U.S. DEPARTMENT OF THE INTERIOR
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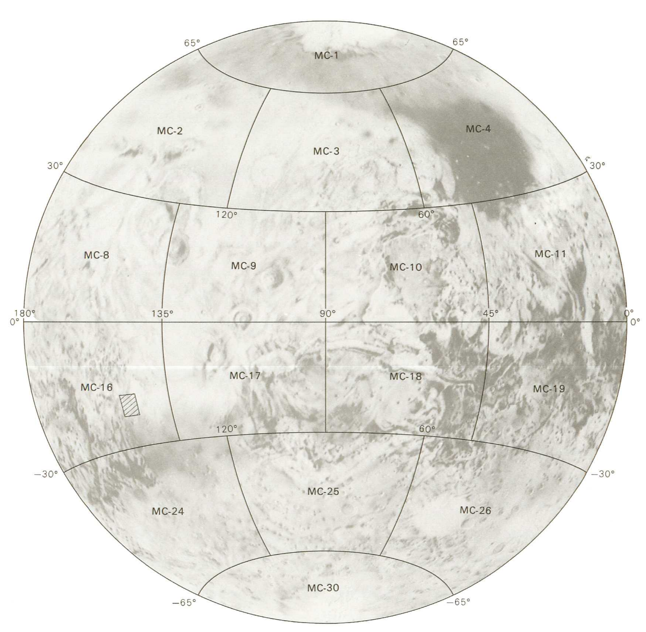
ATLAS OF MARS
1:500,000 GEOLOGIC SERIES
MANGALA VALLES REGION
-20/147 G, 1994
I-2310

SCALE 1:500 000 (1 mm = 500 m) AT 20° LONGITUDE
TRANSVERSE MERCATOR PROJECTION
KILOMETERS



QUADRANGLE LOCATION
Photomosaic location is shown in the western hemisphere of Mars. An outline of 1:5,000,000-scale quadrangles is provided for reference.

GEOLOGIC MAP OF THE MTM -20147 QUADRANGLE, MANGALA VALLES REGION OF MARS

By

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1994

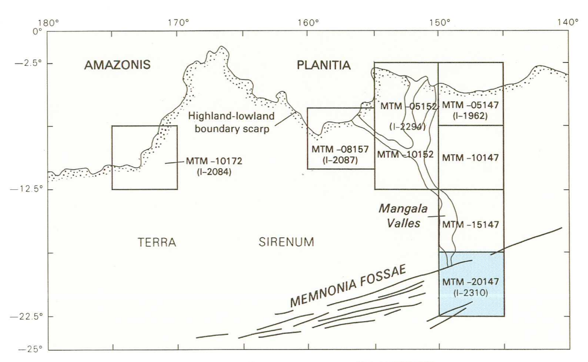
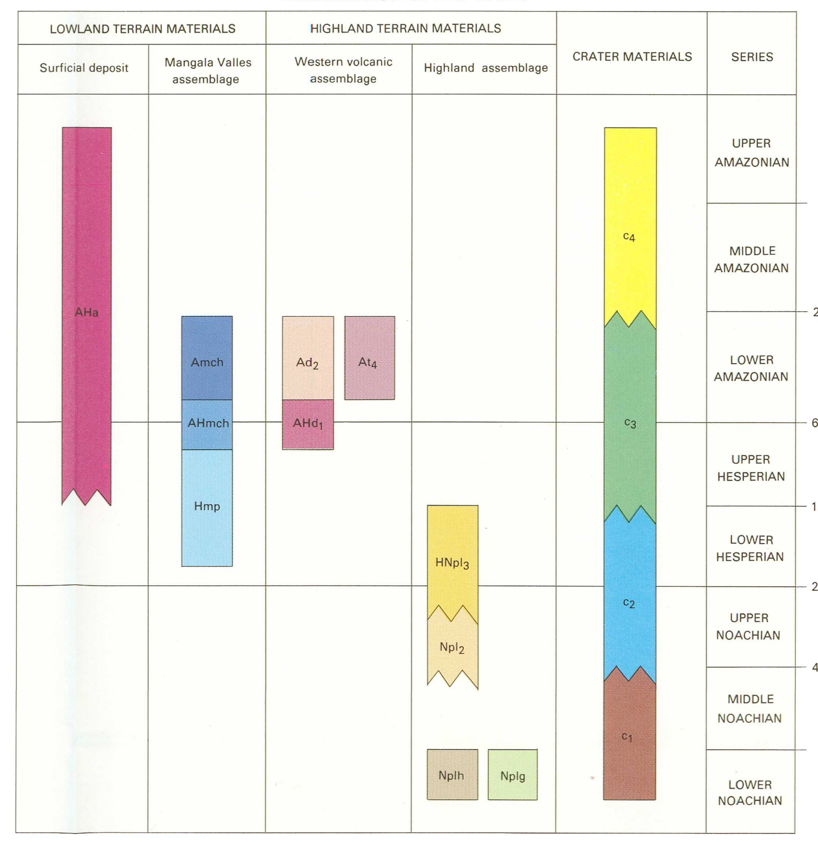


Figure 1. Index map showing major physiographic features and location of 1:500,000-scale maps in Mangala-Memnonia region completed and planned in Mars Geologic Mapping Program. Mars Transverse Mercator (MTM) numbers indicate latitude and longitude of center of maps. I- numbers indicate maps in press or published; such maps are included in References Cited. Large shield volcanoes of Tharsis Montes and Olympus Mons lie to northeast, directly east of quadrangle. Highland-lowland boundary from Scott and Tanaka (1986).

