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GEOLOGIC MAP OF THE NEAR SIDE OF THE MOON

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INDEX MAP OF THE NEAR SIDE OF THE MOON
Number above quadrangle name refers to lunar base (chart LAC series); number below refers to published geologic map

Lunar base mosaic (LEM-1, 1st 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 accompanied 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 230 to 600 km (kilometers) and the spacing of the three outer rings increases from one to the next by a regular ratio (Hartmann and Kuiper, 1962). The observed and inferred crest lines of the most prominent of these structures are shown on the map. The innermost depressions of the basins are occupied in parts of the basins and the concentric troughs which lie between successive rings are completely or partly filled with dark plain 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 craters. The historical geology of the Moon near the surface is, in terms of these dominant, primitive structures much of even present on Earth, have long since been obliterated or deeply buried and metamorphosed.

The general similarity 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 ragged rings of the two best preserved basins, Orientale (just outside the map area) and Imbrium, are surrounded by radial structures (Inst. Ital. Geofisica, 1961; Cummings, 1962; Wilhelms, respectively), which can be traced outward for hundreds of kilometers. Relate of what is probably a third, more degraded and older ejecta blanket (Jansen 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 secondary craters are concentrated in the ejecta blanket or, in the absence of a recognizable blanket, the completeness of the secondary ring structures, the fractions and relief of the rings, the character of the radial structures, and the sizes 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 ending for an internal origin (Spurr, 1944; Green, in Gilt 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.

Relations of the basins and their ejecta blankets to 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 occupies all other basin-related depocenter 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, ejecta blankets, and secondary craters, indicating a younger apparent relative age. (4) Craters which are superposed on the basin ejecta are not basin-related structures but are embayed or filled by mare material near it or within the basin. Examples: Pontdonus, Gassendi, Cleomedes, and Plinius in the Serenitatis, Hermanus, Crozier, and Nectaris basins respectively. The postbasin, premare craters within the Imbrium basin (that is, Imbrium-age craters) are approximately equal in number to the total number of postmare craters (presumably representing equal 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 (Fra Mauro Formation), occurs between the deposits of the Imbrium basin and younger, 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 produce and postdate the ejecta of the Imbrium basin. Thus, the maria in the basins represent events independently of that one. For example, Serenitatis is filled in the first ring and Crisium and Imbrium in the second and third respectively. Uneven filling suggests different volumes of mare material in each, refutating 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 (Pohn and Offield, 1969; Wilhelms, 1970, p. 28). The subsequent configurations of the more degraded and deeply filled basins basins reflect lack of extensive mare filling and its relative youth. The 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 3 km. Mare material, although covering almost 20 percent of the separate surface (and very little of the far side), is therefore, volumetrically a small part of the Moon as a body. The mare fill is thicker than the basin lava lakes like Imbrium may be in regions where potential source material was at shallower depth than it was in the less filled basins like Orientale and Serenitatis. The thickness of the Imbrium basin lava is substantial (Wilhelms and McCauley, 1971) but the far side of the Moon (Lipsky, 1966) 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, however, many circular structures, including some that are clearly multi-ringed craters such as the Flamsteed ring which collectively suggests that the mare is relatively shallow. An overall shape however, appears to be controlled by outer ring structures of the Imbrium basin and two vague, ancient ring structures centered near Copernicus and Plato (and which were identified during this work).

During and after the period of flooding, meteoric bombardment eroded craters and created others. Some craters, particularly those in the mare, underwent fracturing before fragments (Shoemaker, 1962), and second shaking of the surrounding terrain triggering downslope movement of loose material (Cummings, 1962). This process led to the eventual disappearance of the distinctive depositional textures of the circumbasin blankets. Catastrophic processes age and partial obliteration of basins is exemplified by Serenitatis, whose rings have been disturbed structurally and mantled by spots of younger mare than have the others. The trend of the younger Imbrium rings has in turn been influenced by the pressure of the earlier Serenitatis structures 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 younger 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 Ipi which lie predominantly in topographically low areas far from the basins and in the Imbrium basin system. Plains identified as pre-Imbrian (pIp) by superposition of lowermost Imbrian crater ejectors occupy more restricted areas in the northern terra. These two major 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 shattering and subsequent brightening by impact than the younger mare. Dome materials (Id) are of two kinds: hilly and furrowed material, both domes based on shadows plateaus that are flat spots, and pseudomare craters and contain numerous small primary volcanic landforms. The two largest occurrences lie west of Sinfatis between the third and fourth rings and southwest of Humorum ahwayt and beyond the third ring. These plain and plateau units, with their apparently muddy surface basin or crater deposits, suggest a more extensive history of lesser volcanism than the younger mare. Some of the domes are clearly volcanic and are roughness from the dark, relatively smooth mare volcanic deposits and 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 mare could, however, be minor, as in the case of terrestrial mare and lunar mare materials, and the domes may be the last, most viscous, lava volcanic units in controlled predominantly by basin ring structures, some occur at the intersection of younger ring structures with vague circular depressions which are the probable relict 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 Rimd, Emgr and in the terrae (units Id, CEId). Many of these, underlying the largest and most distinctive, the postmare terra domes of the Crüthusen area southwest of the Sinus Iridum, in along circumbasin ring structures.

