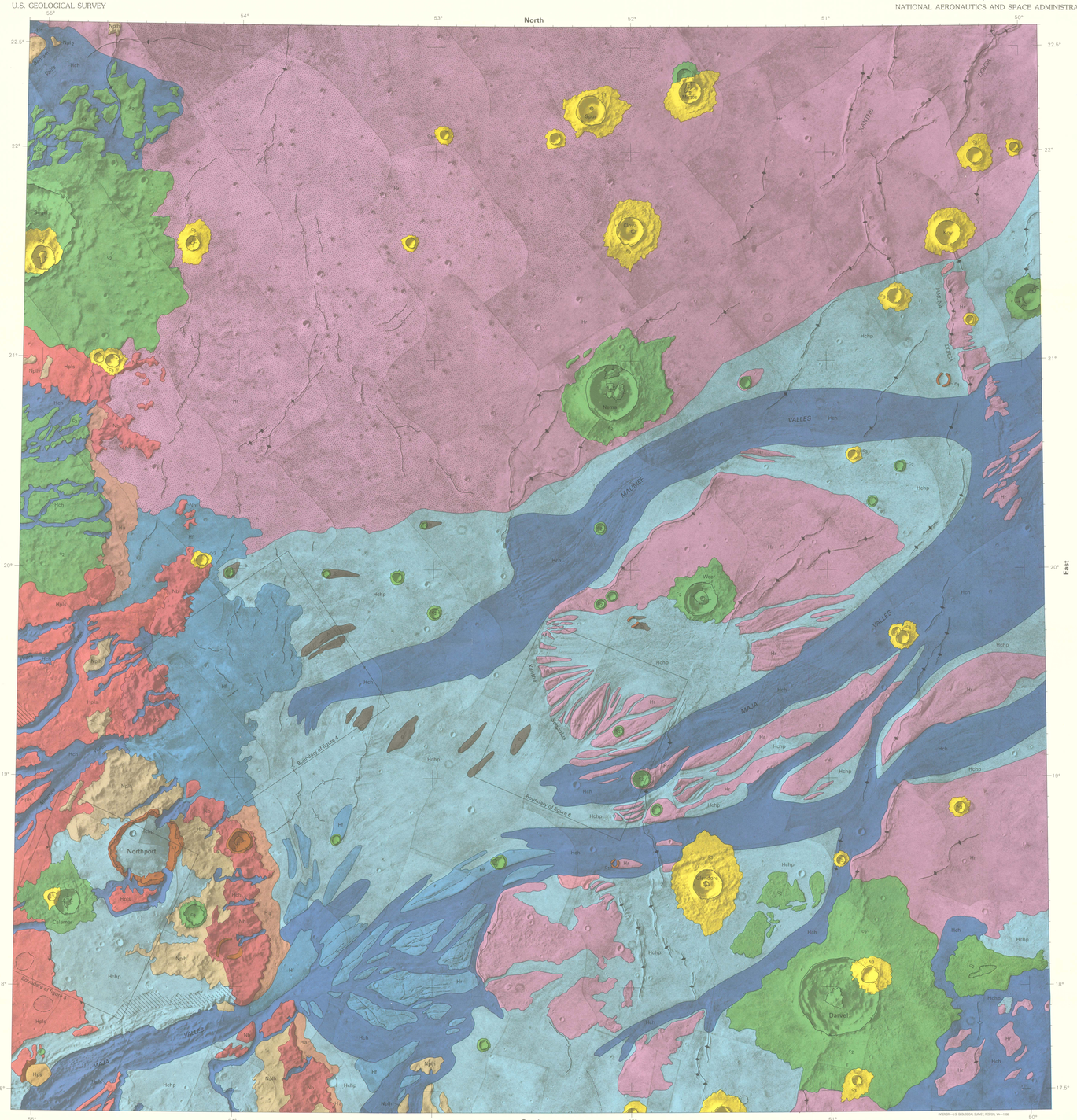
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared for the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ATLAS OF MARS
1:500,000 GEOLOGIC SERIES
MAJA VALLES REGION
M 500k 20/52 G, 1996
MAP I–2432



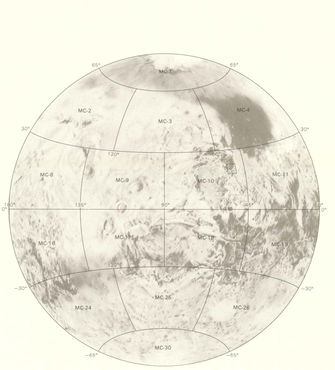
Base from U.S. Geological Survey 1985. Minor error inherent in this and adjacent photomosaics may result in offsets of physiographic features at map borders.