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSIT

AHa Apron-terrain material—Occurs along Memnonia Fossae as smooth, fan-shaped aprons that extend from south-facing walls; may be present along north-facing walls but is not seen due to limited emission angles at which available images were acquired. Occurrence at lat 18.40° S., long 149.15° appears to consist of several aprons that have coalesced; occurrence at lat 18.30° S., long 148.60° appears to be controlled by eroded crater material (unit c_1) at its base (Viking Orbiter image 637A82). *Interpretation:* Landslides caused by failure of weak unit(s) exposed along graben wall. Height of western occurrences may be controlled by thickness of subdued crater ejecta

MANGALA VALLES ASSEMBLAGE

Amch Younger channel material—Smooth, flat material that extends northward along Mangala Valles from lat 18.6° S., long 149.4°. Lateral extent controlled by smooth highland material (unit $HNpl_3$) to west and flood-plain material (unit Hmp) to east. Streamlined forms exist at lat 17.65° S., long 149.85°; other streamlined forms may be represented by slight changes in albedo (Viking Orbiter image 637A82). Subdivision of older channel material (unit Hch) of Scott and Tanaka (1986), but assigned younger age because of superposition relations and lack of craters greater than 2 km in diameter. *Interpretation:* Alluvial deposits from late-stage flooding of Mangala Valles, scoured floor with few or no alluvial deposits, or both

AHmch Older channel material—Subdivision of older channel material (unit Hch) of Scott and Tanaka (1986), but assigned younger age. (See text.) Forms isolated mesas within younger channel material. Many small knobs have streamlined shapes, some of which indicate flow direction other than what appears to be that of regional slope. Surface also exhibits subtle linear features too small to be resolved clearly but consistent in orientation with flow direction inferred from adjacent streamlined "islands." *Interpretation:* Alluvium from early flooding of Mangala Valles deposited on stoss side of obstructions, material sufficiently competent to withstand peak flood velocities, or both

Hmp Flood-plain material—Subdivision of Scott and Tanaka's (1986) flood-plain material (unit Hchp). Forms broad, planar area east of younger and older channel units and west of hilly highland material. Partly fills large crater truncated by valley at lat 18.4° S., long 148.5° and buries small local graben at lat 19.3° S., long 148.55° (Viking Orbiter image 637A82). Margin of northern occurrence is lobate and stands in relief above younger channel material. Streamlined features within 10 km of lobate margin are normal to flood-plain margin rather than oriented toward source of Mangala floods. Texture of flood-plain material is smooth at all scales down to 46 m/pixel resolution. *Interpretation:* Alluvial fill, perhaps capped by lava flows (suggested by lobate pattern of some margins and greater resistance to erosion than other channel materials); associated with earliest and most widespread flood

WESTERN VOLCANIC ASSEMBLAGE

Ad2 Daedalia Planum material, unit 2—Broad, smooth material of uniform albedo separated from Daedalia Planum material, unit 1 by east- and south-facing lobate scarps. Contains several sets of discontinuous lobate scarps, most of which extend southeast from lat 17.8° S., long 146.6° in map area. Embays highland materials and craters to west. Lineated patches of low-albedo streaks in some areas. Stratigraphic relations and crater statistics indicate Early Amazonian age. *Interpretation:* Late-stage volcanic flood lavas erupted from fissures associated with formation of Memnonia Fossae and possibly Mangala Valles. Material appears to have erupted from fissure extending from source graben of Mangala Valles

At4 Tharsis Montes Formation, member 4 (Scott and Tanaka, 1986)—Consists of overlapping light-colored flows with dark wind streaks. Flows are elongate on steep upper slopes, broad on gentler lower slopes. Only a small occurrence in northeast corner of map area. *Interpretation:* Early flood eruptions associated with formation of Arsia Mons

AHd1 Daedalia Planum material, unit 1—Subdivision of Scott and Tanaka's (1986) member 3 of Tharsis Montes Formation (unit AHt_3). Exposures are smooth, containing many discontinuous lobate scarps; grades to east and northeast outside map area into narrow lobate occurrences. Embays highland materials to west. Contains extensive low-albedo patches east of map area. *Interpretation:* Volcanic flood eruptions associated with isostatic adjustment of deep-seated faults from Daedalia basin (Craddock and others, 1990), flood eruptions from formation of Tharsis Montes, or possibly fissure eruptions associated with Memnonia Fossae

