GEOLOGIC MAP OF THE NEAR SIDE OF THE MOON

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DESCRIPTION OF UNITS

DARK MATERIALS

Materials of the extensive and conspicuous dark plains known as maria are the principle constituents of this class, but less extensive dark domes, dome-studded plateaus, and terra mantles, all of which occur within or near the maria, are also included.

MARE MATERIALS

Mare materials cover about 40 percent of the area mapped. Most are located in the centers and concentric troughs of the large approximately circular multi-ring depressions such as the Imbrium basin and within large irregular depressions such as Oceanus Procellarum. Smaller patches are in terra depressions such as those east of Mare Vaporum and in craters such as Archimedes.

Relative age is determined principally from superposition and embayment relations with adjacent units, from density and age of main-sequence craters (see below) superposed on and overlapped by the maria,[1] and to some extent from albedo[2] and color[3] properties. The maria are clearly younger than almost all terra materials, including those of the crater-like multi-ringed basins. They are older, however, than almost all ray craters, such as Copernicus, and non-ray craters such as Eratosthenes, both of which show symmetrical rim deposits and fields of satellitic craters superposed on the mare. Crater frequency counts on telescopic photographs (Shoemaker and others, 1962)[4] suggested that the maria are approximately contemporaneous, and the material at the present mare surface was used to define informally the top of the Imbrian System (Wilhelms, 1970b, p. 23), although the probability of substantial local variations in age was generally recognized (McCauley, 1967b; Wilhelms, 1970b, p. 30–32; Offield and Pohn, 1970). Lunar Orbiter photographs confirm that mare surfaces differ in density and age of superposed and overlapped craters, and an attempt has been made on this map, as on recent larger scale maps (Trask, 1970a), to divide the maria according to relative age. Contacts between mare units as observed on Orbiter IV photographs are, however, gradational and locally diffused by ray cover. In the absence of synoptic coverage at the required higher resolution, the two-fold subdivision used here should be regarded as a preliminary and incomplete portrayal of age variations within maria.

Several lines of evidence indicate that the maria are volcanic (in the sense that they solidified from molten rock probably formed beneath the surface). Their flat smooth surfaces generally terminate against the edges of the confining basins in abrupt contacts along elevation contours, and this indicates emplacement as fluid flows. Their distribution is controlled by the basins, but because the maria are younger they are not considered to be the direct and immediate products of basin formation. A predominantly basaltic composition is suggested by the low albedo, fluid-like emplacement relations, local flow-front morphology, Surveyor analyses, and the recent Apollo 11 and 12 results (Lunar Sample Analysis Planning Team, 1970; Lunar Sample Prelim. Exam. Team, 1970).

Em, *mare material*

Type area: Latitude 3°S. to 4°S., longitude 36°W. to 37.5°W., Wichmann CA region (Cummings, 1971; West and Cannon, 1971) (See Lunar Orbiter III frames 173–180; Orbiter IV, 137; Orbiter V, 169–176).[5] Other typical occurrence: Surveyor I site, 2.5°S., 43.2°W., northeast of crater Flamsteed (Offield, 1972) (Orbiter I, 184–215; Orbiter III, 181–212; Orbiter IV, 143)

Includes mare materials assigned other ages on 1:1,000,000-scale maps

Less extensive than Imbrian mare, constituting about 30 percent of the dark plains; commonly localized near mare-terra contacts. Distinguished from Imbrian mare material by at least two of following criteria: (1) lower albedo[2] than adjacent mare; (2) truncation of rim materials of Eratosthenian craters (such as Manilius and Bullialdus); (3) superposed craters no older than Eratosthenian; (4) lower frequency of craters except where clusters of satellitic craters present; (5) well-preserved primary structures such as smooth-rimmed pits (as in an embayment north of Mare Vaporum), small domes (as at type area), very sharp ridges (as at type area and southeastern Mare Serenitatis), and recognizable flow fronts (in Mare Imbrium—Kuiper, 1965, p. 29–63; Fielder and Fielder, 1968; Schaber, 1969) (Orbiter V, 159–162); (6) relatively strong color[3] contrasts with adjacent mare (usually bluer, but redder along west edge of Oceanus Procellarum)

Probably relatively thin cover of young flows or pyroclastic materials over thicker accumulations of Imbrian mare material. Regolith (impact-produced "soil" layer) thinner than on Imbrian mare. Age of some patches embaying Eratosthenian craters possibly Copernican

Im, *mare material*

Type area: 0.5°N. to 0.5°S., 0.5°W. to 1.5°W., Sinus Medii (Trask, 1970b; Rowan, 1971) (Orbiter II, 93, 113–136; Orbiter III, 86–101; Orbiter IV, 101, 102, 108, 109; Orbiter V, 108–115). Reference area for mapping at Orbiter IV scale: between craters Archimedes (overlapped by mare material) and Eratosthenes (superposed on it) (Orbiter IV, 109,114)

First mapped as Procellarian System and later as Procellarum Group (history of nomenclature given by Wilhelms, 1970b, p. 30–32)

Most extensive single unit, occupying about one-third of map area; mainly dark smooth plains. Color range from relatively bluish to reddish

Mostly basaltic lavas, probably with some pyroclastic materials and impact-produced fragmental layers of varying thickness

DOME AND MANTLE MATERIALS

Emd, *mare dome material*

Type area: Six domes near 7.5°N., 28°W., north of crater Hortensius (Orbiter III, 123; Orbiter IV, 126,133)

Smooth low domes having gentle convex-upward profiles; circular or elliptical in plan view; diameter usually <15 km; heights of several hundred meters. Small craters commonly at summit; small steep-sided hills superposed on some domes

Shield volcanoes or laccoliths. Eratosthenian age implied by apparent superposition on Imbrian mare material, but possibly contemporaneous with uppermost mare material, as shown on most l:1,000,000-scale maps

Emp, *mare plateau material*

Type area: Marius Hills, within 150 km west and north of crater Marius 11.9°N., 50.8°W. (McCauley, 1967a) (Orbiter IV, 150, 157; Orbiter V 210–217)

Includes dark hummocky material of the Procellarum Group (Carr, 1965); Harbinger Formation (Moore, 1965; Orbiter V, 186–193); Tacquet Formation (Carr, 1966); Marius Group (McCauley, 1967a)

Complexes of domes and cones of varied form (bulbous, steep, or flat-topped with ramparts around upper flanks) and associated planar deposits, all elevated above the mare. Similar in albedo to mare

Constructional volcanic features and blanketing flows and pyroclastic materials. Age implied by superposition on mare, generally lower density of superposed craters, and topographic freshness of individual features

CId, *dark mantling material*

Type area: 20°N. to 20.5°N., 10°E. to 10.5°E., northwest of crater Sulpicius Gallus (Orbiter IV, 97; Orbiter V, 90–93)

Includes Vallis Schröteri Formation (Moore, 1965, 1967; Orbiter V, 202–209); Sulpicius Gallus Formation (Carr, 1966); dark mare material (Carr, 1966; Orbiter V, 66–69—Littrow region); Doppelmayer Formation (Titley, 1967)

Darkest lunar material mapped except for some Eratosthenian mare material. Partly subdues subjacent topography (at Orbiter IV scale) within mapped occurrences; high, steep, bright hills within some patches. Surface smooth in detail. Commonly associated with linear troughs at margins of mare basins and irregular craters in mare and terra. Some occurrences embayed by mare material, some superposed on it. Relatively reddish northwest of Aristarchus (Vallis Schröteri Formation); other occurrences relatively bluish. Terrain adjoining mapped occurrences commonly dark but not subdued

