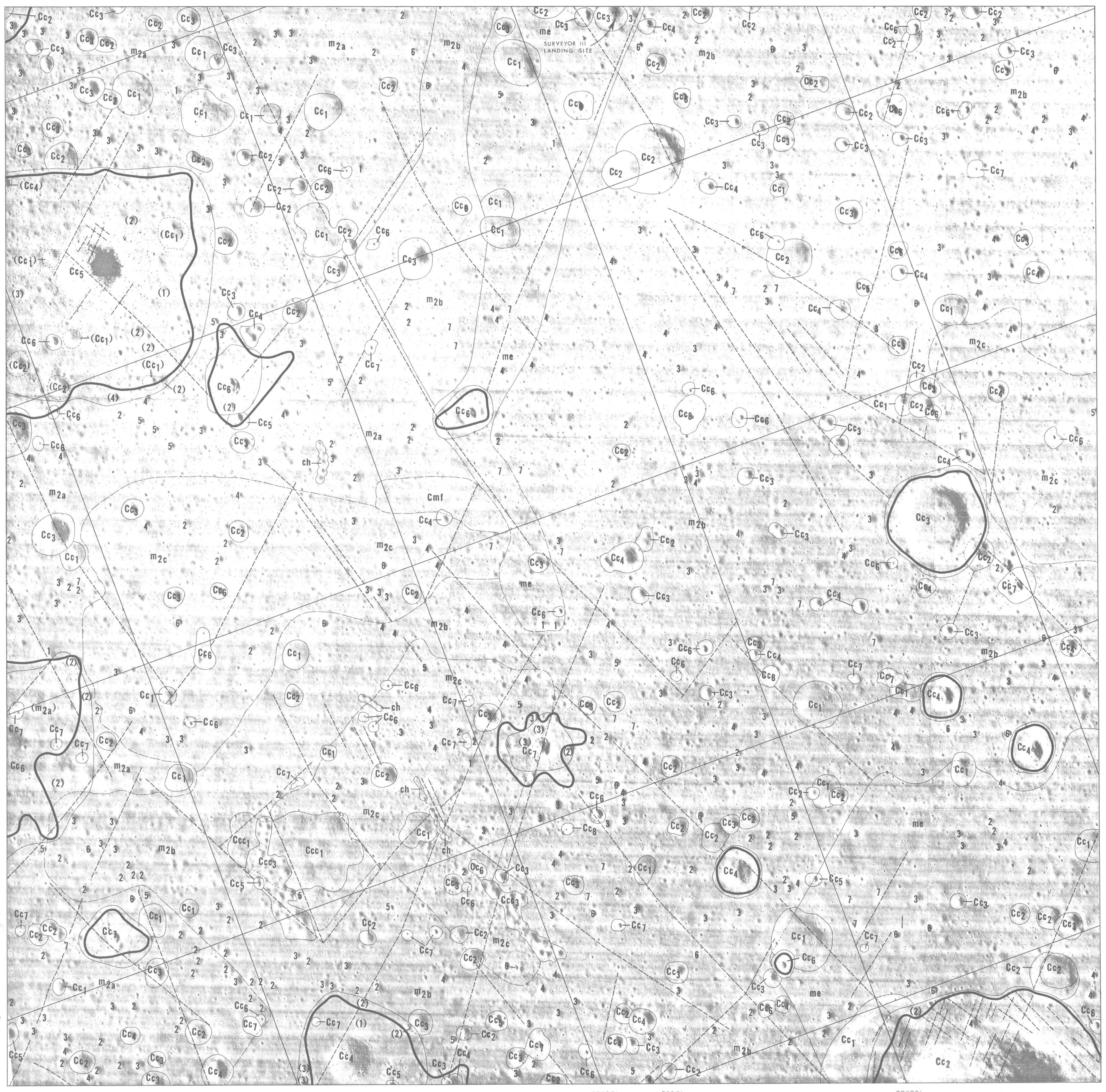
Prepared in cooperation with the
Manned Spacecraft Center,
National Aeronautics and Space Administration



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SCALE 1:25,000 (APPROXIMATE)

KILOMETERS

NAUTICAL MILES

Principal sources of geologic information: Lunar Orbiter III photographs (Langley Research Center, NASA, 1966, 1967); albedo data from Pohn and Wildey (1966) and from full-Moon plates 5818 and 5819 taken at U.S. Naval Observatory, Flagstaff, Ariz.