HIGHLAND ASSEMBLAGE

HNpl3 Smooth unit—Corresponds to smooth unit of plateau sequence (unit Npl_3) of Scott and Tanaka (1986), but crater size-frequency data (table 1, fig. 2) indicate age is in part Noachian. Sparsely cratered, generally flat unit occurring chiefly in low-lying areas in southwestern part of map area; moderate to high albedo; contains scarps that are subdued to sharp and well defined. Covers or embays floors of some craters. Typical locality: lat 21.0° S., long 149.0° (Viking Orbiter image 637A81). *Interpretation:* Thin deposits of eolian or fluvial origin formed concurrently with faulting

Npl2 Subdued unit (Scott and Tanaka, 1986)—Gently undulatory, sparsely cratered unit containing some subdued lineations; stands at higher elevation than surrounding volcanic units. *Interpretation:* Thin lava flows, eolian deposits, or deposits derived from erosion of surrounding units that mantle remnants of ancient highland crust

Nplh Hilly unit (Scott and Tanaka, 1986)—Rugged, undulatory upland unit; heavily cratered, embayed in places by volcanic materials. Small blocks occur throughout map area. *Interpretation:* Ancient crustal material consisting of volcanic flows and ejecta from local and distant craters. Small blocks at lat 18.4° S., long 149.2° may be erosional remnants resistant to floods. Block at lat 18.7° S., long 148.0° may be ejecta materials, or may be uplifted crust along fault trending north at about long 148.38°

Nplg Grooved unit—Moderately rugged upland unit with many parallel to subparallel, narrow troughs oriented generally northwest; embayed in places by volcanic materials. Type locality: lat 21.5° S., long 145.4° (Viking Orbiter image 637A84). *Interpretation:* Ancient crustal materials scoured by large impact basin. Groove orientation suggests basin centered in Daedalia Planum at lat 26.0° S., long 125.0° (Craddock and others, 1990). Mass wasting may have eroded grooves on steep slopes

CRATER MATERIALS

[All crater materials are interpreted to be of impact origin. A four-fold classification system, based on crater degradation, is employed (except for craters less than 5 km across, see below). Craters range in age from c_1 (oldest) to c_4 (youngest). The c_1 craters are characterized as extremely degraded rim and central peak deposits and are of Noachian age; c_2 craters, of Hesperian and Noachian age, have degraded deposits but are superposed on c_1 crater materials. The ejecta deposits of both c_1 and c_2 craters are eroded or are buried by younger materials; c_3 craters, considered Amazonian and Hesperian in age, have extensive preserved ejecta deposits and relatively sharp rim crests. Craters mapped as c_4 are considered Amazonian in age; they are the freshest craters, have sharp rim crests and extensive ejecta deposits, and are superposed on c_3 craters and all other materials. To avoid uneven portrayal, craters less than 5 km in diameter were not mapped. Craters less than 5 km in diameter are assumed to be relatively young; however, because of the limited resolution of available photography (typically about 270 m/pixel), the morphologic characteristics necessary for determining the age of craters 2 to 5 km in diameter cannot be seen. These small craters are colored the same as the materials on which they occur]

c4 Crater material, fresh—Sharp rim crests. Contains small, irregular central peaks in center of crater floors. Ejecta smooth to undulatory, consists of overlapping, discontinuous lobes concentric to crater center; lobes typically become less extensive toward crater rim. Superposed on all other materials. *Interpretation:* Material from young impacts. May have been deposited as fluidized flow due to presence of an atmosphere or due to incorporation of subsurface volatiles during emplacement

c3 Crater material, subdued—Relatively sharp rim crests. Contains small, irregular central peaks in center of crater floors. Ejecta are hilly, undulatory, rarely lobate, and irregularly centered. Ejecta centered at lat 19.0° S., long 149.4° are dissected by channels and appear to be embayed by smooth highland material; unit possibly caps blocks in Memnonia Fossae. Unit at lat 22.50° S., long 147.65° is partly embayed by Daedalia Planum material, unit 1 (Viking Orbiter images 637A81 and 639A13). Unit at lat 21.35° S., long 148.80° appears to be embayed by smooth highland material (Viking Orbiter image 637A81). *Interpretation:* Impact crater material modified by erosion and embayed by younger units

c2 Crater material, degraded—Continuous crater rims with isolated, small, irregular central peaks on crater floors. *Interpretation:* Erosionally resistant impact crater material

c1 Crater material, eroded—Hilly, undulatory, discontinuous forming rim of highly degraded crater; embayed by channel and plains materials and buried by other crater units. Forms one large, irregular hill on floor of eroded crater at lat 18.95° S., long 148.20° (Viking Orbiter image 637A82). *Interpretation:* Erosionally resistant rims and central peaks of ancient impact craters that have been highly modified. Unit typically resembles hilly highland material (unit Nplh); the two units are roughly the same age

