DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED ON BEHALF OF THE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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USAF AERONAUTICAL CHART AND INFORMATION CENTER

GEOLOGIC ATLAS OF THE MOON
NEAR SIDE OF THE MOON
I-703

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). The observed and inferred rings of the basins are shown by solid and dashed structure lines and 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 they are the most conspicuous features of the lunar surface. Much of what 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, Imbrium and Orientale, are flanked by one or two fairly continuous, distinctive ejecta blankets (Imbrium 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 distribution (Shoemaker, 1962). Many of the differences and apparent 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 (Mutch and Saunders, 1964; Hodges and Conel, 1965) are untenable 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 tryasmins 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 distribution than the ejecta blankets and other materials of 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 posthasin, premare craters within the Imbrium basin (that is, Imbrian-age craters) are approximately equal in number to the premare craters of the Orientale basin (pseudoimbrian 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 lp), lies stratigraphically between the deposits of the Imbrian basin and postbasin, premare crater materials, including those of Archimedes, Cassini, and Plato. (6) Features far from and unrelated to the Imbrian 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 are found in the highlands that surround the Mare Orientale basin. (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 Orientale basin (Hartmann and Kuiper, 1962) (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 observed basins like Imbrium is on the order of only 2 to 3 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 of thinner crust (Lyustikov and Vinogradov, 1967) (Toksöz and others, 1972). Even 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 clearly associated with a single multiring structure. Its floor is relatively thoroughout most of its extent, numerous tens islands and large ghost or vestigial craters such as the Flamsteed ring which subtlevirtly 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.

Following the period of flooding, meteoritic bombardment eroded and subdued the basin rings and blankets through down kits, 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 premare aging and partial obliteration of basins is exemplified by Serenitatis, whose rings have been so completely destroyed and masked by ejecta from the nearby Imbrium basin. The trend of the younger Imbrian rings of the Mare Humorum basin is also largely erased by Imbrian ejecta deposits, 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 units is the Imbrium Formation (unit If), which forms the floor of the Imbrian and lower Eratosthenian troughs and on the floors of pre-Imbrian and lower Imbrian craters. Plains identified as pre-Imbrian (plp) 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, unit Ihf) forms the rugged, hilly surfaces of the Imbrian ejecta and postbasin craters and contains numerous small primary volcanic landforms. The two largest occurrences lie west of Nectaris between the third and fourth rings and northwest of Humorum all-wart 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, not 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 mafia could, however, be minor, as in the case of terrestrial ooze 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 relics 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 terras (units Id, Cfd). Many of these, including the largest and most conspicuous, are found in the northwestern Oceanus Procellarum 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, which are the basis for the stratigraphic ages, 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 Revellos 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 Ic). Similar but older secondary craters of probable Imbrian age (unit Ic) are commonly identified on the pre-Imbrian terras as probable secondary craters of the Imbrian basin (unit Ici). Many degraded or partly buried pre-Imbrian chains and clusters (unit plds) 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 terras. A few smooth, low-rimmed craters such as Lassell and Daniell[sic], mostly in the 20 to 30 km size range, lack impact characteristics and could be volcanic craters. The few that are associated with dark plains and with 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 Ids, Ic, Cfds, Cfcs), but some large irregular craters (plci) and chains (plch) of probable pre-Imbrian age could also be volcanic, suggesting a possible early epoch of crater-forming volcanism.

Modification 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 scare may be the loci of long-subsequent volcanism even for features much smaller that 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 established by the stratigraphic position of their ejecta blankets, relative topographic freshness, and ages 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 resulting by thick or thin to discontinuous ejecta from nearby and distant younger basins, and each basin is inferred to have its own individual history of mare emplacement. 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 southcentral part of the map area extending as a wedge-shaped tract broadening from Ptolemaeus to the edge of the south pole. This province contains predominantly of closely packed 100-200 km pre-Imbrian craters of the probable impact sequence along with chains and clusters of Imbrian and probably Nectaris secondary craters. The preservation of this topographically ancient terrain in a region so close to the large Imbrian basin apparently 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 contain, in all, more than 10 older part of the Moon's near side. This essentially nondescript terrain, characterized by a moderate definiency of large pre-Imbrian craters, is considered to represent an interlayered sequence of now unrecognizable crater materials, volcanic material, and basin ejecta. Its present surface is a product of modification and erosion and buried much of the earlier lunar geological record.

