GEOLOGIC MAP OF THE NEAR SIDE OF THE MOON

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RATIONALE, METHODS, AND FORMAT

The chief purpose of the 1:5,000,000-scale map is to summarize the current state of lunar geologic knowledge as developed from the U.S. Geological Survey's systematic lunar mapping program, which began in 1960. Like terrestrial synoptic maps it provides a stratigraphic framework to be used for developing new theory and for determining the regional significance of surface exploration results. The geologic summary which accompanies the map gives the major genetic and historical conclusions which stem from the work. The map explanation provides the descriptive details that led to these conclusions. This pamphlet discusses the rationale, methods, and nomenclature of lunar stratigraphy, specifically for those interested in why and how the map was produced.

The work is based both on results of the telescopic mapping program and on data from the unmanned lunar exploration program, particularly the regional coverage of Lunar Orbiter IV[1]. The early telescopic studies established the geologic heterogeneity of the Moon and produced a workable nearside stratigraphy (Shoemaker and Hackman, 1962; McCauley, 1967b; Wilhelms, 1970b). Prior to the Lunar Orbiters, telescopic resolution limitations dictated emphasis on the grosser aspects of lunar geology: the structures and ejecta blankets associated with the multiringed basins, the major craters, and the stratigraphic relations between the generally younger maria and older terrae. The main products of the telescopic work were 36 1:1,000,000-scale geologic quadrangle maps (those marked "T" in table 1) and a 1:5,000,000-scale preliminary map of the region 32°N. to 32 °S. and 70°E. to 70°W. (Wilhelms, Trask, and Keith, 1965). Before the systematic program began, Hackman and Mason (1961) produced a set of three nearside maps at a scale of 1:3,800,000 from telescopic data; these maps emphasized the geology, physiography and ray-crater distribution.

Lunar Orbiter mission IV, May 1967, provided low-sun photographs of most of the near side of the Moon at a resolution about 10 times better than that of telescopic photographs[2]. Approximately 108 usable photographs whose original readout scale is approximately 1:700,000 cover the area mapped. At Orbiter IV resolution—70 to 150m—the surface of the Moon exhibits a wide variety of land-surface forms, many of which, especially in the terrae, are not seen or are difficult to describe and delineate on Earth-based photographs. The resolution and the equally important contiguous coverage attained by Orbiter IV permitted construction of more detailed and meaningful 1:1,000,000-scale maps, particularly of the terrae, and prompted the preparation of this more refined and areally expanded successor to the earlier 1:5,000,000 map.

This pamphlet supplements several other explanations of the methods and rationale of lunar mapping. Shoemaker and Hackman (1962) summarized the stratigraphy used at the outset of the lunar mapping program. McCauley (1967b) summarized major pre-Orbiter results with emphasis on the rock-stratigraphic approach. Wilhelms (1970b) described in detail the rationale and theory of telescopic geologic mapping of the Moon and the evolution of lunar stratigraphic nomenclature. Trask (1970a) described the techniques for preparation of special large-scale maps (1:100,000 and 1:25,000) prepared in support of the Apollo program and their relation to the 1:1,000,000-scale reconnaissance maps. Mutch (1970) reviewed the broad range of lunar geological investigations of the last decade and stressed the importance of the historical approach derived from longstanding terrestrial geologic practice. In addition, some discussion of methods and nomenclature is given in the explanatory material accompanying most published maps. Lunar students not acquainted with the geologic approach are referred to the excellent collection of articles and annotated references on the philosophy and methodology of geology in the book "The Fabric of Geology" (Albritton, 1963).

Because a permanent and dynamic atmosphere and hydrosphere are absent, the Moon at certain scales is actually more amenable to remote geologic analysis based principally on photographic data than is most of the Earth. On Earth most 100-m scale landforms, except in youthful volcanic provinces, are secondary and produced by the sculpturing effects of water, ice,

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[1] Useful collections of photographs from all Orbiter missions, accompanied by geologically oriented explanations, appear in Lowman (1969) and Kosofsky and El-Baz (1970).