Pyroclastic origin suggested by subduing effect; bright hills probably exhumed older terrain. Age ranges from Copernican in fresh, sparsely cratered patches in Copernicus region and southeastern edge of Mare Serenitatis to Imbrian in mare-embayed occurrences

CIRCUMBASIN MATERIALS

This class of terra units consists of widespread, texturally distinctive materials that lie predominantly beyond the most prominent rings of the best preserved large multi-ring basins. Like crater rim deposits (see below), circumbasin materials are generally uniform in character at a given distance from the basin center but change gradationally in the radial direction. The most prominent parts of the scarps or mountain rings encompassing all multi- ring basins are made up of rugged, isolated or coalescing massifs (unit pIr). The materials outside the most prominent scarps of the Imbrium basin (Shoemaker and Hackman, 1962), the Orientale basin (McCauley, 1968), and the Nectaris basin (Stuart-Alexander, 1971; Scott, 1972) appear to form a thick blanket on subjacent cratered topography near the basin and to become progressively thinner outward; the visible blanket, however, is recognizable for hundreds of kilometers from the basins. The circum-Imbrium material described by Shoemaker and Hackman (1962) is here divided into three units. The two closest to the basin (the Alpes Formation and material of Montes Apenninus) are fairly rugged and grade laterally into the pre-Imbrian rugged material of the mountain-ring structures. The third and outermost unit (Fra Mauro Formation) and the similar unit surrounding the Orientale basin (Hevelius Formation) resemble the more finely textured outer radial rim deposits of smaller young craters such as Copernicus. These deposits are lineated with smooth-surfaced sinuous ridges and intervening troughs whose amplitudes decrease progressively with increasing distance from the basin. The circum-Imbrium units and the Hevelius Formation are continuous around their respective basins, except where buried by younger materials. The Fra Mauro grades laterally outward into another type of lineated terrain (pIl) whose grooves and ridges are relatively straight. The lineaments are radial or subradial to the center of the Imbrium basin. Material with mostly subdued radial lineaments, the Janssen Formation, occurs around the southern part of the Nectaris basin and apparently represents the degraded remnants of a still older circum-basin blanket, possibly including materials like those of the circum-Imbrium lineated terrain.

The Janssen Formation is overlain by upper and middle pre-Imbrian craters and overlies lower pre-Imbrian craters, so it probably was formed in the early part of middle pre-Imbrian time. The Fra Mauro Formation is earliest Imbrian in age by definition (Wilhelms, 1970b); similarity in superposed crater densities, lateral continuity, and the gradational nature of contacts with the Alpes Formation and the Apenninus materials, suggest that these three circum-Imbrium units are essentially contemporaneous. The Hevelius Formation around Orientale is known to be younger than the Fra Mauro because of its far better state of preservation, superposition of contemporaneous satellitic craters on Imbrium-related structure, and the relative freshness of superposed craters. Like the Fra Mauro, it is overlain by mare material, Imbrian terra plains material, and some upper Imbrian craters, but it overlies lower Imbrian craters, so is approximately middle Imbrian in age. The rugged and lineated units (pIr and pIl) are believed to consist mostly of prebasin rocks deformed when the nearby basin was formed. Therefore these units, although considered structural not stratigraphic units, are assigned the pre-Imbrian age of their component rocks and not the age of their deformation.

Ihe, *Hevelius Formation*

Type area: 1°N. to 2°N., 68°W. to 68.5°W., on rim and western part of floor of crater Hevelius (McCauley, 1967a) (Orbiter IV, 169)

Closely spaced ridges and troughs about 7 km long and 1 km wide alined radially or subradially to center of Orientale basin; progressive increase in size from type area towards Cordillera scarp at edge of Orientale basin about 550 km to southwest (outside map area). Subdues underlying topography; orientation of subradial structure influenced by pre-basin subjacent topography. Associated with Orientale satellitic craters (Isc). Gradational eastward into stringers and disconnected patches of faintly lineated materials that become indistinguishable from underlying terra units with increasing distance from basin

Impact ejecta deposited ballistically and by radial flowage at or near ground surface

If, *Fra Mauro Formation*

Type area: 0° to 2°S., l6°W. to 17.5°W., north of crater Fra Mauro (informal definition: Eggleton, 1964; formal: Wilhelms, 1970b, p. 25) (Orbiter IV, 120, 121). Reference area: 3°S. to 4.5°S., 17°W. to 18°W. (Orbiter III, 132-135; Orbiter IV, 120)

Sinuous to straight, smooth-textured ridges or elongate hummocks typically 2 to 4 km across and 5 to 20 km long, oriented radially and subradially to Imbrium basin

Impact ejecta from Imbrium basin. Original form similar to Hevelius Formation but more degraded by erosion and mantling by younger materials

Ial, *Alpes Formation*

Type area: 47°N. to 48°N., 5°E. to 8°E., east of Montes Alpes (Page, 1970) (Orbiter IV, 110, 115; Orbiter V, 102)

Included in Fra Mauro Formation by Eggleton (1965) and Schmitt, Trask, and Shoemaker (1967)

Blocky or knobby but smooth-surfaced, closely spaced hills 2–5 km in diameter without conspicuous preferred orientation or lineation. Occurs both within Apennine ring, as at type area, and beyond, as near Kepler

Related to nearby Imbrium basin; may be (1) erosionally degraded ejecta, (2) structurally deformed pre-basin bedrock, or (3) a combination of both

Iap, *material of Montes Apenninus*

Type area: 16°N. to 17.5°N., 3.5°W. to 4.5°W. (Orbiter IV, 109)

Included in Fra Mauro Formation, hummocky member, by Hackman (1966) and Wilhelms (1968)

Rough coarse blocks of material having elongate rectilinear outlines parallel to Apennine scarp bordering Imbrium basin, and smooth to undulating interblock materials. Blocks gradational in size with Alpes Formation (finer) and pre-Imbrian rugged material (coarser)

Probably bedrock intensely fractured at time of Imbrium impact. Interblock materials possibly basin ejecta

pIj, *Janssen Formation*

Type area: 43°S. to 45°S., 37.5°E. to 39°E., in older crater Janssen (Stuart-Alexander, 1971) (Orbiter IV, 76)

Rolling subdued terrain having numerous linear features including ridges, scarps, and grooves radial to Nectaris basin

Nectaris basin ejecta blanket equivalent to, but more degraded and cratered than, the younger Fra Mauro and Hevelius Formations

pIl, *lineated material*

Type area: 5.5°S. to 7°S., 3.5°W. to 5°W., northwest of crater Ptolemaeus (Orbiter IV, 108)

Sharp, raised ridges, intervening level areas or deep troughs, and smooth whaleback-shaped hills with narrow grooves; linear features oriented radial to Imbrium basin. Distal to and gradational with Fra Mauro Formation

Mostly prebasin rock pervasively faulted by Imbrium impact; some structures tectonically reactivated after basin formation. Some basin ejecta (Fra Mauro Formation) possibly present

pIr, *rugged material*

Type area: Mons Hadley, 26.5° N., 4.5°E. (Orbiter IV, 102; Orbiter V, 106)

Includes material of smooth ridges and hills (Trask and Titley, 1966; Titley, 1967)

Rugged blocks most commonly 10 to 30 km across, generally with rectilinear outlines; forms highest and most rugged parts of arcuate raised ridges in and around major circular multi-ringed basins; most extensive and rugged around Imbrium, more subdued elsewhere. Slopes steep, smooth, and bright at Orbiter IV scale. Gradational contacts with adjacent low terrain, or bordered by apron of material that encroaches on adjacent materials

Prebasin rock uplifted during formation of basins by impact. Possibly some post-impact tectonic rejuvenation. Certain more rounded blocks possibly formed or modified by volcanism

TERRA PLAIN, PLATEAU, AND DOME MATERIALS

This class comprises all bright and intermediate-albedo materials of the terrae or “highlands,” except those of craters and the distinctive circumbasin units; it includes flat or gently undulating light plains materials that occur in depressions at about the same elevation as the maria. The class is divided into nine distinctive and two nondistinctive units.

