DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
MANNED SPACECRAFT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEOLOGIC SUMMARY

This map shows the geology in and around Tranquillity Base where Apollo 11 landed, near the western end of early Apollo landing site 2 (see index map), in the equatorial belt of the Moon. The Sabine D region is in the southwestern part of Mare Tranquillitatis. Most of the region lies within the Julius Caesar Quadrangle (LAC 60) mapped at 1:1,000,000 by Morris and Wilhelms (1967).

The geology of the Sabine D region is dominated by mare materials, which are interpreted to consist largely of basaltic flows extruded during Imbrian time. The surfaces of these flows have been considerably modified by repeated impact cratering, which has produced a mantle of loose rock debris (regolith), and by faulting, which has resulted in the formation of mare ridges and, possibly, structural depressions. Materials not indigenous to Mare Tranquillitatis, but of identifiable source, may occur along rays from Theophilus, a Copernican crater 320 km south-southeast of the Sabine D region, and around secondary craters formed by the impact of ejecta from Theophilus.

The mare material is moderately cratered. It is assigned to the Imbrian System because the oldest craters superposed on it are of Imbrian age. Many large, 500-700 m (meters), gentle circular depressions and pan-shaped craters dot the mare surface, but craters 50-125 m in diameter are fewer than in mare material in early Apollo landing sites in the western part of the equatorial belt. The density of old craters (large depressions and large subdued craters) is higher in some mare areas within the region than in others. This difference in crater populations is interpreted as evidence that the mare materials belong in two age groups: an older unit, mapped as Im_1, and a slightly younger one, mapped as Im_2. These mare units were also mapped at 1:25,000 in early Apollo landing site 2 (Grolier, 1969). On that map, the smoothest parts of unit Im_2, too small to be differentiated at 1:100,000, are shown as mare unit Im_3. Surveyor V, in the northwestern part of the Sabine D region, analyzed mare surface material within a radius of 5 cm and found it to be closely similar to some terrestrial basalts and to basaltic achondrites (Turkevich and others, 1967, p. 637; Gault and others, 1967, p. 641). Although the Moon appears gray to the eye, photographs taken with ultraviolet and infrared filters display distinct color differences; thus, Mare Tranquillitatis has been referred to as one of the "bluer" maria (Kuiper, *in* Heacock and others, 1965, p. 12). In addition, recent studies have disclosed that the spectral reflectivity curve of surficial material in Mare Tranquillitatis apparently shows a strong enhancement at blue wavelengths (McCord, 1969).

Mare ridges (Imr) probably consist of the two mare units, as well as younger basaltic flows of limited extent. They are probably tilted fault blocks, with a steep west-facing escarpment, and a gentle eastward slope. Four of the five ridges mapped trend northward and are radial to Lamont, a circular structure about 50 km to the north (Morris and Wilhelms, 1967). The fifth, in the east-central part of the region, trends N. 55° W., the direction of the so-called "Imbrian sculpture" that forms the horsts and grabens in the highlands west of Mare Tranquillitatis. This structural 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 generated by the impact that formed the Imbrium basin.

Most craters in the Sabine D region probably formed by primary or secondary impacts. A possible exception is an elongate Eratosthenian crater alined with a northward-trending mare ridge in the east-central part of the region. Unlike, many secondary impact craters, which are also elongate, this crater is widest and deepest in the center. This, and the possibility of structural association with the ridge, suggest a volcanic origin. A dimple crater in the west-central part of the map area may also be a volcanic vent.

Early in Copernican time, the surface of Mare Tranquillitatis was modified by an extensive system of rays that originate at Theophilus. Theophilus rays (shown by stippled overprint) trend N. 10° W. across the mapped area. On Ranger VIII photographs the easternmost ray seemed to lack any topographic expression (Kuiper, *in* Heacock and others, 1966, p. 115); however, Lunar Orbiter photographs show that many relatively shallow elongate craters and crater clusters with a slightly angular outline (Crct) occur along the ray.