PRELIMINARY GEOLOGIC MAP OF ELLIPSE III-9-5 AND VICINITY

By
R.S. Saunders and T.A. Mutch
1967

Mercator Projection

General Geology

Ellipse III-9-5 is in a level area between Mare Cognitum and Oceanus Procellarum, approximately 125 km southeast of the crater Lansberg. Mare material within the map area is covered with a greater number of subdued craters than typical smooth mare. A ray from the crater Copernicus, situated to the north, is visible on telescopic and Orbiter IV photographs. It trends directly through the ellipse but dissipates in a short distance and is not clearly discernible in the southern part of the map area. No mare ridges or other positive relief features are visible at telescopic resolution, but a northerly trending subdued ridge is visible on Orbiter photographs.

The 1:100,000 map of site III P-9 (Pohn, 1967) shows that the area contained within this 1:25,000 map is covered with Copernicus ray material. Although this is a mappable unit at the 1:100,000 scale, several mare units which underlie the thin to discontinuous ejecta blanket can be deciphered at the 1:25,000 scale. These mare subunits are mapped on the basis of subtle differences in texture, crater density, and elevation. They are subdivisions of unit m_2, which has been mapped over a large area at the 1:100,000 scale (Pohn, 1967). Unit m_{2b} is most widespread on the present map, and all other units are compared to it as a standard. Lineated, relatively highly cratered, elevated surfaces (m_{2a}) are interpreted as oldest. Level, relatively uncratered surfaces (m_{2c}, mf) are considered youngest. Two prominent sets of lineaments trend northeast and northwest (fig. 1), tending to bound mare units.

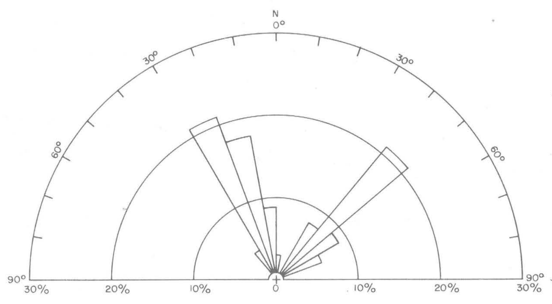

Figure 1.--Orientation of mapped lineaments. Segment lengths correspond to percentage of total length of measured lineations.

Superposition relations of crater materials indicate that craters are degraded with time. Accordingly, all craters are mapped on the basis of interpreted relative age. Crater morphology and details of the rim and floor are used to estimate age; however, as figure 2 shows, crater diameter is also a factor. For example, Cc_5 craters smaller than 100 meters generally are strongly subdued, whereas those between 100 and 400 meters are only moderately subdued. Generally, small craters are more quickly subdued than large ones. Crater materials more than 100 meters in lateral extent are outlined. Below that limit crater materials are identified by number only. Crater materials less than 75 meters in extent are not mapped.

