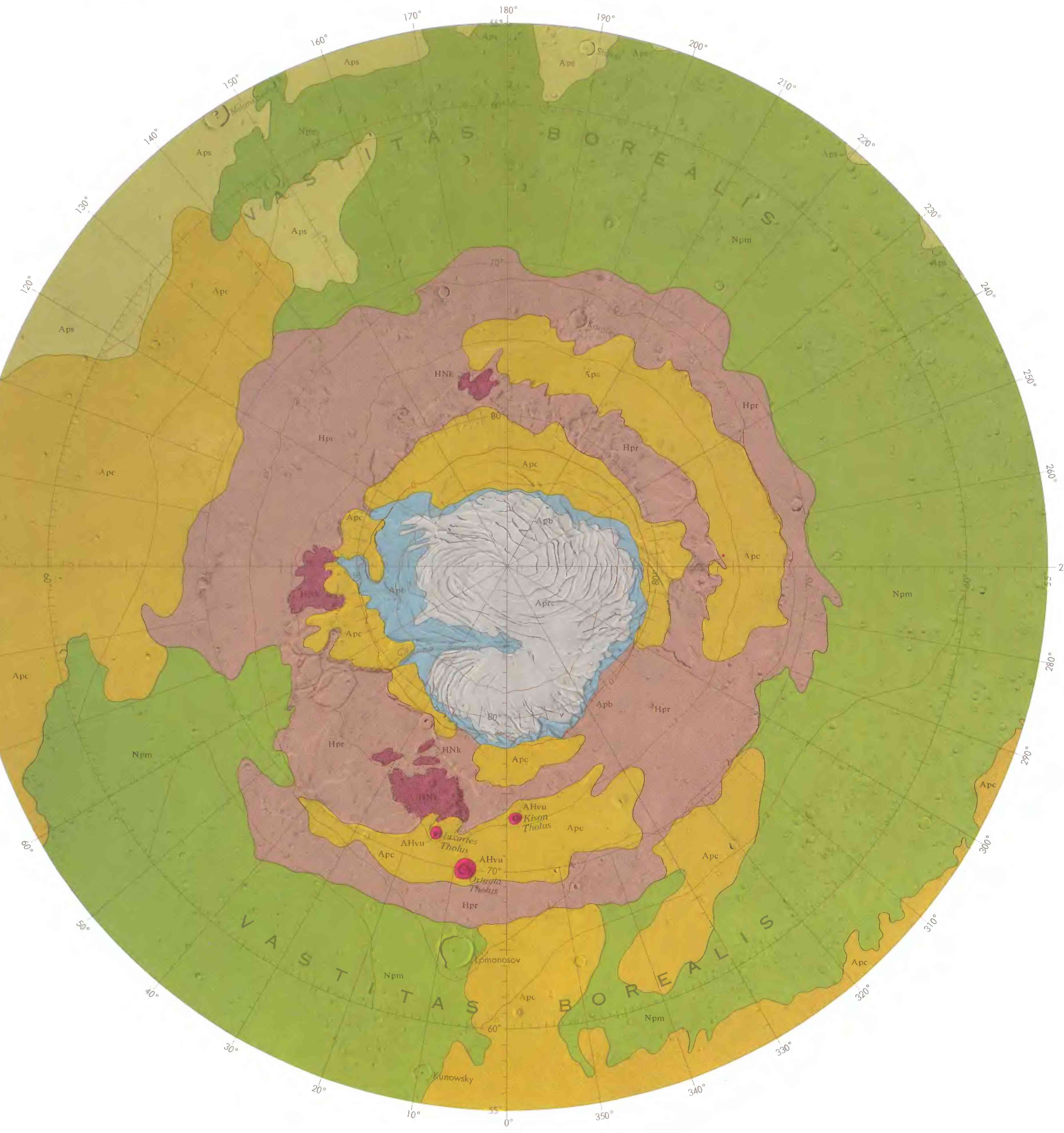
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

Prepared for the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ATLAS OF MARS
1:25,000,000 GEOLOGIC SERIES
M 25M G, 1978
I-1083




NORTH POLAR REGION

SCALE 1:12 549 000 AT 60° LATITUDE
POLAR STEREOGRAPHIC PROJECTION

## NOTES ON BASE

This map sheet is one of a series covering the entire surface of Mars at nominal scales of 1:25,000,000 and 1:5,000,000 (Batson, 1973; 1976). The major source of map data was the Mariner 9 television experiment (Masursky and others, 1970).

### ADOPTED FIGURE

The figure of Mars used for the computation of the map projection is an oblate spheroid (flattening of 1/192) with an equatorial radius of 3393.4 km and a polar radius of 3375.7 km. This is not the height datum which is defined below under the heading "Contours."

### PROJECTION

The Mercator projection is used between the 65° parallels, and the polar stereographic projection is used for the polar regions north and south of the 55° parallels. The scale at the equator is 1:25,000,000 and 1:12,549,000 at the 60° parallels. Longitudes increase to the west in accordance with usage of the International Astronomical Union (IAU, 1971). Latitudes are areographic (de Vaucouleurs and others, 1973).

### CONTROL

Planimetric control is provided by photogrammetric triangulation using Mariner 9 pictures (Davies, 1973; Davies and Arthur, 1973) and the radio-tracked position of the spacecraft. The first meridian passes through the crater Airy-O (lat 5.19° S) within the crater Airy. No simple statement is possible for the precision, but local consistency is within 25 km.

### MAPPING TECHNIQUE

A series of mosaics of rectified and scaled Mariner 9 pictures was assembled at 1:5,000,000. These mosaics were reduced to 1:25,000,000 and transformed where necessary to the projections of this sheet.

Shaded relief was copied from the mosaics and portrayed with uniform illumination with the sun to the west. Many Mariner 9 pictures besides those in the base mosaic were examined to improve the portrayal (Levinthal and others, 1973; Green and others, 1975; Inge and Bridges, 1976). The shading is not generalized and may be interpreted with nearly photographic reliability (Inge, 1972).

Shaded relief analysis and representation were made by J. L. Inge.

### CONTOURS

Since Mars has no seas and hence no sea level, the datum (the 0 km contour line) for altitudes is defined by a gravity field described by spherical harmonics of fourth order and fourth degree (Jordan and Lorell, 1973) combined with a 6.1 millibar atmospheric pressure surface derived from radio-occultation data (Kliore and others, 1973; Christensen, 1975; Wu, 1975).

The contour lines on most of the Mars maps (Wu, 1975) were compiled from Earth-based radar determinations (Downs and others, 1971; Pettengill and others, 1971) and measurements made by Mariner 9 instrumentation, including the ultraviolet spectrometer (Hord and others, 1974), infrared interferometer spectrometer (Conrath and others, 1973), and stereoscopic Mariner 9 television pictures (Wu and others, 1973).

