ATLAS OF MARS
1:500,000 GEOLOGIC SERIES
MANGALA VALLES REGION
M 500k −15/147 G, 1994
I–2402

Base from U.S. Geological Survey (1985)

SCALE 1:502 000 (1 mm=502 m) AT 150° LONGITUDE
TRANSVERSE MERCATOR PROJECTION
10 0 10 20 30 40 50 60 70 80 90 100
KILOMETERS

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1994

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INTRODUCTION

The map area is in the Mangala-Memnonia region (fig. 1), which contains remarkably diverse geologic features and terrain types. Studies of the Mariner 9 images revealed the wide range of ages of the major rock units in this region; age assignments were based on the density of impact craters preserved on the various surfaces (Mutch and others, 1976, p. 56–60; Scott and Carr, 1978; Mutch and Morris, 1979). The region includes ancient cratered highlands, more sparsely cratered smooth plains, young volcanic plains, and the Mangala Valles channel system. The sinuosity of the streamlined landforms within the Mangala Valles, combined with braided channels evident throughout the lower reaches of the valley system, were recognized as indicators that the Mangala area was subject to substantial erosion by a flowing fluid, most likely water (Milton, 1973; Baker and Milton, 1974; Sharp and Malin, 1975). Recent global mapping based on the Viking Orbiter images (Scott and Tanaka, 1986) has refined the relative ages of many rock units on Mars, but it has modified only slightly the basic interpretations of features in the Mangala-Memnonia region.

Some map units are partly equivalent to units on smaller scale maps (Scott and Carr, 1978; Mutch and Morris, 1979; Scott and Tanaka, 1986), and the formal terminology of Scott and Tanaka (1986) and Tanaka (1986) was followed where feasible. The mapped relations have implications for the tectonic history of the Mangala-Memnonia region as well as for the processes of storage and release of volatiles that led to the erosion and deposition evident within the Mangala Valles system. The map units are consistent with units on the other 1:500,000-scale geologic maps shown in figure 1 except where noted in the text and unit descriptions.

Image resolution within the map area ranges from 44 m/pixel for the main channel of Mangala Valles to 250 m/pixel for most of the rugged highlands and lobate plains materials.

PHYSIOGRAPHIC SETTING

The map area includes part of the southern reaches of the Mangala Valles channel system, which is southwest of the Tharsis Montes and south of Amazonis Planitia (fig. 1). The Mangala-Memnonia region is crossed by series of northeast-trending grabens (Memnonia Fossae) that are approximately radial to the crustal bulge associated with the Tharsis Montes. The general elevation of the region ranges from 2 to 4 km above the Mars datum, corresponding to the 6.1-mbar level in the atmosphere (U.S. Geological Survey, 1976). The southern reaches of Mangala Valles are in densely cratered plains typical of the southern highlands of Mars, and relatively young plains resulting from Tharsis volcanism are present in the eastern part of the map area (Scott and Carr, 1978; Scott and Tanaka, 1986).

The regional setting of the map area is evident when the area is considered together with areas adjacent to the north and south (fig. 2). The map area includes part of the boundary between the plains originating near Tharsis and the cratered highlands of the southern hemisphere; this boundary runs approximately north-south through the quadrangle. The main channel of the Mangala Valles heads at a breach (lat 18.5° S., long 149.5°) in the north wall of one of the largest grabens of the Memnonia Fossae, which is interpreted to be the source of the Mangala Valles floods (Sharp and Malin, 1975; Carr, 1981, p. 148). The Mangala Valles are good examples of outflow channels where episodic overflow may have breached a topographic barrier that held a large lake, which in turn led to catastrophic outflow (Sharp and Malin, 1975). A terrestrial outflow system in the channeled scablands of the Pacific Northwest produced the Spokane Flood, which left distinctive drainage and erosional patterns (Baker and Milton, 1974; Baker, 1982, p. 140–160) much like the features visible in the Mangala Valles.

STRATIGRAPHY

NOACHIAN SYSTEM

The oldest materials exposed within the map area are four units defined by Scott and Tanaka (1986): the mountainous material (unit **Nplm**) and the hilly (unit **Nplh**), cratered (unit **Npl$_1$**), and subdued cratered (unit **Npl$_2$**) units of their plateau sequence. The mountainous and hilly materials are degraded and contain many rounded hills and shallow depressions, so that their appearance contrasts with the uniform appearance of the surrounding plains units. The mountainous material has many small channels or gullies oriented dominantly east-west on the west slopes of topographic highs. The hilly material forms subdued planar areas and isolated ridges and knobs. Portions of highland materials mapped as the subdued cratered unit of the plateau sequence by Scott and Tanaka (1986) were mapped here as the hilly unit of the plateau sequence due to their similarities with exposures of the hilly unit in surrounding areas. Both mountainous and hilly units have a wide range of roughness and reflectivity values at radar wavelengths, which is consistent with their extensively eroded topographic highs (Mouginis-Mark and others, 1980). The crater densities of the two units are similar (table 1) and therefore are combined in figure 3.

The cratered unit of the plateau sequence is not well exposed in the map area, but it contains several craters whose morphology is subdued, most notably those having almost no relief exterior to their rims (c$_2$ craters). These craters are found only in Noachian materials within the map area and therefore may result from an ancient resurfacing event identified in the Amenthes and Tyrrhena regions (Craddock and Maxwell, 1990). The higher crater density of the unit compared with densities of older materials within the map area (table 1) may be misleading; the small extent of the unit's exposures gives only a limited statistical base. Contact relations in the map area and in the MTM −10147 quadrangle to the north (fig. 2) indicate that the cratered materials are superposed on the hilly unit, consistent with the regional mapping of Scott and Tanaka (1986). The subdued cratered material occurs only as small, isolated patches in and around older craters on the Noachian materials.

