This report is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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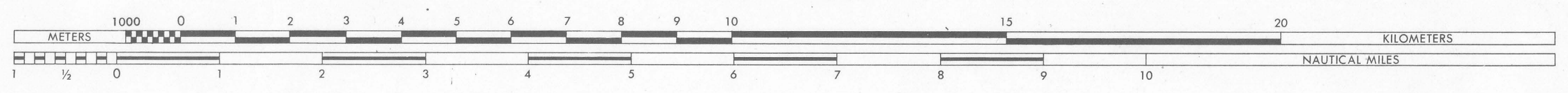
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
OPEN FILE REPORT

ORB II P-6

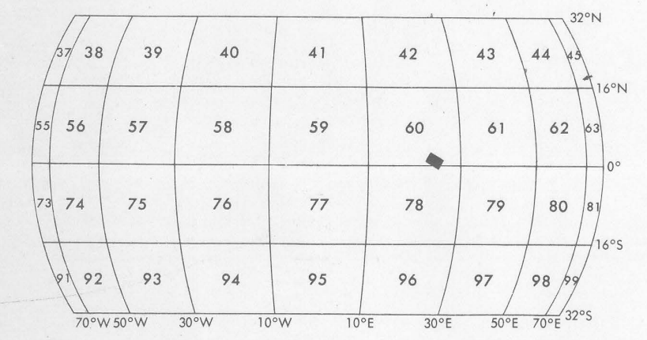
Controlled base prepared by Army Map Service, Corps of Engineers, U.S. Army, Washington, D.C. 20315

SCALE 1:100,000



Principal sources of geologic information: Lunar Orbiter I, II, III, IV, V 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.

SITE LOCATION DIAGRAM KEYED TO LAC



PRELIMINARY GEOLOGIC MAP OF LUNAR ORBITER SITE ORB II P-6

By
M.J. Grolier
1967

Mercator Projection

Ccc

Crater-cluster material

Characteristics
Material of partly overlapping, adjacent craters 75-400 meters in diameter; types of craters range mostly from Cc_1 to Cc_4; reflectivity slightly higher than that of adjacent mare material.

Interpretation
Material of probable impact origin but of indeterminate post-mare age.

Cci | Ccci

Crater and crater-cluster material
irregular

Characteristics
Materials of irregular, rayless craters, usually larger than 800 meters in diameter, occurring singley (Cci) or in clusters (Ccci); crater rim crest sharply polygonal in outline. An irregular blanket, as much as one crater diameter wide, covers the adjacent mare; albedo slightly higher than that of adjacent mare material. Blocks 2-10 meters in diameter are common along rim crest; patterned ground common within crater and on blanket around it.

Interpretation
Materials in impact craters and associated ejecta blankets; probably of secondary impact origin. Age indeterminate.

Contact

(m_1)

Concealed contact

Dots show limit of topographically expressed part of buried unit. Buried unit indicated by symbol in parentheses.

Lineament

Very gentle scarp in mare, or gentle narrow trough in mare and mare ridges.

Flow front

Irregular depression

Probably collapse feature or possibly graben.

Scarp

Barbs point downslope. Gentle mare scarp or mare ridge escarpment. May be fault or flow front.

Very low mare ridge

Crm

Ray material

Characteristics
Material is distinctly brighter than adjacent surfaces. North-trending streaks and grooves common. High density of bright craters less than 100 meters in diameter.

Interpretation
Probably consists of a thin layer of fragmental rock ejected from the impact crater Moltke, 18 km south of the site.

Crt | Cru

Ray material

Characteristics
Crt, bands, 5-10 km wide, of material distinctly brighter than adjacent material. High density of bright craters less than 100 meters in diameter.
Cru, eastward trending band, 3-10 km wide, of bright material in northwestern part of site.

Interpretation
Probably consists of a thin layer of ejecta from impact craters.
Crt, ray material traceable to the crater Theophilus, 320 km south of the site.
Cru, probably ray material; source crater not known.

Cch

Chain-crater material

Characteristics
Material of alined and partly overlapping craters, between 1.2 and 2 km in diameter, with slightly polygonal subdued rims. Narrow rim deposits are present; blocks and boulders 2-10 meters in diameter present on rim crest.