Formal analysis of the accuracy of topographic elevation information has not been made. The estimated vertical accuracy of each source of data indicates a probable error of 1-2 km.

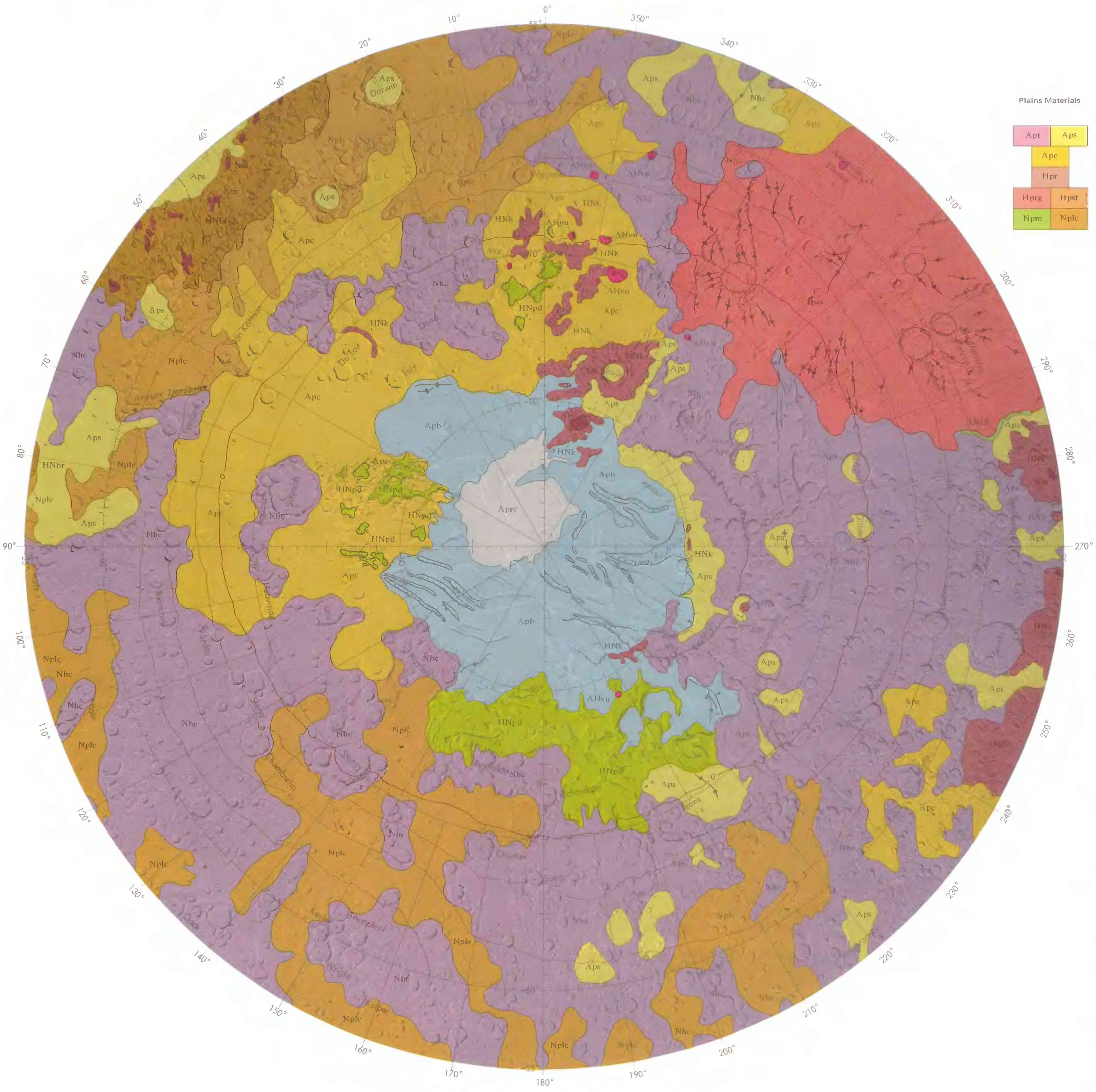
### NOMENCLATURE

All names on this sheet are approved by the International Astronomical Union (IAU, 1974).

M 25M G: Abbreviation for Mars 1:25,000,000 series; geologic map, G.