NOACHIAN AND HESPERIAN SYSTEMS, UNDIVIDED

The smooth material (unit **HNpl$_3$**) of the plateau sequence forms virtually featureless plains on the available low-resolution images (250 m/pixel); the unit lacks the kilometer-scale features visible on other units at the same resolution. To the south (fig. 2), several grabens of Memnonia Fossae cut the smooth material, which implies that they postdate the emplacement of the unit. The unit is relatively uncratered, but its observed crater density in the MTM −20147 quadrangle to the south suggests that it straddles the Hesperian-Noachian boundary (Craddock and Greeley, 1993). Also in the MTM −20147 quadrangle, the unit is superposed by Mangala Valles channel materials (units **Amch** and **AHmch**), but it does not come in contact with the older plains material (unit **Hmp**) east of the Mangala Valles channels.

HESPERIAN SYSTEM

The older plains material (unit **Hmp**) has the greatest areal extent of all the Mangala materials in this quadrangle, embaying the Noachian hilly and mountainous materials along their western margins and covering the southern part of the Noachian cratered unit. The unit contains craters as large as 8 km in diameter whose abundance indicates a Late to Early Hesperian age (table 1). Scott and Tanaka (1986) interpreted the unit to consist of flood-plain material that parallels the margins of the main channel deposits. All three Mangala Valles plains units appear to be more resistant to erosion than other deposits in the channels. The lobate appearance of the western margins of the plains materials suggests that their more competent parts may be lava flows, while the less competent parts could be mudflows (Chapman and Tanaka, 1992). However, the resolution of available images is insufficient to reveal definitive evidence of the origin of the plains units. Some erosional features emanate from the margin of the older plains material, raising the possibility of flow beneath the plains material and breakup of the plains' margin by removal of basal support (for example, at lat 14.7° S., long 148.8°). However, subtle erosional features on the surface of the plains material (at lat 16.3° S., long 149.5°) indicate that surface runoff did occur over parts of the unit. Erosional islands of plains material, some including large craters with prominent ejecta blankets, were carved out by subsequent floods.

AMAZONIAN AND HESPERIAN SYSTEMS, UNDIVIDED

Material deposited on the channel floors can be separated into two units. The older channel material (unit **AHmch**) was deposited over the scoured surface around erosional remnants of Mangala plains materials. (The younger channel material, unit **Amch**, is discussed below under the Amazonian System.) These channel deposits are characterized by many streamlined islands and channels. The crosscutting relations of some of these erosional features indicate that the direction of flow varied at some locations. The lower reaches of the Mangala Valles have braided channels consistent with different current directions during a single pulse of flood waters (Baker and Milton, 1974), but the complex pattern of scour features near lat 15° S., long 149° suggests that floods may have moved down the Mangala Valles along separate paths, many of which do not point back toward the breached Memnonia Fossae graben at the head of the main channel.

No craters larger than 5 km in diameter are present on the channel materials, but their absence is most likely only a sampling problem for units of small areal extent. The density of smaller craters on the older channel material indicates that its age is Late Hesperian to Early Amazonian (table 1), comparable with the age of the Daedalia Planum materials (discussed below) but distinct from the ages of the highland materials. Both the crater counts and the contact relations are consistent with a Late Hesperian to Early Amazonian age for all of the Mangala Valles units except the older plains unit (discussed above) and the younger channel material (discussed below).

Units 3 and 2 of the plains materials eroded by Mangala Valles flooding (units **AHmp$_3$** and **AHmp$_2$**) occur either as a single planar unit with lobate margins (unit 3) or as isolated mesas and knobs (unit 2). Both units have generally smooth surfaces, but unit 2 shows some pits and knobs. Outcrops of both units are more abundant to the north (Chapman and Tanaka, 1992).

A significant feature of the ejecta blankets of most craters larger than 5 km in diameter on the Mangala materials is their distinct terminal ridge, a feature that has been interpreted to indicate fluidized flow during emplacement of the ejecta (Carr and others, 1977; Mouginis-Mark, 1979). If the plains materials retained some of the water that accompanied the fluvial events in the Mangala Valles, then the trapped volatiles could have contributed to the preferential production of fluidized ejecta on the Mangala materials. Perhaps both the sediments and the more competent parts of the Mangala materials might still preserve small, isolated deposits of subsurface volatiles.

Unit 1 of the Daedalia Planum material (unit **AHd$_1$**) is the most extensive plains unit within the map area. Its low crater density (fig. 3, table 1) indicates that it is Late Hesperian to Early Amazonian in age.

AMAZONIAN SYSTEM

The plains east of the Noachian materials are composed of three units. The Daedalia Planum materials (units **AHd$_1$** and **Ad$_2$**) were mapped previously as member 3 of the Tharsis Montes Formation by Scott and Tanaka (1986), but here they are interpreted to be related to nearby Daedalia Planum (Craddock and Greeley, 1993) and the impact basin hypothesized at that location (Craddock and others, 1990). The remaining plains unit is member 4 of the Tharsis Montes Formation (unit **At$_4$**; Scott and Tanaka, 1986). All three units form broad areas containing relatively few craters and displaying many lobate scarps interpreted to be lava-flow margins. The flow margins give the plains an undulatory appearance, but the amplitude of the plains' overall relief is likely on the same order as that of the lobate flow margins, which is many tens of meters. Individual flows on member 4 can be traced back toward the Tharsis Montes to the northeast (Scott and Schaber, 1981; Scott and others, 1981).