Interpretation
Probably materials of secondary impact craters.

mr

Mare ridge material

Characteristics
Forms ridges, usually bounded by a steep escarpment on the west, and a gentler slope gradually merging with the mare on the east. Craters 300-400 meters in diameter are sparse; density of craters 50-200 meters in diameter lower than on adjacent mare; density of small craters (10-20 meters in diameter) about the same as on adjacent mare. No resolvable block or boulder fields on the ridges. Aprons at the break in slope between mare and steep mare ridge escarpments are common. Linear narrow depressions occur on some ridges, and locally along contact between mare and mare ridge.

Interpretation
Probably consists of faulted blocks of mare material (undifferentiated) generally tilted eastward or northeastward. An elongate crater in the southeastern part of the site may be a volcanic vent controlled by the ridge structure. Relatively low crater density on ridges may be caused by downslope movement of fragmental surficial layer.

Crater materials

NOTE: Crater materials occupying areas larger than 800 meters in lateral extent, including deposits outside the rim crest, are outlined by geologic contacts; materials occupying areas between 400 and 800 meters in lateral extent are assigned numbers only; materials within areas of less than 400 meters are unmapped.

Characteristics

Cc_8

Crater materials, undivided. Include very thin bright ray material that extends more than 500 meters from crater center; blocks, 2-3 meters in diameter, are scattered on rim deposits; floor material is hummocky and concentric benches occur in floor; crater rim crest sharp and indistinctly polygonal.

7 | Cc_7

7, crater materials, undivided. Very bright rim material extends as far as 1 1/2 crater diameters from rim crest; include diffuse ray material; a few blocks larger than 2 meters occur on rim crest and rim material; subdued benches occur in crater interior; crater rim crest sharp.
Cc_7, crater materials, undivided. Include very bright ray material; abundant blocks present; structure abundant in floor; crater rim crest sharply raised.

6 | Cc_6

6, crater materials, undivided. Rim deposits are bright and floors are deeply furrowed; abundant blocks present on wall and rim; rim material extends 1-1 1/2 crater diameters from rim crest and is less densely cratered with small craters than surrounding materials; crater rim crest slightly subdued.
Cc_6, crater materials, undivided. Include ray material; abundant blocks present; structure abundant in floor.

5 | Cc_5

5, all are buried and cannot be described.
Cc_5, rim deposits, bright; floors, furrowed scattered blocks 2-15 meters in diameter occur in rim and on surrounding mare material; rim material extends less than 1/2 crater diameter from rim crest; crater rim crest slightly raised. Only occurrence is south of Sabine D.

4 | Cc_4

4, crater materials, undivided. Abundant blocks present in wall material, some on rim crest; concentric benches and patterned ground present in rim material; associated crater is cone shaped and has well-defined rim crest.
Cc_4, crater materials undivided. Rim deposits are brighter than surroundings; abundant blocks present; slightly subdued structure occurs in floor.

3 | Cc_3

3, crater materials, undivided. Blocks present around or on rim crest; few or no blocks on lower walls and floor; patterned ground occurs on wall material; crater density on rim material slightly lower than that of surroundings; crater rim crest subdued.
Cc_3, crater materials, undivided. Rim deposits are not brighter than surroundings and are less cratered; crater rim crest subdued.

2 | Cc_2

2, crater materials, undivided. Blocks present on rim crest and upper wall material; patterned ground conspicuous on both wall and rim material; wall and floor cratered as well as rim; associated crater shallow-bowl shaped.
Cc_2, crater materials, undivided. Few blocks present in rim material; crater density of rim material lower than that of surroundings; crater rim crest moderately subdued.

1 | Cc_1

1, crater materials, undivided. Few blocks present on upper wall material; patterned ground conspicuous on wall material; crater density of rim material same as that of surrounding mare material; associated crater is pan-shaped depression.
Cc_1, crater materials, undivided. Crater density on rim material slightly less than that of surroundings; reflectivity of sunlit wall slightly higher than that of adjacent mare material; crater rim crest subdued.

Interpretation
Poorly sorted shock-metamorphosed breccia of primary and secondary impact craters; may be volcanic deposits around some small craters (less than 800 meters in diameter). Morphology of craters is progressively modified by mass wasting, tectonism, and superposition of craters and ejecta with increasing age (Cc_1, oldest; Cc_8, youngest).

Ec

Crater material

Characteristics
Undifferentiated material of two bowl-shaped rayless craters, Sabine D and E. Crater rims are sharp but low. Ejecta blanket, characterized by relatively low crater density, extends less than 1/2 crater diameter away from rim crest. Patterned ground on walls and on outer rim.