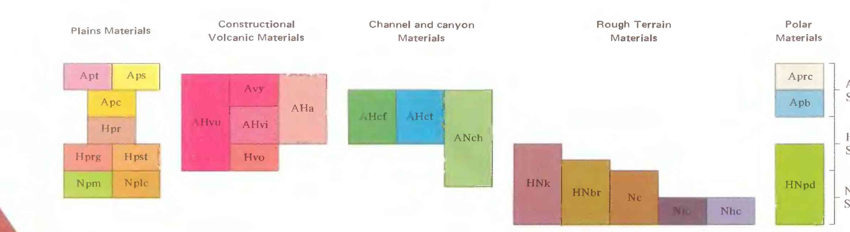
### REFERENCES

Batson, R. M., 1973, Cartographic products from the Mariner 9 mission: Jour. Geophys. Research, v. 78, no. 20, p. 4424-4435.
——1976, Cartography of Mars; 1975: The American Cartographer, v. 3, no. 1, p. 57-63.
Christensen, E. J., 1975, Martian topography derived from occultation, radar, spectral, and optical measurements: Jour. Geophys. Research, v. 80, no. 20, p. 2909-2913.
Conrath, B. J., Curran, R. J., Hanel, R. A., Kunde, V. G., Maguire, W. W., Pearl, J. C., Pirraglia, J. A., Welker, J., and Burke, T. E., 1973, Atmospheric and surface properties of Mars obtained by infrared spectroscopy on Mariner 9: Jour. Geophys. Research, v. 78, no. 20, p. 4267-4278.
Davies, M. E., 1973, Mariner 9: Primary control net: Photogramm. Eng., v. 39, no. 12, p. 1297-1302.
Davies, M. E., and Arthur, D. W. G., 1973, Martian surface coordinates: Jour. Geophys. Research, v. 78, no. 20, p. 4355-4394.
Downs, G. S., Goldstein, R. M., Green, R. R., and Morris, G. A., 1971, Mars radar observations, a preliminary report: Science, v. 174, no. 4016, p. 1324-1327.
Green, W. B., Jepsen, P. L., Kreznar, J. E., Ruiz, R. M., Schwartz, A. A., and Seidman, J. B., 1975, Removal of instrument signature from Mariner 9 television images of Mars: Applied Optics, v. 14, no. 1, p. 105-114.
Hord, C. W., Simmons, K. E., and McLaughlin, L. K., 1974, Mariner 9 ultraviolet spectrometer experiment: Pressure altitude measurements on Mars: Icarus, v. 21, no. 3, p. 292-302.
Inge, J. L., 1972, Principles of lunar illustration: Aeronaut. Chart and Inf. Center Ref. Pub., RF-72-1, 60 p.
Inge, J. L., and Bridges, P. M., 1976, Applied photointerpretation for airbrush cartography: Photogramm. Eng., v. 42, no. 6, p. 749-760.
International Astronomical Union, Commission 16, 1971, Physical study of planets and satellites, *in* Proc. 14th General Assembly, 1970: Internat. Astron. Union Trans., v. XIVB, p. 128-137.
——1974, Physical study of planets and satellites, *in* Proc. 15th General Assembly, 1973: Internat. Astron. Union Trans., v. XVB, p. 105-108.
Jordan, J. F., and Lorell, Jack, 1973, Mariner 9, an instrument of dynamical science: Presented at AAS/AIAA Astrodynamics Conf., Vail, Colo., July 16-18, 1973.
Kliore, A. J., Fjeldbo, Gunnar, Seidel, B. L., Sykes, M. J., and Woiceshyn, P. M., 1973, S-band radio occultation measurements of the atmosphere and topography of Mars with Mariner 9: Extended mission coverage of polar and intermediate latitudes: Jour. Geophys. Research, v. 78, no. 20, p. 4331-4351.
Levinthal, E. C., Green, W. B., Cutts, J. A., Jahelka, E. D., Johansen, R. A., Sander, M. J., Seidman, J. B., Young, A. T., and Soderblom, L. A., 1973, Mariner 9—Image processing and products: Icarus, v. 18, no. 1, p. 75-101.
Masursky, Harold, Batson, R. M., Borgeson, W. T., Carr, M. H., McCauley, J. F., Milton, D. J., Wildey, R. L., Wilhelms, D. E., Murray, B. C., Horowitz, N. H., Leighton, R. B., Sharp, R. V., Thompson, T. W., Briggs, G. A., Chandeysson, P. L. Shipley, E. N., Sagan, Carl, Pollack, J. B., Lederberg, Joshua, Levinthal, E. C., Hartmann, W. K., McCord, T. B., Smith, B. A., Davies, M. E., de Vaucouleurs, G. D., and Leovy, C. B., 1970, Television experiment for Mariner Mars 1971: Icarus, v. 12, no. 1, p. 10-45.
Pettengill, G. H., Rogers, A. E. E., and Shapiro, I. I., 1971, Martian craters and a scarp as seen by radar: Science, v. 174, no. 4016, p. 1321-1324.
de Vaucouleurs, G. D., Davies, M. E., and Sturms, F. M., Jr., 1973, The Mariner 9 areographic coordinate system: Jour. Geophys. Research, v. 78, no. 20, p. 4395-4404.
Wu, S. S. C., 1975, Topographic mapping of Mars: U.S. Geol. Survey Interagency Rept. 63, 191 p.
Wu, S. S. C., Schafer, F. J., Nakata, G. M., Jordan, Raymond, and Blasius, K. R., 1973, Photogrammetric evaluation of Mariner 9 photography: Jour. Geophys. Research, v. 78, no. 20, p. 4405-4410.




SOUTH POLAR REGION

## CORRELATION OF MAP UNITS




## DESCRIPTION OF MAP UNITS

Crater densities shown for larger units are from Condit (1977). These determinations were made for craters in the size range 4-10 km and for geologic units limited between about lat 30° N. and 30° S.

### PLAINS MATERIALS

Apt — VOLCANIC PLAINS OF THARSIS MONTES REGION—Occurs around three large volcanoes of Tharsis Montes (Ascraeus Mons, Pavonis Mons, Arisa Mons). Smooth, featureless, resembles smooth plains (unit Aps) at A-frame resolution (2-3 km); B frames show many lobate escarpments. Crater density $28/10^6 km^2$. *Interpretation:* Young lava plains

Aps — SMOOTH PLAINS MATERIAL—Occurs planetwide but chiefly in low areas such as crater and basin floors and in Vastitas Borealis, the extensive lowland circumferential belt around lat 50° N. Effectively buries most underlying craters and topography. Crater density $59/10^6 km^2$. *Interpretation:* Eolian and volcanic deposits, tens to hundreds of meters thick

Apc — CRATERED PLAINS MATERIAL—Gradational with smooth plains material (Aps) but has higher crater density ($89/10^6 km^2$); subjacent topography shows ridges and lobate scarps in places. Basal rock-stratigraphic unit of Amazonian System. Type area lat 18° N., long 165° W. *Interpretation:* Lava plains covered with a discontinuous veneer of eolian deposits; moderately high crater density reflects inclusion of older partly buried surfaces in crater counts

Hpr — ROLLING PLAINS MATERIAL—Forms undulating relatively level surfaces embaying units Nplc, Nhc, and HNk along base of scarp between upland cratered province and lowland plains. Encircles north polar region and forms partial ring inside north margin Hellas basin. Gradational with volcanic materials of intermediate age (unit AHvi). Crater density $73/10^6 km^2$. More fractured than cratered plains. Lobate fronts visible in some B frames. *Interpretation:* Lava plains

Hprg — RIDGED PLAINS MATERIAL—Occurs mainly in Lunae Planum, Sinai Planum, Solis Planum, Syrtis Major Planitia and Hesperia Planum. Cannot be distinguished from older volcanic deposits (unit Hvo) around Amphitrites Patera (lat 60° S., long 300° W.) and a large unnamed volcano near lat 67° S., long 323° W. At Schiaparelli (lat 3° S., long 344° W.), ridges may partly reflect pre-basin buried crater rims (King, 1977). Martian ridged plains closely resemble lunar maria and have about the same crater density ($124/10^6 km^2$). Basal rock-stratigraphic unit of Hesperian System. Type area lat 20° S., long 245° W. *Interpretation:* Volcanic flows

Hpst — STREAKED PLAINS MATERIAL—Forms moderately to highly cratered surfaces marked by light and dark streaks downwind from craters in Elysium Planitia. Fractures and lobate scarps visible in some high-resolution frames. May be gradational with ridged plains material. Crater density $133/10^6 km^2$. *Interpretation:* Volcanic flows

Npm — MOTTLED PLAINS MATERIAL—Occurs chiefly in boreal region as broad band extending between lat 50° N. and 70° N. almost completely around planet. High albedo in and around craters contrasting sharply with dark plains gives unit a splotchy appearance. Moderately to highly cratered. Image quality poor in this region. *Interpretation:* Cratered lava plains; possibly correlates in part with sequence of Noachian strata (units Nplc, Nhc) forming uplands south of planet-girdling lowland belt of Amazonian plains (units Apc, Aps)

Nplc — CRATERED PLATEAU MATERIAL—Forms extensive, densely cratered ($135/10^6 km^2$) uplands mostly in central and south polar regions. Many buried to partly buried large craters; intercrater areas flat and smooth. In places highly dissected by channels and chaotic terrain. Lobate scarps, grabens common; ridges rare. *Interpretation:* Ancient lava flows and highly brecciated impact ejecta

### CONSTRUCTIONAL VOLCANIC MATERIALS

AHvu — VOLCANIC MATERIAL, UNDIVIDED—Forms relatively small (<30 km) domes and cones mostly associated with large volcanic features of various ages. Summit craters common. Areal extent very small and crater density determinations not reliable. *Interpretation:* Volcanoes; age indeterminate but morphology suggests relatively young

Avy — YOUNG VOLCANIC MATERIAL—Forms prominent shields in Tharsis region; crater densities very low on flanks and aprons. Numerous volcanic channels and long linear flows give surface a fine striated texture. *Interpretation:* Young volcanoes composed of basaltic lavas. Estimated ages (Carr, 1974) range from 200 to 800 m.y.