The lunar stratigraphic record becomes clearer with the catastrophic formation of the Imbrian 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 bombardment by secondary and by a few primary impacts. 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 mid-way between the third and fourth Imbrian rings Steep domes and other distinctive terra landforms were also formed. These various blanketing and filling materials range from early Imbrian to Eratosthenian in age and support the conclusion that basin modification and crustal adjustment appears of long duration.

Some time after formation of the Imbrian basin, extensive modification of parts of the older terras began, especially northwest of Mare Humorum and west of Mare Nectaris. Distinctive terra landforms were formed near these older basins in a manner much like, but Imbrian, a fact which may reflect time dependence in their formative process, possibly magmatic differentiation as the Moon cooled.

The most widespread flooding of the topmost parts of the lunar crust occurred during the Imbrian Period. Mare material, the fill and filling of basins and 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 ejecta blankets of younger craters, particularly those of large ones 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 igneous activity characteristic of terrestrial geology. The face of the Moon does, however, exhibit a geologically heterogeneous surface with a long and complex history which can be partly untwisted 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 the geologic. Implicit in this historical model is that a moderate amount of magmatic differentiation and crustal modification occurred very early, 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.

References cited are listed in the accompanying pamphlet.

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

SCALE 1:5,000,000
ORTHOGRAPHIC PROJECTION

100 0 100 200 300 400 500 STATUTE MILES
100 0 100 200 300 400 500 KILOMETERS

SCALE AT CENTER OF MAP

GEOLOGIC MAP OF THE NEAR SIDE OF THE MOON

By
Don E. Wilhelms and John F. McCauley

1971

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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. Control net compiled on the U.S. Geological Survey's Gyrocartograph.

PRINCIPAL DATA SOURCES

Topographic forms and features: Photographs from Lunar Orbiter IV (Kopal, 1967) (Lunar Orbiter Project Office, Langley Research Center, NASA; index on 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–19, Lick Observatory 36-inch reflector (Kuiper, 1960); Rohn and Wildey (1970)

Thermal: Shorthill and Saari (1969)

Color: Whitaker (1966); McCord (1969)

Crest of basin ring structure (generalized)
Dashed where inferred from more ridges, widely separated terra kills, 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 instances to refer to "crater materials" and "mare materials," which are the geologic units mapped and described.

2 Albedo (brightness at full Moon) values are expressed in qualitative terms rather than photometric numerical quantity in normal albedo determined by Rohn and Wildey (1970):

Very high albedo (very dark at full Moon)	< .074
Low (typical of the maria)	.074–.096
Intermediate (typical of the terras)	.096–.119
High (bright at full Moon)	> .119

All lunar colors are reddish; color is expressed here as bluish or reddish only in comparison with other lunar colors (Whitaker, 1966; McCord, 1969).

3 References cited are listed in the accompanying pamphlet.

4 Lunar Orbiter IV frames listed are high resolution (70–150 m identification blanks), exceptions for 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.

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

EXPLANATION

DARK MARE MATERIALS | CIRCUMBASIN MATERIALS | TERRA PLAIN, PLATEAU, AND DOME MATERIALS | CRATER MATERIALS

Mare materials | Dome and mantle materials | Distinctive materials | Nondistinctive materials | Materials of main-sequence craters | Materials of crater chains and clusters | Irregular-crater materials | Material of smooth-rimmed craters | Undivided crater materials

COPERNICAN SYSTEM

Cp Plains
CEc Dome | Chfd Hilly and furrowed
Cc1, Cc2, Ec
CEch Chains and clusters
Cfch

ERATOSTHENIAN SYSTEM

Em
Emd Mare dome | Emp Mare plateau | Cfd Dark mantling
Im
Ip Plains
Ihf Dome | Ihh Hilly | Ihf Hilly and furrowed | Ihp Hilly and pitted | Ir Terra, undivided
Ihc Hevelius Formation
Ici, Ics
Ichs Chains and clusters | Ics Satellite crater

IMBRIAN SYSTEM

If Fra Mauro Fm. | Ial Alpes Fm. | Im Montes Apenninus
Ir
Iplf Terra, undivided
plp Plains | pld Lineation | Rugged
Iplc Chains and clusters
Ipl Chains and clusters