The Theophilus rays appear to have evened out the lunar surface in the Sabine D region by rounding off large craters and obliterating small ones up to 100 m. This conclusion stems from two observations: (1) Particularly bright areas on the rays generally coincide with areas that appear smoother than adjacent unrayed mare material. (2) In these smooth areas, there is a marked decrease in the density of subdued 50 to 100 m craters.

The crater clusters (Crct) probably formed owing to secondary impact of ejecta from Theophilus, and the Theophilus rays probably consist of the ejecta of these secondary craters mixed with fine ejecta from Theophilus itself. In the western part of the region, crater clusters with down-range furrows approximately radial to Theophilus also apparently coincide with very faint, unmapped rays of the Theophilus system. Blocks 2 meters or more in diameter are lacking on Theophilus rays.

In the south-central part of the region, furrowed mare is mapped as a separate unit (rim material radial to Moltke, Ccrr) to emphasize its genetic relationship to Moltke, a Copernican crater 6 km in diameter about 14 km to the south. This unit extends south of the map area to within one crater diameter of Moltke.

Structural elements in the region are mare ridges (Imr), scarps, buried faults, narrow valleys between mare ridge segments, very low swells and troughs in the mare, and low scarps commonly alined with small craters (the last three are mapped as lineaments).

Wherever the lunar surface slopes steeply down the walls and rims of subdued craters, or down the steep west-facing escarpments of mare ridges, the linear or sinuous features that are known as lunar patterned ground develop in the regolith. In the Sabine D region, this pattern consists of irregular, sub-parallel, anastomosing ridges and troughs, several meters high and approximately 10 m wide. The ridges commonly are asymmetric, with rounded summits. Patterned ground is best developed in the walls and on the rims of Sabine D and E. It is also present at or near the top of mare ridges, where the regional slope is gentle. The lunar patterned ground probably is produced by creep and other processes of mass movement.

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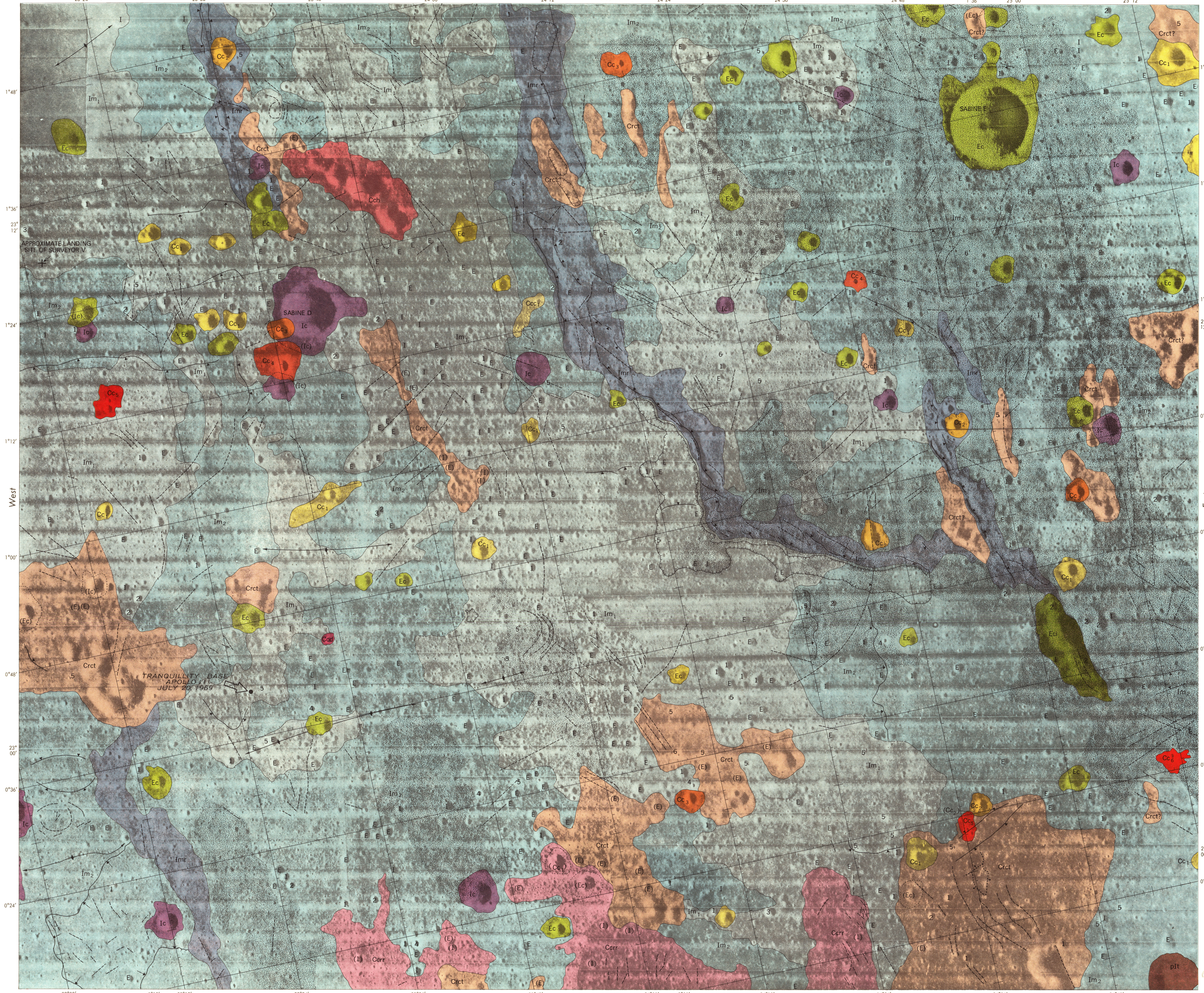