Contact—Dashed where approximately located

Fault or narrow graben—Dashed where partly buried; ball on downthrown side of fault

Lobate scarp—Interpreted as volcanic flow front. Ticks in flow direction; dashed where uncertain or partly buried

Ridge—Interpreted as fold or thrust-fault structure

Groove

Crater rim crest—Dotted where buried

Eroded crater rim crest—Dotted where buried

Small crater rim crest—Age not determined

Crater central peak

INTRODUCTION

This map is one in a series of 1:500,000-scale geologic maps prepared to investigate areas on Mars of high scientific interest. The quadrangle contains the source area for Mangala Valles, one of the largest outflow channel complexes on Mars (Sharp and Malin, 1975). Preliminary mapping by Masursky and others (1986), Zimbelman (1988), and Chapman and others (1989, 1991) showed that several episodes of channel formation and deposition may have occurred in association with Mangala Valles. To elucidate the complex history of Mangala Valles and the general geology of the area surrounding their source, detailed photogeology of the MTM -20147 quadrangle is presented here.

The area has been studied previously through reconnaissance photogeologic mapping. Using Mariner 9 data, Mutch and Morris (1979) derived a 1:5,000,000-scale geologic map of the Memnonia quadrangle and recognized six units within the MTM -20147 quadrangle. These units include three cratered plains units, smooth plains material, mountain material, and materials associated with Mangala Valles. At 1:2,000,000 scale, Scott and Schaber (1981) and Scott and others (1981) simplified the geology within the quadrangle by recognizing only four units: a lava flow from Arsia Mons, ridged plains material, a cratered plains unit, and a deposit from Mangala Valles. More recently, at 1:15,000,000 scale, Scott and Tanaka (1986) recognized two lava flows from Arsia Mons, three ancient cratered (terra) materials, a smooth plains unit, and two separate deposits from Mangala Valles.

Our map was compiled by analysis of Viking Orbiter images (average image resolution of ~270 m/pixel) supplemented by the study of two adjacent quadrangles to the north (MTM -20147 and MTM -15147; fig. 1) and pertinent Mariner 9 images. We used conventional planetary photogeologic mapping techniques (Wilhelms, 1972). We also drew upon results from the Viking infrared thermal mapper (IRTM) to assess the physical properties of surficial materials (Craddock and others, 1987).

PHYSIOGRAPHY

The quadrangle includes part of the boundary separating the old, densely cratered Martian highlands typical of the southern hemisphere from the plains materials originating near the Tharsis Montes to the northeast. The Terra Sirenum highlands within the map area are characterized as rugged, heavily cratered terrains, which have been modified by a wide variety of processes including eolian and fluvial activity. In places, the highlands consist of widespread plateaus. The plateaus and the highlands are cut by a series of east-trending graben of the Memnonia Fossae (fig. 1). The large, primary channel of the Mangala Valles complex appears to have originated from a breach in one such graben centered at about lat 18.5° S., long 149.5°. The main channel continues northward for about 850 km until it separates into smaller channels that debouched into Amazonis Planitia. The eastern part of the quadrangle includes part of the vast lava plains of Daedalia Planum in the Tharsis region. One of the large Tharsis Montes volcanoes, Arsia Mons, is about 1,700 km northeast of the map area.

STRATIGRAPHY

A formal stratigraphy for Mars was presented by Scott and Carr (1978) as part of their 1:25,000,000-scale geologic map. Three stratigraphic systems, the Noachian, the Hesperian, and the Amazonian, were named from regions containing representative, widespread exposures of the materials and as referents. These systems were further subdivided by Tanaka (1986) and applied to the 1:15,000,000-scale map of the western hemisphere of Mars (Scott and Tanaka, 1986). The geologic units derived by Scott and Tanaka (1986) provide the stratigraphic framework for the present map.

NOACHIAN SYSTEM

The oldest recognized geologic units in the map area are highland materials, which consist of the hilly (unit Nplh), grooved (unit Nplg), subdued (unit Npl_2), and smooth (unit $HNpl_3$) units. These materials are a subdivision of Scott and Tanaka's (1986) plateau and high-plains assemblage. The hilly unit has rugged, undulatory surfaces and contains many impact craters, most of which are extremely eroded. Grooves in the grooved unit may be impact features somewhat analogous to Imbrium sculpture on the Moon. Their orientation on Mars suggests an origin from a postulated buried impact structure centered at lat 26.0° S., long 125.0°, southeast of the map area (Craddock and others, 1990). Downslope mass movement has modified and enlarged the grooves in some areas. These two units are interpreted to be ancient materials composed of volcanic flows and uplifted crustal rocks.

Subdued highland material (unit Npl_2) has a gently undulatory surface and sparse craters, many of which are heavily eroded or partly buried. This unit is interpreted as a highland material mantled by thin lava flows, eolian deposits, or deposits eroded from surrounding, topographically higher highland materials.