Interpretation
Craters were probably formed by impact. Relative smoothness of ejecta blanket due to downslope movement of surficial layer and destruction of small craters. Crater age is difficult to determine because of anamalous combination of youthful and old features.

m_4 | m_3 | m_2 | m_1

Mare material

Characteristics
The surface of the mare material is cratered unevenly with craters of different sizes and different morphologies. Surficial relief consists of low scarps, flow fronts, low ridges, depressions and patterned ground. The surfaces of mare material units m_1 through m_4 have successively lower reflectivity and crater density:
m_1, characterized by a high density of Cc_1 and Cc_2, subdued craters, particularly those 350-400 meters in diameter.
m_2, characterized by a high density of Cc_1, Cc_2, and Cc_3 craters 100-150 meters in diameter, fewer Cc_1 and Cc_2 craters and more Cc_3 craters 400 meters or larger in diameter than in unit m_1.
m_3, characterized by a low density of Cc_1, Cc_2, Cc_3, Cc_4, and Cc_5 craters less than 50 meters in diameter. Only occurrence is between the Cc_3 crater, 1.2 km in diameter, and the mare ridge near southwest corner of site.
m_4, characterized by low density of craters of all sizes and morphologies more than 400 meters in diameter; lower density of Cc_1, Cc_2 and Cc_3 craters 75 to 125 meters in diameter than in mare material unit m_2.

Interpretation
Mare material probably consists of a complex series of intertonguing basaltic layers. Differences in reflectivity and crater density probably reflect differences in age. The surficial layer probably consists of fragmented basaltic rock and shock-metamorphosed breccia produced as ejecta from impact craters, and possibly of vesicular volcanic ash derived from low volcanic vents and cinder cones.
m_1 and m_2 probably consist of flood basalt. The presence of low scarps in unit m_2 in the western part of site suggests that younger layers lap over older ones in a northward direction.
m_3 and m_4 probably consist of basaltic flows of local extent.

tu

Terra material, undifferentiated

Characteristics
Forms asymmetric hill rising 100 meters or less above adjacent mare. Albedo is moderately high, and crater density is low; patterned ground is conspicuous on the sides of the hill, being lobate on the east-facing gentler slope.

Interpretation
Probably ultramafic rocks older than mare material. Mantled by fragmented material mixed with crater ejecta. Downslope movement of the surficial layer is indicated by the diminutive ridges and troughs of the patterned ground.

COPERNICAN SYSTEM

ERATOSTHENIAN SYSTEM

IMBRIAN SYSTEM

Site II P-6, in the southwestern part of Mare Tranquillitatis, on the lunar equator, is a mare area crossed by ridges and rays. The principal mare ridges are in the northeastern part of the site. They are the southern extension of a complex of ridges which radiate from Lamont, a subcircular structure, about 80 km across, 100 km north of the site. The rays are associated with the craters Theophilus and Moltke, 320 and 18 km south of the southern boundary of the site.

The geologic history of site II P-6 is first of all the history of Mare Tranquillitatis. The two rings of Lamont may be partly buried analogs of the inner rings in the Orientale and Imbrium basins; that is, Lamont may be the relic of one of the impact craters that formed the Tranquillitatis basin. Under this hypothesis, the northward-trending mare ridges in site II P-6, which are approximately radial to Lamont, may be controlled by pre-mare structures, contemporaneous with the impact that formed Lamont.

The rocks presumably oldest in site II P-6 are terra material (tu) exposed on a small hill in the extreme southeastern corner of the site. The surficial material covering the hill has the patterned ground texture (Heacock and others, 1966, p. 275), but the reflectivity of the hill in Lunar Orbiter photographs IV H-85 and V M-72 is even higher than can be accounted for by patterned ground--it is similar to that of the lunar highlands. Gamma-radiation measurements of lunar highlands by the Luna 10 orbiting spacecraft (Vinogradov and others, 1966) suggest that terra material consists of ultramafic rocks.

The time of emplacement of mare material (m_1-m_4) is uncertain, but a tentative upper limit can be established by determining the age of the oldest superposed craters. A probable relationship between the size, morphology, and age of craters is shown in figure 1. This diagram was constructed on the basis of 1) the premise that all craters are generally similar when first formed but are progressively subdued and degraded with time, and 2) the observation that the rate of modification is inversely proportional to crater size.

