DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

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

GEOLOGIC SUMMARY

The evolution of the Moon's surface shows three successive stages (Hartmann, 1970). The earliest, from the beginning of the decipherable record to the early Imbrian Period, was dominated by frequent large-scale impacts which produced overlapping and interfering craters and giant multi-ringed basins with ejecta blankets. The second stage, extending through most of the Imbrian and early Eratosthenian Periods, was characterized by volcanism, producing the basalt flows of the maria and varied materials on the terrae. The final and longest stage, extending through the greater part of the Eratosthenian Period and the whole of the Copernican, was one of reduced geologic activity. Major modifications of the geologic structure by large impacts or volcanism occurred only locally, although changes by small-scale impact and mass wasting affected the entire surface. The Descartes region, in the central highlands of the Moon about 500 km southeast of the center of the lunar disk, is dominated by features of the middle stage and contains an exceptionally favorable site for their study.

Dolland B, in the northwest part of the mapped region, and the adjacent lineated plateau are clearly of pre-Imbrian age, as they are cut by fractures of the Imbrian sculpture system (most obviously in the part of the Dolland B rim outside the map area). Another lineated plateau in the northeast part of the region is cut by apparent Imbrian sculpture; associated with this plateau are the craters Zöllner D and Zöllner DA. The circularity of the rim of Dolland B suggests that it is of impact origin. Zöllner D and Zöllner DA, on the other hand, belong to a class of craters, particularly abundant around the margin of the Kant Plateau, which have irregular outlines and are probably volcanic collapse features. The assignment of a pre-Imbrian age to these units is based on the gross morphology, and pre-Imbrian materials may not actually crop out or even immediately underlie the regolith. In fact, toward the limits of resolution of the available photographs, the surfaces in the areas mapped as pre-Imbrian resemble those of the Descartes and Kant materials and may well be underlain by a thin layer of these materials. The partial filling of the Eratosthenian crater Zöllner DC and a small crater in the Cayley Formation on the floor of the crater Zöllner DA by material that has moved down pre-Imbrian crater walls indicates that there are sources of fragmental debris in areas mapped as pre-Imbrian.

The relative scarcity of pre-Imbrian terrane may be explainable. A discontinuous circle of scarps and hills appears to outline an ancient and very battered crater 150 km in diameter, about the size of Ptolemaeus or Hipparchus, centered close to the landing site. (This crater was also noted by Sukhanov (1969).) The scarp near Zöllner D may be part of its rim, and Dolland B is a younger crater that is superimposed on the rim; otherwise, the rim lies outside the map region. Within this ancient rim, "basement" rock presumably lies several kilometers deep beneath crater floor breccia and a crater fill of subsequent deposits.

Two multi-ringed basins, Nectaris and Imbrium, are near enough so that significant influence on the geology of the region might be expected. Ejecta deposits or structural disturbances attributable to the Nectaris impact, the nearer but older of the two, are either absent or so deeply buried that there is no evidence of their presence. The Imbrium impact produced "Imbrian sculpture," furrows radial to Mare Imbrium, approximately NW-SE in this region, cutting the older terrane. In the lineated terrane and the rim of Dolland B the furrows are straight and, although there may be some covering material, are regarded as primary Imbrian sculpture. The depressions of the furrowed unit of the Descartes Mountains have similar trends but are generally not straight. These apparently are younger features that reflect structural control by Imbrian sculpture in the basement. A thin blanket of ejecta from Mare Imbrium (Fra Mauro Formation) may exist in the subsurface or even be exposed in the areas mapped as pre-Imbrian, but no morphological evidence for its presence can be seen.