[2] The skill of the Lunar Orbiter Project Office, Langley Research Center, NASA, and of The Boeing Company in planning and executing this highly productive spaceflight is gratefully acknowledged.

or wind; thus these landforms are not readily relatable to the parent materials from which they form. On the Moon the main surface-sculpting forces seem to be meteorite bombardment and the downslope movement of fragmental debris into local depressions. At resolutions of 30 m and better the effects of this type of degradation tend to dominate the scene and almost all surfaces are covered with its product, a particulate regolith, the depth of which apparently depends primarily on the relative age of the surface. At the lower resolution of Orbiter IV, however, the effects of this surficial layer are not as significant, and many primary features such as crater deposits, circumbasin blankets, and positive constructional forms are evident. Moreover, subdued subtly expressed forms can be recognized and often identified confidently as older equivalents of more clearly expressed features that occur elsewhere on the Moon. A comparison of the detailed physiographic properties of craters similar in size such as Tycho (very fresh), Copernicus (somewhat "worn"), and Eratosthenes (fine details obscured) serves to illustrate this point. Thus uniformitarianism in a general sense is as applicable to the Moon as to the Earth; the most youthful and best preserved lunar surface features are the key to recognition of older, degraded, and more subtly expressed forms. The work of Shoemaker (1962, p. 323–347) on the ray crater Copernicus and that of McCauley (1967b, p. 439-446) on the Orientale basin are examples of the utility of studies of young features for the insights they provide about less well expressed landforms.

This map, like all geologic maps of the Moon, of the Earth, and those that might be made of the other terrestrial planets (Carr, ed., 1970), is a combination of observations and interpretations whose accuracy and degree of certainty depend on available data and current cumulative geologic knowledge. Geological analysis helps primarily to reduce the apparent disorder of any complex surface by dividing it into units, each with a limited set of distinctive properties. This is accomplished by delineating areas of relatively uniform textural and albedo characteristics. Judgment as to the relative importance of these observable properties and objective delineation of units are equally critical elements; the units must be both stratigraphically meaningful and sufficiently objective to be recognized by other workers viewing the same photographic data. The goal is to portray units that are not just similar-appearing surfaces or collections of similar topographic forms but, rather, three-dimensional bodies of finite horizontal and vertical extent which are in effect the building blocks of the visible part of the crust. In most instances the units can be treated conceptually as rock-stratigraphic units (Am. Comm. on Strat. Nomenclature, 1961, Art. 4). The origin of these units—whether by impact, volcanism, or some other process-need not be known initially, although genesis is of course an ultimate objective. Lithologic properties or ranges of possible lithologies can be ascribed to many units on the basis of terrestrial field and experimental studies, as well as data from Surveyor and Apollo. Every effort is made, however, to eliminate genetic bias, and interpretations are separated from descriptions of the physical characteristics of each unit.

Each material unit is placed in order of age relative to its neighboring units on the basis of superposition and transection relations. The application of these easily understood, long-established, and almost self-evident geometric relations is the heart of geologic mapping and introduces the dimension of time which allows the reconstruction of the Moon's geologic history. As on Earth, the uppermost rocks in a sequence are younger than those on which they lie;, rocks cut by faults are older than the faults. Temporal relations are commonly revealed in the areal pattern of the units and their surface contact relations; a younger unit overlaps or embays an older unit; the contact of a younger unit cuts across the contact between two older units. Physiographic state of preservation and density of superposed craters are two additional means of estimating relative age, possible on the Moon only because of the lack of differing climatic zones. The inability of some workers to apply effectively these conceptually simple but rigorous tools has led to the misinterpretation of many fundamental relations, such as that between the maria and the older basins which they fill.

Once each local unit is dated relative to its neighbors, all occurrences with the same properties and apparent relative age or range of ages are included together in a map unit. In the case of craters, where two occurrences of a map unit of slightly different age are in contact, the younger crater is shown overlapping the older. Each map unit is assigned to one or more Moon-wide groupings of rocks, called time-stratigraphic units, in order to relate it to the total lunar stratigraphic record. The time-stratigraphic classification first defined in the Mare Imbrium region by Shoemaker and Hackman (1962), with modifications by McCauley (1967b) and Wilhelms (1970b), is used here. There are three formal systems, the Copernican (youngest), Eratosthenian, and Imbrian, and one informal system, the pre-Imbrian. A period of lunar geologic time of presently unknown duration corresponds to each of these. Following are the units of the Mare Imbrium region which comprise these systems.[3]

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[3] The stated age of a geologic unit is the age of its emplacement, not the age of crystallization of its component rocks, which in the case of impact units may substantially predate the emplacement.