The plains gradually rise toward the Tharsis Montes (Roth and others, 1980), presumably due to increased flow accumulation toward this locus of volcanic activity. The plains units thin near their western margin, where they embay old cratered highland materials, and their flow margins are generally only tens of meters thick (estimated from shadow lengths), as compared with 450- to 750-m thicknesses for Tharsis flows inferred from the diameter of partly buried craters at lat 21° S., long 118° (De Hon, 1982). The thinness of the flows at the western margin of the rolling plains indicates that the ridge of highland materials did not stop a large volume of lava from flowing farther west, ponding against the highlands.

At least one broad lobe of unit 2 of the Daedalia Planum materials (unit **Ad$_2$**) is present east of the highland materials. Flow margins of this unit south of the map area show that it is isolated from the Tharsis flows to the east and appears to be associated with the Memnonia Fossae graben that was the source for the floods in the Mangala Valles (Pfau and Saunders, 1984; Craddock and Greeley, 1993). The size of the flow margins indicate a strong material such as a volcanic flow or a well-indurated sediment (possibly a thick mudflow). Unit 2 may have been emplaced by reactivation of Memnonia Fossae faulting as recorded by various crosscutting relations (for example, Plescia and Saunders, 1982). The paucity of craters on unit 2 indicates an Early Amazonian age (table 1), which seems to postdate most of the activity in Mangala Valles. Both unit 2 and member 4 of the Tharsis Montes Formation are superposed on unit 1.

The craters on the lobate plains have much sharper rims than those on the adjacent ancient deposits. In contrast to the Daedalia Planum craters, all craters on member 4 of the Tharsis Montes Formation east of the map area have raised rims and remnants of ejecta, but only one crater has a complete ejecta blanket with a sharply defined outer margin.

The final depositional event within the Mangala Valles was confined to the main channel, laying down the younger channel material (unit **Amch**), which overlies all other Mangala units. At places the material is seen to have discrete margins when viewed at a resolution of 46 m/pixel (lat 13.2° S., long 150.0°).

STRUCTURAL FEATURES

The most conspicuous structural features in the vicinity of Mangala Valles are several high scarps in the Noachian materials. Earth-based radar data obtained during the 1971 and 1973 oppositions of Mars (Downs and others, 1973, 1975) provide detailed information about the relief in the middle reaches of Mangala Valles (fig. 4). Due to orbital constraints during the data collection, the measurements follow lines of latitude on Mars. The topographic valleys correlate well with individual linear troughs, interpreted to be fault traces, in the ancient materials. Because large topographic variations can affect the timing of reflected radar signals, potentially indicating a low point where one does not exist, it is instructive to note that shadow measurements made along the fault at long 148.5° provide upper limits to the vertical relief of 2.4 to 2.8 km, in good agreement with the results indicated by the radar data. The valley of this fault is crosscut by the same graben that is the source of the main channel of Mangala Valles. The north-oriented faults are exposed only in Noachian materials, while the younger Memnonia Fossae grabens cut units of Hesperian age.

RELEASE OF VOLATILES INTO MANGALA VALLES

The gullies on the highland materials exposed in the map area are aligned in the local downslope direction, primarily headed toward the Mangala Valles channels. Also, several erosional islands within the channel system point toward the mountainous areas, *not* toward the source of the most recent flood events. A possible interpretation for the gullies is that they are the result of downslope flow, perhaps carved by seeps from the ancient materials (Zimbelman, 1988). Some gullies also have been interpreted to result from scour by basin ejecta, evidenced by a systematic orientation throughout the Memnonia region (Craddock and others, 1990). The similar orientations of the gullies over wide areas indicate a consistent tectonic orientation throughout much of the Memnonia region, substantiated by the orientation of scarps, ridges, and grabens (Schultz, 1985). The proposed basin-forming event at Daedalia Planum (Craddock and others, 1990) may have established joint trends displayed in the Memnonia region, potentially explaining the coincidence between the basin-ejecta scour and the local downslope direction. Both ejecta scour and downslope mass movement probably contributed to gully formation in the Memnonia region; perhaps mass movement enlarged the scoured gullies.

The association of outflow channels with ancient materials is not confined to the Memnonia region. Most outflow channels on Mars, such as the series of channels that empty into Chryse Planitia, are concentrated in older geologic units (Carr, 1981, p. 140–144). The ancient materials may well have been highly fractured by intense cratering early in the history of Mars (for example, Mutch and others, 1976, p. 69–74; Carr, 1981, p. 65–70). Such fractured materials could allow not only the passage but also the storage of volatiles (for example, Carr, 1986; MacKinnon and Tanaka, 1989). If the gullies on the mountainous material are also related to downslope movement accompanying volatile release, the ancient materials in the Memnonia region not only stored the vast quantities of water needed for the formation of the Mangala Valles but also may have contained volatiles released more gradually through seeps. The release of volatiles thus may be responsible for some small-scale features in the southern highlands and may have contributed to later erosion in the Mangala Valles.