Three stratigraphic units dominate in the region: the Cayley Formation, materials of the Descartes Mountains, and materials of the Kant Plateau, all believed to be of volcanic origin and of Imbrian age. The first two form clearly distinct terranes, although with some transitional facies. The last is a less well defined unit which shares features with each of the other two. Subdivision of each unit is more arbitrary. Imbrian sculpture is absent in all three units, or expressed only as basement control, indicating a maximum age of Imbrian. If the small craters in the Cayley Formation are of random impact origin, as is commonly assumed, their relative abundance indicates the Cayley is older than the maria. The three units were probably each emplaced by intermittent volcanic activity within approximately the same span of time, so that locally determined age relations may not be valid over wide areas. Crater densities suggest that the bulk of the Cayley and the furrowed subunit of the Descartes are approximately contemporaneous, while the hilly Descartes and the smooth member of the Cayley are younger.

Materials of the Descartes Mountains comprise two units previously mapped as the rugged member within materials of the Kant Plateau and as furrowed terra material (Milton, 1968). It is well exposed on the north rim of the crater Descartes (lat. 10°S., long. 16°E.) outside the map area about 60 km south of the proposed landing site. The unit is one of the better examples of a type of material that occurs in many places in the lunar terrae as patches of rugged terrane unrelated to any crater or multi-ring basin. The partial filling of the crater Descartes by this material indicates that this unit forms a deposit of considerable thickness, perhaps about a kilometer, and that its relief is largely intrinsic. The unit in approximately the north half of the map region was previously interpreted on the basis of telescopic observations (Milton, 1968) as tectonically disturbed pre-Imbrian terrane incompletely masked by younger volcanic materials. Higher resolution orbital photographs show, however, that the bulk of the relief in this area is intrinsic to the formation and not significantly different from that farther south.

Many positive landforms in the Descartes Mountains can with fair confidence be called volcanoes. Broad domes (domed unit) appear to be analogous to terrestrial shield volcanoes. Some have summit craters that, although too small on the available photography for unambiguous determination, appear to be "funnel craters" with convex interior slopes rather than the concave interior slopes characteristic of most lunar craters, suggesting that they are a form of caldera, produced by slumping into a void caused by withdrawal of material at depth. As individual domes broaden, they coalesce into broad plateaus cut by irregular furrows (furrowed unit). These furrows may be merely spaces between constructional features, but probably most are graben or sites of fissure eruptions. The hilly unit resembles the furrowed unit, but individual positive features are smaller and steeper, perhaps analogous to terrestrial cumulodomes or stratovolcanoes.

Materials of the Descartes Mountains apparently had much less tendency to spread from the eruptive centers than the mare basalts or the materials of the Cayley Formation. They probably consist of comparatively silicic rock types, mostly lavas, but may include pyroclastics. The bright facies, which occurs south of the map area but probably contributes to the ray southeast of the landing site, may be composed of particularly silicic material.

Light-colored plains-forming units such as the Cayley Formation cover about seven percent of the near side of the Moon, more than any other identifiable material except mare material, (D.E. Wilhelms, oral commun., 1971). Characteristically, the Cayley forms level plains in the floors of older basins. Small craters are abundant over most of the surface. The higher albedo suggests a composition more silicic than the basalts of the maria. The rarity of ridges and flow front scarps suggests that the Cayley may consist of ash-flow deposits rather than lava beds. Eruptive vents have not been identified, and may even lie outside the area of the Cayley exposure if the Cayley materials represent that fraction of a consanguineous series, of volcanic products which was most mobile and spread farthest from vents in the Descartes Mountains or the Kant Plateau.

The Kant Plateau occupies much of the central region of the Theophilus quadrangle. The terrain varies from smooth to rugged. The broader, level expanses resemble the Cayley plains, but characteristically extend as rolling surfaces from one general level to another with little change in the fine-scaled surface texture, in contrast to the sharp break at the edge of the Cayley Formation in each basin. Only the west edge of the Kant Plateau extends into the map area, and the morphology in large part reflects the scarps over which Kant Plateau materials are apparently draped. Materials of the Kant Plateau are presumably volcanic but, in contrast to the Descartes Mountains, distinct volcanic landforms are only doubtfully recognized.