Smooth highland material (unit $HNpl_3$) is characterized by a lack of relief and is present chiefly in low-lying areas (Zimbelman, 1989). The unit is sparsely cratered, has moderate to high albedo, contains subdued lobe fronts and crater rims, and is superposed on some faults and crosscut by others. These observations suggest that the unit is an eolian mantle, fluvial material deposited concurrently with the faulting, or a series of thin lava flows possibly erupted in association with the formation of the Memnonia Fossae. The unit has about the same age as the plains material of the Mangala Valles assemblage (described below), perhaps suggesting a relation between the smooth material and the formation of Mangala Valles (fig. 2).

HESPERIAN AND AMAZONIAN SYSTEMS

Hesperian and Amazonian channel materials include flood-plain material (unit Hmp) and older and younger channel materials associated with Mangala Valles (units AHmch, Amch). Volcanic materials constitute the remaining principal units in the map area (units AHd_1, At_4, and Ad_2). Because of their many streamlined features, Mangala Valles are thought to be the result of catastrophic flooding (Milton, 1973; Baker and Milton, 1974; Sharp and Malin, 1975). Masursky and others (1986) suggested that Mangala Valles are the result of multiple episodes of channel formation, but only two episodes, or stages, of flooding are represented in the map area. The first stage, forming the flood-plain material (unit Hmp), was much more widespread than the second and appears to have completely flooded the inferred source graben. A channel breached the source graben wall and flooded a large crater at lat 18.4° S., long 148.5°, partly filling it with plains material. The older channel material (unit AHmch) may have been deposited on the stoss side of craters and other features of positive relief as flood velocities subsided. The younger channel material (unit Amch) was emplaced by subsequent flooding that appears to have been confined to a small section of the source graben and is represented by the deepest part of the channel. An Amazonian age is inferred for this unit because of the lack of craters greater than 2 km in diameter; however, the small areal extent of the units may result in misleading crater counts. Mangala Valles may have formed in a single, catastrophic event that became more confined with time. The youngest unit of the assemblage may represent substantial erosion associated with higher flood velocities in the middle of the channel or tapering velocities in floods that covered the lowest lying surfaces.

The oldest of the three volcanic units is unit 1 of the Daedalia Planum material (unit AHd_1), which corresponds to member 3 of the Tharsis Montes Formation mapped by Scott and Tanaka (1986). Unit 1 consists of broad, smooth materials of uniform albedo. This unit contains several sets of discontinuous lobate scarps in the map area. The most likely interpretation of its origin is that it represents late-stage, mare-style volcanism that infilled the Daedalia basin (Craddock and others, 1989, 1990).

Unit 2 of the Daedalia Planum material (unit Ad_2) is separated from unit 1 by east-facing lobate scarps. The two Daedalia Planum units resemble each other morphologically; however, the lobate scarps associated with unit 2 appear to originate near lat 17.8° S., long 146.6° from an extension of the Mangala Valles source graben, now partly covered by volcanic materials. Although these materials may be flood lavas that ponded next to the highland boundary, unit 2 may have formed from eruptions associated with the formation of Mangala Valles. If so, the association is evidence for the correlation of volcanic activity and the formation of Martian outflow channels, as suggested by McCauley and others (1972) and Masursky and others (1977). Figure 3 shows the crater size-frequency curves for the two Daedalia Planum units and supports the age designations for these materials (table 1). A crossover of curves at crater diameters larger than 4 km suggests that craters larger than this diameter were not buried by unit 2. According to the rim-height equation for Martian craters (Pike and Davis, 1984), the thickness needed to bury a 4-km-diameter crater is about 145 m. Because 4-km-diameter craters are apparently not buried, unit 2 is probably about 100 m thick. Its surface area of approximately 5,300 km^2 (table 1) yields an eruption volume of about 530 km^3, which is comparable with most of the eruption volumes composing the Saddle Mountain or Wanapum Basalts of the Columbia Plateau (Tolan and others, 1989).

A small exposure of the Tharsis Montes Formation, member 4 (unit At_4) occurs near the northeast corner of the map area and is characterized by a mottled appearance and lobate scarps. This unit is interpreted to represent a change in volcanic styles associated with the formation of the Tharsis Montes/Daedalia basin infilling: early flood eruptions evolved to more channelized flows (Hawaiian-style eruptions), characterized by possible leveed channels northeast of the map area.

The remaining unit of Amazonian-Hesperian age is apron material (unit AHa), which occurs along the south wall of the Mangala Valles source graben as smooth, fan-shaped aprons. Although a crater-retention age cannot be determined because of its small extent, its relative age is inferred from superposition relations. The height of the western occurrences appears to be controlled by the thickness of the subdued crater material centered at lat 19.0° S., long 149.4°. The apron material is interpreted to be landslides caused by failure of one or more weak units exposed along the source-graben wall after channel formation.