The sequence of flood events within the Mangala Valles presumably may be explained by a single outflow of diminishing volume, but the present topography places important constraints on such an event. The main channel (whose floor is covered by the younger channel material) follows the topographic low created by the eastward-sloping cratered unit of the highland plateau sequence to the west and the older channel and plains materials to the east (U.S. Geological Survey, 1991). The younger channel material is at least 300 m lower than the highest parts of the older plains material, as shown by the radar elevations (fig. 4). A single flood event would have had to span the entire valley (filling it to widths of 100 to 250 km) and cover at least the highest parts of the plains material; peak flow at the present main channel would have reached a depth of more than 300 m. More importantly, some of the craters on streamlined islands of plains material would have been submerged beneath such a volume of water. However, the crater rims show no evidence of fluvial erosion, and crater ejecta are eroded only along the lower several tens of meters, well down within the Mangala Valles channels. An alternative to a single, very deep flood is a series of flood events: flow could have been confined within the existing channels, below the eroded ejecta blankets of the large craters; highland gullies also may have contributed to overland flow.

The radar data provide an opportunity to quantify the downstream gradient of a Martian channel. A gradient of 0.001, indicating a drop of only 100 m over 100 km, fits the available data well for distances of 40 to 220 km from the source area at the breached graben (fig. 5). Leopold and others (1964) listed a gradient of 0.0015 for the Yellowstone River at a location 120 km from its headwaters, consistent with the value obtained here. The low gradient raises the possibility that some of the fluvial activity at Mangala Valles may have been sufficiently long lived to begin development of a graded profile. The flood waters would not have moved at a high speed down such a low gradient, so that the observed erosion may have required an extended period of flow (Zimbelman and others, 1992).

What was the source of the floods that created the Mangala Valles? Sharp and Malin (1975) speculated that ground water, seeping to the surface, may have formed a large lake near the headwaters of the Mangala Valles; the ponded water could then have been released by episodic overflow and catastrophic failure of the reservoir wall. No shorelines of the hypothesized lake are visible south of the Mangala Valles, although the resolution of the images in this area may be insufficient to distinguish subtle features. Carr (1979) proposed water release from confined aquifers to explain the outflow channels around Chryse Planitia, but at Mangala there are no large accumulations of chaotic terrain that could be attributed to the collapse of the evacuated aquifer.

The topography of the region suggests other alternatives. The eastward-sloping cratered highlands material (west of long 150° in fig. 4) could have contained an aquifer through which ground water flowed toward the east. An aquifer in highland materials beneath the lava flows from the Tharsis volcanoes could also have been a conduit for subsurface water flowing west to the Mangala Valles region (Tanaka and Chapman, 1990; Zimbelman and others, 1992). Upon reaching the weakened (or already breached) graben wall, the water could then have flowed north on the surface, carving the channel system. Whether from a lake accumulated from seeping water or from a gently dipping aquifer feeding system, the water responsible for the channeling must have travelled through or been stored within the fractured highland materials.

GEOLOGIC SUMMARY

(1) Noachian—The early crust of Mars was subjected to intense bombardment, resulting in the cratered surface preserved in the Memnonia region as mountainous material and the hilly and cratered units of the highland plateau sequence.

(2) Late Noachian—Tectonic forces produced north-oriented faults, some with more than 2 km of vertical displacement, along long 148°. West of the faulted terrain the cratered plains were tilted 0.6° east. The subdued cratered material was emplaced in the highlands in isolated lows such as craters.

(3) Noachian to Hesperian—The smooth unit of the highland plateau sequence was emplaced from the south, covering the cratered plains south of about lat 17.5° S. (fig. 2). Then, south of the map area, faults cut both the smooth unit and the ancient materials, producing the many grabens of Memnonia Fossae.

(4) Hesperian—Initial flooding of the Mangala Valles region deposited plains materials north along the eastern margin of the tilted cratered plains, perhaps over lava flows associated with the flooding.

(5) Hesperian to Early Amazonian—Mangala Valles floods issued from a breach in one of the Memnonia Fossae grabens. At least two phases of erosion scoured ejecta around large craters and other materials within the path of the floods.

(6) Early Amazonian—Lavas from the Tharsis Montes and Daedalia Planum formed the plains east of long 147°, where the faulted ridge of ancient material halted the westward advance of the lava and prevented its entering the Mangala Valles channel system.

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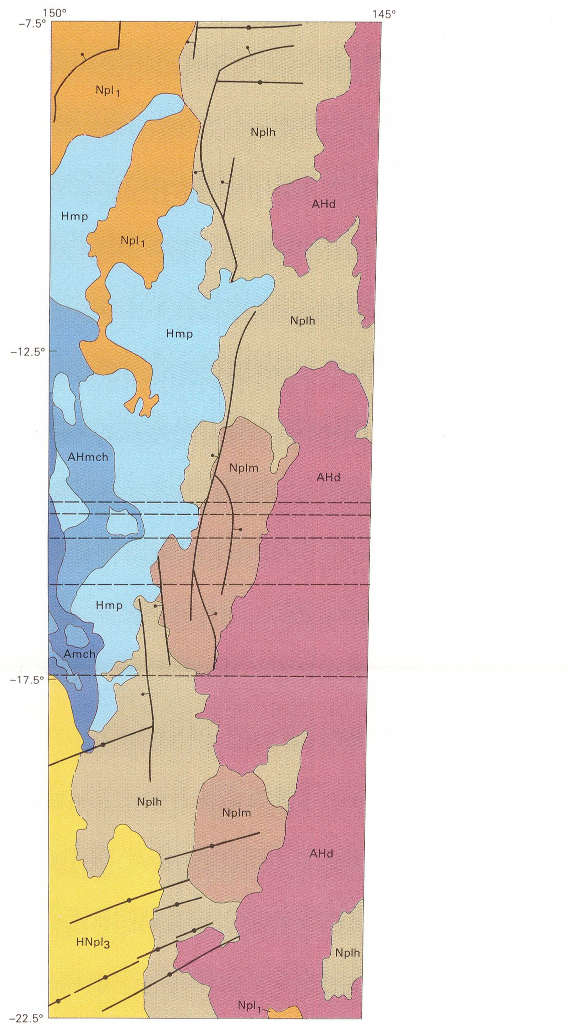