AHa — AUREOLE MATERIAL—Forms low elongate hills or ridges around bases of Olympus Mons, Elysium Mons, Albor Tholus, and Apollinares Patera. In Elysium region appears to be gradational with rolling plains material (unit Hpr). *Interpretation:* Lava flows from vents and fissures around main volcanic center

AHvi — VOLCANIC MATERIAL, INTERMEDIATE AGE—Forms moderately subdued shields, domes, and steep-sided construct of Elysium Mons. Crater density somewhat higher than unit Avy. Associated in places with unit Hpr. *Interpretation:* Shield volcanoes, stratovolcanoes, and volcanic domes; made up of basalt flows, interbedded flows and pyroclastic material, and relatively viscous lavas

Hvo — OLD VOLCANIC MATERIAL—Occurs chiefly along southern part of volcanic chain extending from Hecates Tholus (lat 32° N., long 210° W.) southwestward beyond Amphitrites Patera (lat 60° S., long 300° W.). Forms highly subdued, low-relief shields; commonly associated with ridged plains (unit Hprg). *Interpretation:* Shield volcanoes and associated flow units; low relief may result from isostatic adjustment, or low-viscosity lava

### CHANNEL AND CANYON MATERIALS

AHcf — CANYON FLOOR MATERIAL—Forms floors of chasmas in Valles Marineris system; flat and smooth to ridged; gradational in places with chaotic material (unit AHct). *Interpretation:* Fluvial deposits, landslide debris, eolian material, and possibly bedrock exposed in places

AHct — CHAOTIC MATERIAL—Forms blocky, fractured, and grooved terrain within craters, channels, and other depressions mostly in region between Chryse Planitia and Argyre Planitia. *Interpretation:* Material formed by subsurface collapse probably resulting from melting of ground ice

ANch — CHANNEL MATERIAL—Occurs on floors of sinuous to linear depressions resembling terrestrial stream beds. Buried in places by unit Aps; gradational with unit Apc. *Interpretation:* Fluvial and eolian deposits

### ROUGH TERRAIN MATERIALS

HNk — KNOBBY MATERIAL—Occurs along zone between lowland plains of Vastitas Borealis and upland Noachian cratered plateau and hilly terrain (units Nplc, Nhc); forms part of Noachian rim material of basins and large old craters; in places associated with chaotic material. *Interpretation:* Diverse origins; erosional remnants of old highland materials left by scarp retreat, basin and crater ballistic ejecta, eroded basin and crater rim material, and blocks dislocated by subsurface collapse probably caused by ground ice decay

HNbr — BASIN RIM MATERIAL—Forms rims and walls of Hellas, Argyre, Isidis, Schiaparelli, and Lowell basins. Includes some knobby materials. *Interpretation:* Ejecta and uplifted blocks of ancient terrain

Nc — CRATER MATERIAL—Forms rims and walls of craters larger than about 400 km diameter. Includes some knobby material. *Interpretation:* Crater ejecta

Nm — MOUNTAIN MATERIAL—Forms prominent masses 10 km or more in size; commonly elongate. Associated with basin rim material and with Phlegra Montes (lat 35° N., long 195° W.). *Interpretation:* Fault blocks formed during and subsequent to basin impacts; occurrence in Phlegra Montes may represent presence of unrecognized basin

Nhc — HILLY AND CRATERED MATERIAL—Occurs mostly in highlands of southern hemisphere. Forms highly cratered rough terrain. Unlike cratered plateau material (unit Nplc), intercrater areas rugged. Albedo contrasts below lat 50° S. give mottled appearance to unit (De Hon, 1977). Believed to be oldest rock-stratigraphic unit of Noachian System. Type area centered near lat 45° S., long 340° W. *Interpretation:* Oldest extensively exposed surface on Mars

### POLAR MATERIALS

Aprc — POLAR RESIDUAL CAP MATERIAL—Forms bright zones around north and south poles that persist during martian late spring and summer. North cap shows outward radiating counterclockwise spiral pattern centered near lat 90° N. South cap shows clockwise spiral; center offset 2°-3° from lat 90° S. *Interpretation:* Perennial ice caps, mostly water ice (Murray and Malin, 1973; Dzurisin and Blasius, 1974)

Apb — BEDDED PLAINS MATERIAL—Forms smooth undulating sculptured terrain with mesas and hollows showing fine horizontal stratification. Extends outward from and appears to underlie polar ice. Low crater density. *Interpretation:* Eolian deposits of young age

HNpd — DEFLATION PLAINS MATERIAL—Forms varitextured but generally rough planar surfaces exposed in windows of younger plains materials (units Aps, Apc, Apb) and some cratered plateau material (unit Nplc). Partly buried relict craters visible in places. Occurs chiefly in south polar region. *Interpretation:* Older surfaces exhumed by wind erosion of relatively soft materials

Contact

Narrow depression—Fracture or graben

Fault—Bar and ball on downthrown side

Lobate scarp—Line at base. Barb points downdip. Lava flow front

Curvilinear scarp—Fault scarp or collapse depression

Broad arcuate scarp—Marks rims of Isidis and South Polar basins

Mare-type ridge

Narrow sinuous depression—Fluvial channel

Caldera

## INTRODUCTION

This geologic map of Mars was compiled largely from Mariner-9-based 1:5,000,000-scale geologic maps prepared by several authors. However, many of the geologic units of the larger scale maps have been combined and revised to provide continuity of portrayal so that this map expresses our own concepts as well as those of the mappers at the larger scale. The techniques used are similar to those used on the Moon and have been described in detail elsewhere (Wilhelms, 1970). Geologic units are identified by and named for their outstanding physical charcteristics, mainly as determined from Mariner 9 orbiter pictures. The units so defined are those that dominate the topography at the scale of the pictures; younger, finer textured units may be present although not portrayed. Low-resolution (2-3-km) Mariner 9 A-frame pictures, which cover the entire planet, were the prime data source; B-frames with resolution of 200-300 m were used where available.