PRE-IMBRIAN

DESCRIPTION OF UNITS

DARK MATERIALS

Materials of the extensive and conspicuous dark plains known as maria are the principal elements of this class, but less extensive dark domes, domeunlinked plateaus, and low 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 multiring depressions such as the Imbrian 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 crater units. Mare materials are younger than main-sequence craters (see below) superposed on and overlapped by the mare, and to some extent from albedo[2] and color[2] properties. The maria are clearly younger than almost all pre-mare craters, 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 studies of the mare surface (Hartmann and Kuiper, 1962; Soderblom, 1970) suggested that the maria are approximately contemporaneous, and the size of the present mare surface was used to define informally the top of the Imbrian System (Wilhelms, 1970, p. 23), although the probability of substantial local variations in age was generally recognized (McCauley, 1967b; Wilhelms, 1970a, p. 25–32; Offield and Pohn, 1970). Lunar Orbiter photographs confirm that mare surface 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. The differences in crater density among the mare units on the geographs 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). They fill broad, regional depressions of internal origin, and the floors of younger basins in abrupt contacts along circumbasin 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 (Cunningham, 1977; West and Cannon, 1971) (See Lunar Orbiter III frames 172–180; Orbiter IV, 127; Orbiter V, 169–176)[4] Other typical occurrences: Sinus Medii (Orbiter I, 84–85; Orbiter V, 169–176) Planetoid crater (29°2 Orbiter I 164–215; Orbiter III, 161–212; Orbiter V, 140)

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

Less extensive than Imbrian mare, occupying about 20 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 Eratosthenes and Stadius) or superposed craters no older than Eratosthenian; (4) lower frequency of craters except where clusters of satellitic craters are superposed on the mare from nearby craters; (5) superposition of crenated 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. 29–43; Fielder and Fielder, 1968; Schaber, 1969) (Orbiter V, 159–162); (6) albedo[2] and color[2] similar to that of younger mare (usually lower, 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. Engelfelt (impactformed) terrain is more common than on Imbrian mare. Age of some patches embaying Eratosthenian craters possibly Copernican

Ems, *mare material*

Type area: Mare Smythii, 86°E., 2°S., Mare Medii (Trask, 1970b; Arvin, 1971) (Orbiter I, 84–85; Orbiter III, 161–212; Orbiter IV, 101, 102, 108, 109; Orbiter V, 168–175). Reference area for mapping at 1:1,000,000 scale: Mare Smythii (Trask and Wilhelms, 1970)

Mare material of Smythii Basin, exposed in a window in younger mare. First mapped as Procellarian System and later as Procellarian Group (history of nomenclature given by Trask and Wilhelms, 1970).

Most extensive single unit, occupying about one-third of map area; mainly dark, smooth plains, but some ridged areas of low albedo[2] and color[2]. Mostly basaltic lavas, probably with some pyroclastic materials and impactformed ejecta mantled over areas of varying thickness

DOME AND MANTLE MATERIALS

End, *mare dome material*

Type area: Six domes near 7.3°N., 28°W., north of crater Hortensius (Orbiter II, 135, 136; Orbiter V, 126, 127)

Smooth low domes having gentle (often <1°) convex-upward profiles circular or elliptical in plan view; diameters mostly <15 km; heights of several hundred meters. Albedo[2] and color[2] similar to that of adjacent mare; some are superposed on some domes

Shield volcanoes or lacoliths. Eratosthenian age implied by apparent superposition on Imbrian mare material, but possibly contemporaneous with younger mare. Color range from ridged mare to bluish mare

Emp, *mare plateau material*

Type area: Marius Hills, 50°W. to 49°W. and north of crater Marius, 11.9°N., 50.9°W. (McCauley, 1967a) (Orbiter IV, 150, 157; Orbiter V, 205–217)

Includes dark hummocky material of the Procellarum Group (Carr, 1965); Harbinger Formation (Carr, 1966); Marius Hills Hummocky Member, Reiner Formation (Carr, 1966); Marius Group (Trask, 1970a)

Irregular plateau of low to high relief, form lisbous, steep, or flat-topped with rampart fronts, and other flanker and pyroclastic plaster deposits, all elevated above the mare. Similar in albedo to mare