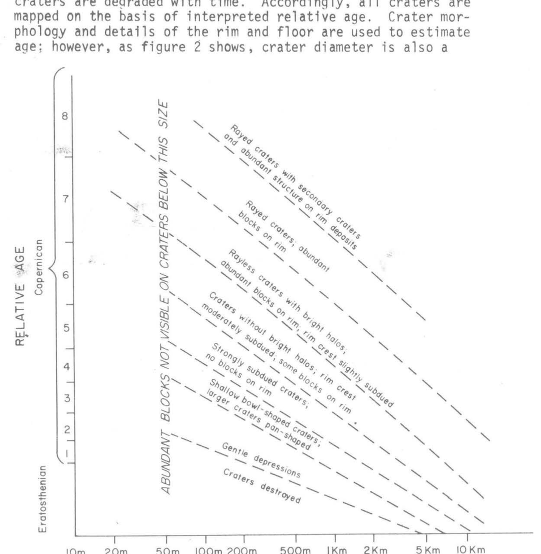

Figure 2.--Graph showing relation between crater diameter, crater properties, and crater age. The model assumes that crater destruction has proceeded in a single direction uniformly throughout the map area. Each crater category grades without a break into the next.

The sequence of geologic events within the map area is as follows: Emplacement of lava flows, subsequent minor vertical movement along regional lineaments, blanketing with ejecta from Copernicus, continuing intermittent volcanism, and periodic small-scale blanketing with ejecta from local impact events.

The morphologies of all craters within the map area indicate an age no greater than Copernican. This establishes an upper age limit of early or middle Copernican for the mare units. The lower limit remains uncertain, but the absence of superposed craters Eratosthenian or older suggests that the mare surface itself is no older than Eratosthenian. One interpretation is that this relatively young age pertains only to the surficial lunar regolith, which happens to be the material mapped at this detailed scale of 1:25,000. An alternate interpretation is that volcanic bedrock beneath the regolith may, indeed, be younger than previously suspected in this and other mare regions. Accordingly, the Procellarum Group, which is the rock-stratigraphic unit mapped within this region at the 1:1,000,000 scale (Eggleton, 1965) may, at least in part, be much younger than late Imbrian.

The stated absence of Eratosthenian craters, on which the arguments of the previous paragraph are based, is perhaps more apparent than real. First, the crater classification shown in figure 2 has not been correlated rigorously with existing stratigraphic systems. Secondly, only large craters are preserved over long periods of time. Absence of such craters may simply be a consequence of the small size of the map area and the random areal distribution of large craters.

Engineering Geology

Craters and their surrounding block fields constitute the chief landing hazards. In Cc_3-Cc_8 craters, slopes may be as much as 10° to 15°. This estimate is based on a consideration of slope measurements reported in the Surveyor III report (Natl. Aeronautics and Space Adm., 1967a), and on several photogrammetrically determined topographic profiles prepared for the present report. Many blocks in the fields shown on the map are more than 2 meters in diameter, and some are as much as 40 meters. Most, if not all, Cc_5-Cc_8 craters are also surrounded by hazardous block fields not resolvable on Orbiter photographs. For example, Surveyor III photographs show blocks as large as 2 meters surrounding a crater only 13 meters in diameter (Natl. Aeronautics and Space Adm., 1967a, p. 27).

Lineaments are another potential hazard. Some may actually be open fissures; others may be fissures covered with a thin veneer of unconsolidated rubble susceptible to collapse. Covered fissures are especially hazardous since they will be difficult to see, particularly from ground level.

Thicknesses of the fragmental surface layer have been estimated using the Oberbeck-Quaide technique (1967). Combined data for the entire ellipse are shown in figure 3. Slight variations exist between individual units. The fragmental layer thickness for m_{2b}, the most widespread unit, is in the 4-6 meter range. On steep crater walls, downslope movement of talus causes the fragmental layer to be unusually thin at the top of the slope and unusually thick at the crater center.