SCALE 1:502 000 (1 mm=502 m) AT 50° LONGITUDE
TRANSVERSE MERCATOR PROJECTION

10 0 10 20 30 40 50 60 70 80 90 100
KILOMETERS

M7806—U.S. GEOLOGICAL SURVEY, RESTON, VA—1996

Prepared on behalf of the Planetary Geology Program, Solar System Exploration Division, Office of Space Science, National Aeronautics and Space Administration, under contract W–15,814
Edited by Doris Weir and Derrick Hirsch; cartography by Michael E. Dingwell
Manuscript approved for publication June 28, 1993



LOCATION OF QUADRANGLES

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

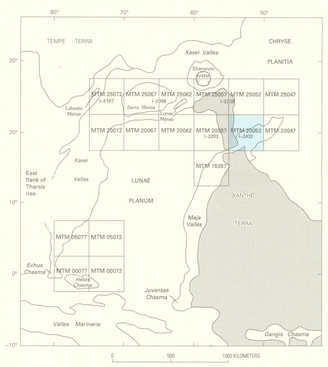


Figure 1. Index map showing major physiographic features and location of 1:500,000-scale geologic maps in vicinity of Lunar Planum completed and planned Mars Geologic Mapping Program. Mars Transverse Mercator (MTM) numbers indicate latitude and longitude of center of map. I–number indicates maps that are published or in press.

GEOLOGIC MAP OF THE DARVEL QUADRANGLE (MTM 20052), MAJA VALLES REGION OF MARS

By
James W. Rice, Jr., and René A. De Hon
1996

SERIES	PLATEAU MATERIALS	PLAINS MATERIALS	CHANNEL- AND VALLEY-RELATED MATERIALS				CRATER MATERIALS
AMAZONIAN							c3
HESPERIAN	Hpks	Hps Hr	Ha	Hch	Hchp	Hf	c2
NOACHIAN	Npl2 Nplh Nb						c1

DESCRIPTION OF MAP UNITS

[Most names and symbols are those of Scott and Tanaka (1986)]

PLATEAU MATERIALS

Hpks **Smoothed cratered plateau material**—Rounded or smoothed surface of moderate to low relief. Many faint valleys and drainage lines. Small craters highly degraded or absent; outer ejecta blankets of large craters degraded at lower elevations. *Interpretation*: Thin sheetflood deposits of reworked surficial material

Npl2 **Subdued cratered plateau material**—Cratered, uneven surface of moderate relief. Underlies large part of Xanthe Terra but crops out in only one place in quadrangle, in northwest corner. *Interpretation*: Degraded, impact-brecciated highland material.

Nplh **Hilly plateau material**—Forms hills or isolated low massifs within Xanthe Terra. *Interpretation*: Highly fractured basement and impact brecciated materials

Nb **Basement complex**—Rugged massif material near east edge of Xanthe Terra. Similar to hilly plateau material but greater relief and more rugged. *Interpretation*: Highly fractured and impact brecciated materials. May be old crustal rocks uplifted by basin-forming impact or tectonic processes

PLAINS MATERIALS

Hps **Smooth plains material**—Smooth, level, featureless plains occupying floor of unnamed crater in southwest corner of quadrangle. Moderate to low albedo. *Interpretation*: Crater was catchment basin along flow course; material either lacustrine and fluvial or sediments moved by gravity or wind from local sources. May be extremely coarse to fine; bedding probably graded

Hr **Ridged plains material**—Broad, planar surface characterized by low albedo and mare-type, linear to sinuous, low ridges. *Interpretation*: Lava flows erupted at high rate. Ridges may be formed by flow or later compression

CHANNEL- AND VALLEY-RELATED MATERIALS

Ha **Apron material**—Bands of smooth material at foot of Xanthe Terra-Chryse Planitia boundary scarp. Moderate albedo. Buries ridges in plains material. *Interpretation*: Sedimentary apron deposited by sheetflood flow and coalescing of small alluvial fans on east slope of Xanthe Terra

Hch **Channel material**—Forms floors of outflow channels within well-defined topographic valleys of Xanthe Terra and Chryse Planitia. Channels range from shallow and rounded to steep sided and flat floored. Channel margins mapped at break in slope. *Interpretation*: Channels formed by rapid outburst of water. May have contained entrained ice or had ice cover

Hchp **Channel flood-plain material**—Characterized by streamlined islands, scours, and other faint flow features; outer edges poorly defined. Wrinkle ridges scarce and subdued. *Interpretation*: Result of unconfined or semiconfined outflow and ponding in craters and in ill-defined, poorly drained basins

