DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared for the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ATLAS OF MARS
1:15,000,000 GEOLOGIC SERIES
WESTERN REGION
M 15M, 0/90 G, 1986
I-1802-A

SCALE 1:15,000,000 1 mm=15 km AT 0° LATITUDE
MERCATOR PROJECTION

0 500 1000 1500 2000
KILOMETERS

INDEX OF THE 1:15,000,000 GEOLOGIC SERIES

NOTES ON BASE

The map sheet is one of a series covering the entire surface of Mars at a scale of 1:15,000,000. Most of the map base were 1:5,000,000-scale shaded relief maps described by Batson and others (1979). Data used in the map portrayal were obtained from Viking Orbiter images.

ADOPTED FIGURE

The figure of Mars used in the Mercator map projections is an oblate spheroid (flattening of 1/192) with an equatorial radius of 3,393.4 km and a polar radius of 3,375.7 km.

PROJECTIONS

The Mercator projection is used between the 57° parallels; the Lambert conformal conic projection is used in the polar regions north and south of the 57° parallels. Scales are 1:15,000,000 at the equator and 1:9,205,626 at the poles. The projections have a common scale of 1:8,418,000 at 14°.06' Longitude increases to the west in accordance with astronomical convention for planets whose rotations are retrograde.

CONTROL

Planimetric control for the 1:5,000,000-scale maps used to compile the bases for these sheets was derived from photogrammetric triangulations by use of Mariner 9 pictures (Wu, 1978). The horizontal control network consisted of use of Viking data (Davies and others, 1978). At least 80 percent of the image control points lie within 0.5 nm of the positions published in 1978.

MAPPING TECHNIQUE

The mapping bases were originally assembled from 1:5,000,000-scale shaded relief maps and digitally transformed where necessary to fit the projections. Base transformation was carried out by the U.S. Geological Survey's Interactive Digital Mapping System (Idlabs) on a Prime computer. Features were drawn as interactively digitized graphics by means of the use of airbrush techniques described by Inge (1972) and photoimpressive methods described by Inge and Bridges (1976). To ensure consistency and accurately represent the character of surface features.

Shaded relief analysis and portrayal were made by Barbara J. Hall.

NOMENCLATURE

All names on this sheet are approved by the International Astronomical Union (IAU; 1974, 1977, 1980, 1985, and 1986).

Additional names are informal and are used only on this map sheet or Mars that have scales of 1:2,000,000, 1:5,000,000, and 1:25,000,000.

M-15M 0/90 G — Abbreviation for Mars; 1:15,000,000 series; center of map, lat 0°, long 90°; geologic map, GQ

INTRODUCTION

This map of the western equatorial region of Mars supersedes previous geologic maps based on Mariner 9 data. It represents a more advanced study of the region and is published by the U.S. Geological Survey at the request of the National Aeronautics and Space Administration (NASA) as part of the Mars Data Analysis Program. The map is at 1:15,000,000 scale and shows the geology, stratigraphy, and structure. The text describes the major tectonic, volcanic, and fluvial episodes that have contributed to Mars' evolutionary history. The base used for compilation includes improved imagery and photogrammetric control (Wu, 1978).

Geologic units were identified and mapped from 1:2,000,000-scale photomosaics and individual images, most of which range in resolution from 100 to 300 m/pixel. The units were mapped on the consolidation part to the 1:5,000,000-scale topographic bases previously formulated (Scott and Carr, 1978) from the Mariner 9 mapping. Relative ages of the units were established by stratigraphic, structural, and crater-density relations as described in the following sections.

Cumulative crater densities of units in the three highland terrains were determined. Because of crater degradation, resurfacing, and declining crater-flux rates, relative ages of increasingly older surfaces on Mars are determined by densities of progressively older units. These density values for craters larger than 2 km in diameter were also used to establish ages for relative-age correlation within the Amazonian, Hesperian, and Noachian Systems, respectively. Overlap of the scales was found necessary because of the wide range in crater densities at different localities for units mapped over a wide range of crater sizes.