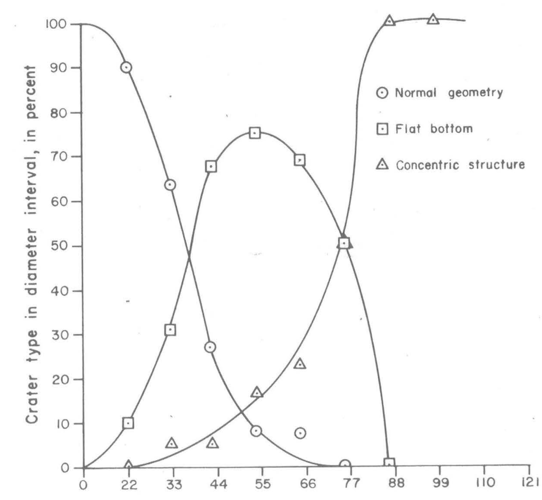

Figure 3.--Percentages of normal, flat-bottomed, and concentric craters of diameter D. Method described by Oberbeck and Quaide (1967). The thickness of the fragmental layer, h, is related to crater diameter, D, as follows:

Normal geometry $h > \frac{D}{6.5}$

Flat bottom $\frac{D}{11} < h < \frac{D}{6.5}$

Concentric $h < \frac{D}{11}$

Blocks that have impacted the surface and bounced, leaving an empty crater, provide additional information on the character of the surface layer. One such association of block and crater is visible on Orbiter III high-resolution frame 151, which shows an area about 60 km northeast of the map area. Relationships indicate that the properties of the uppermost few meters at this spot are similar to those at the Surveyor I and III landing areas (Natl. Aeronautics and Space Adm., 1967b, p. 62).

The mare subunits may well be indistinguishable from an engineering and trafficability point of view. Crater densities, slope distributions, and inferred thickness for fragmental layer are not markedly different for m_{2a}, m_{2b}, and m_{2c}.

A cumulative distribution for slopes throughout the map area is shown in figure 4. It is based on analysis of three photogrammetrically determined topographic profiles constructed from Orbiter III medium-resolution photographs. Each profile extends from the east margin of the map to the west margin.

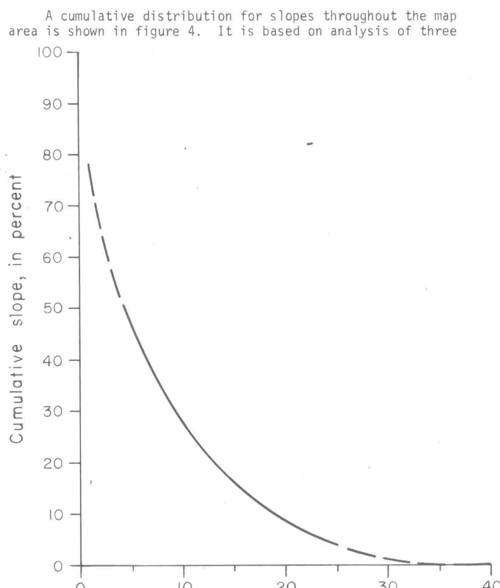

Figure 4.--Cumulative slope distribution calculated from three topographic profiles extending across the map area parallel to framelets. Profiles were photogrammetrically determined from Orbiter III moderate-resolution photographs. Horizontal increments for individual slope determinations are 65 meters.

Experiments conducted by Surveyor III, which landed in the north-central portion of the map area, indicate a static bearing capability of 3 to 8 pounds per square inch for the surface soil. Surveyor photographs reveal that craters are present to a lower limit of about 10 cm; the cumulative distribution is an extension of the same power function calculated from Orbiter and Ranger photographs (Natl. Aeronautics and Space Adm., 1967a, p. 23). Surface debris is widespread. The frequency of occurrence of blocks 2.5 cm and larger is about 10 per square meter (Natl. Aeronautics and Space Adm., 1967a, p. 28).

The surficial features photographed by Surveyor III can be assumed to be typical of the entire area mapped. The spacecraft landed in a greatly subdued and modified crater (Cc_3). Within this crater, the recent history of small-scale impacts, ejecta blanketing, and surficial weathering closely approximates that for the entire ellipse. Only in and around Cc_5-Cc_8 craters will the surficial materials be markedly different.