Hf **Fan material**—Fan-shaped deposits at mouths of outflow channels. Locally cut by longitudinal channel segments. Low to moderate relief. Most contacts clearly defined but locally gradational. *Interpretation*: Alluvial fan or deltaic sediments

CRATER MATERIALS

[All craters in map area are interpreted to be of impact origin. Only craters 3 km in diameter and larger are mapped. They are assigned to three classes based on state of preservation and stratigraphic control]

c3 **Material of well-preserved craters**—Craters have sharp, complete rim crest and extensive ejecta blanket superposed on surrounding materials

c2 **Material of slightly to moderately degraded craters**—Large craters (greater than 30 km in diameter) have sharp rim crest and extensive ejecta blanket; small craters have narrow ejecta blanket. May have superposed younger craters or be cut by channels. Most craters cut by channels are Early Hesperian in age; some may be Late Hesperian

c1 **Material of highly degraded craters**—Craters have low or discontinuous rims and shallow floors

Contact—Dashed where approximately located

Base of scarp—Barb points downslope

Ridge in plains material—Line marks crest. Filled symbol denotes well-defined ridge; open symbol denotes low, poorly developed ridge. Dotted where buried

Crenelated ridge in fan material—Line marks crest

Small distributary channel

Rimless depression—Origin undetermined

Crater rim crest—Dotted where buried

Crater central peak—Rugged peak or broad mound on crater floor

Crater central pit

Terrace—Flat bench adjacent to valleys; probable erosional surface cut during episode of maximum discharge

Bar on flood plain or within channels—Interpreted to be alluvium but in places difficult to distinguish from erosional remnants

Slump material—Arrow shows direction of movement

Surface of mottled albedo—Variegated or dappled-appearing surface of ridged plains material

INTRODUCTION

The quadrangle is in the northern Maja Valles region on the west edge of Chryse Planitia (fig. 1). This map is one in a sequence of three that also includes MTM 15057 and 20057. The sequence covers that part of the lower reaches of Maja Valles that includes the transition from the higher Lunae Planum surface to the lower Chryse Planitia surface. The major interest in this quadrangle is the effects of catastrophic outflow and its associated morphologic modification of Chryse Planitia.

The quadrangle contains two physiographic provinces. Part of the Xanthe Terra highland (fig. 1) occupies a narrow strip along the west border of the map area. The highland has a moderately rugged and cratered surface and is incised by four major valley systems that drain from the higher Lunae Planum surface in the west into the Chryse Basin. (The "basin" is herein considered the same as the "planitia.") From north to south the valley systems are Bahram, Vedra, Maumee, and Maja Valles. (The last three mentioned are shown in fig. 2.) Most of the quadrangle lies in Chryse Planitia, which here has a relatively smooth, flat, sparsely cratered surface characterized by wrinkle ridges and a broad scour zone marking the path of outflow from the valley mouths.

The photomosaic base for the quadrangle (U.S. Geological Survey, 1985) was assembled from 84 Viking Orbiter images that range in resolution from 40 to 100 m/pixel and were acquired with sun angles of 40° to 50°. Five moderate-resolution (240 m/pixel) images were also used for mapping; they provide better definition of low-relief surfaces than the high-resolution, lower sun-angle images, especially of the fan and apron materials at the mouths of outflow channels (fig. 3).

Material units are assigned to the three time-stratigraphic systems previously described by Scott and Carr (1978) from Mariner 9 images and refined on the basis of Viking Orbiter imagery by Scott and Tanaka (1986), Tanaka (1986), and Greeley and Guest (1987). The relative ages of the units were determined by superposition and transection.

The Maja Valles region has been extensively modified by erosion and deposition. The problem of distinguishing the age of surface modification from the age of emplacement in the region was first addressed by Milton (1974) on the basis of Mariner 9 imagery. Much of the geology of the Darvel quadrangle was mapped by Greeley and others (1977) and Theilig and Greeley (1979) with the improved imagery of the Viking 1 and 2 Orbiters. The geomorphology of the Maja Valles outflow system was investigated by Baker and Kochel (1979). A regional overview, based on Viking imagery, was provided by Scott and Tanaka (1986). De Hon (1987) likened the extensive trans-Xanthe canyon system to overbank flooding and crevassing in a low-gradient river at flood stage. The MTM 20057 quadrangle to the west (fig. 1), containing the heads of the trans-Xanthe valleys, was mapped by De Hon (1992).

STRATIGRAPHY

The major stratigraphic units in the quadrangle are plateau and highlands materials of Xanthe Terra, plains materials of Chryse Planitia, and channel-related materials associated with the Maja Valles outflow. This quadrangle, like many others on Mars, has been significantly modified by wind and water; hence, its rocks may have erosional and depositional morphologies not related to their mode or time of emplacement. Some units in this region consist of thin layers of reworked material; although they were formed by events of short duration, they are mapped because they are significant parts of the stratigraphic record.