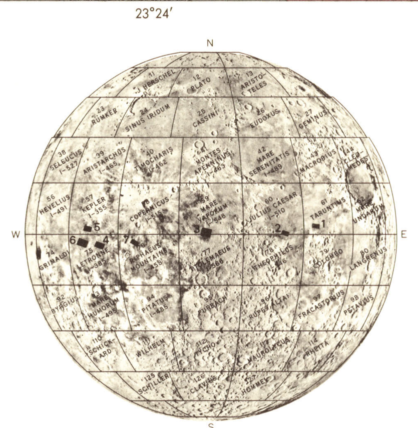
INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1970—G69485

Controlled base photomap ORB II-6 (100) prepared by Army Map Service, Corps of Engineers, U.S. Army, Washington, D.C. 20315

Large numbers 1-7 refer to regions that include early Apollo landing sites

1. Maskelyne DA region
2. Sabine D region
3. Oppolzer A region
4. Wichmann CA region
5. Maestlin G region
6. Flamsteed K region
7. Lansberg P region

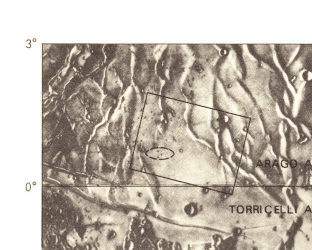
Small number above quadrangle name refers to lunar base chart (LAC series):
Small number below refers to published geologic map (scale 1:1,000,000)



INDEX MAP OF THE EARTHSIDE HEMISPHERE OF THE MOON

MERCATOR PROJECTION
Scale 1:100 000

1 ½ 0 1 2 3 4 5 6 NAUTICAL MILES
1 ½ 0 1 2 3 4 5 6 STATUTE MILE
1 .5 0 1 2 3 4 5 6 KILOMETERS



MAP OF PARTS OF THE ARAGO AND TORRICELLI QUADRANGLES OF THE MOON (AIC SERIES)

Area of this report shown by solid line; dashed line indicates LM landing dispersion ellipse (99% landing probability)
Approximate scale 1:3,000,000

Principal sources of geologic information: Lunar Orbiter moderate-resolution photographs: I-M85, M88; II-M76-91; III-M58, M60, M63; V-M71-78. Lunar Orbiter high-resolution photographs: IV-H78 (3 of 3), H85 (3 of 3); V-H64 (oblique); albedo data from Pohn and Wildey (1970) and from full-Moon plates 5818 and 5819 taken at U.S. Naval Observatory, Flagstaff, Ariz.