The Viking map series shares some of the uncertainties inherent in earlier maps of Mars in that many of the primary depositional characteristics of units have been modified and obscured by erosion, deposition, and tectonism. In particular, deformation has destroyed all morphologic properties of the materials that are normally used to infer rock type in the highly faulted and fractured areas north and south of Thaumá Montes and on the Tempe Terra plateau. These units from these areas are grouped under highly deformed terrain materials and mapped as basement complex (unit Nbd) and fractured materials (unit Nf).

The map is divided into lowland and highland terrain materials.

The major lowland terrain is subdivided into lowland and highland northern plains assemblage. The lowland northern plains north of the highland-lowland boundary scarp that mostly in the northern hemisphere. Much of the lowland region is covered by small knobs and conical hills. South of the boundary scarp, plateau terrain of higher elevation and greater relief extends to the south polar region.

A rock-stratigraphic classification of both formations and members is employed here for the first time in the geologic mapping of Mars. Its use minimizes the need for adjectival map-unit descriptions that may be both inadequate and confusing. In this classification, the rock units are defined by their stratigraphic relations, lithologic properties, and structural characteristics. Units of crater-density classification, these "statistical boundaries" are dashed. To avoid obscuring relations among geologic units, only superposed crater blankets wider than 100 km and partly buried impact craters larger than about 100 km in cre-rest diameter are mapped. No attempt has been made to classify craters by relative age except where the crater is clearly younger or the more significant factor—the stratigraphic position of craters relative to adjacent terrain—is shown by color. This relative stratigraphic position is indicated by the crater's ejecta blanket or floor deposits.

The Viking map thus differs from earlier Mariner 9 maps in many respects, of which the principal ones are significant: (1) a nearly three-fold increase of mapped rock units over those on the geologic map of Mars based on Mariner images (Scott and Carr, 1978); (2) the subdivision of lava flows and plains into numerous eruptive sequences at Tharsis Montes in Gother large volcanic centers; (3) the expansion of areas mapped as channel-system deposits, especially their greater extension into the northern plains; (4) the recognition of smooth, vast deposits, easily eroded, (some deposits of possible ash flow or eolian origin that cover large areas in the equatorial region of Medusae Fossae; and (5) the addition of many small- to moderate-size features interpreted as volcanic vents, domes, and shields. Many of these features were not visible in the Mariner 9 images and are now recognized in different time-stratigraphic systems. For example, the mottled plains material, formerly classified as Noachian in age, has been placed in the upper part of the Hesperian System on the basis of crater counts and stratigraphic position, and it is now considered to form part of the Vastitas Borealis Formation.

Detailed studies of the stratigraphy and geology of Mars have increased dramatically since the Mariner 9 orbiter first transmitted an encyclopedic pictorial library of the surface. Higher resolution data gathered from the Viking mission have enabled surface processes to be described in greater detail and their interpretations modified or changed. Much of this increase in knowledge is due to the synoptic coverage provided by orbital reconnaissance, which is the most important factor in the development and application of new technologies. Many geologic questions on Mars have yet to be resolved, but a vast literature now exists that addresses such problems as tectonism and volcanism in the Tharsis and other regions, development of Valles Marineris, the cause and chronology of channel-system development, and the origin of the northern lowlands. Although the geologic evolution of Mars is complex and involves many processes, the major events in the planet's history can be deciphered. The first 1.5 billion years of Martian history are recorded in the ancient cratered surface of the southern uplands, which is the oldest exposed surface of the planet. The next 2 billion years are represented by the vast expanses of ridged plains and the extensive shield volcanoes and lava plains of the Tharsis region. The last 1 billion years of Martian history are recorded in the younger lava plains and sedimentary deposits of the northern lowlands and the chaotic terrain of Valles Marineris and in a large fissure at the head of the Mangala Valles. Visible remnants of large impact basins, volcanic edifices, and tectonic features from the Noachian period, which was the most active erosion and deeper burial on Mars by eolian and fluvial activity and by widespread volcanism on both the highlands and the lowlands. Volcanism apparently continued episodically throughout the Hesperian and Amazonian Periods, but on a greatly reduced scale. There has been a broad flat floor (Argyre Planitia) covered by eolian material and volcanic flows; the floor is several kilometers below its encompassing rough mountainous rim.