The oldest materials in the map area are in the highland terrain of Xanthe Terra. These Noachian units are impact breccias formed during a period of high impact flux (Scott and Tanaka, 1986). The *basement complex* (unit Nb), the oldest rock unit (Scott and King, 1984), is rugged massif material exposed in the western part of the map area along the highland-lowland boundary scarp (which separates the rougher southern highlands of Mars from the smoother, less cratered northern lowlands). The high relief of the unit may be due to deep erosion of a formerly high regional surface, to uplift by regional tectonism, or to formation of the Chryse Basin by impact (Schultz and others, 1982). The *hilly plateau material* (unit Nplh) forms isolated hills or low massifs within Xanthe Terra. The unit is similar to the basement material but is of lower relief and less rugged. *Subdued cratered plateau material* (unit Npl_2), which crops out more widely west of the map area (De Hon, 1992), underlies most of Xanthe Terra in this quadrangle, but it has been modified or buried by *smoothed cratered plateau material* (unit Hpks).

Materials of Hesperian age were deposited somewhat episodically following a long period of relatively little geologic activity except for the formation of impact craters. *Ridged plains material* (unit Hr) crops out over much of the quadrangle and underlies widespread channel materials. The ridged plains material is characterized by broad, planar surfaces with linear mare-like ridges. The lightly cratered unit overlies or embays highly cratered Noachian materials. The ridged plains material is believed to have been extensive, low-viscosity lava flows erupted at high discharge rates from multiple sources, probably fissures (Greeley and Spudis, 1981).

The *smoothed cratered plateau material* (unit Hpks), in Xanthe Terra, typically has an uneven surface of moderate to low relief dissected by many faint valleys and small drainage channels. It is rounded and smoothed, and many small craters are highly degraded or nearly obliterated.

Smooth plains material (unit Hps) of low to intermediate albedo forms a thin layer overlying floor material of a highly degraded crater. The unit may be lacustrine, alluvial, or colluvial materials of local origin.

Apron material (unit Ha) subdues the subjacent topography along part of the Xanthe Terra-Chryse Planitia boundary. The material was deposited by many small channels and by sheetflood flow from Xanthe Terra down onto Chryse Planitia.

Channel material and *channel flood-plain material* (units Hch and Hchp) are associated with many valleys apparently carved by running water. Cross-sectional profiles of the channels on Xanthe Terra range from shallow and rounded to steep-sided and flat-floored. The floors of the Maja Valles are marked by striations, longitudinal grooves, inner channels, mid-channel bars, and streamlined islands. Terraces and hanging valleys can be seen on the sides of the Maja channels. Channel material is mapped in Chryse Planitia wherever well-defined channel walls indicate a confined flow. Material modified by surface-flow features (such as bars, scours, and flow lines) but lacking well-defined boundaries is mapped as flood-plain material. The contact between this and subjacent units is located by the proximity of streamlined bars or apparent flow modification of adjacent topography. The channels and related features were formed by the rapid outburst of water from Juventae Chasma (fig. 1) or other impoundments along the outflow path. Crater counts on the flood-plain material in Chryse Planitia suggest that outflow channel activity was mostly restricted to the Late Hesperian (Tanaka, 1986).

Fan material (unit Hf) forms wedge-shaped deposits where Maja, Maumee, and Vedra Valles debouched into the Chryse Basin. The material is of low to moderate relief and is locally cut by longitudinal channel segments (fig. 3).

CRATER MATERIALS

Martian craters, although similar to lunar craters, have some unique characteristics. Generally, fresh craters on Mars tend to be shallower than lunar craters of the same diameter (Pike, 1980), and many Martian craters have ejecta blankets that exhibit lobate terminations rather than the transition from hummocky to thin deposits that is typical of lunar craters (Carr and others, 1977).

Secondary crater fields around small, young craters are not as well preserved as are those on the Moon. Secondary craters from craters Glendore, Clova, Spur, and Mintos are scarce at this mapping scale despite their young age. Secondary craters less than 0.5 km in diameter are superposed on channel material northwest of the crater Glendore. The paucity of secondary craters may be related to the poor retention properties of the target materials or to the low impact energy of the secondary ejecta.

STRUCTURE

The Xanthe Terra-Chryse Planitia boundary coincides in this quadrangle with the planetwide highland-lowland boundary scarp. The rugged massifs of Xanthe Terra in the map area may be remnants of the rim of an ancient Chryse impact basin (Schultz and others, 1982; Schultz and Frey, 1990), or the boundary scarp may be tectonic (Wise and others, 1979; Phillips, 1988; Turcotte, 1988). No other evidence of faulting is apparent in the quadrangle.