Figure 2. Simplified regional geologic map of southern reaches of Mangala Valles (MTM −10147, −15147, and −20147 quadrangles, fig. 1). Crater materials are excluded for clarity. Symbols are those of main map except that all lobate plains materials are shown here with symbol **AHd**, all Mangala plains materials with symbol **Hmp**; grabens indicated by heavy line overlain by ball. North-south orientation of Noachian materials follows trend of major scarps exposed only in these ancient rocks. Noachian materials are embayed by Mangala Valles deposits on their west margin and by volcanic plains of Tharsis Montes and Daedalia Planum on their east margin. Grabens of Memnonia Fossae (south of lat 17.5° S.) cut across both Noachian and Hesperian materials. Dashed lines indicate groundtracks for radar profiles shown in figure 4.

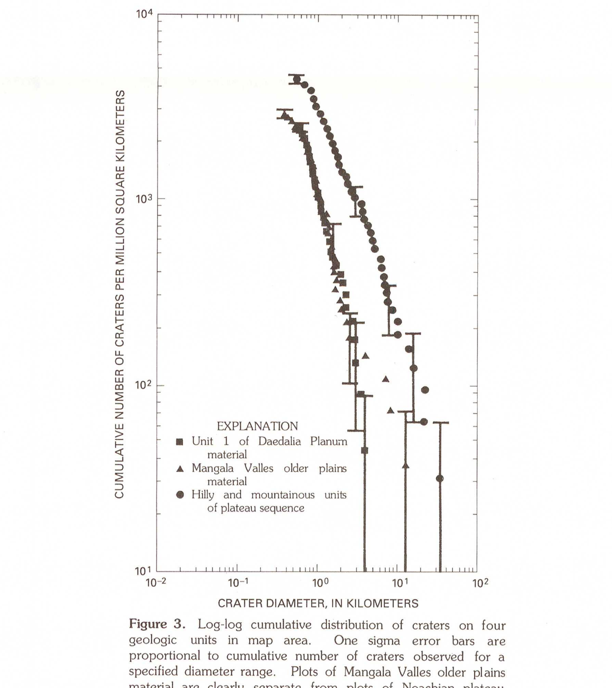


Figure 3. Log-log cumulative distribution of craters on four geologic units in map area. One sigma error bars are proportional to cumulative number of craters observed for a specified diameter range. Plots of Mangala Valles older plains material are clearly separate from plots of Noachian plateau materials but are statistically indistinguishable from data for unit 1 of the Daedalia Planum material, except for craters greater than 10 km in diameter.

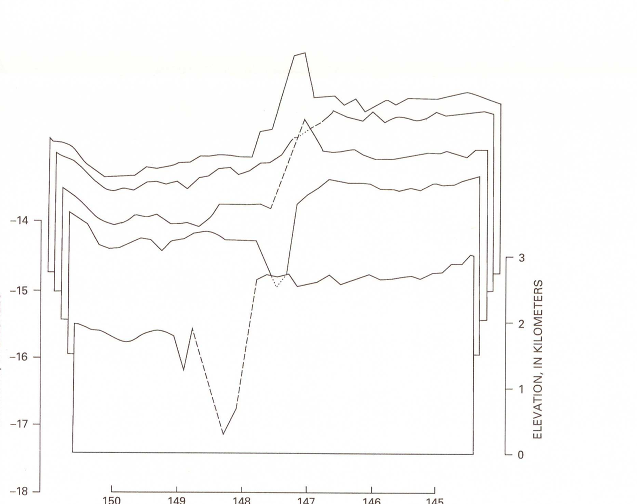


Figure 4. Five topographic profiles across the geologic map obtained from Earth based radar measurements (Downs and others, 1973, 1975). Bottom of each profile corresponds to data groundtrack; latitudes of groundtracks (fig. 2) are 17.4° S., 16.0° S., 15.4° S., 15.0° S., and 14.8° S. Profiles have vertical exaggeration of ×57. Greatest relief is associated with north-trending faults within Noachian materials. Subtle topographic low along long 150° corresponds to Mangala Valles. Profiles dashed where radar measurements not available, most likely due to scattering associated with large local relief, and dotted where covered by another profile in this view. Radar data have a resolution size of about 10 km (0.16°) in longitude by about 80 km (1.3°) in latitude and a vertical resolution of 100 m (Downs and others, 1973, 1975).