STRATIGRAPHY

The type areas and basal geologic units originally adopted (Scott and Carr, 1978) to define the three Martian time-stratigraphic systems (Noachian, Hesperian, and Amazonian) are modified here. Because of the new data gathered from the Mariner 9 map, however, have been reclassified or subdivided and assigned a different position in the correlation chart. The chart is calibrated according to crater densities and superposition relations.

Noachian System

The Noachian System consists of the oldest rocks exposed on most of the units mapped in the southern highlands. The rocks are generally densely cratered and, in places, highly deformed by faulting. Although the Martian highlands have roughly twice the crater density of the lunar New Basin material, the age of the oldest Martian surfaces is probably not greater than the oldest lunar rocks sampled during Apollo 16 and 17 missions. The Noachian System is named for the old, densely cratered terrain of the Moon (Wilhelms and others, 1978). The Noachian, therefore, may be similar in age to the middle of the much larger Nectarian. Because the Martian highlands are more than twice as old as the lunar highlands, the Martian system may be subdivided into lunar highlands, which have substantial proportions of both Nectarian and pre-Nectarian materials. The fact that fewer large impact basins are found on Mars than on the Moon may indicate that the Martian crust was more mobile and that the contrast between the two bodies or in the average age of their surfaces is greater than it appears to be. Crater densities on Martian highland surfaces suggest either that the early population of crater-producing bodies followed a log-normal distribution law (Neukum and Wise, 1976; Hartmann, 1978) or that the crater-retention ages in 0-30 km ranges were underestimated (Chapman and Jones, 1977).

The Noachian geologic unit (unit Nb) is the oldest identifiable material in the western hemisphere of Mars (Scott and King, 1984). The unit is highly faulted and cratered and has prominent relief. Most exposures occur in three areas: (1) In Claritas Fossae (lat 30° S., long 110° W.), (2) in the Thaumá Montes region (lat 30° S., long 90° W.), and (3) in the Tempe Terra region (lat 40° N., long 90° W.). Crater densities for the Noachian unit are similar to those for the Nectarian material on the Moon. The Noachian rocks are the oldest exposed on Mars and are found in the highest topographic areas, an outcrop that forms a geological ridge (centered at about lat 40° N., long 80° W.) along the northwest margin of the plateau appears to have been uplifted relative to the Tempe Terra highlands to the south. The Noachian rocks are also the most densely cratered and isolated peaks project well above the surrounding plains that are flooded and partly buried by lava flows. The basement complex of the Tempe Terra highlands (unit Nbd) is the oldest unit mapped in the western hemisphere. Noachian rocks are the most densely cratered and highly relief areas associated with the oldest exposed surfaces on Mars. Noachian rocks may be due partly to erosion of a formerly high regional surface, but it is also the result of structural uplift along normal faults that bound the Tempe Terra plateau. Noachian rocks are also exposed in the central and older fractured areas of the Thaumá Montes (unit Nbf) and Claritas Fossae (unit Nbc) highlands and in the Tempe Terra and Mareotis Fossae (unit Nbm) highlands (see Scott and Tanaka, 1980; Plescia and Saunders, 1982). These units probably consist mostly of impact breccia formed during early stages of high meteorite flux, similar to the cratae of the lunar highlands.