The only significant structural features observed in the quadrangle are ridges of varied size, spacing, and orientation, which superficially resemble wrinkle ridges of the lunar maria. Martian ridges may be formed by either volcano-tectonic (Scott and Carr, 1978) or tectonic mechanisms (Maxwell, 1978; Plescia and Golombek, 1986; Watters, 1988). Scott (1989) pointed out that the ridges are characteristic of lava plains and, thus, may be lava extrusions from fissures. However, on the basis of observations of terrestrial surface deformation that accompanies shallow thrust faults, Plescia and Golombek (1986) suggested that the ridges are structural in origin and may not be unique to volcanic materials.

The largest wrinkle ridges in this quadrangle—Iamuna Dorsa, Xanthe Dorsa, and Xanthe Scopulus—are broad, low arches in the northeast and central parts of the map area. They are 20 to 40 km long and 3 to 8 km wide. Xanthe Scopulus is highly dissected by the outflow from Maja and Maumee Valles; a remnant is mapped at about lat 20.4° N., long 52.5°, north of Maumee Valles.

Intermediate-size wrinkle ridges are steep, narrow, crenulated structures. One group is found mainly in the northwestern part of Chryse Planitia. Either these ridges are considerably subdued or they show only narrow, crenulated crests unmodified by fluvial activity. They trend dominantly north to northnorthwest, but they have no regular spacing. Their lengths range from 5 to 40 km, spacing averages 30 km, and widths range from less than 1 to 3 km.

Other intermediate-size wrinkle ridges are found throughout the south-central and southeastern parts of the map area and have been dissected by flooding. These ridges trend northwest to northeast and have random spacing. They are 5 to 20 km long and less than 3 km wide.

Wrinkle ridges that postdate the Hesperian flooding event are of particular interest because they indicate at least two episodes of ridge formation. These ridges, formed on the channel floors, are small and relatively pristine with distinct, sharp margins. The origin of these ridges is also unclear.

The smallest ridges are east of the mouth of Vedra Valles (fig. 4). They are 1 to 9 km long, less than 1 km wide, and sinuous. They have random trends and spacing; some crosscut others. Because they appear fresh and are seen near the Vedra mouth, they are probably postfluvial, formed by soft-sediment deformation in delta materials. Some prominent ridges are circular and may result from surface deformation over buried crater rims.

FLUVIAL HISTORY

The Maja Valles originate in Juventae Chasma (fig. 1), a large box canyon. The north wall of the canyon is breached, and the Maja Valles extend northward along a broad trough formed by the intersection of the east slope of the Lunae Planum ridged plains and the highland surface of Xanthe Terra (fig. 1). The course of the water flow is marked by scours, inner channels, and streamlined islands. Eleven hundred kilometers north of their primary source, the Maja Valles turn northeastward to cross Xanthe Terra in a steep-sided canyon. Channeled fan material, streamlined islands, and scoured surfaces mark the path of the flow from the mouth of the canyon into the western part of the Chryse Basin. Wide, shallow, flat-floored channels then carried the flow northeastward toward the topographic low in the north-central part of the basin. All traces of the flow are lost approximately 1,600 km from its source.

North of the Maja Valles canyon section, a complex system of anastomosing and subparallel valleys (fig. 2) traverses Xanthe Terra from Lunae Planum to Chryse Planitia. The Darvel quadrangle includes the east end of the Maja canyon section; the mouths of Bahram and Vedra Valles as they open onto Chryse Planitia; and the continuation of Maja and Maumee Valles, which join to form a single wide outflow channel at the east edge of the quadrangle.

Much of the highlands of Xanthe Terra in the quadrangle is covered by smoothed cratered plateau material, which was smoothed by sheetflooding so that its surface has less relief and fewer craters than unmodified plateau material. The higher elevations of the crater Sögel retain fresh morphologic detail, but the lower parts of the ejecta blanket are degraded by sheetflood flow and incipient channeling.

The flow was split into many small channels on the eastern slope of Xanthe Terra, and it ponded in local closed basins and craters. An example is the crater Northport, whose upstream rim is cut by two inlet channels (fig. 5). After the crater was filled, it was eventually drained through an outlet channel on its downslope rim. Some early, rapidly abandoned channels have branching and anastomosing patterns and rounded cross-sectional profiles. As the flow was captured by a few major channels that were incised deeper into the highland material, the channels became steep sided and flat bottomed. Smaller abandoned channels were left as hanging valleys. Finally, flow was confined to four major channels: Maja, Maumee, Vedra, and Bahram Valles. Both Maumee and Vedra Valles have U-shaped cross-sectional profiles, steep walls, and fairly uniform widths.