Some terra materials overlap the mare materials in age but most are older, as shown by embayment relations and crater density comparisons. Plain, plateau, and dome materials transect and cover the circumbasin units or modify their textures, thus are younger than nearby multi-ringed basins.

The distinctive deposits are believed to be mostly of volcanic origin, and the nondistinctive materials are of mixed or unknown origin.

DISTINCTIVE MATERIALS

These units are characterized by distinctive surface textures or aggregates of similar distinctive landforms. The category includes (a) plains deposits interrupted only by circular craters, and (b) deposits containing positive landforms which resemble terrestrial volcanic features. The units are commonly superposed on the rims and floors of large pre-Imbrian craters, fewer of which are thereby visible within the confines of the units than in adjacent terrain. The plains deposits are the most extensive of these units and fill troughs concentric with the circular multi-ringed mare basins, floors of large craters, and many depressions of irregular shape. The plains units are easily mapped on all photographs, whereas the other units are difficult to see or delineate on telescopic photographs and their distinctive character was not fully recognized until Orbiter IV photographs became available. The units containing positive landforms are subdivided according to the following criteria: (1) physiographic freshness of the landforms, (2) size of the central depression of the landform relative to the rim or flank deposit, and (3) shape of the central depression—furrowlike or round to irregular “pits.” They are further divided into: (a) “domes” consisting of a single landform and (b) more extensive units consisting of aggregates of landforms. (Individual occurrences and small closely spaced aggregates in which the central crater dominates are mapped separately as “crater materials.”)

Deposits are dated by means of superposition and intersection relations, and, less rigorously, by relative states of degradation. Pre-Imbrian plains deposits are dated by the superposition of lowermost Imbrian crater clusters. Imbrian deposits, the most abundant type, are commonly embayed by Imbrian mare materials, are generally more densely cratered than mare, and transect or overlap Imbrium or Orientale basin deposits or structures. Some dome and all clustered hilly materials are tentatively dated as Imbrian because of their subdued appearance. Imbrian plains material commonly appears to embay or overlie the hilly, hilly and pitted, and hilly and furrowed deposits and therefore is younger Imbrian. A morphologic sharpness comparable to that of the Gruithuisen domes, which are superposed on mare material, serves as the basis for dating two units as Eratosthenian or Copernican. Plains deposits in Copernican-age craters are necessarily Copernican; other sparsely cratered plains are tentatively assigned a Copernican age. In general, terra materials are complex and each deposit probably includes materials of a wide age range.

All materials in this category are believed to be predominantly volcanic; some formed from isolated sources and some from multiple sources distributed over a wide region. The steep landforms may be accumulations of relatively viscous lavas. The lack of distinctive landforms in the plains deposits prevents confident interpretation; they may be composed of fluid lavas, ash-flow tuff, freefall tuffs, or, partly, erosional debris. The shape and size-frequency distribution of craters superposed on the plains are consistent with an impact origin, but some of these craters could be volcanic and genetically related to the unit. The plains and extensive aggregates of positive landforms accumulated to sufficient thickness in some depressions to bury large pre-Imbrian craters, indicating extensive pre-mare volcanism. These deposits are of higher albedo and contain steeper landforms than the maria, suggesting a distinctive composition. The higher albedo may be partly explained by (l) mass movement of surficial material on slopes, exposing fresh, brighter bedrock, and (2) repeated impact cratering, which has created many steep bright subresolution microslopes.

Cp, *plains material*

Type area: Rim (8.9°S., 26.8°E.) and floor (10.8°S., 26.9°W.) of crater Theophilus (Orbiter III, 78; Orbiter IV, 77, 84)

Includes Theophilus Formation (Milton, 1968); terra mantling material in Mare Tranquillitatis (Carr, 1970; Wilhelms, 1970a) (Orbiter II, 35–42; Orbiter III, 5, 9, 11; Orbiter V, 55–62); part of Vallis Schröteri Formation

Smooth, relatively uncratered at Orbiter IV scale. Intermediate albedo, similar to Imbrian terra plains material. Recognized mostly in floor and rim depressions of Copernican-age craters; plains near Rima Bode II (13°N., 3.5°W.; Orbiter V, 120–123), undulatory material at south edge of Mare Tranquillitatis, and moderately dark plains near Vallis Schröteri also included. System of fine cracks and small domes on some crater floors and dunelike texture at Rima Bode II visible at Orbiter V scale (5-40 m)

Occurrences in craters mostly post-impact volcanic materials, possibly with admixture of erosional debris. Occurrences in Eratosthenian craters possibly Eratosthenian in age. Rima Bode and V. Schröteri material volcanic; Tranquillitatis material either volcanic material or erosional debris

CEd, *dome material*

Type area: Gruithuisen γ and δ, 35.7°N. to 37°N., 39°W. to 41°W. (Orbiter IV, 145,151; Orbiter V, 182–185)

Includes Cobra Head Formation (Moore, 1965; Orbiter V, 202–205)

Individual fresh-appearing bright domes or cones, some having small craters or furrows at summits or on flanks. Round to elliptical, as much as 30 km in diameter; height-to-width ratio approximately 1:10, steeper than mare domes

Mostly viscous lava deposits with some pyroclastics

CEhf, *hilly and furrowed material*

Type area: 10.5°S. to 11°S., 15.5°E. to 16.5°E. north of crater Descartes (Orbiter IV, 89)

Includes rugged, bright material of Kant Plateau (Milton, 1968)

Aggregates of closely spaced fresh-appearing hills capped by sinuous or straight furrows. Hills mostly steep, with short furrows, like unit Ihf but brighter and topographically sharper. Includes ridges along long narrow fissures in floor of crater Vitello, 30.4°S., 37.4°W. (Orbiter IV, 136, 137, 142, 143; Orbiter V, 168); high thermal anomaly[6]

Mixed volcanic deposits erupted from fissures

Ip, *plains material*

Type area: 3.5°N. to 4.5°N., 15.5°E. to 16.25°E., east of crater Cayley (Orbiter II, 59–66; Orbiter IV, 90)

Includes Apennine Bench Formation (Hackman, 1966); Cayley Formation (Morris and Wilhelms, 1967); pre-Imbrian or Imbrian plains-forming material (Carr, 1966; Titley, 1967)

Mostly smooth and flat but some undulatory areas included. Intermediate albedo, brighter than mare material, darker than most circumbasin and other terra materials. In topographic lows within terrae. Craters more numerous than on mare except for local occurrences in southern highlands. Most contacts with higher terrain abrupt; some gradational with mare

Probably mostly volcanic; emplacement in fluid state suggested by some contact relations and resemblance of planar surfaces to those of mare. Crater density indicates unit generally older than mare, but isolated smooth occurrences possibly contemporaneous with or younger than mare. Some smaller occurrences surrounded by high source areas possibly derived by erosion

Id, *dome material*

Type area: 4.2°S., 14.7°E., on east rim of crater Taylor B (Orbiter IV, 89)

Individual subdued domes or cones mostly without summit craters or furrows. Some similar to Eratosthenian or Copernican domes but smoother; others irregular to arcuate (as at type area); height-to-width ratio apparently less than for younger domes; as much as 25 km in diameter. Intermediate albedo

Similar to Eratosthenian or Copernican domes but more eroded. Arcuate domes emplaced over sites of older impact or volcanic crater rims. Some may be extensively eroded structural blocks like those of unit pIr