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

Cfd, *dark mantling material*

Type area: 26°S., 10°E. to 10.5°E., northwest of crater Sulpicius Gallus (Orbiter IV, 97; Orbiter V, 90–93)

Includes Vallis Schröteri Formation (Carr, 1965, 1967; Orbiter V, 202–209); Sulpicius Gallus Formation (Carr, 1966); dark mare material (Carr, 1966; Orbiter V, 168—Littrow region); Sulpicius Gallus Group (Trask, 1970a)

Darkest lunar material mapped except for some Eratosthenian craters. Subdued, smooth, discontinuous mantle, generally <100 m thick, locally with mapped thickness greater, high, bright hills within some patches. Ridges not shown in detail. Commonly associated with linear troughs at margins of mare and terra basins and terra-filled craters in terra. Some occurrences embayed by mare material, some superposed on it. Relatively reddish northeast of Aristarchus (Vallis Schröteri Formation) other occurrences relatively bluish. Terrain spinning mapped occurrences commonly also dark but not subdued

Dark pyroclastic mantle deposits, largely of fine glass, probably of several color terrain. Age ranges from Copernican to fresh, sparsely cratered patches in Copernicus region and southeast edge of Mare Serenitatis to Eratosthenian in some terra 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 basins. Although they are found in all terra areas mapped, the circumbasin materials are generally uniform in character at a given distance from the basin center and are mapped as a single unit. Exceptions are the most prominent parts of the scarps or mountain rings encompassing all multiring basins and the ejecta deposits of younger superposed craters (unit plc). The materials outside the most prominent scarps of the Imbrian basin (Montes Apenninus, Montes Carpatus, Montes Alpes, Montes Haemus, and the Nectaris Alps (Hodges and Conel, 1965; Scott, 1970)) appear to form a thick blanket on subjacent cratered topography near the basin and to become progressively thinner outward. The outer edge, however, is recognizable for hundreds of kilometers from the basin. The circum-Imbrian material is also found on the floors of the Imbrian basin in dome fields and in some units. The two closest to the basin (the Alpes Formation and material of Montes Spitzbergen) are mapped separately. Similar, but older, circumbasin ejecta material of the Janssen region (Janssen Formation; Trask and Wilhelms, 1970 and Fra Mauro Formation) and the similar unit surrounding the Orientale basin (Hevelius Formation) have been locally mapped 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). They fill broad, regional depressions of internal origin, and the floors of younger basins in abrupt contacts along circumbasin 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).

Ic, *mare material*

Type area: Latitude 3°S. to 4°S., longitude 36°W. to 37.5°W., Wichmann CA region (Cunningham, 1977; West and Cannon, 1971) (See Lunar Orbiter III frames 172–180; Orbiter IV, 127; Orbiter V, 169–176)[4] Other typical occurrences: Sinus Medii (Orbiter I, 84–85; Orbiter V, 169–176) Planetoid crater (29°2 Orbiter I 164–215; Orbiter III, 161–212; Orbiter V, 140)

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

Less extensive than Imbrian mare, occupying about 20 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 Eratosthenes and Stadius) or superposed craters no older than Eratosthenian; (4) lower frequency of craters except where clusters of satellitic craters are superposed on the mare from nearby craters; (5) superposition of crenated 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. 29–43; Fielder and Fielder, 1968; Schaber, 1969) (Orbiter V, 159–162); (6) albedo[2] and color[2] similar to that of younger mare (usually lower, 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. Engelfelt (impactformed) terrain is more common than on Imbrian mare. Age of some patches embaying Eratosthenian craters possibly Copernican

DOME AND MANTLE MATERIALS

End, *mare dome material*

Type area: Six domes near 7.3°N., 28°W., north of crater Hortensius (Orbiter II, 135, 136; Orbiter V, 126, 127)

Smooth low domes having gentle (often <1°) convex-upward profiles circular or elliptical in plan view; diameters mostly <15 km; heights of several hundred meters. Albedo[2] and color[2] similar to that of adjacent mare; some are superposed on some domes

Shield volcanoes or lacoliths. Eratosthenian age implied by apparent superposition on Imbrian mare material, but possibly contemporaneous with younger mare. Color range from ridged mare to bluish mare