The Maja Valles canyon section is the largest and youngest valley in the map area. The canyon tapers in width from greater than 50 km west of Xanthe Terra to about 5 km in a narrow constriction in the rugged highlands of eastern Xanthe Terra (lat 17.9° N., long 53.9°). Prior to carving an exit through Noachian massif material, water was impounded in a large lake within Xanthe Terra (De Hon and Pani, 1992). Some of the flow escaped by carving a relief channel southward (from lat 17.8° N., long 53.9°) to bypass the retaining massif. As water continued to rise in the lake, it spilled over the highland barrier into Chryse Planitia. Noachian basement material on either side of the breach at the canyon mouth is scoured by flow that crested the barrier. The breach rapidly enlarged to drain the lake and divert the remaining flood waters into Chryse.

Fan material is most extensive at the east end of the Maja Valles canyon section (fig. 3). The fans were deposited during the waning stages of the major flow, and the Maja fan was later eroded by episodic discharges that produced an array of ill-defined channels. Fan deposits are also observed where Maumee Valles debouched into Chryse, at the mouth of Vedra Valles (fig. 4), and at the mouth of crater Northport's outlet channel. Patches of high-albedo material are found at the debouchment of Maumee Valles and on their fan-delta deposits. These bright mounds resemble longitudinal bars found in terrestrial braided streams (Baker and Kochel, 1979).

No fan deposit is identified with the mouth of Bahram Vallis, but extensive smoothing of terrain in northern Chryse Planitia may be due to blanketing of ridged plains materials by thin alluvial deposits. Albedo mottling of these materials is caused either by small-crater ejecta of contrasting albedo or by light materials in local sediment traps. The area shown by overlay pattern may be mantled by thin sediments deposited by unconfined overland flow during the earliest stages of the trans-Xanthe overflow (Theilig and Greeley, 1979).

In addition to fan deposits, the outflow features across Chryse Planitia include streamlined islands of plains-forming material and bars. Many of these islands and bars formed downstream from craters and, therefore, can be interpreted as mostly erosional, but some features on the lee side of obstacles such as craters or ridges are depositional. The tops of many bars have small longitudinal grooves, which indicates that they were completely submerged for a time. Some wrinkle ridges along the path of the outflow appear pristine, whereas others have been eroded and subdued by the flow.

Xanthe Scopulus temporarily impounded the flow to form a lake in western Chryse about 115×170 km in area, roughly the same size as Lake Ontario. Eventually the ridges were crested and dissected as the flow drained eastward (fig. 6). Longitudinal grooves and striations on remnant patches of ridged plains material indicate that the initial breakout from the impoundment was as a shallow, sheetflood flow spread over a front wider than 150 km. At maximum discharge, the flow may have briefly skirted the north flank of crater Nema, as indicated by a few discontinuous patches of rim ejecta. The water rose a few tens of meters to scour the surface of islands of ridged plains material in the central and eastern parts of the quadrangle. The northwestern part of the ejecta blanket of crater Darvel was eroded by the outflow.

As the flood level dropped, two channels were established, the lower parts of Maumee and Maja Valles, that carried the flow toward the north-central part of Chryse Basin. The two channels merge near the east border of the map area. Channel patterns and features become progressively more diffuse toward the northeast, and the merged channel is undetectable in central Chryse Planitia, in the vicinity of the Viking 1 landing site located northeast of the quadrangle (at lat 22° N., long 48°).

A time-dependent sequence of water-formed features is recorded along the outflow system.– The outflow and its associated features may have been either the product of a short-lived series of events or the result of a complex, protracted history. Theilig and Greeley (1979) suggested that Bahram, Vedra, and Maumee Valles were formed by a separate event before the development of Maja Valles. De Hon (1987) proposed that Maumee, Vedra, and lower Bahram Valles first formed by outflow from the Lunae Planum catchment and that the Maja Valles canyon section across Xanthe Terra formed as the last event of that episode. Once the Maja Valles canyon was established, it captured the remaining flow and became the dominant channel for the final drainage of the impounded waters on Lunae Planum and for subsequent discharges from the upper Maja source areas.

The duration of discharge from the Lunae Planum catchment basin has been estimated to have been at least 14 terrestrial months (De Hon and Pani, 1993). The west Chryse impoundment held less water than the Lunae Planum basin. Consequently, the west Chryse impoundment overflowed, releasing water to continue flowing toward central Chryse. As the outflow eroded through the Xanthe Scopulus barrier, the Chryse impoundment was completely emptied, but discharge continued from the larger Lunae Planum basin. Discharge through the canyon system and across the lake bed eroded the recently deposited sediments. The only evidence of the short-lived lake in Chryse is streamlined islands of remnant sediments on the lake floor.