There is no assurance that the mapped units everywhere represent rock-stratigraphic divisions. The primary depositional characteristics of rocks on Mars are more extensively modified than those on the Moon. In places the erosional and tectonic overprint so modifies the surface that primary distinctions between different rock units are lost. In these cases new units are defined to encompass the modified materials. The distributions of 24 martian-rock stratigraphic units are shown. They are divided into five general categories: (1) plains materials, (2) constructional volcanic materials, (3) channel and canyon materials, (4) rough terrain materials, and (5) polar materials. In the interest of showing uncluttered relations between stratigraphic units, only the larger craters (>400 km) and ringed basins have been mapped. All geologic units are relatively dated or subdivided into age groups on the basis of crater densities, superposition and embayment relations, and degree of degradation. Most plains materials are intergradational with units shown above and below them on the correlation chart. To test the validity of the age designations, the density of craters 4 to 10 km in diameter was determined for each unit (Condit, 1977). These studies substantiated the general age classification of major rock units shown in the correlation chart.

The rock units have been assigned to a martian time-stratigraphic system here introduced for the first time. Recognition of stratigraphic units on the Moon and determination of their time relations are facilitated by the presence of extensive marker horizons and extremely low erosion rates that have prevailed throughout much of its history. For Mars, the time-stratigraphic divisions have been more difficult to systematize because of the absence of extensive basin ejecta blankets, which on the Moon serve as excellent time horizons. Furthermore, the enhanced efficacy of fluvial and eolian erosion and various mass-wasting processes on Mars renders crater counts less reliable as indicators of age. Nevertheless, the advantages of developing a time-stratigraphic classification of martian rocks are believed to outweigh the attendant uncertainties. Therefore a formal classification is herein defined that subdivides the rocks of the five major physiographic expressions into three fundamental time-stratigraphic units or systems. The martian systems are named after the areas in which their typical rock successions occur.

## STRATIGRAPHY

**Noachian System**

The Noachian System is here named for the Noachis quadrangle (MC-27), in which the oldest rocks on the planet are best exposed. These rocks include hilly and cratered material, basin and crater rim material, and mountain material. All of these units are believed to represent highly brecciated and faulted crustal rocks formed during an early period of high impact flux on Mars. Their bases are nowhere visible. The type area of the extensive unit of hilly and cratered material, believed to be the oldest exposed rock unit in the Noachian System, is centered near lat 45° S. and long 340° W. (A-DAS 5527023, B-DAS 5526988). This unit is chiefly composed of the overlapping and interbedded ejecta blankets of many old craters. Other ancient rocks in the lower part of the system are mountain material and basin rim material. These two units are associated with individual basins and craters. They are best exposed along the western margin of the Hellas basin, from lat 35° S. to 50° S. and long 310° W. to 320° W. This basin was probably formed during the early cratering history of the planet (Potter, 1976).

Cratered plateau material is the uppermost rock unit of the Noachian System. It is like hilly and cratered material but has plains between and within craters. The type area is near lat 20° S., long 350° W. The top of the Noachian System is defined as the base of the ridged plains material (unit Hprg), the basal rock-stratigraphic unit of the Hesperian System. Boundaries between cratered plateau and hilly and cratered materials are transitional in places and difficult to map. Also, densities of large craters are comparable in both units, and the important distinguishing criteria of relative smoothness and flatness of intercrater areas in the plateau material (Wilhelms, 1976) are highly dependent on the quality of the Mariner images. The smoothness of the cratered plateau material, however, appears to be real and may represent widespread flooding by lava of the hilly and cratered surface after the flux of large impacts had declined. Both the hilly and cratered and cratered plateau units seem to be similar in age to some rim materials of large craters, some hills that form the basal parts of knobby terrain along the highland-lowland boundary, and some of the material exposed in deflation plains of the south polar region.

A somewhat arbitrary mapping distinction is made between rocks that form the mountain and the knobby units, especially around Isidis Planitia (lat 15° N., long 270° W.) and Phlegra Montes (lat 35° N., long 195° W.). A size limit for differentiating between these units is not everywhere satisfactory because of the great overlap in their morphologic characteristics. For this reason, the provenance and geologic setting of these units is considered in their classification. Large clusters of material along the plateau front are clearly erosional remnants formed by scarp retreat; these are mapped as knobby material. Prominent masses around circular basins may be partly tectonic in origin and are classified as mountain units.

**Hesperian System**

The Hesperian System is here named for Hesperia Planum in the Mare Tyrrhenum quadrangle. The base of the system is delineated by the base of the ridged plains material, the type area of which is centered near lat 20° S., long 245° W. (A-DAS 7578303, B-DAS 6175188). In this locality, the ridged plains are partly streaked with light and dark plumes, which clearly are not a primary characteristic but a secondary modification. Part of this unit may correlate with the streaked plains material (unit Hpst) in the Elysium quadrangle (Scott and Allingham, 1976); however, no boundary between the two units is distinguishable in Hesperia Planum. Ridged plains overlie large areas of hilly and cratered and cratered plateau materials within the Lunae Palus (MC-10), Arabia (MC-12), Syrtis Major (MC-13), Coprates (MC-18), and Mare Tyrrhenum (MC-22) quadrangles. Both the ridged and streaked plains materials exhibit several features characteristic of lunar maria such as lobate scarps, rilles, and wrinkle ridges. They are interpreted to be basaltic lava flows. The three main rock units in the Hesperian System form rolling plains, ridged plains, and streaked plains, but other materials are tentatively believed to be at least partly of this age as indicated by crater populations or stratigraphic relations. For example, rolling plains (unit Hpr) and volcanic material of intermediate age (unit AHvi) are intergradational in the Elysium (lat 20° N., long 210° W.) and the Apollinares (lat 8° S., long 185° W.) regions; both units are overlain by Amazonian smooth plains around Apollinares but overlie and embay knobby material in many other places. Most knobby material is probably degraded and reworked material of late Noachian age, but its morphology may have been developed in the Hesperian Period, especially where it borders the highlands or occurs with chaotic terrain. Channel deposits transect Amazonian cratered plains and Hesperian rolling plains in several places but in the Aeolis quadrangle appear to be partly covered by Noachian cratered plateau material and so may have a wide range in age. Also possibly included in the Hesperian are some of the deflation plains common around the South Pole but also present in the Aeolis quadrangle and Mare Acidalium quadrangle (Underwood and Trask, 1978). They appear to represent a sequence of eroded surfaces beneath plains and plateau materials of Amazonian and Hesperian age and thus expose lower Hesperian and Noachian rocks. The top of the Hesperian System is defined as the base of the cratered plains material, the basal rock unit of the Amazonian System.