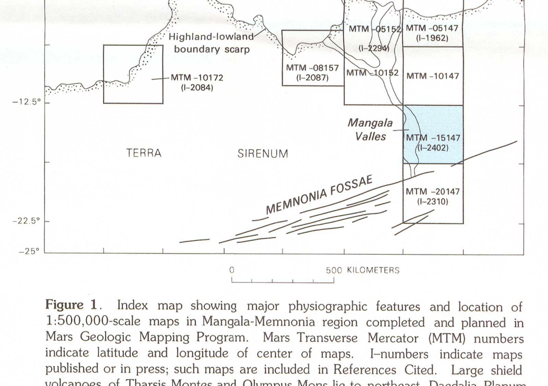


Figure 1. Index map showing major physiographic features and location of 1:500,000-scale maps in Mangala-Memnonia region completed and planned in Mars Geologic Mapping Program. Mars Transverse Mercator (MTM) numbers indicate latitude and longitude of center of maps. I–numbers indicate maps published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

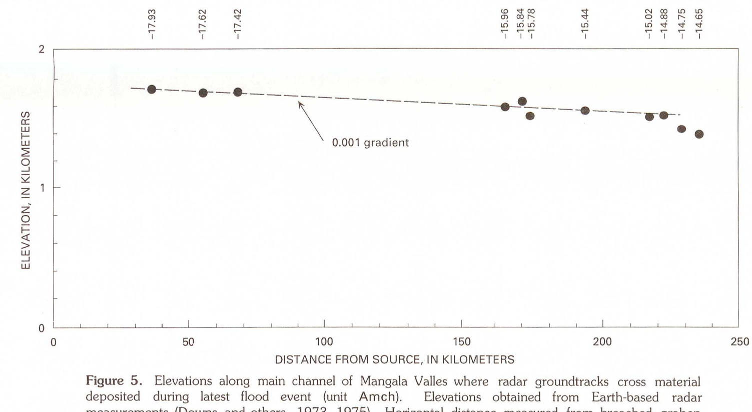
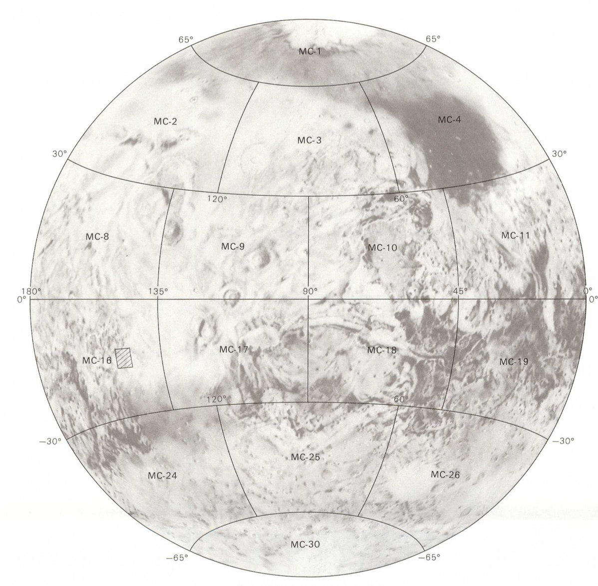


Figure 5. Elevations along main channel of Mangala Valles where radar groundtracks cross material deposited during latest flood event (unit **Amch**). Elevations obtained from Earth-based radar measurements (Downs and others, 1973, 1975). Horizontal distance measured from breached graben in Memnonia Fossae (see text). Gradient consistent with observed gradients of young terrestrial rivers at comparable distances from their headwaters (Leopold and others, 1964). Vertical exaggeration ×50.



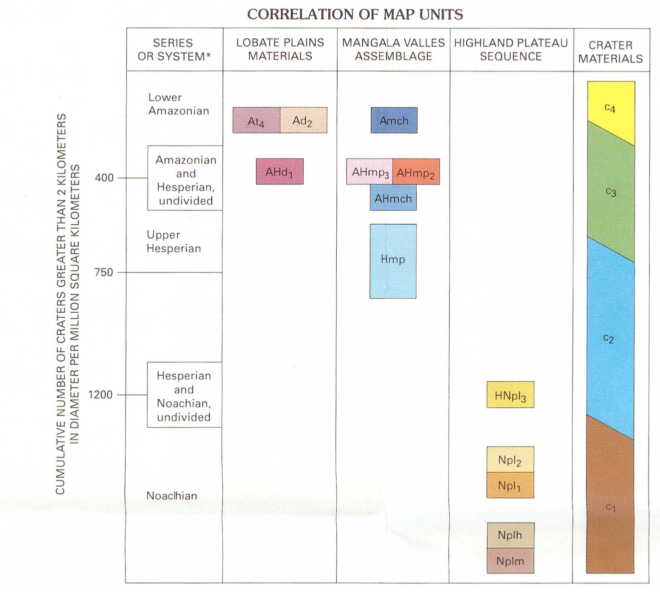
QUADRANGLE LOCATION
Photomosaic location is shown in the western hemisphere of Mars. An outline of 1:5,000,000-scale quadrangles is provided for reference.

Table 1. *Crater-frequency data for major geologic units within MTM −15147 quadrangle*

Unit	N[2][1]	N[5][1]	N[16][1]	System[2]
Daedalia Planum material, unit 2 (Ad$_2$)[3]	330±110	—	—	Amazonian
Daedalia Planum material, unit 1 (AHd$_1$)	450±140	—	—	Amazonian/Hesperian
Older channel material (AHmch)	420±200	—	—	Amazonian/Hesperian
Plains material, unit 3 (AHmp$_3$)[4]	390±280	280±280	—	Amazonian/Hesperian
Older plains material (Hmp)[4]	460±130	150±60	—	Hesperian
Hilly unit (Nplh)[4]	1350±300	620±210	170±110	Noachian
Mountainous unit (Nplm)	1820±340	820±230	200±110	Noachian
Cratered unit (Npl$_1$)[4]	1980±450	1410±380	470±220	Noachian

[1] N[x]=Cumulative number of craters greater than or equal to x km in diameter per 106 km^2.
[2] Crater-density boundaries from Tanaka (1986).
[3] Data include craters in MTM −20147 quadrangle (Craddock and Greeley, 1993).
[4] Data include craters in MTM −10147 quadrangle.