The southern highlands consist largely of the seven rock units of the plateau sequence. The highlands nearly encircle the Hellas Basin and are exposed in the Libya Montes, Malea Planum, Hesperia Planum, Noachis Terra, Terra Sirenum, Amenthes Rise, Xanthe, and Tempe Terra highlands (see Scott and Carr, 1978). The oldest rocks in the highlands are exposed in the Valles Marineris and Ny Nasei Valles. Some units in the sequence have clearly distinguishing morphologic characteristics, whereas others represent transitional stages in resurfacing of the highlands by lava flows and eolian and fluvial processes.

The hilly unit (unit Nplh) at the base of the plateau sequence forms a rough terrain of irregular peaks, ridges, and ancient crater rims exposed in the Thaumá Montes, Claritas Fossae, Tempe Terra, Mareotis Fossae, and Amenthes Rise highlands and in the Valles Marineris and Ny Nasei Valles. Some units in the sequence have clearly distinguishing morphologic characteristics, whereas others represent transitional stages in resurfacing of the highlands by lava flows and eolian and fluvial processes.

The rolling unit (unit Nplr) at the base of the plateau sequence forms a rough terrain of irregular peaks, ridges, and ancient crater rims exposed in the Thaumá Montes, Claritas Fossae, Tempe Terra, Mareotis Fossae, and Amenthes Rise highlands and in the Valles Marineris and Ny Nasei Valles. Some units in the sequence have clearly distinguishing morphologic characteristics, whereas others represent transitional stages in resurfacing of the highlands by lava flows and eolian and fluvial processes.

The smooth unit (unit Nps) forms a broad, relatively smooth surface that is commonly bounded by scarps and is commonly embayed by younger plains units. Some units in the sequence have clearly distinguishing morphologic characteristics, whereas others represent transitional stages in resurfacing of the highlands by lava flows and eolian and fluvial processes.

The knobby unit (unit Npk) forms a rough terrain of irregular peaks, ridges, and ancient crater rims exposed in the Thaumá Montes, Claritas Fossae, Tempe Terra, Mareotis Fossae, and Amenthes Rise highlands and in the Valles Marineris and Ny Nasei Valles. Some units in the sequence have clearly distinguishing morphologic characteristics, whereas others represent transitional stages in resurfacing of the highlands by lava flows and eolian and fluvial processes.

The ridged unit (unit Npr) forms a rough terrain of irregular peaks, ridges, and ancient crater rims exposed in the Thaumá Montes, Claritas Fossae, Tempe Terra, Mareotis Fossae, and Amenthes Rise highlands and in the Valles Marineris and Ny Nasei Valles. Some units in the sequence have clearly distinguishing morphologic characteristics, whereas others represent transitional stages in resurfacing of the highlands by lava flows and eolian and fluvial processes.

The rugged unit (unit Npu) forms a rough terrain of irregular peaks, ridges, and ancient crater rims exposed in the Thaumá Montes, Claritas Fossae, Tempe Terra, Mareotis Fossae, and Amenthes Rise highlands and in the Valles Marineris and Ny Nasei Valles. Some units in the sequence have clearly distinguishing morphologic characteristics, whereas others represent transitional stages in resurfacing of the highlands by lava flows and eolian and fluvial processes.

The Noachian System is subdivided into lower Noachian and upper Noachian series. The lower Noachian series is represented by the oldest exposed surfaces in the Thaumá Montes, Claritas Fossae, Tempe Terra, Mareotis Fossae, and Amenthes Rise highlands and in the Valles Marineris and Ny Nasei Valles. The upper Noachian series is represented by the younger exposed surfaces in the Thaumá Montes, Claritas Fossae, Tempe Terra, Mareotis Fossae, and Amenthes Rise highlands and in the Valles Marineris and Ny Nasei Valles.