Ih, *hilly material*

Type area: 1.3°S. to 1.7°S., 6.4°E. to 7.7°E., north of crater Pickering (Orbiter IV, 96, 97)

Aggregates of closely spaced, subdued to moderately steep domes or cones with or without small summit craters or furrows. Circular or elliptical, mostly 1 to 5 km in diameter. Similar to some occurrences of Alpes Formation, but hills more regular in size and plan

Volcanic constructional features or eroded blocks of other origin

Ihf, *hilly and furrowed material*

Type area: 19°S. to 20°S., 50.5°W. to 51°W., northwest of crater Mersenius (Orbiter IV, 149)

Includes rugged material of Kant Plateau (Milton, 1968)

Aggregates of closely spaced, subdued hills and ridges 3 to 15 km long and 2 to 6 km wide capped by distinctive sinuous furrows. Irregular craters and chain craters abundant (where >10 km, mapped individually). Includes low ridges along long narrow fissures in crater floors

Densely packed array of pyroclastic or composite cones like those in some youthful terrestrial volcanic provinces

Ihp, *hilly and pitted material*

Type area: 18°S. to 19°S., 60°W. to 61°W. (Orbiter IV, 161)

Gently rolling to hilly terrain containing aggregates of subdued irregular to circular craters and hills. Craters mostly narrow-rimmed or rimless, 2 to 10 km in diameter. Hills equidimensional to elongated by 3:1, mostly <10 km in greatest dimension

Complex volcanic deposits, possibly predominantly pyroclastic, accumulated to considerable thickness over older crater terrain. Pits probably of internal origin and related to the deposits, but some may be secondary impact craters from unrecognized sources pIp, *plains material*

Type area: 44°S. to 45.5°S., 22.5°E, to 25°E. (Orbiter IV, 88)

Generally flat terrain with a greater population of large and older craters than on Imbrian plains-forming material an basal Imbrian units. Some craters circular, some irregular; many superposed craters of lower Imbrian clusters (Icc). Intermediate albedo

Probably volcanic, representing an older variant of the Imbrian plains-forming material

NONDISTINCTIVE MATERIALS

Terrain of intermediate albedo and moderately subdued nondescript surface texture is separated on the basis of relief into two units. The older (IpIt) has moderately high relief and forms parts of the basin-concentric rings and upland terrain between basins. The younger unit (It) has moderately low relief and generally occupies topographic depressions.

These units are not readily datable, and their assigned ages are approximations. The unit assigned a pre-Imbrian or Imbrian age is mostly pre-Imbrian inasmuch as it contains remnants of many large, very subdued pre-Imbrian craters (unmapped). In addition, exposures commonly coincide with structural highs concentric with pre-Imbrian basins such as Humorum and Crisium, so that the unit probably consists in great part of now unrecognizable basin ejecta. Its relatively smooth surface, however, suggests that the materials or processes responsible for smoothing are of Imbrian age. Occurrences of the second unit, on the other hand, show no underlying pre-Imbrian basement and seem to have a population of underlying and superposed craters like that of Imbrian units. Also, some of these occurrences lie in or near the Imbrium basin and interrupt textures of its blanket or its structures. Therefore the bulk of these materials are believed to be of Imbrian age—possibly a thicker accumulation of the same materials as on unit IpIt. The formation of both units probably extended over a considerable time.

Although basin ejecta is probably a major component of both units, they also may contain complexly interbedded impact-crater and volcanic deposits, mixed with local erosional debris. The stratigraphy of these units may never be unraveled in detail by photogeologic methods.

It, *terra material, undivided*

Type area: 21°S. to 22°S., 45°W. to 46°W., southwest of crater Gassendi (Orbiter IV, 143, 149)

IpIt, *terra material, undivided*

Type area: 8°S. to 9°S., 20.5°E. to 21.5°E. (Orbiter IV, 84)

CRATER MATERIALS

This class includes materials of all types of craters that are 10 km and larger in rimcrest diameter, or that form clusters or chains of this size. The term “crater” here includes rimmed depressions of diverse shapes less than 250 km in rimcrest diameter and excludes other types of depressions such as linear rilles and the large multi-ringed basins and their concentric troughs. Each mapped occurrence comprises all materials associated with the crater including, without subdivision, those of the rim flank, wall, floor, and peak. The outer limit is drawn to include textures such as concentric terraces and radial ridges which are conspicuous, are clearly related to the crater, and which obscure subjacent units; satellitic craters and rays are not mapped but some are visible on the base chart. (On l:l,000,000-scale maps, subunits are separated and the outer limit is drawn farther out, to include all crater-related textures.) Materials within the crater believed to be significantly younger than the crater, such as mare and plains material, are separated on this map. Crater materials are divided into five major morphologic categories believed to reflect genetic distinctions, and these in turn are divided into from one to eight age categories.

MATERIALS OF MAIN-SEQUENCE CRATERS

This category comprises about 40 percent of all nearside craters ≥10 km in diameter. It includes individual craters and chains and clusters of dissimilar individuals, and pairs of similar individuals partly separated by septa. The craters have a circular or subcircular outline, a collar of rugged and terraced materials around the rim about one-half crater diameter wide, and concentric terraces on interior walls if rimcrest diameter ≥20 km. Floors are lower than the surrounding terrain except where filled by younger materials. The best preserved craters have radial ridges and grooves in the rim material beyond one-half crater diameter from the rim crest and chains and loops of satellitic craters beginning at about one diameter.

Relative age is determined from superposition relations where stratigraphic markers are present: Copernican crater materials are superposed on Eratosthenian materials; both are superposed on Imbrian mare material; Imbrian crater materials are overlapped locally by mare material but are superposed on the circum-Imbrium materials and associated structures. Pre-Imbrian crater materials are overlapped or cut by these circum-Imbrium materials or structures. Where not in contact with a datum plane, crater materials are dated by physiographic freshness on the assumption that within a given size class the degree of subdual of similar topographic elements— rim-flank structure, rim crest, interior terraces, and central peak—is a function of crater age as suggested by Dietz (1946), Baldwin (1949), and Hackman (1961). A refined physiographic dating scheme by Pohn and Offield (1970) based on Orbiter photographs is used here, with modification appropriate to the mapping scale. A continuum of crater types is recognized, starting with very sharp, bright-rayed craters having large thermal anomalies[6] such as Tycho and Aristarchus, here assigned a late Copernican age (Cc_2), and ending with degraded, vaguely expressed, thermally bland ring structures or craters such as Hommel, assigned an early pre-Imbrian age (pIc_1). Coincident with this degradation is the disappearance of rays in Eratosthenian craters, and of other associated features such as radially ridged rim material and satellitic craters, in Imbrian craters. As a crater becomes more degraded its membership in the sequence becomes more uncertain; that is, it may not be a degraded equivalent of a Tycho-type crater—it may have had a different original morphology. In addition, geologic environment affects crater physiography. Within the terrae the rays and rim deposits of many craters are more poorly defined than on the maria. Many craters in the terrae could therefore be younger than indicated, as suggested by a deficiency of craters mapped as Eratosthenian in the southern terrae.

An impact origin for the larger young craters seems required to account for the energy necessary to eject the projectiles that produced the long rays (as much as 20 times the crater diameter) and the loops and chains of satellitic craters (Shoemaker, 1962). Smith (1966) noted that most lunar craters have rougher, higher rims than terrestrial calderas of comparable size. In general, the morphology of all the craters of the sequence suggests an explosive origin (Baldwin, 1949, 1963). Their generally random distribution and the observed cumulative frequency-versus-diameter relations for a given geologic unit (Dodd and others, 1963; McCauley, 1967b, p. 444–446) support an impact origin.