Surficial materials, such as thin mantles of windblown sediments, are not mapped. However, the occurrence of streaks and other albedo patterns associated with topography suggests the presence of dust that is subject to present winds. In addition, high-resolution Viking IRTM data show low thermal-inertia values near the source area of Mangala Valles, suggesting the presence of a thin veneer of windblown dust. Rock abundances derived through Christensen's (1982) model show that greater than 15 percent of the exposed surface material is composed of material effectively 15 cm in diameter, which suggests that brecciated materials possibly related to channel formation are present in the source graben (Craddock and others, 1987).

STRUCTURE

Faults of the Memnonia Fossae system are widespread in the map area and are part of the tectonic pattern radial to the Tharsis rise (Wise and others, 1979). Two orientations of faults in the Memnonia region have been recognized by Plescia and Saunders (1982). Through structural analysis, they demonstrated that faults oriented N. 60°–70° E. are radial to a center near Pavonis Mons (lat 1° N.; long 113°), whereas faults oriented N. 75°–80° E. are radial to a center in Syria Planum (lat 1°–20° S., long 97°-112°; Plescia and Saunders, 1982). Both sets of faults are contemporaneous with the emplacement of the subdued and the smooth units of the highland assemblage, as indicated by crosscutting relations.

By comparing geologic maps with Earth-based radar data, several north-oriented faults within Noachian highland materials have been identified (Zimbelman, 1988, 1989); the vertical relief of their scarps ranges from 500 to 2,500 m. These faults are not related to Tharsis principal stresses (Schultz, 1985). Thermal stresses related to a cooling lithosphere have been suggested as their cause (Schultz, 1985; Zimbelman, 1988); however, compressional features such as wrinkle ridges are commonly associated with them (Craddock and others, 1989). The faults are also approximately concentric to a proposed Noachian impact basin in Daedalia Planum and may be related to an extended ring system for that basin (Craddock and others, 1990). The compressional features suggest that zones of weakness caused by the impact were reactivated during isostatic rebound following basin formation or crustal loading from mare-style volcanism (Craddock and others, 1989) represented by unit 1 of the Daedalia Planum material and member 4 of the Tharsis Montes Formation. An irregular crater about 10 km across occurs in the former at lat 21.2° S., long 146.6° at the end of a Memnonia Fossae graben; the crater may be a volcano-tectonic depression formed by collapse in association with the development of the graben and extrusion of volcanic materials.

GEOLOGIC HISTORY

From an assessment of the physiography, stratigraphic relations, and structural features observed in the map area, the following geologic history can be derived.

1. Early Noachian—Intense impact cratering and deformation of basement rocks; intense brecciation by impact; formation of large impact basin in Daedalia Planum, the ejecta of which produced the grooved highland unit (Nplg). North-trending faults result from the cooling lithosphere or the formation of the Daedalia basin.
2. Middle to Late Noachian—Terminal stages of heavy bombardment continued to fracture and brecciate ancient crust. Erosion of the uplands by wind and water to produce mantling deposits of the subdued highland unit.
3. Hesperian—Massive crustal deformation associated with the early stages of formation of the Tharsis plateau (fig. 1) produced northeast-trending faults in the highland plateau sequence of the Memnonia Fossae system. Eruption of lavas and continued degradation of older rocks by wind and water led to the emplacement of the smooth highland unit.
4. Late Hesperian-Early Amazonian—Release of water from the brecciated megaregolith of the highlands produced Mangala Valles; their source was associated with a graben whose formation may have triggered the release of water. Water release may have been episodic; two stages of flooding are recorded in the map area. Flood eruption of fluid lavas emplaced flows in western Daedalia Planum; vent areas were subsequently buried.
5. Amazonian—Late eruptions of flood lavas, possibly from local fissure vents associated with Memnonia Fossae.
6. Late Amazonian—Modification of the surface by the formation of debris aprons on steep slopes and by eolian processes to produce wind streaks and other albedo patterns.