Scientific Possibilities

The most accessible geologic samples will be rock fragments of hand-specimen size lying on the surface throughout the ellipse. In Surveyor III and V photographs, many of these appear to be volcanic rock fragments. Blocks shown on Orbiter photographs of this area are all in or adjacent to craters. Correlation of many of the smaller fragments with particular cratering events will be difficult, but fragment shape will serve as a guide to relative age (e.g., recently ejected fragments will be sharp and angular; older fragments will be subrounded and more equidimensional).

Bright halo and ray craters (Cc_6-Cc_8) occur throughout the ellipse; at least one of these could probably be studied during a mission. Ejecta blankets around these craters will contain fresh, recently excavated rock fragments. Comparison of these samples with the more common rubble exposed elsewhere will provide information on weathering processes.

There are no singularly distinctive geologic features within the ellipse. Bedrock underlying the regolith is probably exposed in young craters more than 30 meters in diameter. Surveyor III photographs reveal a crater only 13 meters across which has excavated blocks (Natl. Aeronautics and Space Adm., 1967a, p. 25-26). However, this crater is on the upper slope of a larger crater, and the fragmental layer there probably is atypically thin.

REFERENCES

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Eggleton, R. E., 1965, Geologic map of the Riphaeus Mountains region of the Moon: U.S. Geol. Survey Misc. Geol. Inv. Map I-458.
Oberbeck, V. R., and Quaide, W. L., 1967, Estimated thickness of a fragmental surface layer of Oceanus Procellarum: Jour. Geophys. Research, v. 72, p. 4697-4704.
Pohn, H. A., 1967, Preliminary geologic map of Site III P-9 [scale 1:100,000]: U.S. Geol. Survey open-file report.

Contact

Dashed where uncertain, dotted where buried.

(Cc_1)

Buried contact

Buried unit indicated by symbol in parentheses.

Lineament

Characteristics
Shallow linear depressions. Some lineaments display relief of several meters. Craters smaller than 50 meters may be alined along some lineaments; commonly craters are slightly extended or polygonized along lineament directions. Closely spaced lineaments are locally present, especially on walls and rims of craters greater than 400 meters in diameter. Patterned ground results where lineament sets are closely spaced.

Interpretation
Joints determined by a regional stress field forming the lunar grid. Vertical displacement of several meters may have occurred along some fractures, particularly those with the greatest lateral continuity. Periodic seismic shaking, caused by internal movement or impact, produces and accentuates these joints in young materials as well as older basement rock. Conspicuous close-spaced joints on the large crater rim in the lower right corner are evidence of the correlation between cratering events and surficial propagation of the joint system.

Block field

Abundant blocks present greater than 1 meter; 10-meter blocks not uncommon; 40 meters maximum size on ellipse.

(3)

Buried crater

Crater buried by younger crater material. Number indicates surface morphologic characteristics.

ch

Chain-crater material

Characteristics
Material in overlapping and alined craters.

Interpretation
Probably volcanic crater material or possibly secondary impact crater materials.

+

Surveyor III landing site

Cmf

Flow material

Characteristics
Only one occurrence, 1 km west of the map center. Level surface broken by sharp craters less than 25 meters in diameter. Few craters larger than 50 meters in diameter.

Interpretation
Volcanic flow; probably most recent within the map area.

Interpreted engineering properties
Thin fragmental cover; no blocks on surface larger than 1 meter.

Scientific interest
May provide surface outcrop of flow material.

Crater materials, undivided

NOTE: Crater materials occupying areas larger than 100 meters in lateral extent, including deposits outside the rim crest, are outlined by geologic contacts; materials occupying areas between 75 and 100 meters in lateral extent are assigned numbers only; materials within areas of less than 75 meters are unmapped.

Characteristics

Cc_8

Rim crest diameter less than 100 meters. Includes very bright ray material; hummocks occur on floor; crater rim crest sharp.

7 | Cc_7

7 and Cc_7, rim crest diameter less than 100 meters. Includes ray material; hummocks occur on floor; crater rim crest slightly subdued.
Cc_7, rim crest diameter 100-400 meters. Includes ray material; blocks moderately abundant; relief conspicuous in floor; crater rim crest slightly subdued.