Craters superimposed on the regional units are arbitrarily considered Eratosthenian (non-rayed) or Copernican (rayed). The satellitic craters (unit Csc) near the east edge of the map area are apparently secondary impact craters of Theophilus. Some smaller unmapped craters farther west are presumably also Theophilus (or Cyrillus) secondaries, but none are obviously so. The chain craters (unit Cloe) resemble secondary craters, and the WNW-ESE orientation of some chains is close to that expected for Theophilus or Cyrillus secondary crater chains, but their orientation also parallels the great Abulfeda volcanic crater chain south of the region. Some of these crater chains (for example, one in the floor of Zöllner D) lie on long lineaments expressed as furrows beyond the chain. These chain craters are interpreted to be of internal origin, perhaps volcanic craters analogous to terrestrial maars.

The most prominent rays in the area are the rather local ones around the very fresh South Ray Crater. Besides the mapped rays from the craters within the region and from Dolland E to the south, ray materials from Tycho, Theophilus, and Alfraganus are widely and thinly dispersed over most of the region, but the limits are too diffuse to be mapped.

Structural grain is not strongly marked in the region. Besides the Imbrian sculpture and the widely spaced lineaments parallel to the Abulfeda chain, there is a north-south lineation marked by the prominent scarp at the west edge of the Kant Plateau and by several parallel scarps and scarp line ridges (unit Irs).

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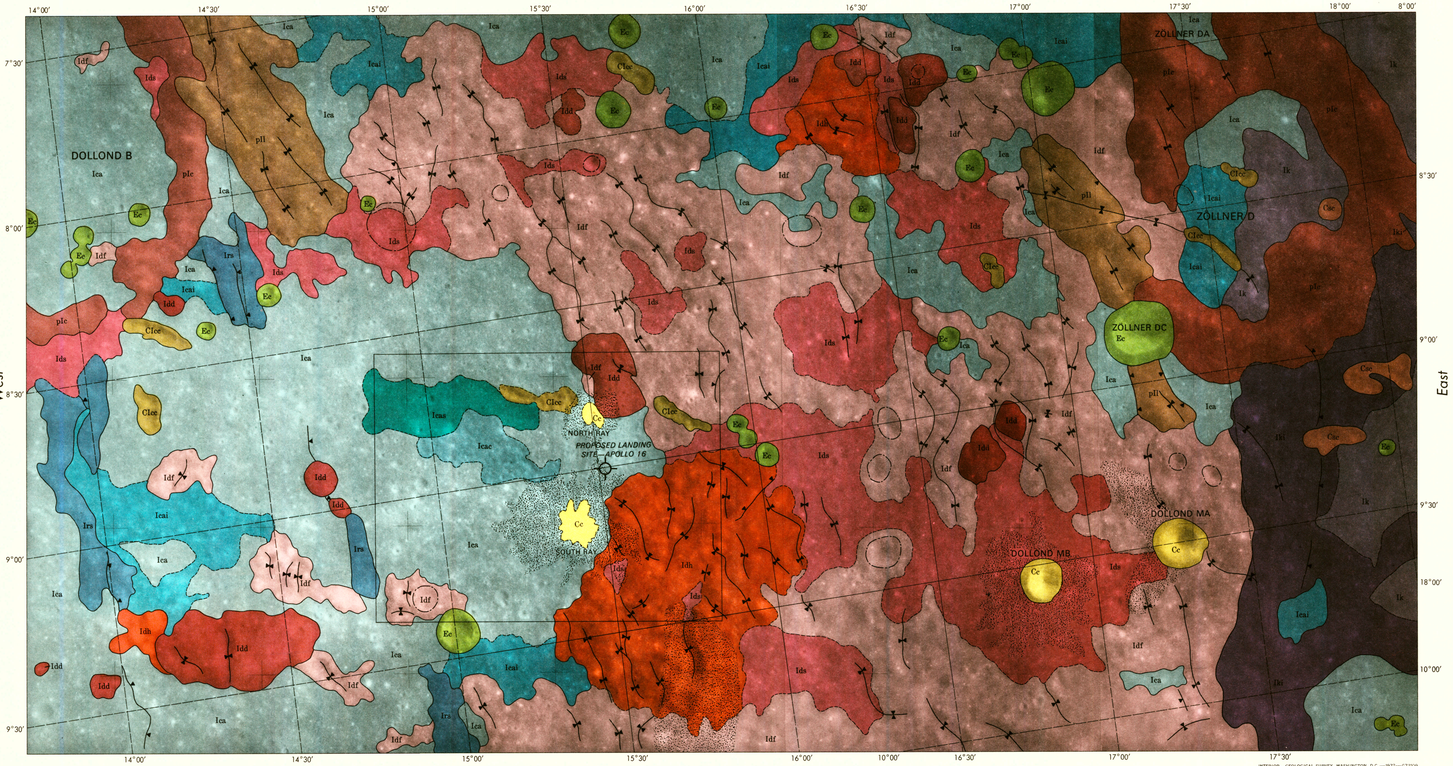