REFERENCES CITED

Baker, V.R., and Milton, D.J., 1974, Erosion by catastrophic floods on Mars and Earth: Icarus, v. 23, no. 1, p. 27–41.
Chapman, M.G., Masursky, Harold, and Dial, A.L., Jr., 1989, Geologic maps of Science Study Site 1A, east Mangala Valles, Mars [MTM -05147]: U.S. Geological Survey Miscellaneous Investigations Series Map I–1962, scale 1:500,000.
______1991, Geologic map of Science Study Area 1B, west Mangala Valles region of Mars [special MTM -08157 quadrangle]: U.S. Geological Survey Miscellaneous Investigations Series Map I–2087, scale 1:500,000.
Chapman, M.G., and Tanaka, K.T., in press, Geologic map of the MTM -05152 and -10152 quadrangles, Mangala Valles region of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–2294, scale 1:500,000.
Christensen, P.R., 1982, Martian dust mantling and surface composition: Interpretation of thermophysical properties: Journal of Geophysical Research, v. 87, no. B12, p. 9985–9998.
Craddock, R.A., Greeley, Ronald, and Christensen, P.R., 1987, Martian outflow channels, IRTM and visual observations, *in* Abstracts of papers submitted to the Eighteenth Lunar and Planetary Science Conference, part 1, Houston, March 16–20, 1987: Houston, Lunar and Planetary Institute, p. 203–204.
______1990, Evidence for an ancient impact basin in Daedalia Planum, Mars: Journal of Geophysical Research, v. 95, no. B7, p. 10,729–10,741.
Craddock, R.A., Zimbelman, J.R., and Watters, T.R., 1989, Normal faulting associated with the Daedalia impact basin, Mars, *in* Abstracts for the MEVTV-LPI Workshop, Tectonic features on Mars, Richland, Washington, 1989: Houston, Lunar and Planetary Institute, Technical Report Number 89–06, p. 18–20.
Masurksy, Harold, Boyce, Joseph, Dial, A.L., Jr., Schaber, G.G., and Strobell, M.E., 1977, Classification and time of formation of martian channels based on Viking data: Journal of Geophysical Research, v. 82, no. 28, p. 4016–4038.
Masursky, Harold, Chapman, M.G., Dial, A.L., Jr., and Strobell, M.E., 1986, Ages of rocks and channels in prospective martian landing sites of Mangala Valles region, *in* Abstracts of papers submitted to the Seventeenth Lunar and Planetary Science Conference, part 1, Houston, March 17–21, 1986: Houston, Lunar and Planetary Institute, p. 520–521.
McCauley, J.F., Carr, M.H., Cutts, J.A., Hartmann, W.K., Masursky, Harold, Milton, D.J., Sharp, R.P., and Wilhelms, D.E., 1972, Preliminary Mariner 9 report on the geology of Mars: Icarus, v. 17, no. 2, p. 289–327.
Milton, D.J., 1973, Water and processes of degradation in the martian landscape: Journal of Geophysical Research, v. 78, no. 20, p. 4037–4047.
Mutch, T.A., and Morris, E.C., 1979, Geologic map of the Memnonia quadrangle of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1137, scale 1:5,000,000.
Pike, R.J., and Davis, P.A., 1984, Toward a topographic model of martian craters from photoclinometry, *in* Abstracts of papers submitted to the Fifteenth Lunar and Planetary Science Conference, part 2, Houston, March 12–16, 1984: Houston, Lunar and Planetary Institute, p. 645–646.
Plescia, J.B., and Saunders, R.S., 1982, Tectonic history of the Tharsis region, Mars: Journal of Geophysical Research, v. 87, no. B12, p. 9775–9791.
Schultz, R.A., 1985, Assessment of global and regional tectonic models for faulting in the ancient terrains of Mars: Journal of Geophysical Research, v. 90, no. B9, p. 7849–7860.
Scott, D.H., and Carr, M.H., 1978, Geologic map of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1083, scale 1:25,000,000.
Scott, D.H., and Chapman, M.G., 1990, Geologic map of Science Study Area 6, Memnonia region of Mars [MTM -10172]: U.S. Geological Survey Miscellaneous Investigations Series Map I–2084, scale 1:500,000.
Scott, D.H., and Schaber, G.G., 1981, Map showing lava flows in the northeast part of the Memnonia quadrangle of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1270, scale 1:2,000,000.
Scott, D.H., Schaber, G.G., Horstman, K.C., and Dial, A.L., Jr., 1981, Map showing lava flows in the southeast part of the Memnonia quadrangle of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1271, scale 1:2,000,000.
Scott, D.H., and Tanaka, K.L., 1986, Geologic map of the western equatorial region of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1802–A, scale 1:15,000,000.
Sharp, R.P., and Malin, M.C., 1975, Channels on Mars: Geological Society of America Bulletin, v. 86, no. 5, p. 593–609.
Tanaka, K.L., 1986, The stratigraphy of Mars: Journal of Geophysical Research, v. 91, no. B13, p. E139–E158.
Tolan, T.L., Reidel, S.P., Beeson, M.H., Anderson, J.L., Fecht, K.R., and Swanson, D.A., 1989, Revisions to the estimates of the areal extent and volume of the Columbia River Basalt Group, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 1–20.
U.S. Geological Survey, 1985, Shaded relief maps of the eastern, western, and polar regions of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1618, scale 1:15,000,000.
Wilhelms, D.E., 1972, Geologic mapping of the second planet: U.S. Geological Survey Interagency Report, Astrogeology 55, 36 p.
Wise, D.U., Golombek, M.P., and McGill, G.E., 1979, Tharsis province of Mars: Geologic sequence, geometry, and a deformation mechanism: Icarus, v. 38, no. 3, p. 456–472.
Zimbelman, J.R., 1988, Preliminary geologic mapping in the Memnonia region of Mars [abs.], *in* Reports of the Planetary Geology and Geophysics Program, National Aeronautics and Space Administration Technical Memorandum 4041, p. 541–543.
______1989, Geologic mapping of southern Mangala Valles, Mars, *in* Abstracts of papers submitted to the Twentieth Lunar and Planetary Science Conference, part 3, Houston, March 13–17, 1989: Houston, Lunar and Planetary Institute, p. 1239–1240.