GEOLOGIC HISTORY

The earliest geologic events recorded in this quadrangle are represented by highly cratered Noachian materials and the formation of the Chryse Basin. Whether the basin is the remnant of a giant impact remains undetermined. The impact flux diminished during Late Noachian time and was followed by the formation of relatively smooth plains of volcanic or debris origin in the lower lying terrains.

Early Hesperian time is marked by the emplacement of vast flood basalts characterized by smooth surfaces with long, sinuous wrinkle ridges, similar to those on the Moon. In the Late Hesperian, after an extended period of relative inactivity (but when the impact craters Sögel, Darvel, Nema, and Weer were formed), catastrophic flooding occurred in the Maja Valles region. Overflow from a large impoundment on Lunae Planum carved channels across Xanthe Terra that debouched into Chryse Planitia.

Large wrinkle-ridge systems impounded the water, forming a large lake in western Chryse Planitia. Once waters crested the ridges, the flood surge continued eastward toward the center of Chryse Planitia to be lost by evaporation and infiltration. The outflow was for the most part a single occurrence, but it may have been prolonged by temporary restraining of flood waters in local basins and secondary releases from other sources. A few isolated wrinkle ridges were formed in the channel floors after the outflow.

Impact cratering continued into Amazonian time, although at a much lower rate. The most active process at present is probably the eolian redistribution of surficial material, as shown by crater wind streaks in northwestern Chryse Planitia.

REFERENCES CITED

Baker, V.R., and Kochel, R.C., 1979, Martian channel morphology: Maja and Kasei Valles: Journal of Geophysical Research, v. 84, no. B14, p. 7961–7983.
Carr, M.H., Crumpler, L.S., Cutts, J.A., Greeley, Ronald, Guest, J.E., and Masursky, Harold, 1977, Martian impact craters and emplacement of ejecta by surface flow: Journal of Geophysical Research, v. 82, no. 28, p. 4055–4065.
De Hon, R.A., 1987, Eastern Lunae Planum outflow complex: Analogy to overbank flooding, *in* Abstracts of papers submitted to the Eighteenth Lunar and Planetary Science Conference, pt. 1, Houston, March 16–20, 1987: Houston, Lunar and Planetary Institute, p. 227–228.
———1992, Geologic map of the Pompeii quadrangle (MTM 20057), Maja Valles region of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–2203, scale 1:500,000.
De Hon, R.A., and Pani, E.A., 1992, Flood surge through the Lunae Planum outflow complex, Mars, *in* Lunar and Planetary Science Conference, 22d, Houston, March 18–22, 1991, Proceedings: Houston, Lunar and Planetary Institute, p. 63–71.
———1993, Duration and rate of discharge, Maja Valles, Mars: Journal of Geophysical Research, v. 98, no. E5, p. 9129–9138.
Greeley, Ronald, and Guest, J.E., 1987, Geologic map of the eastern equatorial region of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1802–B, scale 1:15,000,000.
Greeley, Ronald, and Spudis, P.D., 1981, Volcanism on Mars: Reviews of Geophysics and Space Physics, v. 19, no. 1, p. 13–41.
Greeley, Ronald, Theilig, Eilene, Guest, J.E., Carr, M.H., Masursky, Harold, and Cutts, J.A., 1977, Geology of Chryse Planitia: Journal of Geophysical Research, v. 82, no. 28, p. 4093–4109.
Maxwell, T.A., 1978, Origin of multi-ring basin ridge systems: An upper limit to elastic deformation based on a finite element model, *in* Lunar and Planetary Science Conference, 9th, Houston, March 13–17, 1978, Proceedings: Lunar and Planetary Institute, p. 3541–3559.
Milton, D.J., 1974, Geologic map of the Lunae Palus quadrangle of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–894, scale 1:5,000,000.
Phillips, R.J., 1988, The geophysical signal of the Martian global dichotomy: Eos, Transactions, American Geophysical Union, v. 69, p. 389.
Pike, R.J., 1980, Formation of complex impact craters: Evidence from Mars and other planets: Icarus, v. 43, p. 1–19.
Plescia, J.B., and Golombek, M.P., 1986, Origin of planetary wrinkle ridges based on a study of terrestrial analogs: Geological Society of America Bulletin, v. 97, no. 11, p. 1289–1299.
Schultz, P.H., Schultz, R.A., and Rogers, John, 1982, The structure and evolution of ancient impact basins on Mars: Journal of Geophysical Research, v. 87, no. B12, p. 9803–9820.
Schultz, R.A., and Frey, H.V., 1990, A new survey of multiring impact basins on Mars: Journal of Geophysical Research, v. 95, no. B9, p. 14,175–14,189.
Scott, D.H., 1989, New evidence—old problem: Wrinkle ridge origin, in Abstracts for the METV-LPI Workshop, Tectonic Features on Mars, Richland, Washington, 1989: Houston, Lunar and Planetary Institute, p.26–28.
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 King, J.S., 1984, Ancient surfaces on Mars: The basement complex, *in* Abstracts of papers submitted to the Fifteenth Lunar and Planetary Science Conference, pt. 2, Houston, March 12–16, 1984: Lunar and Planetary Institute, p. 736–737.
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.
Tanaka, K.L., 1986, The stratigraphy of Mars, *in* Lunar and Planetary Science Conference, 17th, Houston, March 17–20, 1986, Proceedings, pt. 1: Journal of Geophysical Research, v. 91, no. B13, p. E139–E158.
Theilig, Eilene, and Greeley, Ronald, 1979, Plains and channels in the Lunae Planum-Chryse Planitia region of Mars: Journal of Geophysical Research, v. 84, no. B14, p. 7994–8010.
Turcotte, D.L., 1988, Early evolution of the Martian interior: Eos, Transactions, American Geophysical Union, v. 69, p. 389.
U.S. Geological Survey, 1985, Controlled photomosaic of part of the Maja Valles region of Mars (MTM 20052): U.S. Geological Survey Miscellaneous Investigations Series Map I–1693, scale 1:500,000.
Watters, T.R., 1988, Wrinkle ridge assemblages on the terrestrial planets: Journal of Geophysical Research, v. 93, no. B9, p. 10,236–10,254.
Wise, D.U., Golombek, M.P., and McGill, G.E., 1979, Tharsis province, Mars: Geologic sequence, geometry, and a deformational mechanism: Icarus, v.38, p. 456–472.