6 | Cc_6

6 and Cc_6, rim crest diameter less than 100 meters. Unit is bright; crater rim crest moderately subdued.
Cc_6, rim crest diameter 100-400 meters. Unit is bright; blocks moderately abundant; structural relief moderate in floor; crater rim crest slightly subdued.

5 | Cc_5

5 and Cc_5, rim crest diameter less than 100 meters. Unit not bright; crater rim crest strongly subdued.
Cc_5, rim crest diameter 100-400 meters. Unit not bright; scattered blocks occur; structural relief slight in floor; crater rim crest well defined but slightly subdued.
Cc_5, rim crest diameter 400-800 meters. Unit is bright; blocks abundant; crater rim crest well defined but slightly subdued.

4 | Cc_4

4 and Cc_4, rim crest diameter less than 100 meters. Crater rim crest slightly raised and crater has shape of shallow bowl.
Cc_4, rim crest diameter 100-400 meters. Unit not bright; blocks sparse around most craters but several craters have conspicuous block fields; concentric structure occurs in rim material; crater rim crest strongly subdued.

3 | Cc_3

3, rim crest diameter 75-100 meters. Associated crater is gentle pan-shaped depression.
Cc_3, rim crest diameter 100-400 meters. Density of small craters on rim material same as on surroundings; indistinct concentric structure in rim deposits; crater rim crest slightly raised; crater has shape of shallow bowl.
Cc_3, rim crest diameter 400-800 meters. Few blocks occur on rim deposits; blocks moderately abundant on wall; crater rim crest strongly subdued.

2 | Cc_2

2, rim crest diameter 75-100 meters. Associated crater is very gentle depression.
Cc_2, rim crest diameter 100-400 meters. Patterned ground occurs on wall; associated crater has pan-shape or is gentle depression.
Cc_2, rim crest diameter 400-800 meters. Few blocks occur on wall; patterned ground occurs on wall; concentric structure occurs on rim deposits; crater density on rim slightly lower than that of surroundings; associated crater has shape of shallow bowl.
Cc_2, rim crest diameter 800 meters-3 km. Few blocks occur on rim; abundant blocks on wall; crater density on rim lower than that of surroundings; crater rim crest moderately subdued.

1 | Cc_1

1, rim crest diameter less than 100 meters. Associated crater is very gentle depression.
Cc_1, rim crest diameter 100-400 meters. Associated crater is gentle depression.
Cc_1, rim crest diameter 400-800 meters. Few blocks occur on wall; patterned ground occurs on wall; crater density on rim same as that of surroundings; associated crater is pan-shaped depression.

Interpretation
Materials of both primary and secondary impact craters; youngest Cc_8, oldest Cc_1. Individual craters are degraded and subdued by erosion from micrometeorites and by slumping due to seismic shaking. These effects are progressively more apparent in older (lower numbered) craters. The subdued character of some Cc_1 to Cc_3 craters results from the mantling of the craters with volcanic flows or ejecta materials.

Interpreted engineering properties
All craters except 100 to 400 meters Cc_1 to Cc_2 and 50 to 100 meters Cc_2 to Cc_3 have blocks on their walls and rims and hence constitute landing hazards. Depth to cohesive substrate on large subdued craters is higher than average on floors and lower than average on rims.

Scientific interest
The freshest sample of ejected materials will be found around the youngest craters. Samples from craters of all ages may provide information on radiation history.

Crater-cluster materials

Ccc_3

Characteristics
Materials of many shallow contiguous craters, about 100 meters in diameter. No blocks larger than 2 meters occur around craters.

Interpretation
Materials formed by secondary impact, probably of ejecta from Copernicus.

Interpreted engineering properties
The fragmental layer is unusually thick and rubbly.

Scientific interest
Around secondary impact craters, samples may contain fragments from considerable depth.