**Amazonian System**

This system comprises the youngest rocks on the planet and includes smooth plains, cratered plains, volcanic plains of the Tharsis region, parts of the canyon floors, bedded polar plains, and ice caps. A large part of the smooth plains may be eolian deposits and is best represented in the Amazonis quadrangle (MC-8), for which the system is named. The type area is centered near lat 18° N., long 165° W., where both the upper (smooth plains) and lower (cratered plains) rock units are exposed (A-DAS 6679508, B-DAS 6607928). The base of the Amazonian is defined as the base of the cratered plains material. This unit overlies ridged plains in Hesperia Planum and rests upon rolling plains, the uppermost rocks of the Hesperian System, in the Amazonis, Elysium, Casius, Cebrenia, and Hellas quadrangles.

Crater populations are less than those of the lunar maria for most rock units within the Amazonian System (Soderblom and others, 1974; Condit, 1977). On low-resolution photographs only small distinctions are visible between surface textures of some of the units, especially cratered plains and smooth plains. At high resolution, however, fractures, ridges, and lobate scarps are much more easily recognized on the cratered plains than on the smooth plains. Volcanic plains of the Tharsis region are distinguished from smooth plains mainly by the presence of lobate flow fronts on high-resolution pictures. The prominent, topographically fresh volcanoes of the Tharsis region (unit Avy) and numerous small cratered domes and cones mapped as undivided volcanic deposits (unit AHvu) are also assigned wholly or partly to the Amazonian. The canyon floor deposits of Valles Marineris have very low crater densities, and the valley system itself transects Amazonian cratered plains material and thus is younger. Channel material also appears to cut across Amazonian cratered plains and smooth plains in the Hellas (lat 40° S., long 260° W.) and Ismenius Lacus (lat 45° N., long 350° W.) quadrangles but has a very subdued appearance and may be older. The bedded plains of the polar areas appear to be intergradational in some areas with smooth plains and were probably deposited during the Amazonian Period.

The rock units that make up the Amazonian System are mostly volcanic materials, alluvium, and eolian deposits. Their thicknesses are highly variable, ranging from thin sheets that barely cover subjacent terrain to thick accumulations that effectively bury crater rims many kilometers in diameter. Amazonian rocks occur in low areas of regional extent and in craters and minor declivities of the uplands and cover a large part of the Tharsis Mountains; their albedo is generally higher than that of older rock units.

## STRUCTURE

Mars, like the Moon, appears to have a tectonic grid with northwest and northeast trends predominating (Scott and others, 1972, Binder and McCarthy, 1972, Harp, 1976). This structural pattern is neither simple nor evident in all areas. It commonly is interrupted or overprinted by faults, fractures, and ridges that are radial or concentric to specific features such as impact basins, volcanic centers, and uplifts. Neither this nor a previous study (Carr, 1974) has revealed any evidence of great horizontal movement along the faults. Among the most notable structural features that appear to conform to the planetwide grid are: (1) the great northwest-trending escarpment separating the lowland plains and cratered highlands between long 200° W. and 310° W.; (2) the fault and graben systems that trend northwest for 3,500 km across Elysium Planitia; (3) ridges in and around Hesperia Planum and Syrtis Major; (4) the large graben systems of the Mareotis, Tempe, and Sirenum Fossae, although they also appear to be part of the radial fracture system around Tharsis; and (5) the two major lines of volcanoes on the planet, those in Tharsis and the Amphitrites-Hadriaca-Tyrrhenum-Elysium line that extends northeast along a great circle for a distance of about 9,000 km. Many of the grid features are buried by smooth and cratered plains materials and so are Hesperian or older.

The updoming of the region around Montes Tharsis and Syria Planum has produced a widespread network of intersecting fractures that are generally radial to the center of the uplifted area (Carr, 1974). The development of the equatorial canyon system Valles Marineris appears to have been controlled by this set. The radial fractures tend to be best developed where the radial direction is coincident with the grid direction, as with the Mareotis and Tempe Fossae. Crosscutting relations and graben morphology suggest that the fracture system developed throughout a long period of the planet's history (McGill, 1976; Masursky and others, 1978), probably extending from the Noachian to the Amazonian Periods. East of the highly fractured terrain at Syria Planum, a broadly arcuate series of ridges curve partly around the Tharsis uplift from about lat 20° N. to 25° S. These ridged plains overlap cratered plateau material south of Valles Marineris, where their concentric structural pattern is continued a few hundred kilometers by fractures in the older rocks. Thus, in a huge area, covering some 25 million $km^2$ around Tharsis, the planetwide grid is masked by radial and concentric structures produced by deep-seated doming of crustal rocks. A similar radial and concentric fracture system has developed around the Elysium region, although on a much smaller scale.