Cc_2 , *crater material*

Type area: Tycho, 43.2°S., 11.2°W. (Orbiter IV, 119, 124; Orbiter V, 125–l28). Reference areas: Aristarchus, 23.7°N., 47.3°W. (Orbiter V, 194–201); Dionysius, 2.8°N., 17.3°E. (Orbiter V, 80–83)

Very sharp topographic detail at all Orbiter scales. High thermal anomaly[6]. Extensive radial rim materials and rays with associated loops and chains of sharply defined satellitic craters (not mapped)

Cc_1, *crater material*

Type area: Copernicus, 9.7°N., 20°W. (Shoemaker and Hackman, 1962) (Orbiter IV, 121, 126; Orbiter V, 150–157)

Sharp topographic detail at Orbiter IV resolution; subdual of all crater elements evident at higher resolutions. Either bright rays or high thermal anomaly, or both. Extensive radial rim material and related fields of satellitic craters around large craters (Orbiter V, 142–145)

Ec, *crater material*

Type area: Eratosthenes, 14.5°N., 11.3°W. (Shoemaker and Hackman, 1962) (Orbiter IV, 114; Orbiter V, 133–136)

Fairly sharp topographic detail, but without surrounding bright rays or pronounced thermal anomaly. Extensive radial rim material and fields of satellitic craters around large craters, but topographic detail of these less sharp than around Copernican craters

Ic_2, *crater material*

Type area: Plato, 51.4 N., 9.2°W. (Orbiter IV, 122, 127, 128; Orbiter V, 129–132—east rim flank)

Rim crest and interior terraces moderately sharp. Fairly numerous superposed small craters. Radial rim material and satellitic craters recognizable around largest craters (Plato, Archimedes)

Ic_l, *crater material*

Type area: Piccolomini, 29.8°S., 32.3°E. (Orbiter IV, 76, 77)

All topographic elements subdued. Radial rim material and satellitic craters inconspicuous or not visible except in largest craters (Petavius, Iridum crater). Moderately high density of small superposed craters, often with one or more craters in the ≥10 km range

pIc_3, *crater material*

Type area: Alphonsus, 13.5°S., 2.7°W. (Ranger IX, Orbiter IV, 108; Orbiter V, 116–119)

Considerably subdued, having rim material consisting of raised ring with little apparent textural detail except smooth external terraces. Concentric terraces on interior wall partly coalesced and cut locally by channels. Floors of these and older craters generally filled with younger plains units

pIc$_2$, *crater material*
Type area: Clavius, 58.4°S., 14.4°W. (Orbiter IV, 118, 130, 131, 136, 142)
Very subdued, with rim material consisting of low, often incomplete ring. Wall terraces subdued, incomplete, broken by channels. High density of superposed craters

pIc$_1$, *crater material*
Type area: Hommel, 54.5°S., 33°E. (Orbiter IV, 82, 88, 95)
Broad, low-rimmed ring structure. Inner and outer terraces similar to those of younger craters recognized only in largest examples

MATERIALS OF CRATER CHAINS AND CLUSTERS

Crater chains are of two types: (1) three or more individual craters alined and similar in size and morphology that are overlapping, tangential, or alined along a rille; and (2) pairs of similar overlapping craters not separated by septa. Crater clusters are nonlinear arrays of three or more similar overlapping or tangential individuals (with or without septa). Individual craters are either circular or irregular in outline, mostly ≤10 km in diameter. Rim materials, if present, are relatively smooth. Interior terraces are generally lacking, and floors are shallow. The chain and cluster category is gradational with the irregular crater category in cases where outlines merge to form a single occurrence ≥10 km in diameter.

Morphology is a less reliable age criterion than for the main-sequence craters because most chain cluster craters are small and topographically simple. As a first estimate, however, they are assigned an "Eratosthenian or Copernican" age if they are sharp-rimmed, relatively uncratered, and otherwise fresh appearing; an Imbrian age if moderately subdued; and a pre-Imbrian age if strongly subdued and highly cratered.

Crater chains and clusters are believed to be of internal and secondary impact origin because the alinement, grouping, distribution patterns, and morphology argue against primary impact. Alinement along fractures suggests internal origin. Concentration of similarly sized craters between one and two diameters from a crater or basin and partial alinement of clusters and chains radial to it suggest secondary impact origin. This origin is believed certain for satellitic craters (Isc) of the Iridum crater and Orientale basin (which resemble smaller unmapped secondaries of craters such as Copernicus and Eratosthenes), quite likely for crater clusters and chains (Icc) at the appropriate distance from the Imbrium basin, and possible for certain chains and clusters (pIch) around the Nectaris basin.

CEch, *material of crater chains and clusters*
Type area: northwest segment of Rima Hyginus, 8°N., 6°E. (Orbiter IV, 97, 102; Orbiter V, 94–97)
Tangential and overlapping craters of similar size and morphology, or linear furrow with scalloped edges (in Pitatus). Individual craters 2–5 km at type area, 1–3 km at Rima Davy I (11°S., 6°W.); topographically sharp; bowl-shaped profile or small flat floor. Distinct thermal anomaly at type area. Albedo high at Rima Davy and type area
Volcanic, analogous to terrestrial maars or collapse craters

Ich, *material of crater chains and clusters*

Type areas: (a) Chain extending east-southeast from 14.8°S., 13.8°E., south rim of crater Abulfeda (Orbiter IV, 89; Orbiter V, 84); (b) cluster centered at 30°S., 4°W. (Orbiter IV, 107, 108, 112, 113)

Most individual craters moderately subdued. Three general types: circular and bowl shaped, circular or irregular with narrow ridgelike rims and broad shallow floors, or linear furrow with scalloped edges

Most are probably volcanic, but some may be clusters of secondary impact craters, particularly of Imbrium and Orientale basins; linear chains in central part of Moon and radial to Imbrium probably produced during basin formation by radial faulting or secondary impact. Age range early to late Imbrian.

Isc, *satellitic-crater material*

Type areas: Clusters and chains centered (a) at 55.5°S., 48°W., on southeastern side of crater Schiller C (Orbiter IV, 160, 167) and (b) at 53 N., 24°W., northeast of the crater around Sinus Iridum (Orbiter IV, 140, 145)

Type (a) individual craters in 10–15 km size range with sharp rim crests and bowl-shaped interiors without distinct floors. Alined in closely packed chains or clusters with the walls down-range from Orientale basin commonly breached and grading outward into a herringbone ridge-and-trough pattern. Most but not all located beyond mappable extent of Hevelius Formation, typically 1200 to 1500 km from center of Orientale basin. Similar in general properties and distribution to secondary impact craters identified around Copernicus but averaging about three times larger. Type (b), around Iridum, similar but in 5-8 km size range

Secondary craters formed by impact of large blocks ejected at low to intermediate trajectory angles from (a) Orientale basin and (b) Iridum crater, which are nearly of same age

Icc, *material of crater clusters and chains*

Type area: Cluster centered at 36°S., 27°E., on rim of crater Riccius (Orbiter IV, 83)

Individual craters as much as 25 km in diameter; majority of each mapped cluster and chain composed of craters >10 km. Moderately subdued rimcrest and bowl-shaped interior without distinct floor, except where (in some western occurrences) filled by younger materials. Early Imbrian age indicated by similarity of rimcrest sharpness and density of superposed craters to oldest main-sequence craters on Imbrium blanket; but interior more bowl-shaped than in main sequence. Concentrated in southern and southeastern terrae, on pre-Imbrian units. Grouped in closely packed clusters and chains of overlapping individuals; some chains radial to Imbrium basin. Similar in general grouping and morphology to Orientale satellitic craters but more subdued, and individuals and clusters somewhat larger

Either secondary impact origin or volcanic. Secondary impact from Imbrium basin favored for most on basis of distribution, size, and apparent early Imbrian age

pIch, *material of crater chains and clusters*

Type areas: (a) Vallis Rheita, 39°S., 47°E. (Orbiter IV, 64, 71); (b) Southeast of Schiller (Orbiter IV, 148, 154, 155)

(a) Large linear valleys with separated and overlapping, circular or elliptical craters, and (b) chains or clusters of at least four tangential or overlapping circular individuals; some individual craters resemble main-sequence pre-Imbrian craters, others only narrow, broad-floored rings

Linear valleys produced during basin formation by radial faulting or secondary impact. Some craters outside fourth ring of Nectaris basin, as at 45°S., 48°E., possibly Nectaris secondaries; others possibly primary impacts alined by chance, or volcanic

IRREGULAR-CRATER MATERIALS

This category includes materials of individual craters or overlapping craters without septa; the category may locally be gradational with the chain and cluster category. Outlines are irregular with marked reentrants or elongated by more than 2:1. Rim materials are relatively smooth. Inner profiles may be like those of other classes, but most examples lack terraces on walls and have relatively shallow floors.