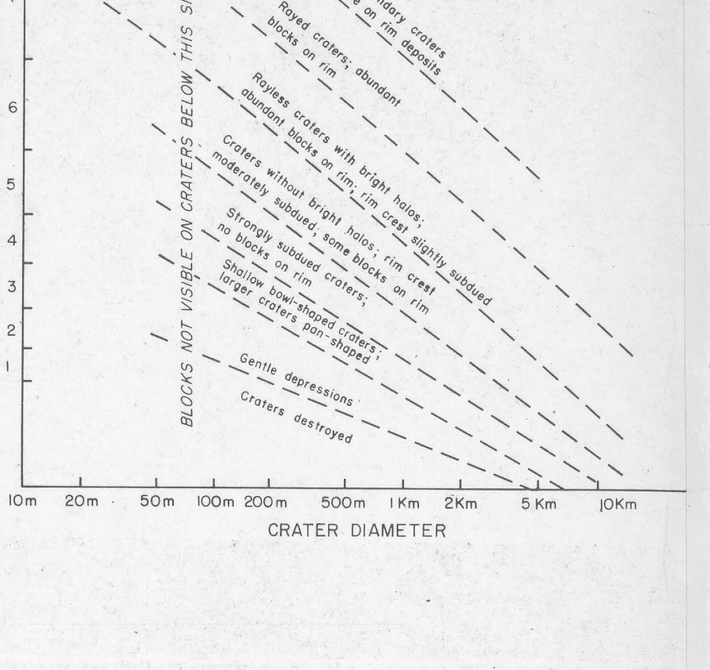


Figure 1

According to the classification of figure 1, Sabine D and E are Eratosthenian in age and are the oldest craters within the site. Thus, the mare surface on which they are superposed is Eratosthenian or older. But a different interpretation is possible if one assumes that the two craters formed on a pre-mare surface that was later flooded by mare materials which almost inundated the craters but did not breach their walls. The narrowness of the Sabine E rim and the fact that it terminates sharply at the mare surface lend support to this idea. According to this hypothesis, the mare material could be as young as Copernican. However, if the age of Mare Tranquillitatis in site II P-6 is Copernican, it must be very early Copernican, because of the unusually great number of large subdued (Cc_1) craters, ranging from 0.4 to 1.2 km in diameter. The high density of large subdued (Cc_1) craters suggests that the surface of Mare Tranquillitatis existed throughout most of the period when large subdued craters (Cc_1) were being formed on the Moon. This conclusion is based on two widely held assumptions: 1) The larger the crater of a given type, the older the crater, and 2) the more densely cratered the mare with craters of that type, the older the mare. In the absence of more definitive criteria, the age of mare material must remain in doubt: probably Eratosthenian or older, but possibly as young as early Copernican.

Mare material (m_1-m_4) in site II P-6 is of intermediate to low albedo, and probably consists of mafic silicate rocks. The gamma-radiation intensity measured over Mare Humorum and Mare Nubium by the orbiting Luna 10 is compatible with that of terrestrial mafic rocks (Vinogradov and others, 1966). At the Surveyor V landing site, the chemical composition of surficial material in a circle, 10 cm in diameter, was evaluated by means of an alpha back-scattering instrument and found to be similar in many respects to that of a terrestrial basalt (Turkevich and others, 1967, p. 637; Gault and others, 1967, p. 641).

Some mare material (m_1-m_2) may occur as layered sheets of flood basalt, extending beyond the boundaries of the site; possible terrestrial analogs, like some flows of the Yakima Basalt in the Columbia Plateau, cover thousands of square kilometers and are hundreds of cubic kilometers in volume (Bingham and Grolier, 1966, p. 9). Mare material (m_3, m_4) may also consist of lava flows that extend only a few kilometers from the place of origin.

Late in its evolution, the surface of Mare Tranquillitatis was modified by an extended system of ray deposits that originate near Theophilus, a Copernican crater about 300 km south-southeast of the site. Patches of four Theophilus rays (Crt) cross site II P-6 in a N. 10° W. direction. Ranger VIII photographs show that one of the rays (easternmost in the site) "apart from brightening the surface slightly, has left no visible marks" (Kuiper and others, 1966, p. 115). The same observation applies to Lunar Orbiter II and V photographs, at effective resolutions of 2, 10, 20, and 100 meters. The Theophilus rays have no apparent topographic expression; they are identified only by anomalous surface brightness. The short lineaments of the Moltke ray (Crm), which probably are grooves in the lunar surface, are absent on Theophilus rays, and the clusters of secondary impact craters so typical of rays from Copernicus and other primary impact craters are lacking. Blocks and boulder fields larger than 2 meters in diameter are absent within the Theophilus rays, probably because of the great distance from the primary crater. The ray material probably forms a discontinuous deposit, thickest around secondary impact craters. Pre-existing craters perhaps were rounded off or subdued by the incoming ejecta from Theophilus; such craters might be identified when photogrammetric and photoclinometric methods become available.