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GEOLOGIC MAP OF THE SABINE D REGION OF THE MOON

LUNAR ORBITER SITE II P-6, SOUTHWESTERN MARE TRANQUILLITATIS INCLUDING APOLLO LANDING SITE 2

By
Maurice J. Grolier

1970

EXPLANATION

NOTE: A crater's materials are mapped according to the size (rim-crest diameter) and interpreted relative age of the crater. The apparent freshness of the crater on Orbiter photographs is used to determine its age, and allowance is made for an inverse relation between the sizes and rates of degradation of craters (see enclosed pamphlet). The larger craters in each age group are mapped in color (mappable materials extend relatively farther from the rim crests of young craters than from the rim crests of old craters of comparable size). The map symbols that identify these materials consist of a capital letter to designate lunar time-stratigraphic division (system), lower case letters to designate rock unit, and, in the Copernican System, a subscript number to designate relative age within that system. To keep the map from becoming crowded, materials of the smaller craters in each age group are not outlined; such craters are indicated by number or letter symbol only. For example, materials mapped as Cc_1, outlined, and colored are associated with a relatively old Copernican crater more than 600 m (meters) in diameter; materials designated simply 1 are the same age but are associated with craters from 400 to 600 m in diameter. The mapping is extended to smaller size craters for younger craters than for older craters; the smallest craters in all age groups are unmapped.

COPERNICAN SYSTEM

Cc_6 | 6
Crater material
Characteristics
Cc_6, material of crater with very bright-appearing ray material extending two to three crater diameters away from rim crest. Concentric structure in wall material and radial structure in rim. Abundant blocks in rim deposits. Floor is hummocky. Crater rim crest very sharp and distinctly polygonal
6, similar to Cc_6, except floor is not hummocky and rim crest is not polygonal. Crater rim crest sharp

Cc_5 | 5
Crater material
Characteristics
Cc_5, material of craters with bright-appearing ray material. Concentric structure in wall subdued. Blocks in rim deposits. Crater rim crest sharp
5, material of craters with both bright-appearing and diffuse ray material. Concentric structure in wall material slightly subdued. Abundant blocks in rim deposits. Crater rim crest sharp

Cc_4 | 4
Crater material
Characteristics
Cc_4, material of craters whose rim deposits appear brighter than surroundings. No rays. Some concentric structure in wall material. Abundant blocks in rim deposits. Crater rim crest slightly subdued and crater cone shaped
4, similar to Cc_4, except no concentric structure on walls and only a few blocks present in rim deposits

Cc_3 | 3
Crater material
Characteristics
Cc_3, material of craters with rim deposits that appear only as bright as surroundings. Crater slightly cone shaped. Rim crest moderately subdued
3, similar to Cc_3

Cc_2 | 2
Crater material
Characteristics
Cc_2, material of craters with moderately subdued rim crests. Moderately abundant blocks on walls, a few blocks on rims
2, similar to Cc_2

Cc_1 | 1
Crater material
Characteristics
Cc_1, material of craters with moderately subdued rim crests and some concentric structure on rims. A few blocks on walls
1, material of craters with strongly subdued rim crests. A few blocks on upper parts of walls. Patterned ground (see Geologic Summary) on walls

Interpretation of Copernican crater material
Cc_6-Cc_1; 6-1
Poorly sorted shock-metamorphosed breccia of primary and secondary impact craters; may be volcanic deposits around some small craters (< 800 m). Morphology of craters is progressively degraded in time by mass wasting, tectonism, impact, and deposition of fragmental debris

Ccd
Dimple crater material
Characteristics
Material of moderately subdued 300 m crater. Walls convex upward; slope of walls increases slightly with depth. Crater rim crest is rounded and outer rim is narrow
Interpretation
Material of small volcanic vent or of impact crater on which the fragmental layer has drained through a narrow fracture or opening into the underlying bedrock