Age criteria are the same as for chains and clusters.

The irregular shape suggests an internal origin. Some, however, could be clustered secondary impact craters; overlapping, modified primary impact craters; or primary impact craters produced by fragments of a body broken up by tidal force before impact (Sekiguchi, 1970).

CEci, *irregular-crater material*

Type area: Crater adjacent to Rima Bode II, 13°N., 4°W. (Orbiter IV, 109; Orbiter V, 120–123)

Sharp topographic detail at all scales, distinct thermal anomaly, and high albedo at type crater. Other occurrences also fairly sharp but less bright and without detected thermal anomaly

Ici, *irregular-crater material*

Type area: Catharina D, 17°S., 21.5°E. (Orbiter IV, 84)

Moderately subdued. Small to large (10 to 40 km); diverse in outline and profile, majority having narrow rims, smooth profiles, and broad floors. Age range early to late Imbrian

pIci, *irregular-crater material*

Type area: Schiller, 51.8°S., 40°W. (Orbiter IV, 148, 154, 155, 160)

Range from deep, with steep inner walls that are terraced or radially streaked, to shallow, with narrow rims and broad floors. Type example as subdued as young pre-Imbrian main-sequence craters

MATERIAL OF SMOOTH-RIMMED CRATERS

This category is composed of individual craters having outlines similar to those of main-sequence craters. Rim materials are smooth, without pronounced terraces or radial rim deposits. Satellitic craters are absent. Concentric interior terraces are present in some craters, and floors are commonly about level with the surrounding terrain. Diameters are mostly in the 20–40 km range.

All craters in this category are assigned an Imbrian age on the basis of rimcrest sharpness and common embayment by Imbrian mare material; however, some craters appear to be superposed on the mare material or gradational with it and could be post-Imbrian. Although topographic features are subdued to a degree that would indicate early Imbrian or pre-Imbrian age in main-sequence craters, superposition of the type example on middle or late Imbrian features of the Orientale basin floor suggests relative youth and, therefore, an original form distinct from that of the main-sequence craters.

These craters differ sufficiently from main-sequence craters to suggest a different origin. Non-impact origin is suggested by the lack of rugged exterior terraces. The craters resemble terrestrial ash-flow calderas in morphology and size (Smith, 1966). They could have been formed, however, by an unusual type of impacting body or unusual conditions (fluidity?) in the target materials at time of impact.

Ics, *material of smooth-rimmed craters*
Type area: Crater Kopff in Orientale basin at 18°S., 90.5°W., outside the map area (McCauley, 1968) (Orbiter IV, 187). Reference area in map area: Lassell, 15.5°S., 7.8°W. (Orbiter IV, 113)

UNDIVIDED CRATER MATERIALS

Crater materials are placed in one of three "undivided" categories if the craters are too small or too greatly modified to show the criteria necessary for assignment to one of the major morphologic categories or to the age categories of the main sequence. Their distribution is similar to that of the main-sequence craters, and most are probably degraded equivalents of craters originally like Tycho; some may be small or modified equivalents of the smooth-rimmed category. Because their original form is unknown, physiographic dating is precluded; individuals can be dated, however, from local superposition relations. "Undivided" craters constitute about a third of the nearside craters larger than 10 km.

Cc, *undivided crater material*
Type area: Guericke C, 11.5°S., 11.5°W. (Orbiter IV, 113)
Sharp-crested fresh craters and associated deposits with bright (in a few cases, dark) rays or halos and (or) high thermal anomaly. Rimcrest diameter mostly ≤15 km

Ic, *undivided crater material*
Type areas: (a) Large, Stadius, 10.5°N., 13.5° W. (Orbiter IV, 114, 121); (b) small, Aratus A, 22°N., 5°E. (Orbiter IV, 102); (c) atypical, Alpetragius, 16°S., 4.5°W. (Orbiter IV, 108)
Moderately subdued form. Includes craters of two types: (1) those difficult to assign to either the upper or lower Imbrian because of small size, resolution limitations, extensive flooding by younger materials, or proximity to large youthful craters; (2) those whose central peaks and interior profiles are unlike those of main-sequence craters. Prominent inner ring concentric with rim of some small (10–15 km) craters (such as Hesiodus A, 30.1°S., 17°W.)

pIc, *undivided crater material*
Type areas: (a) Large, Ptolemaeus, 9.3°S., 1.8°W. (Orbiter IV, 108); (b) small, craters between 42°S. and 46°S., 27°E. and 31°E. (Orbiter IV, 83)
Subdued ring structures either deeply buried or too degraded for assignment to a pre-Imbrian subdivision. Craters generally ≤20 km, but larger severely degraded rings narrow relative to rimcrest diameter also included

Crest of basin ring structure (generalized)
Dashed where inferred from mare ridges, widely separated terra hills, or relatively low terra features

NOTES TO DESCRIPTION OF UNITS

[1] Terms “crater(s)” and “mare” (plural, maria) which, strictly, refer to topographic forms, are used for brevity in many descriptions in place of “crater materials” and “mare materials,” which are the geologic units mapped and interpreted.

[2] Albedo (brightness at full Moon) values are expressed in qualitative terms which correspond approximately to normal albedos determined by Pohn and Wildey (1970) as follows:

Very low albedo (very dark at full Moon)	< .074
Low (typical of the maria)	.074-.096
Intermediate (typical of the terrae)	.096-.159
High(bright at full Moon)	>.159

[3] All lunar colors are reddish; color is expressed here as bluish or reddish relative to a reddish average (Whitaker, 1966; McCord, 1969).

[4] References cited are listed in the accompanying pamphlet.

[5] Lunar Orbiter IV frames listed are high resolution (70–150 m identification resolution); for other Orbiter missions the number given includes both the high- and moderate-resolution frames (ranging from 1 to 40 m), though some high-resolution frames do not include the feature in question.

[6] Thermal data are expressed as relative strength of near-infrared signal at eclipse. Thermal anomalies above a background (Shorthill and Saari, 1969). Thermal anomalies are believed to result from a local abundance of exposed rock.

Mapped 1968–1969. Wilhelms mapped the area east of long 10° W. and the remaining parts of the Tycho and Clavius quadrangles; McCauley mapped the rest of the area and prepared most of the geologic summary.