CRATER MATERIALS

Craters of all ages, mostly crater materials, the basins have 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, 1968) 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.

Terrestrial analogs of the craters grouped in the "main sequence" are chains and clusters of 10-15 km diameter craters, best developed in irregular craters long within and beyond the confines of the Hevelius Formation (not to 1500 km from the Orientale basin center) and confidently identified as secondary impact craters formed by ejecta from the Orientale basin (unit Ics). 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 Ipcs). The chains and clusters (unit pIcs) near the edge of the Imbrian Formation may be secondary craters of the moderately well preserved Nectaris basin. These secondary craters of large basins constitute an (ingenius) part of the total lunar crater population in 10-20 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 volcanic craters. Many of the secondary craters and clusters and chains of smooth-rimmed craters that are superposition of basin, regional, mareas, trends are also considered to be volcanic. Intermediate craters, mostly relatively small and relatively young (units Ic, Ic, CIcs, CIcs), but some large irregular craters (pIcs) and chains (pIcs) 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 cones and have floors that are flat and lack mare material. The presence of these landforms suggests either that the host craters are volcanic or that impact mare may be the last 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. Absolute ages are difficult to assign to the basins, but they are clearly older but difficult to date with respect to one another because of their geographic separation. Serenitatis and Pecunditatis 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 stressing, and mantling by dark or thin to discontinuous ejecta from nearby and distant younger basins, and each basin has its own history of later impacts. 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 southeastern part of the map area extending as a wedge-shaped tract broadening from Posidonius to the region 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 rugged terrain, which is relatively high in albedo, is due to its relative inaccessibility, as evidenced by its location beyond the range of extensive blanketing and structural disturbance of the younger 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 nonbasinal terrain, characterized by a moderate abundance of large pre-Imbrian craters, is considered to represent an interlayered sequence of now metamorphosed crater material, volcanic material, and basin ejecta. Some of the craters may be secondary craters that around Orientale and buried much of the earlier basin geological record.

The lunar stratigraphic record becomes clearer with the relatively late formation of the Imbrian basin which begins the Imbrian Period. The basin and the blanket, however, have undergone considerable modification since their formation, and only relicts of the original depositional patterns are now recognized. Most of this blanketing of original textures is attributed to the mantling by subsequent Imbrian-age ejecta from the basin. Imbrian-age light plains materials filled low areas within the basin and in the troughs between rings, terminating the loaded and hummocky texture of the blanket and basin radial structures. Dark blanketing material was deposited in a broad arc midway between the third and fourth Imbrian rings. Steep domes and other diminutive terra landforms were also formed. These various blanketing and filling materials range from early Imbrian to late Imbrian in age and have been interpreted as evidence that basin modification by volcanic processes is of long duration.

Some time after formation of the Imbrian basin, extensive modification of parts of the older terrae began, especially northward 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 finding of the depressed parts of the lunar crust occurred in the Nectarian Period. Mare Nectaris is the type locality of a tectonic multi-ring basin, by mare material. This was followed by a less extensive episode of mare generation, terra blanketing, and volcanic mare plateau formation (as in the Mare Nubis, mostly in the Eratosthenian Period.

Impact cratering, at a rate probably substantially reduced from that of pre-Imbrian to early Imbrian time, continued uninterrupted with these events. The Imbrian Period was a period of extensive cratering, as shown by 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 Lichtenberg 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 volcanism characteristic of terrestrial evolution. The near side of the Moon does, however, exhibit a geographically heterogeneous surface of long and complex history which can be partly unraveled from existing photographic data. Geologic mapping reveals a Moon that is suggested by many "volcanic" and 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 impact structures of various ages and conditions of preservation. The impact implies a thermal model in impact, 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 primitive 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 Apollo 11 and 12 to be as old or older than any presently dated terrestrial rocks. Thus the geologic record on the Moon appears to extend back beyond that on Earth to covering the period of time for which the record is missing on Earth.