## GEOLOGIC HISTORY

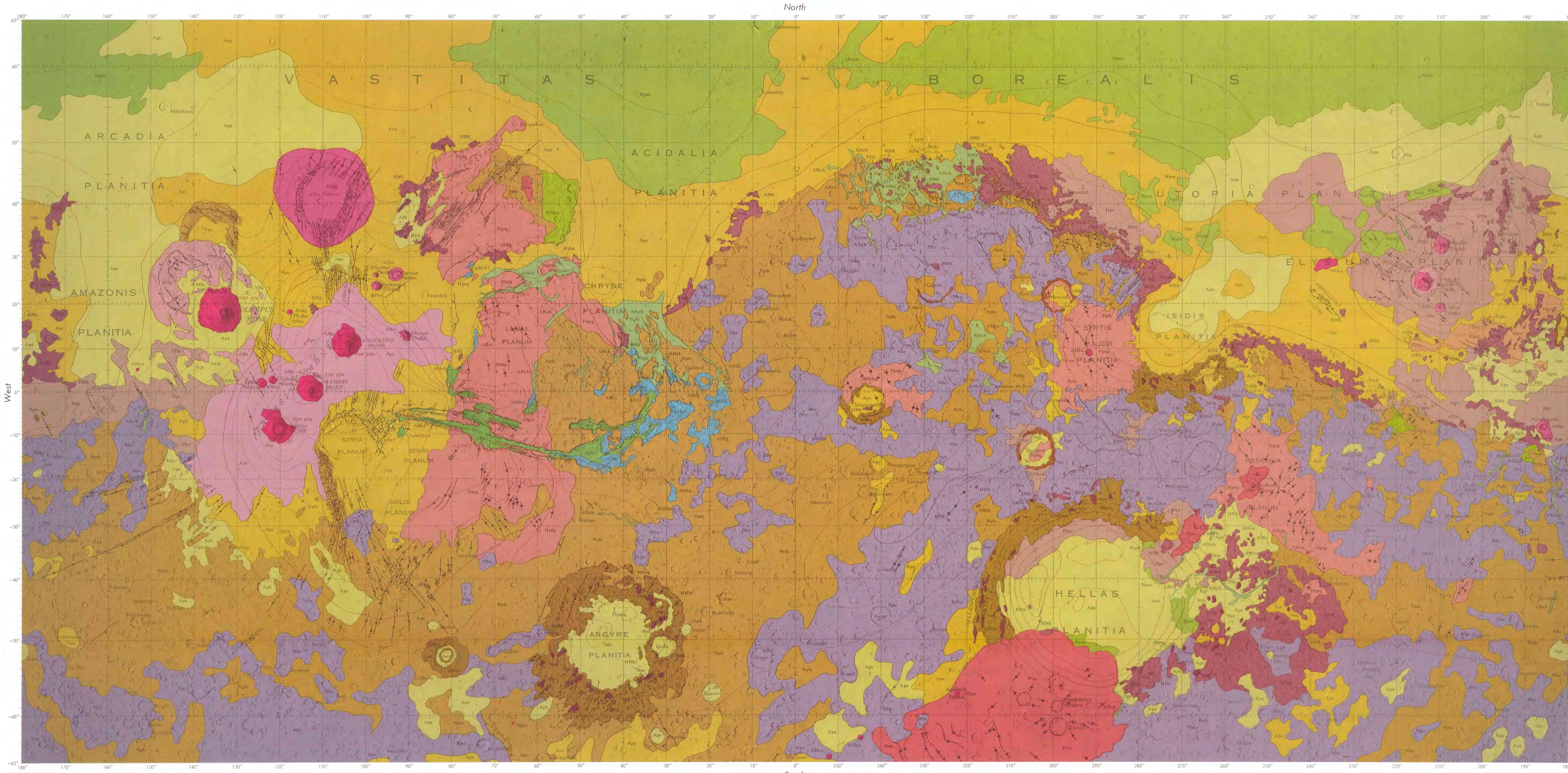
After initial stages of planetary accretion, heating, and differentiation, the Noachian Period began with the rapid degradation of the primordial crust under high impact flux. During this early period, a hilly and cratered surface was formed resembling that of the lunar highlands but having fewer known basins. Block faulting associated with large basin rings formed mountain ranges, but there is no evidence of mountain building by tectonic processes like those on earth. A planetwide structural grid developed, and large-scale fracturing accompanied the beginning of regional uplift in the Tharsis area. Toward the close of the Noachian, flood basalts forming the cratered plateau unit were probably extruded from fissures and covered large parts of the hilly and cratered terrain. Although these lavas were voluminous, they were relatively thin. Intercrater areas were buried and smoothed, but large and moderate-size craters were not completely covered. The Noachian Period may correspond with the pre-Nectarian-Nectarian high-flux interval on the Moon, but their relative age equivalency is uncertain. Many of the Noachian and Hesperian rocks are modified by fine channels, implying the presence of surface runoff water and climatic conditions different from those that prevail at the present (Sagan, 1976).

At the onset of the Hesperian Period, the style of volcanism appears to have changed. Fissure eruptions continued but mostly were localized around volcanic edifices such as Tyrrhena Patera and Elysium Mons, although extensive Hesperian deposits could be beneath the younger rocks of the northern plains. Streaked and ridged plains formed during the early part of this period; later Hesperian plains are characterized by smooth rolling topography. The rolling plains embay large areas of the frontal escarpment between the lowland plains and the cratered highlands as well as some fractured plains in the Memnonia quadrangle. The southward erosional retreat of the escarpment left numerous isolated remnants of knobby material projecting above the plains along its boundary. The first large water floods occurred, probably from melting of ground ice initiated by volcanism, meteoroid impact, or climatic changes (Milton, 1975). Formation of fine channel networks also appears to have continued through this period. The Hesperian Period is broadly equivalent to the Imbrian and probably part of the Eratosthenian Period on the Moon and includes an interval of rapidly decreasing impact flux.

The Amazonian Period, like the Copernican Period on the Moon, includes an interval of very low impact flux; the similarity, however, between late stages in the development of the two planets ends there. On Mars, the Amazonian Period was a very active one, whereas the Moon was nearly dormant late in its history. Volcanism culminated in the formation of colossal volcanoes on the Tharsis ridge and deposition of the vast plains around them. Water erosion may have continued but at a much reduced rate; few catastrophic floods occurred during the period. Winds were probably active throughout the history of the planet, but the first recognizable eolian deposits occur in the Amazonian. The violent storms on Mars still produce surface changes that are visible on time scales of several days.

## REFERENCES

Binder, A. B., and McCarthy, D. W., Jr., 1972, Mars: The lineament systems: Science, v. 176, p. 279-381.
Carr, M. H., 1974, Tectonism and volcanism of the Tharsis region of Mars: Jour. Geophys. Research, v. 79, p. 3943-3949.
Carr, M. H., Masursky, Harold, and Saunders, R. S., 1973, A generalized geologic map of Mars: Jour. Geophys. Res., v. 78, p. 4031-4036.
Condit, C. D., 1977, The distribution and relationships of 4-10 km diameter craters to global geologic units on Mars: U.S. Geol. Survey open-file report 77-421, 24 p.
De Hon, R. A., 1977, Geologic map of the Eridania quadrangle of Mars: U.S. Geol. Survey Misc. Geol. Inv. Map I-1088.
Dzurisin, Daniel, and Blasius, K. A., 1975, Polar layered deposits on Mars: I. Topography: Jour. Geophys. Research, v. 80, p. 3286-3306.
Harp, E. L., 1976, The fracture systems of Mars: Proc., First Internat. Conf. on the New Basement Tectonics; Utah Geol. Assoc. Publ. No. 5, p. 389-408.
King, J. S., 1977, Geologic map of the Arabia quadrangle of Mars: U.S. Geol. Survey Misc. Geol. Inv. Map I-996.
Masursky, Harold, Strobell, M. E., and Dial, A. L., 1978, Geologic map of the Phoenicis Lacus quadrangle of Mars: U.S. Geol. Survey Misc. Geol. Inv. Map I-896 (in press).
McGill, G. E., 1976, Geologic history of the Thaumasia quadrangle, Mars: NASA Technical Memorandum, TMX-3364, Report of Accomplishments of Planetology Programs, 1975-1976, p. 224-228.
Milton, D. J., 1975, Geologic map of the Lunae Palus quadrangle of Mars: U.S. Geol. Survey Misc. Geol. Inv. Map I-894.
Murray, B. C., and Malin, M. C., 1973, Polar volatiles on Mars—Theory versus observations: Science, v. 182, p. 437-443.
Peterson, J. D., 1977, Geologic map of the Noachis quadrangle of Mars: U.S. Geol. Survey Misc. Geol. Inv. Map I-910.
Potter, D. B., 1976, Geologic map of the Hellas quadrangle of Mars: U.S. Geol. Survey Misc. Geol. Inv. Map I-941.
Sagan, Carl, 1976, Preliminary investigations of the physics of martian channels: NASA Technical Memorandum, TMX-3364, p. 166-168.
Scott, D. H., Peterson, J. D., and Wilhelms, D. E., 1972, Prototype and preliminary geologic mapping of Mars from Mariner 6 and 7 data, Part 2: Preliminary small-scale regional mapping (1:5,000,000). U.S. Geol. Survey open-file report, p. 11-17.
Scott, D. H., and Allingham, J. W., 1976, Geologic map of the Elysium quadrangle of Mars: U.S. geol. Survey Misc. Geol. Inv. Map I-935.
Soderblom, L.A., Condit, C.D., West, R. A., Herman. B.M., and Kriedler, T.J., 1974, Martian planet-wide crater distributions: Implications for geologic history and surface processes: Icarus, v. 22, no. 3, p. 239-263.
Underwood, J. R., Jr., and Trask, N. J., 1978, Geologic map of the Mare Acidalium quadrangle of Mars: U.S. Geol. Survey Misc. Geol. Inv. Map I-1048.
Wilhelms, D. E., 1970, Summary of lunar stratigraphy—Telescopic observations: U.S. Geol. Survey Prof. Paper 599-F p. 1-47.
——1976, Geologic map of the Oxia Palus quadrangle of Mars: U.S. Geol. Survey Misc. Geol. Inv. Map I-895.