Authors relied heavily on the 1,000,000-scale maps listed in the accompanying pamphlet

PRINCIPAL DATA SOURCES

Topographic forms and textures: Photographs from Lunar Orbiter IV (11–25 May 1967), courtesy of Lunar Orbiter Project Office, Langley Research Center, NASA; index *in* Kuiper and others (1967); U.S. National Space Science Data Center (1969); Kosofsky and El-Baz (1970); supplemented by near-terminator telescopic photographs (Kuiper and others, 1967) in the eastern regions where Orbiter photographs are poor

Albedo: Unpublished near-full-Moon photographs 5818 and 5819 taken with the U.S. Naval Observatory 61-inch reflector (Flagstaff, Ariz.); published photograph L-18, Lick Observatory 36-inch refractor (Kuiper, 1960); Pohn and Wildey (1970)

Thermal: Shorthill and Saari (1969)

Color: Whitaker (1966); McCord (1969)

Lunar base mosaic LEM-1, 3rd edition, 1966, by the USAF Aeronautical Chart and Information Center, St. Louis. Missouri 63118

GEOLOGIC SUMMARY

MARIA AND MULTI-RING BASINS

The circular basins, generally encompassed by three or more partly complete scarps or ring systems, dominate the geology of the Moon's near side. Diameters of the innermost ring range from 250 to 600 km (kilometers), and the spacing of the three inner rings increases from one to the next by a regular ratio (Hartmann and Kuiper, 1962).[1] The observed and inferred crest lines of the most prominent of these structures are shown by brown lines on the accompanying map. The depressed central parts of the basins and the concentric troughs which lie between successive rings are completely or partly filled with dark plains material (mare) which is younger than the basins and which appears to have been emplaced in a fluid and probably molten state. These basins and their subsequent mare fill have destroyed large parts of the earlier geologic record, and in this respect have acted like terrestrial orogenies. The historical geology of the Moon can be understood only in terms of these dominant, primitive structures which, if ever present on Earth, have long since been obliterated or deeply buried and severely modified.

The general circularity of the basins, the textural similarity of the materials of the ring structures, and the regularity of the ring spacing suggest a common origin. If all basin-related features are considered, particularly for the best preserved basins, an impact origin, as first suggested by Gilbert (1893), is strongly favored. The inner rugged rings of the two best preserved basins, Orientale (just outside the map area) and Imbrium, are surrounded by distinctive ejecta blankets (Hevelius Formation and Fra Mauro Formation respectively) which can be traced outward for hundreds of kilometers. Relicts of what is probably a third, more degraded and older ejecta blanket (Janssen Formation) can be recognized south of the Nectaris basin. Within and beyond these blankets, chains and clusters of craters have been identified as probable secondary impact craters on the basis of morphology, size, and distance from the basin (see section on crater materials). Observable differences among basins—such as the presence or absence of a recognizable blanket, the completeness of the concentric ring structures, the freshness and relief of the rings, the character of the radial structures, and the types and numbers of superposed craters—can be explained by variations in relative age, degree of filling by younger mare, or proximity to younger basins. Alternative explanations for the multi-ring basins calling for an internal origin (Spurr, 1944; Green, *in* Oriti and Green, 1967) are inadequate because of failure to account for all of the basins' observable properties, relative ages, and relations to subjacent and superposed units such as the maria.

A considerable body of stratigraphic evidence shows that the mare material in the basins is not the immediate and direct product of the basin-forming impact but is a later volcanic fill: (1) The mare truncates all other basin-related deposits and structures. (2) It is located in basin-related topographic lows, including troughs between the outer rings far from the basin centers. (3) The mare surface materials in all basins appear to have a narrower age range (determined from the number of superposed craters) than the basins, which differ greatly in state of preservation and apparent relative age. (4) Craters which are superposed on the basin ejecta or basin-related structures but are embayed or filled by mare material occur in every basin (for example, Posidonius, Gassendi, Cleomedes, and Fracastorius in the Serenitatis, Humorum, Crisium, and Nectaris basins respectively). The postbasin, premare craters within the Imbrium basin (that is, Imbrian-age craters) are approximately equal in number to the total number of postmare craters (Eratosthenian and Copernican ages) in the same area. Thus a considerable interval between basin formation and final mare filling is suggested. (5) A distinct geologic unit, light plains material (unit Ip), lies stratigraphically between the deposits of the Imbrium basin and postbasin, premare crater materials, including those of Archimedes, Cassini, and Plato. (6) Features far from and unrelated to the Imbrium basin are also of Imbrian age, demonstrating an extensive history between the formation of the basin and the last mare fill. Orientale is one such Imbrian-age feature, and many Imbrian craters apart from those in the Imbrium basin both predate and postdate Orientale. (7) The nearside basins are filled by mare to varying structural levels independently of their size. For example, Nectaris is filled to the first ring and Crisium and Imbrium to the second and third respectively. Uneven filling suggests different volumes of mare material in each, reflecting internal rather than external (impact melting) controls on their filling.

Each basin immediately after excavation and early gravitational slumping probably resembled the present youthful-appearing Orientale basin (McCauley, 1967b, p. 439-446; 1968). Orientale is the key to the internal configuration of the more degraded and deeply filled basins because of its lack of extensive mare filling and its relative youth. Its present shallow profile suggests that the thickness of the mare fill even in more deeply flooded and obscured basins like Imbrium is on the order of only 2 to 5 km. Mare material, although covering almost 30 percent of the nearside surface (and very little of the far side) is, therefore, volumetrically a small part of the Moon (radius 1738 km). The deeply flooded basins like Imbrium may lie in regions where potential source material was at shallower depth than it was in the less filled basins like Orientale and Nectaris. The existence of numerous thalassoids (basins without mare fill) on the far side of the Moon (Lipskiy, 1965) further supports the conclusion that the location of a basin and local crustal conditions determine the degree of later flooding.

Oceanus Procellarum is unusual because of its non-circular, somewhat irregular shape. It is the largest expanse of mare on the Moon that is not obviously controlled by a single circular multi-ringed basin. It contains, throughout most of its extent, numerous terra islands and large ghost or vestigial craters such as the Flamsteed ring which collectively suggests that the mare is relatively shallow. Its overall shape however, appears to be controlled by outer ring structure of the Imbrium basin and two vague, ancient ring structures centered near Copernicus and Flamsteed which were identified during this work.

During and after the period of flooding, meteorite bombardment eroded and subdued the basin rings and blankets through direct hits, impact of far-flung secondary ballistic fragments (Shoemaker, 1965), and seismic shaking of the surrounding terrain triggering downslope movement of loose materials (Titley, 1966). This process led to the eventual disappearance of the distinctive depositional textures of the circumbasin blankets. Catastrophic premature aging and partial obliteration of basins is exemplified by Serenitatis, whose rings have been disturbed structurally and mantled by ejecta from the nearby Imbrium basin. The trend of the younger Imbrium rings has in turn been influenced by the presence of the earlier Serenitatis structure as seen in the change in the trend of the “Apennine” ring in the Montes Caucasus region.

TERRA PLAIN, PLATEAU, AND DOME MATERIALS

Prior to formation of the youngest mare material, the basins were also modified by the deposition of several types of distinctive terra units described in detail in the accompanying explanation. The most extensive of these are the light terra plains materials of Imbrian age (unit Ip) which lie predominantly in circumbasin troughs and on the floors of pre-Imbrian and lower Imbrian craters. Plains identified as pre-Imbrian (pIp) by superposition of lowermost Imbrian crater clusters occupy more restricted areas in the southern terra. These two marelike plains units may represent earlier generations of volcanism and crustal flooding, their present high albedo relative to the mare material being due either to initial compositional differences or to more extensive churning and consequent brightening by prolonged meteorite bombardment. The most distinctive terra unit (hilly and furrowed material, Ihf) forms level or shieldlike plateaus that cover basin ejecta and postbasin craters and contain numerous small primary volcanic landforms. The two largest occurrences lie west of Nectaris between the third and fourth rings and northwest of Humorum athwart and beyond the third ring. These plain and plateau units, which apparently modify earlier basin or crater deposits, suggest a more extensive history of lunar volcanism than previously recognized. Moreover, they differ markedly in albedo and roughness from the dark, relatively smooth mare volcanic deposits and they may thus represent the products of a distinct terra magma or of mare magma contaminated by terra materials. The bulk differences in composition from the maria could, however, be minor, as in the case of terrestrial cone and flow materials within the same volcanic field. The distribution of the terra volcanic units is controlled predominantly by basin ring structures; some occur at the intersection of younger rings structures with vague circular depressions which are the probable relicts of very ancient basins. In addition to these more extensive deposits, several types of domes, mostly in the 10 km size range, have been identified both in the maria (units Emd, Emp) and in the terrae (units Id, CEd). Many of these, including the largest and most distinctive, the postmare terra domes of the Gruithuisen area southwest of Sinus Iridum, lie along circumbasin ring structures.