Unrectified photomosaic base made by U.S. Geological Survey, Center of Astrogeology from Apollo 14 photographs 9783, 9784, 9785 (80 mm) supplied by Manned Spacecraft Center, National Aeronautics and Space Administration.

Selenographic grid plotted (solid lines) and extended (dashed lines) by U.S. Geological Survey, Center of Astrogeology from U.S. Army Topographic Command, Lunar Photomap Descartes, scale 1:100,000, 1st ed., September 1971.

Informal names of surface features supplied by Apollo 16 crew and U.S. Geological Survey mission planning personnel.

Principal sources of geologic information: Apollo 14 Command Module 80 mm photography and Lunar Orbiter photograph IV H-089. NASA contract No. T-66353G.

APPROXIMATE SCALE 1:250,000

5 0 5 10 15 NAUTICAL MILES
5 0 5 10 15 STATUTE MILES
5 0 5 10 15 KILOMETERS

GEOLOGIC MAP OF THE DESCARTES REGION OF THE MOON
APOLLO 16 PRE-MISSION MAP

By
Daniel J. Milton
1972

EXPLANATION

Ray material

Characteristics
Streaks of high albedo associated with sharp-rimmed craters
Interpretation
Areas with a high density of exposed rocks ejected from impact craters

Csc — Satellitic-crater material

Characteristics
Material of shallow craters occurring individually or in clusters and having asymmetric outlines and profiles. Rims sharpest and highest at southeast end
Interpretation
Craters formed by ejecta from crater Theophilus, southeast of map area

Cloe — Chain-crater material

Characteristics
Linear chains of coalescing small craters. Resemble satellitic craters but in places lie along lineaments
Interpretation
Some may be Theophilus or Cyrillus secondary craters. However, others are with lineaments suggests internal origin

Irs — Scarp-line ridge material

Characteristics
Forms smooth ridges with rounded crests. Ridge trend commonly extended by a slightly sinuous scarp. Crater density lower than in adjacent Cayley Formation
Interpretation
Probably volcanic materials erupted along faults, or may, at least in part, be areas uplifted by unexposed intrusions

Cc — Crater material

Characteristics
Material of craters having sharp rimcrests and bright halos. Contact drawn at base of raised rim or where continuous halo separates into distinct rays
Interpretation
Impact craters. Order of increasing age is South Ray, North Ray, Dolland MB, Dolland MA

Ec — Crater material

Characteristics
Material of craters having slightly rounded rimcrests and no observable bright halo or rays
Interpretation
Impact craters, slightly modified by impact erosion and mass wasting

COPERNICAN SYSTEM

ERATOSTHENIAN SYSTEM

Ik, Ikl — Materials of the Kant Plateau

Characteristics
Forms level or broadly rolling surfaces. Surface resembles that of the Cayley Formation, but the unit occurs on plateaus as well as in low basins and commonly extends across slopes rather than abruptly terminating at the base of slopes
Ikl, *irregular member* unit. *Surface similar in detail to undivided unit but with greater relief*
Interpretation
Volcanic materials with less tendency to flow than those of the Cayley Formation and greater than those of the Descartes material. Relief within irregular unit mostly reflects underlying topography over which material is draped