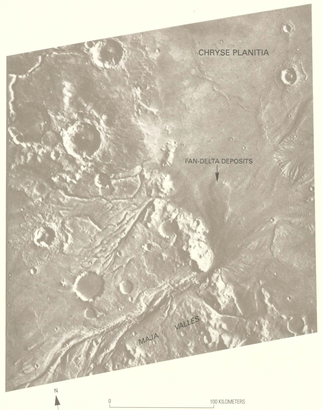


Figure 3. Low-relief fan deposit at east end of canyon section of Maja Valles. Image is 300 km across, centered at lat 18.5° N., long 54.8°. Viking Orbiter image 825A25.

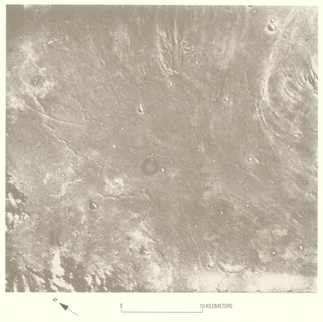


Figure 4. Small, irregularly spaced ridges in fan deposits near mouth of Vedra Valles. Ridges may be caused by deformation of soft sediments during compaction of fan. Viking Orbiter image 22A79; boundary shown on geologic map.

Figure 5. South rim of crater Northport (18.5 km in diameter). Rim was breached by flood waters that filled crater. Crater Calamar (7 km in diameter) is superposed on channel that fed into Northport. Viking Orbiter image 46A58; boundary shown on geologic map.

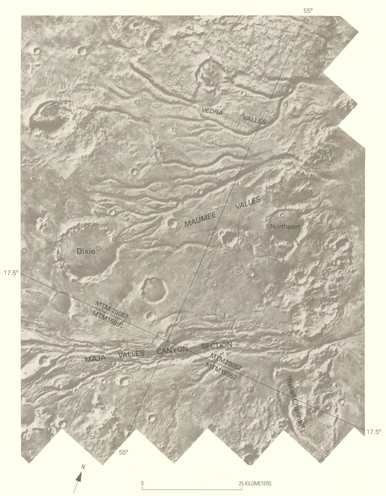


Figure 2. Photomosaic of valleys crossing part of Xanthe Terra. (Only southwestern part of Darvel quadrangle is shown.) Maumee and Vedra Valles head at west edge of Xanthe; multiple channels cross Xanthe in anastomosing, subparallel drainage pattern. Tributaries coalesced into trunk channels that discharged into Chryse Planitia. (See Fluvial History.) Photomosaic of more than 35 Viking images.

Figure 6. Dissected ridge, Xanthe Scopulus, once impounded water from valley systems in western Chryse Planitia. Viking Orbiter image 46A66; boundary shown on geologic map.

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