Hesperian System

The Hesperian System records extensive evidence of volcanism, tectonism, and canyon and channel formation that is relatively unscathed by impact cratering and other severe degradation. Crater size-frequency distributions for pristine Hesperian surfaces closely follow a -2 power law for craters larger than about 2 km in diameter (Neukum and Wise, 1976). This relation allows comparison of crater ages determined for different Hesperian terrains. Deposition of the Hesperian materials was dominated by the widespread emplacement of lava flows and sediments that were derived from the highlands, particularly from Lunae Planum, where its western margin is buried by the lower member (unit Hel) of the Syria Planum Formation. It is also exposed in scattered patches around the south end of the Tharsis rise, forming a broad, low apron that extends into Amazonis Planitia. Northward of Ravnil Valles, a major volcanic unit, from the Tharsis volcanoes. Alternatively, Pinterson (1981) has ascribed the occurrence of layered deposits in Hebes Chasma (just north of Ophir Chasma) to the erosional remnants of a thick sedimentary deposit.

In the western hemisphere of Mars, the Hesperian System includes more than 400 km of rock units that are exposed in the Valles Marineris and Ny Nasei Valles. The Hesperian System is divided into lower Hesperian series and upper Hesperian series.

The Tharsis Montes Formation and its giant eruptive centers record the most voluminous outpouring of lava known on Mars and one of the largest sequences of lava flows on the inner planets. The lava flows are thinly spread across the broad, gently arched Tharsis swell, in the flanks of the Tharsis Montes, and in the Valles Marineris and Ny Nasei Valles. Topical and comparative studies (Greeley and others, 1978), compressional folding associated with the Tharsis swell (Wise and others, 1979; Watters and Maxwell, 1983), and regional subsidence (Carr and others, 1977) have contributed to the deformation of the lava flows.

Most development of the Valles Marineris canyon system and associated outflow channels and chaotic terrain occurred during the Hesperian Period, resulting in fault systems that trend mostly northeast to north but also radial to a sequence of centers that defined from Syria Planum to Noctis Labyrinthus (Masursky and others, 1977; Plescia and Saunders, 1979). Plescia and Saunders (1979) have shown that the Valles Marineris canyon system is a complex graben system that is bounded by normal faults and that the canyon floors are highly deformed. Numerous lava flows and sedimentary deposits are exposed in the canyon walls and floors. The most extensive lava flows were erupted from fissures that include Alba Patera, Syria Planum, and features on the Tempe Terra plateau.

As the structural history of the Martian highlands, wrinkle ridges similar in morphology to lunar mare ridges formed on smooth plains surfaces of Hesperian age; prominent occurrences include Solis, Felis, Sacra, and Xanthe Dorsa. The ridges trend northwest-southeast, are commonly sinuous, and have amplitudes of several hundred meters and lengths of several hundred kilometers. Some ridges are superposed on younger lava flows, indicating that they are among the youngest structural features. They may be either nearly parallel or normal to faults and linear depressions; some grade into large, linear edifices interpreted to be volcanoes. Thaumá Montes, Claritas Fossae, and Tempe Terra highlands are characterized by a complex pattern of fractures and fractured lava flow trends (Greeley and others, 1977), compressional folding associated with the Tharsis swell (Wise and others, 1979; Watters and Maxwell, 1983), and regional subsidence (Carr and others, 1977). Fractures are also common in the Valles Marineris.

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The Alba Patera Formation consists of six members. The oldest four (units Ahs1 to Ahs4) are eroded basaltic shield volcanoes and associated lava flows that are exposed in the Tempe Terra, Mareotis Fossae, Mareotis Tempe, and Alba Patera highlands and in the Acidalia Planitia, Arcadia Planitia, and Amazonis Planitia lowlands. The younger two members (units Ahf and Ahfs) are fan-shaped deposits that are exposed in the Acidalia Planitia and Arcadia Planitia lowlands.

The Olympus Mons Formation consists of six members. The oldest four (units Aop to Aos4) are eroded basaltic shield volcanoes and associated lava flows that are exposed in the Tharsis Montes, Olympus Mons, and Alba Patera highlands and in the Amazonis Planitia, Arcadia Planitia, and Acidalia Planitia lowlands. The younger two members (units Aof and Aofs) are fan-shaped deposits that are exposed in the Amazonis