Idf, Idh, Idd, Ids — Materials of the Descartes Mountains

Characteristics
Topography rugged, with local relief of several hundred meters. Very hilly in ground. Albedo higher than most terra units, locally very high
Idf, *furrowed unit. Characterized by somewhat twisting elongate depressions 1 or 2 km wide, which are more continuous than the positive features*
Idh, *hilly unit. Characterized by equidimensional hills or ridges 1 km across in a patterned array. Hills are higher and steeper and have sharper summits than the positive features of the furrowed unit and furrows between the hills are narrower and more V-shaped in cross section*
Idd, *domed unit. Convex shields broader than the hills of the hilly unit. Some have summit craters with convex interior slopes, contrasting with the usual concave slopes of small craters. Surfaces comparatively smooth*
Ids, *subdued unit. Similar to furrowed unit, but with lower relief, transitional to Cayley Formation*
Interpretation
Volcanic materials. Positive features are volcanic cones or shields. Some furrows may be graben or the sites of fissure eruptions. Erupted materials had little tendency to spread widely; may have consisted of viscous lavas or pyroclastics or both

pll — Lineated terrane material

Characteristics
Plateaus and high terrane marked by straight furrows or bounded by straight scarps trending NW-SE
Interpretation
Original nature of material unknown. Furrows and scarps mark faults generated by the Imbrium impact

Ica, Icas, Icac, Icai — Cayley Formation

Characteristics
Forms level plains in low areas, with abundant craters less than 250 m in diameter. Albedo intermediate
Icas, *smooth member. Craters less abundant than in unit Ica*
Icac, *cratered member. Craters more abundant than in unit Ica*
Icai, *irregular member. Contains low features of positive relief*
Interpretation
Volcanic materials of high fluidity, either ash flows or lava flows of low viscosity. Chemically, probably more silicic than mare basalt. Nonuniform distribution of craters may reflect relative age, with the cratered member older and the smooth member younger than bulk of the Formation. The irregular member may consist of Cayley materials thinner than elsewhere, not completely masking underlying topography, or may consist of material transitional to Descartes, forming intrinsic relief features

pIc — Crater rim material

Characteristics
Rims of craters Dolland B, Zöllner D and Zöllner DA. Surfaces steeply sloping but smooth in detail. Albedo somewhat higher than surroundings and commonly streaked downslope
Interpretation
Dolland B is an impact crater; Zöllner D and Zöllner DA probably volcanic collapse features (and possibly of Imbrian age). Steep slopes mostly covered with loose debris that has slid downslope intermittently at least into Copernican time. A thin blanket of other mapped units may overlie much of the pre-Imbrian bedrock

PRE-IMBRIAN

IMBRIAN SYSTEM

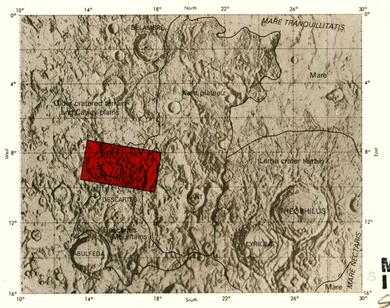
Contact
Dashed where approximately located

Scarp
Probably fault scarps, modified by mass wasting

Furrow
May be faults and graben or sites of fissure eruptions

Rim crest of buried crater

Outline of area covered by 1:50 000 scale map of this report



THEOPHILUS QUADRANGLE SHOWING LOCATION OF DETAILED GEOLOGIC MAPS OF THE APOLLO 16 (DESCARTES) LANDING AREA AND GENERALIZED GEOLOGIC PROVINCES

1. Area of 1:250,000 scale map (Milton, 1972)
2. Area of 1:50,000 scale map (Hodges, 1972)

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Moon (Descartes area). Geol. 1:250,000. 1972.
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