References cited are listed in the accompanying pamphlet.

EXPLANATION

DARK 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 | EMPLACEMENT SYSTEM | IMBRIAN SYSTEM | PRE-IMBRIAN

DESCRIPTION OF UNITS

DARK MATERIALS

Materials of the extensive and conspicuous dark plains known as maria are the principal constituents of the Moon's near side. Five units are recognized, subdivided into two mare materials, all of which occur within or near the maria, are also included.

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 basins 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 other units (from dark-floored craters with superposition relations (mare) superposed on and overlapped by the maria, and in some craters from albedo and color 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 Bullialdus, both of which show symmetrical rim deposits and falls of smaller craters superposed on the mare. Crater frequency counts on telescopic photographs (Moore, and others, 1962) suggest that the mare are younger than most terra units, including the material of the present mare surface was used to define informally the top of the Imbrian System (Wilhelms, 1970b, p. 28), although the probability of substantial local variation in age was generally recognized (McCauley, 1967b; Wilhelms, 1970a, p. 30-32; Offield and Pohn, 1970). Lunar Orbiter photographs suggest that mare units differ in density and age of superposed and overlapped craters, and an attempt has been made on the map to recognize the extremes in age and to show the general stratigraphic and relative age. Certain 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 vertical of age relations of the mare.

Several lines of evidence indicate that the maria are volcanic in the sense that they are composed of extrusive igneous rocks (Wilhelms and McCauley, 1971). These flat smooth surfaces generally terminate against the edges of the enclosing basins in abrupt contacts along elevation contours, and this indicates emplacement as fluid lava. 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, flat-floored craters, and the recent Apollo 11 and 12 results (Lunar Sample Analysis Planning Team, 1970; Lunar Sample Petro Exam Team, 1970).

Em, mare material

Type area: Lacus Somniorum, 64°N. to 72°N., Wichmann (A) region (Cummings, 1971; West and Cannon, 1971) (See Lunar Orbiter IV photo 4-1 and 4-2, 42.5°N. 23.5°E. Orbiter IV, 100; Orbiter V, 146). Other typical occurrences: Serenitatis (lat. 2.2°N., 17.7°E.), northeast of crater Plinius (Orbiter IV, 1364-21); Orbiter III, 141-202; Orbiter IV, 143).

Includes most of the mare material in the Imbrium basin and Oceanus Procellarum. Less extensive than Imbrian mare, constituting about 20 percent of the dark plains, commonly occupies more elevated parts of the basins than Imbrian mare material but forms no distinct topographic units. Distinguished from Imbrian mare material by at least two of following criteria: (1) lower albedo than adjacent mare; (2) more cratered than adjacent Eratosthenian crater floors; (3) Mendlius and Bullialdus; (4) superposed craters no older than Eratosthenian craters; (5) superposition relations with Eratosthenian craters; (6) well-preserved primary structures such as smooth-rimmed pits (as in an embayment north of Mare Vaporum); small domes (as at lower mare); very clear albedo or color contrast with adjacent Imbrian mare; flat floors of craters (as in Sinus Iridum and southeastern Mare Imbrium).

Im, Imbrian mare material

Type area: Mare Imbrium, 56°N. to 21.5°W., north of crater Fra Mauro (informal definition; Eggleton, 1964; formal Wilhelms, 1970a, p. 3). (Orbiter IV, 121; Orbiter III, 141-202; Orbiter IV, 1364-21; Orbiter III, 141-202; Orbiter IV, 142-110; Orbiter IV, 120).

Includes most of the moderate-albedo plains of the Imbrian basin, including the type area. Commonly occupies the lowest topographic parts of the basin, but includes some of the highest parts, such as the Montes Apenninus (typically 2 to 4 km across and 5 to 20 km long, oriented radially and subradially to the basin center).

Mare domes (Imd) are low, gentle domes, commonly 10 km in diameter, with a central pit. Some are associated with Eratosthenian craters (Lansberg, Milichius, Krieger, and others) and may be volcanic vents. Some are associated with Imbr