SCALE 1:25 000 000 AT 0° LATITUDE
1:12 549 000 AT 60° LATITUDE
MERCATOR PROJECTION

KILOMETERS 0 1000 2000 3000 4000 5000

CONTOUR INTERVAL 1 KILOMETER

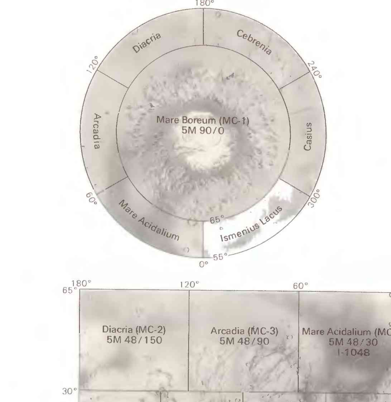
Interior—Geological Survey, Reston, Va.—1978—G77230
Prepared on behalf of the Lunar and Planetary Programs Office, National Aeronautics and Space Administration under contract W-13,709

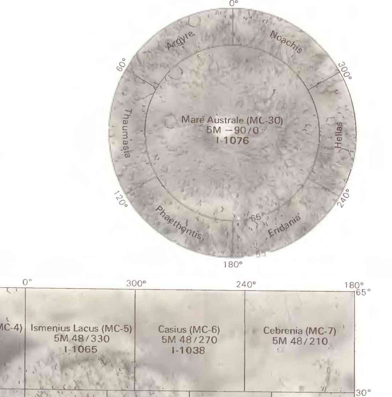
# GEOLOGIC MAP OF MARS

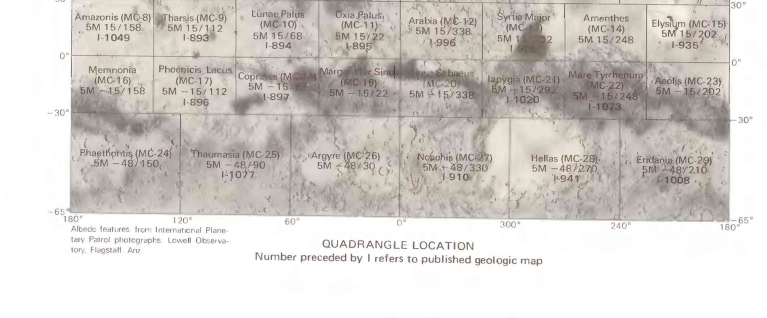
By
David H. Scott and Michael H. Carr
1978

## 1:5,000,000-SCALE GEOLOGIC MAPS USED IN PREPARING THIS 1:25,000,000-SCALE MAP OF MARS

| | MAP | AUTHOR(S) | AFFLIATION |
|---|---|---|---|
| MC-3 | Arcadia | D. U. Wise | Univ. Massachusetts |
| MC-4 | Mare Acidalium | J. R. Underwood, Jr. and N. J. Trask | W. Texas State Univ.; USGS, Washington, D. C. |
| MC-5 | Ismenius Lacus | B. K. Lucchitta | USGS, Flagstaff, Ariz. |
| MC-6 | Casius | Ronald Greeley and J. E. Guest | Ames Research Center, Calif.; Univ. of London |
| MC-8 | Amazonis | E. C. Morris and S. E. Dwornik | USGS, Flagstaff, Ariz.; NASA Lunar and Planetary Programs office, Washington, D. C. |
| MC-9 | Tharsis | M. H. Carr | USGS, Menlo Park, Calif. |
| MC-10 | Lunae Palus | D. J. Milton | USGS, Menlo Park, Calif. |
| MC-11 | Oxia Palus | D. E. Wilhelms | USGS, Menlo Park, Calif. |
| MC-12 | Arabia | J. S. King | Univ. N. Y., Buffalo |
| MC-13 | Syrtis Major | J. D. Meyer and M. J. Grolier | Univ. Tulane; USGS, Washington, D. C. |
| MC-14 | Amenthes | K. H. Hellar | Univ. Munich |
| MC-15 | Elysium | D. H. Scott and J. W. Allingham | USGS, Flagstaff, Ariz.; USGS, Washington, D. C. |
| MC-16 | Memnonia | T. A. Mutch | Brown Univ. |
| MC-17 | Phoenicis Lacus | Harold Masursky, M. E. Strobell, and A. L. Dial | USGS, Flagstaff, Ariz. |
| MC-18 | Coprates | J. F. McCauley | USGS, Flagstaff, Ariz. |
| MC-19 | Margaritifer Sinus | R. S. Saunders | Jet Propulsion Lab., Calif. |
| MC-20 | Sinus Sabaeus | H. J. Moore | USGS, Menlo Park, Calif. |
| MC-21 | Iapygia | G. G. Schaber | USGS, Flagstaff, Ariz. |
| MC-22 | Mare Tyrrhenum | E. A. King, Jr. | Univ. Houston |
| MC-23 | Aeolis | D. H. Scott, E. C. Morris, and M. N. West | USGS, Flagstaff, Ariz. |
| MC-25 | Thaumasia | G. E. McGill | Univ. Massachusetts |
| MC-26 | Argyre | C. A. Hodges | USGS, Menlo Park, Calif. |
| MC-27 | Noachis | J.E. Peterson | Univ. Colorado |
| MC-28 | Hellas | D. B. Potter | Hamilton College, N. Y. |
| MC-29 | Eridania | R. A. De Hon | Univ. Arkansas, Monticello |
| MC-30 | Mare Australe | C. D. Condit and L. A. Soderblom | USGS, Flagstaff, Ariz. |




Albedo features from International Planetary Patrol photographs. Lowell Observatory, Flagstaff, Ariz.

QUADRANGLE LOCATION
Number preceded by I refers to published geologic map

For sale by Branch of Distribution, U.S. Geological Survey,
1200 South Eads Street, Arlington, VA 22202, and Branch of Distribution,
U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225