Emp, *mare plateau material*

Type area: Marius Hills, 50°W. to 49°W. and north of crater Marius, 11.9°N., 50.9°W. (McCauley, 1967a) (Orbiter IV, 150, 157; Orbiter V, 205–217)

Includes dark hummocky material of the Procellarum Group (Carr, 1965); Harbinger Formation (Carr, 1966); Marius Hills Hummocky Member, Reiner Formation (Carr, 1966); Marius Group (Trask, 1970a)

Irregular plateau of low to high relief, form lisbous, steep, or flat-topped with rampart fronts, and other flanker and pyroclastic plaster deposits, all elevated above the mare. Similar in albedo to mare

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

Cfd, *dark mantling material*

Type area: 26°S., 10°E. to 10.5°E., northwest of crater Sulpicius Gallus (Orbiter IV, 97; Orbiter V, 90–93)

Includes Vallis Schröteri Formation (Carr, 1965, 1967; Orbiter V, 202–209); Sulpicius Gallus Formation (Carr, 1966); dark mare material (Carr, 1966; Orbiter V, 168—Littrow region); Sulpicius Gallus Group (Trask, 1970a)

Darkest lunar material mapped except for some Eratosthenian craters. Subdued, smooth, discontinuous mantle, generally <100 m thick, locally with mapped thickness greater, high, bright hills within some patches. Ridges not shown in detail. Commonly associated with linear troughs at margins of mare and terra basins and terra-filled craters in terra. Some occurrences embayed by mare material, some superposed on it. Relatively reddish northeast of Aristarchus (Vallis Schröteri Formation) other occurrences relatively bluish. Terrain spinning mapped occurrences commonly also dark but not subdued

Dark pyroclastic mantle deposits, largely of fine glass, probably of several color terrain. Age ranges from Copernican to fresh, sparsely cratered patches in Copernicus region and southeast edge of Mare Serenitatis to Eratosthenian in some terra 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 basins. Although they are found in all terra areas mapped, the circumbasin materials are generally uniform in character at a given distance from the basin center and are mapped as a single unit. Exceptions are the most prominent parts of the scarps or mountain rings encompassing all multiring basins and the ejecta deposits of younger superposed craters (unit plc). The materials outside the most prominent scarps of the Imbrian basin (Montes Apenninus, Montes Carpatus, Montes Alpes, Montes Haemus, and the Nectaris Alps (Hodges and Conel, 1965; Scott, 1970)) appear to form a thick blanket on subjacent cratered topography near the basin and to become progressively thinner outward. The outer edge, however, is recognizable for hundreds of kilometers from the basin. The circum-Imbrian material is also found on the floors of the Imbrian basin in dome fields and in some units. The two closest to the basin (the Alpes Formation and material of Montes Spitzbergen) are mapped separately. Similar, but older, circumbasin ejecta material of the Janssen region (Janssen Formation; Trask and Wilhelms, 1970 and Fra Mauro Formation) and the similar unit surrounding the Orientale basin (Hevelius Formation) have been locally mapped 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). They fill broad, regional depressions of internal origin, and the floors of younger basins in abrupt contacts along circumbasin 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).

Ihc, *Hevelius Formation*

Type area: 17°S. to 3°S., 66°W. to 65.3°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 aligned radial to the Orientale basin. Also includes some less extensive terrain outside its 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 (Ics). Gradational eastward into retrogres and disconnected patches of faintly lineated materials that become indistinguishable from underlying terra at distances of several hundred kilometers from basin

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

Ihf, *Fra Mauro Formation*

Type area: 0° to 2°S., 16°W. to 17.5°W., north of crater Fra Mauro (informal definition: Eratosthenian System, Fra Mauro Formation, Interior IV, 120, 121). Reference area: 3°S. to 4.5°S., 17°W. to 18°W. (Orbiter III, 132–135; Orbiter V, 182–189)

Sinuous to straight, smooth-textured ridges or elongate hummocks typically 1 to 2 km wide, spaced 5 to 10 km, and 100 to 200 m high; mostly Orbiter IV, 101, 102, 108, 109; Orbiter V, 168–175). Reference area for mapping at 1:1,000,000 scale: Mare Smythii (Trask and Wilhelms, 1970)

First mapped as Procellarian System and later as Procellarian Group (history of nomenclature given by Trask and Wilhelms, 1970).

Most extensive single unit, occupying about one-third of map area; mainly dark, sm