Table 1. *Crater-frequency distributions for major geologic units within MTM -20147 quadrangle*

Unit	Area (km^2)	Number of craters	N[2][1]	N[5][1]	System[2]
Daedalia Planum material, unit 2	5,314	30	322±132	---	Amazonian
Daedalia Planum material, unit 1	22,167	56	450±142	~20	Amazonian/Hesperian
Flood-plain material[3]	16,909	82	460±130	150±60	Hesperian
Smooth highland material	19,873	46	775±195	288±129	Hesperian/Noachian
Subdued, hilly, and grooved highland materials	29,931	104	1937±254	735±157	Noachian

[1]N = number of craters greater than [x] km diameter/10^6 km^2.
[2]Crater-density boundaries from Tanaka (1986).
[3]Data include craters in MTM -15147 quadrangle (Zimbelman and others, work in progress, 1991).

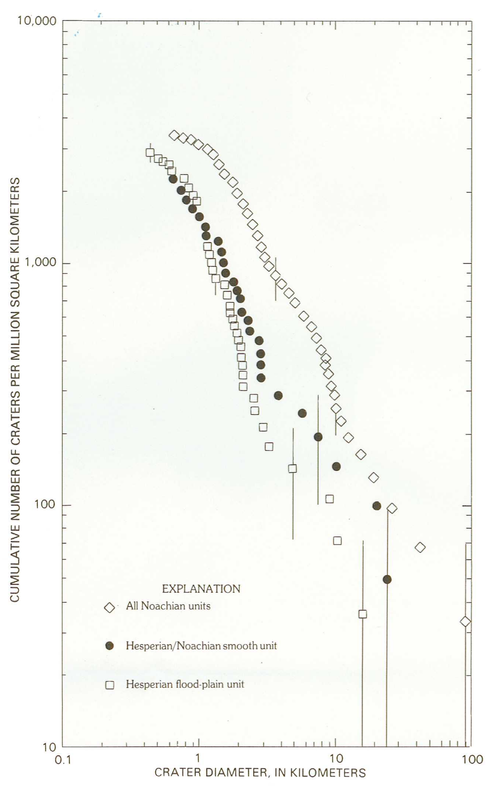


Figure 2. Log-log cumulative crater size-frequency curves for major units in map area other than units of western volcanic assemblage. Noachian hilly, grooved, and subdued cratered materials (units Nplh, Nplg, and Npl_2, respectively) are grouped together to make counting area statistically significant. Curve for plains material was calculated using additional data from MTM -15147 quadrangle (Zimbelman and others, work in progress, 1991). One-sigma error bars are proportional to cumulative number of craters observed for a specified diameter.

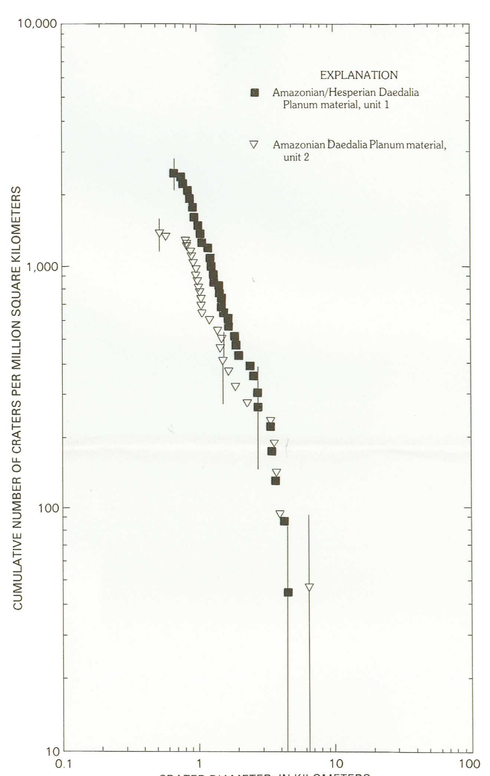


Figure 3. Log-log cumulative crater size-frequency curves for Daedalia Planum units in map area. Although crater-frequency distribution of unit 2 (N[2]=322±132, table 1) is based on small areal extent, this value and stratigraphic relations suggest an Early Amazonian age for unit. Crossover of curves at crater diameters of 4 km indicates that these materials are about 100 m thick. Crater-frequency distributions of N[2]= 450±142 and N[5]~20 (table 1) indicate a Late Hesperian and Early Amazonian age for unit 1, the same age determined by Scott and Tanaka (1986). One-sigma error bars are proportional to cumulative number of craters observed for a specified diameter.