CRATER MATERIALS

Craters of all ages, mostly circular, dominate the lunar landscape at all scales. The circular craters, except those deeply buried or in a poor state of preservation because of their antiquity, have physiographic characteristics that indicate an explosive origin (Baldwin, 1949, 1963). Their cumulative frequency distributions are difficult to explain by a volcanic model (Green, 1962) but do fit well with an impact model (Baldwin, 1963). The circular craters, probably of primary impact origin, are here grouped in a “main sequence” divided into eight age categories.

Foremost among the craters not grouped in the “main sequence” are chains and clusters of 10-15 km bowl-shaped to irregular craters lying within and beyond the confines of the Hevelius Formation (out to 1500 km from the Orientale basin center) and confidently identified as secondary impact craters formed by ejecta from the Orientale basin (unit Isc). Similar but larger, less well preserved clusters and chains of early Imbrian craters can be identified on the pre-Imbrian terrae as probable secondary craters of the Imbrium basin (unit Icc). Many degraded or partly buried pre-Imbrian chains and clusters (unit pIch) near the edge of the Janssen Formation may be secondary craters of the moderately well preserved Nectaris basin. Thus secondary craters of large basins constitute an important part of the total lunar crater population in the 10–25 km size range on the older parts of the terrae. A few smooth, low-rimmed craters such as Lassell and Damoiseau, mostly in the 20 to 30 km size range, lack impact characteristics and could be calderas (unit Ics). Certain irregular craters and clusters and chains of smooth-rimmed craters that are controlled by local or regional structural trends are also considered to be volcanic features. Most of these are relatively small and relatively young (units Ich, Ici, CEch, CEci), but some large irregular craters (pIci) and chains (pIch) of probable pre-Imbrian age could also be volcanic, suggesting a possible early epoch of crater-forming volcanism.

A number of craters, particularly those of the older, subdued variety such as Pitatus, exhibit numerous superposed volcanic landforms such as domes and crater chains (mostly too small to be mapped as separate features). The presence of these landforms suggests either that the host craters are volcanic or that impact scars may be the loci of long-subsequent volcanism even for features much smaller than basins.

GEOLOGIC HISTORY

From these regional observations and interpretations a geological history of the Moon can be extensively defined. The relative ages of the multi-ring basins can be partly established by overlap relations with one another, relative topographic freshness, and age of superposed and subjacent craters. Orientale is younger than Imbrium; Nectaris, Crisium, and Humorum are older but difficult to date with respect to one another because of their geographic separation; Serenitatis and Fecunditatis are next in the sequence, and Nubium and Tranquillitatis are the most ancient of the prominent multi-ring basins. Each basin is inferred to have undergone its own cycle of early volcanic filling, impact erosion, and mantling by thick or thin to discontinuous ejecta from nearby and distant younger basins, and each contains mare fill in varying amounts. Thus the stratigraphic sections in and around each of these basins are complex and reflect variable local interplay between external and internal lunar processes.

The most primitive appearing terrain on the near side lies in the south-central part of the map area extending as a wedge-shaped tract broadening from Ptolemaeus to the region of the south pole. This province consists predominantly of closely packed 100-200 km pre-Imbrian craters of the probable impact sequence along with chains and clusters of Imbrium and probably Nectaris secondary craters. The preservation of this topographically positive area, within which volcanic filling played a role of uncertain importance, is explained by its location beyond the range of extensive blanketing and structural disturbance of the recognizable circular basins.

The regions south and southeast of Mare Humorum, between Serenitatis and Crisium, and southeast of Crisium also consist of basically pre-Imbrian terrain and represent the next most primitive part of the Moon’s near side. This essentially nondescript terrain, characterized by a moderate deficiency of large pre-Imbrian craters, is considered to represent an interlayered sequence of now unrecognizable crater material, volcanic material, and basin ejecta blankets; each blanket originally resembled that around Orientale and buried much of the earlier local geological record.

The lunar stratigraphic record becomes clearer with the catastrophic formation of the Imbrium basin which began the Imbrian Period. The basin and the blanket, however, have undergone considerable modification since their formation, and only relicts of the original depositional pattern are now recognized. Most of this blurring of original textures is attributed to subsequent meteorite bombardment, but some is also due to volcanism. Extensive light plains materials filled low areas within the basin and in the troughs between rings, truncating the braided and hummocky textures of the blanket and basin-radial structures. Dark blanketing material was deposited in a broad arc midway between the third and fourth Imbrium rings. Steep domes and other distinctive terra landforms were also formed. These various blanketing and filling materials range from early Imbrian to Copernican in age, further supporting the conclusion that basin modification by volcanic processes is of long duration.

Some time after formation of the Imbrium basin, extensive modification of parts of the older terrae began, especially northwest of Mare Humorum and west of Mare Nectaris. Distinctive terra landforms were formed near these older basins in greater number than near Imbrium, a fact which may reflect time dependence in their formative process, possibly magmatic differentiation as the Moon evolved.

The most widespread flooding of the depressed parts of the lunar crust occurred near the end of the Imbrian Period with the filling of most of the nearside multi-ring basins by mare material. This was followed by a less extensive episode of mare generation, terra blanketing, and volcanic mare plateau formation (as in the Marius Hills), mostly in the Eratosthenian Period.

Impact cratering, at a rate probably substantially reduced from that of pre-Imbrian to early Imbrian time, continued simultaneously with these events. The most recent impacts produced the prominent ray craters such as Copernicus and Tycho, whose ejecta blankets are superposed on almost all other units. No widespread volcanic activity appears to have occurred since this cratering, although some activity, as in the Littrow region at the southeastern edge of Mare Serenitatis, may be approximately contemporaneous with it.

GENERAL CONCLUSION

Systematic regional mapping shows the Moon to be a primitive body without the orogenic belts, mobile plates, oceanic ridges, and widespread waterlaid sedimentary deposits characteristic of the Earth's crust. The Moon does, however, exhibit a geologically heterogeneous surface with a long and complex history which can be partly unraveled from existing photographic data. Geologic mapping reveals a Moon that is neither dominantly “volcanic” nor dominantly “impact” but rather one in which both processes have been operative. Most of the volcanic units are restricted to regionally depressed areas, the distribution of which is controlled by ancient multi-ring basins formed by impact relatively early in lunar history. Implicit in this historical model is that a moderate amount of magmatic fractionation and vertical differentiation took place throughout at least the middle parts of lunar history (Imbrian Period). Thus most of the present surface, although less reworked than that of the Earth, is neither primordial nor of meteoritic composition. However, even the mare rocks, which are relatively young on the lunar time scale, have been shown by preliminary results from Apollos 11 and 12 to be as old or older than any presently dated terrestrial rocks. Thus the geologic record on the Moon appears to complement that of the Earth by covering the period of time for which the record is missing on Earth.

[1] References cited are listed in the accompanying pamphlet.