CORRELATION OF MAP UNITS



*Series boundaries from Tanaka (1986)

DESCRIPTION OF MAP UNITS

[Names and stratigraphic descriptions of major units are adapted from Scott and Tanaka (1986). See table 1 for crater-count information for selected units]

LOBATE PLAINS MATERIALS

At$_4$ **Member 4 of the Tharsis Montes Formation (Scott and Tanaka, 1986)**—Forms broad plains delineated by lobate flow fronts whose margins face west. Surface smooth on available images (resolution 250 m/pixel). Unit superposed on unit 1 of Daedalia plains materials but covers only small area in quadrangle. *Interpretation:* Fluid lavas associated with Tharsis Montes volcanism

Ad$_2$ **Unit 2 of the Daedalia Planum material**—Forms gently undulatory plains whose conspicuous lobate margins face east. Surface smooth on available images (resolution 250 m/pixel). Plains material radiates from graben in highlands material south of map area (at lat 17.8° S., long 146.6°) that is aligned with source graben for Mangala Valles (Craddock and Greeley, 1993). Unit superposed on unit 1 of Daedalia Planum materials; included in member 3 of Tharsis Montes Formation by Scott and Tanaka (1986). Typical exposure at lat 17.0° S., long 146.5° (Viking frame 639A14). *Interpretation:* Fluid lavas or mud flows emanating from graben in highlands material, possibly associated with release of floods into Mangala Valles. East-facing lobate margins south of map area show unit is isolated from other plains units that have west-facing lobate margins (Pfau and Saunders, 1984; Craddock and Greeley, 1993)

AHd$_1$ **Unit 1 of the Daedalia Planum material**—Makes up gently undulatory plains with many west-facing lobate margins. Surface smooth on available images (resolution 250 m/pixel). Unit superposed on eastern margin of highlands materials east of about long 147°. Included in member 3 of Tharsis Montes Formation by Scott and Tanaka (1986). *Interpretation:* Fluid lavas associated with volcanism of Daedalia Planum or Tharsis Montes

MANGALA VALLES ASSEMBLAGE

Amch **Younger channel material**—On floor of youngest channel within upper reaches of Mangala Valles, which crosscuts materials of all other channels. At low resolution (270 m/pixel) channel floor appears smooth, but at high resolution (46 m/pixel) abundant streamlined knobs are seen surrounded by deposit with observable thickness (Viking frame 446S36). Irregular pits and sinuous depressions observed downslope from low fault scarp that crosses channel (lat 14.2° S., long 150°; Viking frame 447S32). Unit included in older channel material (unit **Hch**) of Scott and Tanaka (1986). Typical exposure at lat 14.4° S., long 150.0° (Viking frame 446S35). *Interpretation:* Alluvium emplaced by most recent flood. Streamlined islands and scoured channel margins indicate erosion of older materials

AHmp$_3$ **Plains material, unit 3**—Smooth, planar unit with lobate margins; more resistant to erosion than channel materials (Viking frame 447S36). In map area, no features other than impact craters visible at 45 m/pixel resolution, but to north, at lat 11.5° S., long 150.1°, unit displays broad, shallow, leveed channel (Chapman and Tanaka, 1992). Unit extends downslope within Mangala Valles from source near lat 15.2° S., long 148.3° that is visible only at 250 m/pixel resolution. Unit superposed on older channel material (unit **AHmch**); extends north beyond map area (fig. 2). Typical exposure at lat 14.7° S., long 148.7° (Viking frame 447S36). *Interpretation:* Competent unit associated with Mangala Valles flooding. Leveed channel suggests that unit was emplaced as fluid volcanic flow (Chapman and Tanaka, 1992). Alternatively, unit might be indurated sediments or mudflow, but no source is readily apparent. Fluvial scour normal to unit margin may be due to undermining by subsurface water flow

AHmp$_2$ **Plains material, unit 2**—Isolated planar outcrops surrounded by erosional features scoured by floods. Caprock more resistant to erosion than are surrounding materials. Several irregular pits and knobs provide surface texture distinct from that of nearby unit 3 plains material (Viking frame 447S33). Unit also forms isolated, streamlined knobs. Typical exposure at lat 13.0° S., long 149.8° (Viking frame 447S33). *Interpretation:* Competent unit severely eroded by floods. Unit is likely indurated sediments or once-fluid volcanic flows, although no lobate margins visible in map area

AHmch **Older channel material**—Composes irregular floor of Mangala Valles. Streamlined shapes of common small knobs indicate flow directions that have multiple orientations; many orientations imply flow over adjacent materials (such as unit 3 of plains material and older plains material) rather than flow directly from breached Memnonia Fossae graben. Deposits have varied texture at 46 m/pixel resolution (Viking frame 446S35): some are smooth and gently streamlined while others consist of many ridges and knobs aligned with inferred flood direction. Unit included within older channel material of Scott and Tanaka (1986). Typical exposure at lat 14.5° S., long 149.3° (Viking frame 447S34). *Interpretation:* Alluvium emplaced by floods that preceded deposition of younger channel material. Emplacement of unit strongly influenced by erosional overprint of underlying (preflood) materials. Floods associated with younger channel material may have inundated some or all of older channel material, but identifiable deposits from most recent flood present only on younger channel material