SYSTEM (PERIOD)	UNITS
Copernican	Deposits of Copernicus and other fresh-appearing rayed craters
Eratosthenian	Deposits of Eratosthenes and similar slightly subdued craters whose rays are no longer visible or are very faint at high sun illuminations
Imbrian	Dark mare materials in the Imbrium basin and Oceanus Procellarum
	Deposits of Archimedes and other mare-flooded craters superposed on circum-Imbrium deposits and structures
	Circum-Imbrium deposits and structures
pre-Imbrian	Deposits of Julius Caesar and other similar degraded craters covered by Imbrium basin deposits and cut by its structure s

Extensive and synchronous stratigraphic datum planes are used for regional correlation where possible. Recognition of the distinctive deposits and structures around the Imbrium, Orientale, and Nectaris basins permits determination of events that precede, are synchronous with, or postdate these large basins. Additional widespread synchronous deposits around the rims of large craters such as Copernicus and Eratosthenes and approximately synchronous deposits such as the Imbrian mare material also are valuable stratigraphic datum planes. The determination of relative ages of craters in the terrae and in areas where these datum planes are not well developed is a special problem. Such craters are dated by morphologic methods described by Pohn and Offield (1970; Offield, 1971) which permit time-stratigraphic assignment in regions where previously only broad age ranges could be established. Although less desirable than more direct stratigraphic methods (using regional blankets as marker horizons or superposition and intersection relations), the dating of craters by their physiographic appearance works well in practice if age categories are not too finely drawn. The results are consistent with established stratigraphic relations where they can be tested. For example, no severely degraded craters of the type assigned to the pre-Imbrian can be identified on either the Imbrium or the Orientale circumbasin units.

Each map unit is given a distinctive name, letter symbol, and color. Most names are abbreviated descriptions, but formal names are applied here to four circumbasin units of unwieldy description that are of special stratigraphic significance. The symbol for a unit consists of an abbreviation of the age (capital letter) and of the name (lowercase). Considerable age variation is recognized among individual occurrences of many map units, and for these units only the predominant age of the collective occurrences is shown. Units that may belong with equal likelihood to either of two systems or any of three are given two capital letters representing the possible range (youngest first). The ages of individual occurrences of a unit relative to other units sometimes can be read from local superposition relations. Boxes for the map units are arranged vertically in the explanation with the youngest at the top and the oldest at the bottom and laterally by class or category of materials. The major classes are: dark materials (mostly of the flat maria); circumbasin materials; materials of terra plains, plateaus, and domes (the non-basin terra); and crater materials; these classes are further subdivided into categories mainly on the basis of topographic properties.

Beneath the array of color-keyed boxes are general descriptions and interpretations for each major class of materials and the essential descriptive data for each map unit. The first item in each unit description is type area, which is the lunar equivalent to the type section of terrestrial practice.

The type area is the locality where the unit is most distinctive; to be correlated with this occurrence, other occurrences must possess most of the stated characteristics. The second item lists units of other map series, mostly of the 1: 1,000,000-scale, which have been included in each unit on the present map, except where the present treatment is substantially novel. The third and fourth items describe and interpret the unit; as on previous U.S. Geological Survey lunar geologic maps, the salient topographic and albedo characteristics, distribution, and age relations of the units are given in a separate paragraph from genetic interpretations. Colors are assigned with the intent to associate materials of like type and age and separate unlike ones. The map and explanation, therefore, combine to give a picture of the distribution in time and space of the various kinds of materials which compose the visible parts of the lunar surface.

Most features 10 km and larger are geologically classified on this map. Small clustered features shown on the 1:1,000,000-scale maps are frequently combined into single patches or omitted if they do not contribute to the portrayal of regional relations. In many places contact relations have been generalized in order to emphasize age relations. Because of foreshortening in the limb regions on the orthographic base, the areas beyond longitudes and latitudes of 50° are more generalized than the central parts of the map. Many units are defined somewhat differently than on previous maps, and other units have been combined in order to keep the number of units to a minimum and to standardize the presentation. In addition, the necessity of correlating units by the same criteria over the whole nearside has led to some differences from the previous maps in age assignments. Structures are omitted, except the concentric rings of the multi-ring basins and those coincident with unit contacts and implied by stratigraphic relations. The authors plotted the contacts exclusively from Orbiter IV photographs and thus did not strictly compile earlier work, although they have relied extensively on the results of the 1:1,000,000 series (table 1).