Ccrr
Crater rim material, radial
Characteristics
Surficial material having north- or north-west-trending ridges and grooves subradial to crater Moltke. Grooves most abundant along narrow bands extending into region from the ejecta dunes surrounding Moltke (south of region). Bands are best observed on Lunar Orbiter V frames M71 and M72. Rim of large secondary crater (Crct) in southeastern corner of map is not grooved, but topographic lows near crater are
Interpretation
Thin blanket of base-surge material ejected from crater Moltke, mixed with pre-existing regolith. Lack of grooves within large crater (Crct) indicates debris ejected more than one diameter away from Moltke followed very low trajectories

Crct
Theophilus ray cluster material
Characteristics
Material in and around clusters of elongate approximately 0.2-1.8 km craters. Material seems to mantle walls, rims, and floors of craters. Crater morphology subdued. Direction of elongation is northwestward. Grooves and "streamers" of material extend northwestward from the craters
Interpretation
Material of secondary impact craters and ejecta, probably derived from the crater Theophilus. Queried where genetic relationship to Theophilus is uncertain

Theophilus ray material
Characteristics
Material of irregular streaks, as much as 10 km wide, that are distinctly brighter than adjacent mare material on full-Moon telescopic photographs. Streaks are radial or subradial to crater Theophilus, 320 km southeast of the site. One ray covers much of the easternmost quarter of the region and is associated with unit Crct. Normal albedo of Theophilus rays increases inward from 0.096 at edges to 0.114; normal albedo of adjacent mare ranges from 0.090 to 0.096. Topographic features in rays are subdued. Distribution of ray material generally coincides with areas of either greater surficial smoothness or higher reflectivity on Orbiter photographs. Only in a few places does the mapped pattern depart from that observed on full-Moon telescopic photographs
Interpretation
Probably consists of thin blanket of ejecta traceable to the crater Theophilus and to the secondary impact craters that formed at the time of the Theophilus event. Mixing of ray material with crater cluster material and with the surficial fragmental material is likely. Actual size and texture of the fragments that probably account for ray material are not resolvable

Cch
Chain-crater material
Characteristics
Material of alined and partly overlapping craters, between 1.2 and 2 km in diameter, with slightly polygonal subdued rim crests. Narrow rim deposit. Blocks 2-10 meters in diameter on rim crest
Interpretation
Probably material of secondary impact craters

Ccc_1
Crater-cluster material
Characteristics
Material of irregular, 30-150 m craters, occuring in cluster, elongate northeastward, at 1° 12′ N, 24° 2′ E
Interpretation
Material of secondary impact craters. Origin of projectiles unknown

ERATOSTHENIAN SYSTEM

Ec | E
Crater material
Characteristics
Ec, material of craters with strongly subdued rims. A few resolvable blocks in rim deposits of some craters. Relatively smooth rim deposits extending as far as one half crater diameter from rim crest. Patterned ground on walls and in outer rim deposits
E, material of pan-shaped, bowl-shaped, and strongly subdued craters
Interpretation
Material of craters that were probably formed by impact. Relative smoothness of rim deposits may be due to downslope movement of surficial layer causing destruction of small superposed craters. The age of Sabine E is difficult to determine; crater morphology suggests Eratosthenian age, but the rim may be embayed by mare material suggesting an older age

Eci
Irregular crater material
Characteristics
Material of large elongate crater, 3.5 km long and 2 km wide, widening northward, and oriented N. 10° W. near southeast edge of map area. Patterned ground well developed in wall material and in outer rim. Crater is at the southern end of a low mare ridge and is within a ray, also trending N. 10° W.
Interpretation
Material of a large volcanic vent, structurally controlled along a fault, or material of a secondary impact crater