Hmp **Older plains material**—Broad, planar deposit east of Mangala Valles channel units; embays western margins of Noachian hilly and mountainous units. West edge of unit has lobate outline that stands in relief above channel materials. Surface smooth at all scales down to 46 m/pixel resolution. Streamlined features in unit margin at lat 16.4° S., long 149.5°. Unit corresponds to parts of older flood-plain material of Scott and Tanaka (1986). Typical exposure at lat 14.0° S., long 148.2° (Viking frame 447S36). *Interpretation:* Competent material emplaced against highlands as earliest major plains-forming unit associated with Mangala Valles. Lobate margins interpreted to indicate volcanic-flow origin (Chapman and Tanaka, 1992), but sapping along margins by basal flow may contribute to margin morphology. Indurated alluvium may be alternative to volcanic flow. Streamlined features at margin indicate flow perpendicular to margin rather than along main channel

HIGHLAND PLATEAU SEQUENCE

HNpl$_3$ **Smooth unit**—Planar unit lacking significant surface texture at 250 m/pixel resolution. More abundant south of southwest corner of map area (fig. 2; Craddock and Greeley, 1993). Similar to smooth unit of plateau sequence (unit **Hpl$_3$**) of Scott and Tanaka (1986), except that crater counts indicate an Early Noachian to Late Hesperian age (Craddock and Greeley, 1993). *Interpretation:* Once-fluid lavas most likely covered by either eolian materials or sediments from ponded water that contributed to Mangala Valles floods (Sharp and Malin, 1975)

Npl$_2$ **Subdued cratered unit (Scott and Tanaka, 1986)**—Forms plains with subdued scarps and small knobs; occurs as isolated patches within highlands or on floor of subdued craters. *Interpretation:* Interbedded lava flows and eolian deposits that partly bury underlying rocks

Npl$_1$ **Cratered unit (Scott and Tanaka, 1986)**—Makes up highly cratered, gently undulatory plains that, at 45 m/pixel resolution, appear hummocky with irregularly spaced hills and ridges. Overlain by Mangala Valles channel materials. *Interpretation:* Lava flows and impact breccia generated early in Martian history, most likely during intense heavy bombardment that followed formation of solid crust

Nplh **Hilly unit (Scott and Tanaka, 1986)**—Highland material that has broad topographic undulations and subdued morphology. Common scarps and ridges oriented generally north. *Interpretation:* Brecciated highland material. Overall subdued appearance result of prolonged weathering and mass wasting

Nplm **Mountainous unit**—Densely cratered, uneven surface of high relief; intensely modified by groups of parallel to subparallel, shallow gullies oriented mostly east-west. Superposition of older plains material over gullies indicates modification occurred prior to Mangala Valles floods. Ridges and arcuate scarps abundant; north-trending linear valleys less common. Equivalent to mountain unit of Scott and Tanaka (1986). Typical exposure at lat 15.7° S., long 147.3° (Viking frame 639A12). *Interpretation:* Brecciated highland material uplifted by north-trending faults, possibly related to basin formation in Daedalia Planum (Craddock and others, 1990). Remobilization in gullies due to mass wasting related to groundwater seepage (Zimbelman, 1988), basin-ejecta scour (Craddock and others, 1990), or both

CRATER MATERIALS

[Only craters greater than or equal to 3 km in diameter are mapped. All mapped craters are interpreted to be of impact origin]

c$_4$ **Material of well-preserved craters**—Craters have sharp, raised rims and, typically, continuous ejecta that have terminal ridge. Walls of large craters are terraced; floors of many craters contain abundant hills, central peak, or both. Materials have been relatively unmodified except where channel-related floods have eroded parts of ejecta blanket

c$_3$ **Material of slightly degraded craters**—Craters have distinct but rounded raised rims; ejecta blankets incomplete, largely absent around small craters. Large craters have terraced walls, central peak, or both

c$_2$ **Material of moderately degraded craters**—Craters have subdued, low-relief rims, flat floors, and no visible ejecta. Central peak absent

c$_1$ **Material of highly degraded craters**—Craters have very subdued, disrupted rims; where highly modified, rims only partly preserved. No discernable ejecta or floor deposits

Contact—Dashed where approximately located; queried where no surface trace evident
Fault—Dashed where approximately located. Bar and ball on downthrown side
Ridge
Wrinkle ridge
Linear scarp—Line at base; dashed where approximately located
Lobate scarp—Dashed where approximately located; ticks point downslope. Interpreted as margin of lava flow or mud flow
Narrow channel or gully
Crater rim crest—Dotted where partly buried or subdued
Dome or central peak of crater
Slump material—Arrow shows direction of movement
Flow direction—Inferred from streamlined islands or elongated scour features

GEOLOGIC MAP OF THE MTM −15147 QUADRANGLE, MANGALA VALLES REGION OF MARS

By
James R. Zimbelman, Robert A. Craddock, and Ronald Greeley
1994

For sale by U.S. Geological Survey, Map Distribution, Box 25286, Federal Center, Denver, CO 80225