The type of analysis presented on the 1:5,000,000 lunar geologic map, and indeed all remote planetary mapping, can be considered as geological taxonomy. In addition to serving as a framework for interpreting surface exploration results, the effort to classify units into type and age by photogeology narrows the range of possible origins for many features. An absolute time scale cannot be derived directly from the relative stratigraphy shown, and attempts to establish absolute ages based on crater counts and meteorite and cometary flux data (Shoemaker and others, l962; Gault, 1970) are independent of this work. Preliminary radiometric dating of the samples returned from the Apollo program has produced the first reliable correlation between the terrestrial and lunar time scales (see geologic summary). Future Apollo results will permit more detailed correlation and should render a new significance to the relative stratigraphy shown on the map.

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TABLE 1.—*Authors, dates, data sources, and publication status of U.S. Geological Survey 1:1,000,000-scale geologic maps (see index map on map sheet)*

LAC number	Author	Date	Prepared from telescopic data (T) or Lunar Orbiter data (O)	Published in Misc. Geol. Inv. Series (I) or available in preliminary uncolored form in the open files (P)
11	G. E; Ulrich	1969	T & O	I
12	J. W. M‘Gonigle }	{1966	T	P
	and D. L. Schleicher	in press	O	I
13	B. K. Lucchitta	in press	O	I
23	R.E. Eggleton and E.I. Smith	1967	T & O	P
24	G. G. Schaber	1969	T & O	I
25	N. J Page	1970	T & O	I
26	N. J Page	1967	T	P
	D. H. Scott	in press	O	I
27	M. J. Grolier	1970	O	P
38	H. J. Moore	1967	T	I
39	H. J. Moore	1965	T	I
40	M. H. Carr	1965	T	I
41	R. J. Hackman	1966	T	I
42	M. H. Carr	1966	T	I
43	H. A. Pohn	1965	T	P
44	A. B. Binder	1965	T	P
	C. J. Casella and } A. B. Binder	in press	O	I
56	J. F. McCauley	1967	T	I
57	R. J. Hackman	1962	T	I
58	H. H. Schmitt, N. J. Trask and E. M. Shoemaker	1967	T	I
59	D. E. Wilhelms	1968	T	I
60	E. C. Morris and D. E. Wilhelms	1967	T	I
61	D. E. Wilhelms	1965	T	P
		in press	O	I
62	H. Masursky	1965	T	P
74	J. F. McCauley	1964	T	P
		in prep.	O	I
75	C. H. Marshall	1963	T	I
76	R. E. Eggleton	1965	T	I
77	K.A. Howard and H. Masursky	1968	T	I
78	D. J. Milton	1968	T	I
79	D. P. Elston	1965	T	P
		in press	O	I
80	J. D . Ryan and D. E.Wilhelms	1965	T	P
	C. A. Hodges	in prep.	O	I
92	N. J. Trask	1965	T	P
	H. C. Wilshire	in prep.	O	I
93	S. R. Titley	1967	T	I
94	N. J. Trask and S. R. Titley	1966	T	I
95	H. E. Holt	1965	T	P

TABLE 1 continued—*Authors, dates, data sources, and publication status of U.S. Geological Survey 1:1,000,000-scale geologic maps (see index map on map sheet)*

LAC number	Author	Date	Prepared from telescopic data (T) or Lunar Orbiter data (O)	Published in Misc. Geol. Inv. Series (I) or available in preliminary uncolored form in the open files (P)
96	L. C. Rowan	1965	T	P
		in press	O	I
97	D. P. Elston	1965	T	P
	D. E. Stuart-Alexander and R. W. Tabor	in press	O	I
98	D. E. Wilhelms	1965	T	P
	C. A. Hodges	in prep.	O	P
110	T. N. V. Karlstrom	1971	O	P
111	R. S. Saunders	1970	O	P
112	H. A. Pohn	in press	O	I
113	N. D. Cozad and S. R. Titley	1966	T	P
	D. H. Scott	in press	O	I
114	D . E . Stuart-Alexander	1966	T	P
		in press	O	I
125	T. W. Offield	in press	O	I
126	D. Cummings	in press	O	I
127	T. A. Mutch and R. S. Saunders	in press	O	I