IMBRIAN SYSTEM

Ic | I
Crater material
Characteristics
Ic, material of pan-shaped and shallow bowl-shaped, 0.7-1.7 km craters, and of strongly subdued 3-10 km craters with smooth rim deposits. Crater rim crest is low but distinct in larger craters such as Sabine D. Patterned ground on walls and in outer rim deposits of larger craters
I, material of gentle depressions
Interpretation
Material of craters probably formed by impact. Relative smoothness of rim deposits probably due to the downslope movement of the surficial layer and the destruction of small superposed craters. The age of Sabine D is difficult to determine; its morphology is relatively youthful but the apparent embayment of the rim deposits by mare material suggests an Imbrian age

Imr
Mare ridge material
Characteristics
Forms ridges, bounded in most places by a steep escarpment on the west and a gentler slope gradually merging with the mare on the east. Craters 300-400 m sparse; density of 50-200 m craters lower than on adjacent mare; density of small 10-20 m craters about the same as on adjacent mare. No resolvable block fields on the ridges. Aprons at the break in slope between mare and steep mare ridge escarpments common. Narrow linear depressions occur on some ridges and locally along contact between mare and mare ridge. Patterned ground well developed
Interpretation
Probably consists of faulted blocks of mare material (undivided) generally tilted eastward or northeastward. An elongate crater in the southeastern part of the site (unit Eci) may be a volcanic vent structurally controlled along the ridge. Relatively low crater density on ridges may be caused by downslope movement of fragmental surficial layer

Im_2 / Im_1
Mare materials
Characteristics
Form gently rolling to level, moderately cratered mare surface. Density of large subdued pan-shaped craters (>500 m) higher than in mare material in other potential Apollo sites. Relatively fewer subdued craters (50-125 m) in region compared to mare material in the western landing sites
Im_2, appears slightly darker than unit Im_1. Density of large subdued craters (500-700 m) lower than on Im_1. Craters >125 m cover about 10 percent of unit. Smoothest parts of Im_2 mapped as Im_3 on geologic map of landing site 2 (scale 1:25,000) (Grolier, 1969)
Im_1, appears slightly brighter than unit Im_2. Density of large subdued craters (500-700 m) higher than on Im_2. Craters >125 m cover about 15 percent of unit. Unit Im_1 corresponds to Im_1 on the map of landing site 2 (scale 1:25,000) (Grolier, 1969). Surveyor V landed on mare unit Im_1. It indicated compositional and textural properties in the uppermost meter of the surficial layer not greatly different from those in other Surveyor sites in the maria. Apollo 11 also landed on mare unit Im_1
Interpretation
Probably consists of basaltic flows or ash flow tuffs; vesicular volcanic ash (or lapilli) derived from volcanic vents (such as in units Ccd or Eci) may also be present. Uppermost flows are deeply cratered, and mantled by a fragmental layer. Layers of older fragmented rock may occur at depth stratified between two succesive basaltic flows. The mare surface in the region is interpreted as older than in the other potential early Apollo landing sites because older craters appear to be superposed on it. Therefore comminution of surficial rocks by repeated impact may have lasted longer, and the surficial layer may be thicker and finer grained than in other landing sites

PRE-IMBRIAN

pIt
Terra material
Characteristics
Forms asymmetric hill rising 100 m or less above adjacent mare material. Appears brighter than surrounding mare material; crater density low. Patterned ground conspicuous on the slopes of the hill
Interpretation
Mafic or ultramafic rocks older than mare material. Slopes of hill mantled by fragmental terra material mixed with crater ejecta. Downslope movement of the surficial layer indicated by the small ridges and troughs of the patterned ground

Contact
Dashed where uncertain

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

Buried fault
Bar and ball on apparent downthrown side

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

Scarp
Barb points downslope. Gentle mare scarp or mare ridge escarpment. May be fault or flow front

Gentle sinuous scarp
Arrow points downslope. May be a flow front

Low linear ridge

Irregular depression
Probably collapse feature or possibly graben

Moon (Sabine D area). Geol. 1:100,000. 1970.
cop. 1.

For sale by U.S. Geological Survey, price $1.00
Explanatory pamphlet accompanies map