Ray material (Crm) covering an irregularly shaped area in the southeastern part of the site is from Moltke, a Copernican crater about 18 km to the south (three to four crater diameters distant). It is probably superposed on Theophilus ray material (Crt). Many subdued craters are visible through the ray material. The surface of this ray is scoured and gouged, as suggested by the short north-trending lineaments on the map.

The eastward-trending ray material (Cru) in the northwestern part of the site appears as a band of diffuse brightness, of higher albedo than the adjacent mare. This band perhaps is due to a widening and merging of Theophilus rays; if so, the northwestward-trending lineaments mapped there perhaps are genetically related to Theophilus.

Structural elements in site II P-6 are the mare ridges (mr), narrow structural valleys between mare ridge segments, very low swells and troughs in the mare, and low scarps commonly alined with small craters. (The last three features are shown on the map as lineaments.)

Mare ridges (mr) probably consist of both types of mare material: flood basalt (m_1, m_2) and younger flows of limited extent (m_3, m_4). Four of the mare ridges shown on the map trend northward and are radial to Lamont. A fifth ridge trends N. 55° W. and connects the two easternmost northward-trending ridges. The ridges are generally bounded on the west by a steep escarpment; the eastern or northeastern slope is less steep, as if blocks of mare material had been faulted and tilted eastward. The northwestward-trending ridge appears to be broken up into smaller blocks by northward-trending faults (unmapped), suggesting that it is older than the others. It is oriented similarly to the horsts and grabens in the highlands west of Mare Tranquillitatis--the so-called "Imbrian sculpture." This coincidence may be due to late faulting of the mare substratum, renewed after flooding of the Tranquillitatis basin by mare material, and accompanied by volcanic activity along deep-seated zones of weakness associated with the Imbrian event.

Surveyor V photographs of the lunar "soil" or "regolith" (the surficial fragmental layer) in the northwestern part of the site show that it consists of weakly cohesive, very slightly compressible granular material, in which a variety of larger fragments are buried (Shoemaker and others, 1967b). The debris observed near footpad 2 of Surveyor V includes (1) bright angular fragments, (2) dark rounded objects, which are probably aggregates of very fine grained particles, and (3) dark lumpy objects, perhaps aggregates of aggregates (Shoemaker and others, 1967, p. 646). The regolith on the mare is probably a poorly sorted mixture of vesicular volcanic ejecta and of brecciated volcanic rocks shock metamorphosed and blasted out by primary and secondary impacts. The regolith on terra probably consists predominantly of fragmented ultramafic rocks.

Terraces within craters are probably a reflection of penetration to bedrock; the depths of the largest craters lacking terraces approximately equal the thickness of the fragmental layer. Therefore, the surficial layer is probably at least 10 meters thick. Doubtless the layer is thicker in regions covered by ray material. The patterned ground in and around large craters and the existence of talus aprons at the base of mare ridges attest to the mass movement of particulate matter.

Scientific objectives of a ground mission could include testing the lateral homogeneity of the lunar surficial rocks by collecting granular, rounded, and angular samples, analyzing them, and comparing the results with those of the Surveyor V analyses (Turkevich and others, 1967, p. 637). Sampling of ray material from both Theophilus and Moltke and study of the surficial characteristics of rays may help clarify differences between rayed and unrayed mare, and establish the characteristics of lunar rays at a great distance from the crater of origin. Sampling of rocks on top of ridges and in low scarps on the mare might help determine the multilayered nature of the mare, the composition of the layers, and the possible difference between lava flows of local and regional extent.

Mare Tranquillitatis is a "blue" mare (Whitaker, in Heacock and others, 1965, p. 27, fig. 14). The overall color of the surface in site II P-6 should be observed for comparison with the colorimetric data of Mare Cognitum, which is reported to be a "red" mare at the small scale (1-km resolution) of telescopic plates, but is mostly gray at the very large scale of the Surveyor III experiment (Shoemaker and others, 1967a, p. 49). Subtle color contrasts should be looked for to find out whether color boundaries coincide with the boundaries between lava flows as on Mare Imbrium (Whitaker and Strom, in Heacock and others, 1965, p. 29-32, figs. 16-18).

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