Ccc_1

Characteristics
Materials of many pan-shaped contiguous craters, about 200 meters in diameter. No blocks larger than 2 meters occur around craters.

Interpretation
Materials formed by secondary impact.

Interpreted engineering properties
The fragmental layer is unusually thick and rubbly.

Scientific interest
Around secondary impact craters, samples may contain fragments from considerable depth.

COPERNICAN SYSTEM

m_{2c}

Level mare material

Characteristics
Surface level to slightly undulating; abundant fresh craters smaller than 50 meters; strongly subdued craters 50-200 meters more numerous than on unit Cmf, less numerous than on unit m_{2b}.

Interpretation
Volcanic flows with mantle of fragmental debris thicker than Cmf.

Interpreted engineering properties
Fragmental material at the surface and extending to a depth of 2-4 meters. Blocks larger than 1 meter are not abundant. Relief slightly less than that of unit m_{2b}.

Scientific interest
Typical mare material mantled by fragmental debris slightly thinner than the average mare cover in the map area. Upper part of fragmental layer may provide sample of Copernicus ray.

me

Elevated mare material

Characteristics
Occurs in elongate, polygonal areas bounded by segments of lineaments and standing higher than adjacent areas. Ridge tops have strong to gentle undulations with wavelengths of approximately 100 meters. Subdued craters smaller than 50 meters are less common than in unit m_{2b}.

Interpretation
Material upwarped by pressure from shallow intrusions. More prominent mare ridges in the Riphaeus Mountains quadrangle (Eggleton, 1965), which have the same northerly trend as the ridge in the center of this area, exhibit features suggestive of doming over shallow intrusions.

Interpreted engineering properties
Surficial fragmental layer is slightly thinner than that of unit m_{2b}. Extensive slopes bound this unit but are not sufficiently steep to cause unstable slope conditions.

Scientific interest
Shallow intrusion may be exposed locally along ridge crest or along marginal slopes.

m_{2b}

Mare material

Characteristics
Gently undulating to level material, covering approximately half the map area. Sharp-rimmed craters, 10-50 meters, cover less than 5 percent of the terrain and are superposed on a background of larger subdued craters which cover no more than 20 percent of the surface. Lineaments are present but are relatively less common than in m_{2a}. Low sinuous scarps occur throughout. Visible blocks absent except for local fields around large craters.

Interpretation
Volcanic flows covered, at least in part, with ejected debris from Copernicus and ejecta from superposed craters. Small indistinct sinuous scarps may mark flow fronts.

Interpreted engineering properties
Fragmental material at the surface and extending to a depth of 4-6 meters, slightly greater than in most other regions of the map area. Blocks larger than 1 meter are sparse. Approximately 40 percent of the slopes within the region are greater than 5°.

Scientific interest
Typical mare material. Craters large enough to have penetrated the substrate may provide samples. It is probable, however, that many of the surficial fragments are not derived from local substrate but from distant impact events, notably Copernicus.

m_{2a}

Pitted and lineated mare material

Characteristics
Appearance variable, but all surfaces show more small-scale relief than m_{2b}. Clusters of subdued overlapping craters smaller than 50 meters are common. Several areas contain overlapping subdued craters with diameters approximately 200 meters. Patterned ground is conspicuous, with lineations trending northwest and northeast, similar to lineaments throughout the map area.

Interpretation
Similar to m_{2b} except that surface material is older and has been subjected to more cratering. Patterned ground is produced by repeated periods of stress concentrated along regional joints. The stress is induced by local impact events (seismic shaking).

Interpreted engineering properties
Similar to m_{2b} except the fragmental layer may be thicker and more cohesive; greater thickness results from more ejecta rubble. Seismic shaking has compacted the rubble, making it progressively more cohesive with depth.

Scientific interest
The oldest mare surface. Surficial fragments are more severely weathered than in other units. Owing to longer exposure of this unit, samples might provide data on long-term weathering effects.

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Moon (Ellipse area). Geol. 1:25,000. 1967.
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