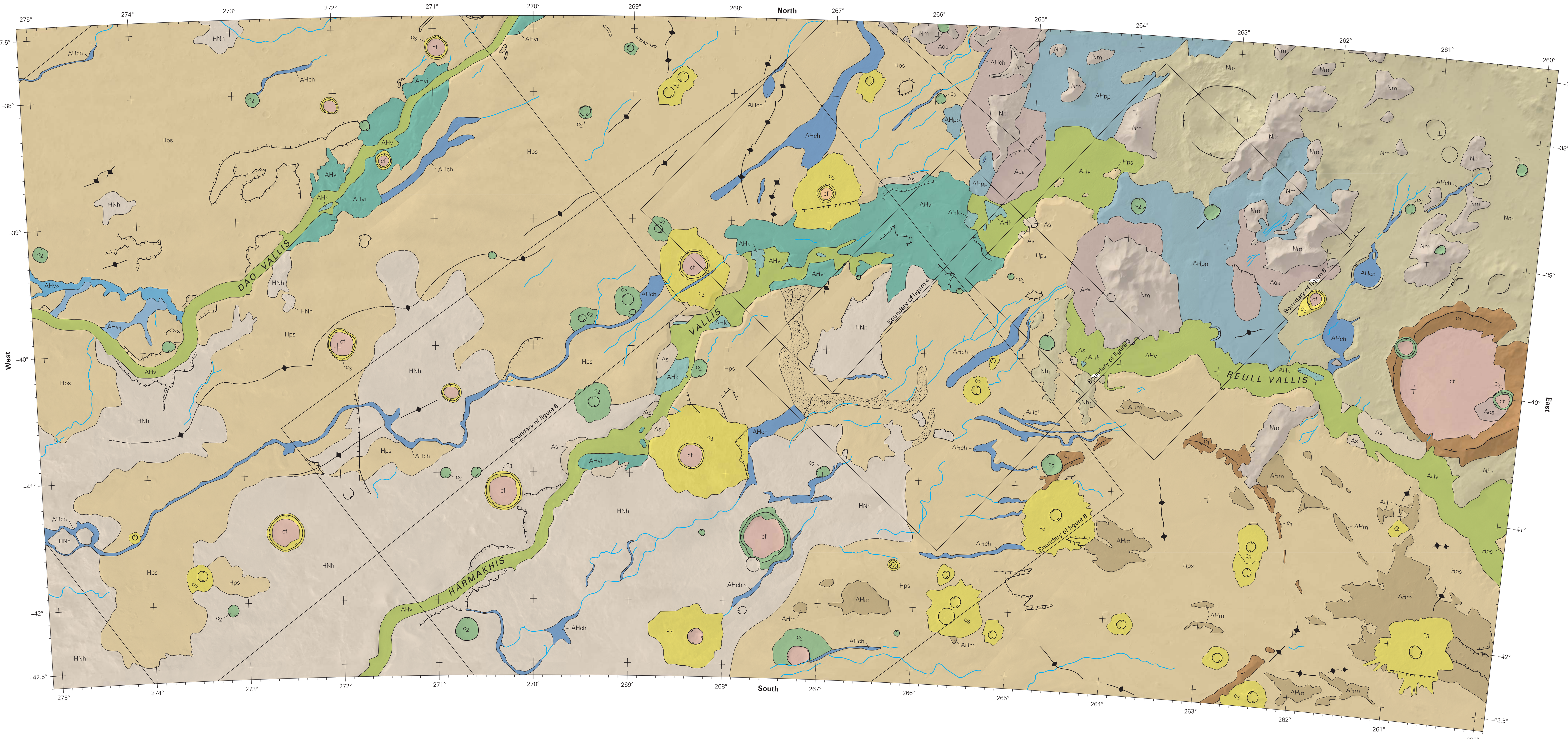
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared for the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ATLAS OF MARS
1:1,000,000 GEOLOGIC SERIES
DAO, HARMAKHIS, AND REULL VALLES—MARS
M 1M –40/262, –40/267, –40/272 G, 1998
I–2557



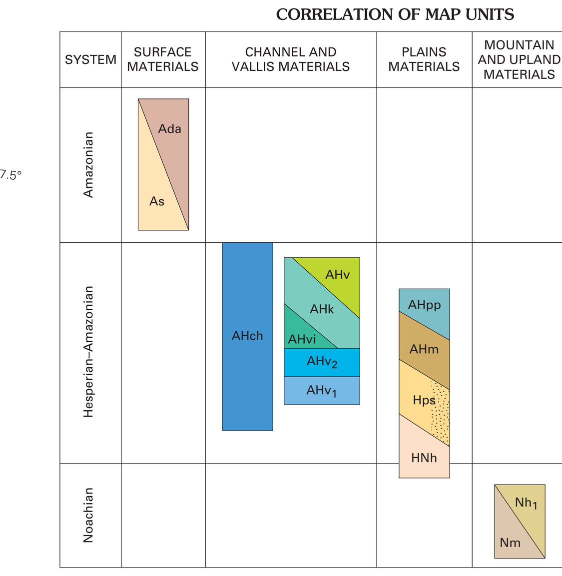
Base from U.S. Geological Survey (1990a, b, c)

SCALE 1:1 004 000 (1 mm = 1.004 km) AT 270° LONGITUDE
TRANSVERSE MERCATOR PROJECTION

KILOMETERS

Prepared on behalf of the Planetary Geology Program, Solar System Exploration Division, Office of Space Science, National Aeronautics and Space Administration
Edited by Derrick D. Hirsch; cartography by Darlene A. Casebier
Manuscript approved for publication December 21, 1993

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

SURFACE MATERIALS

Ada — **Debris apron material**—Smooth or pitted lobate deposits form slopes at base of mountains. *Interpretation*: Weathered debris from mountainous terrain moved downslope as viscous or partly fluid mass. Surfaces pitted by collapse of water- or ice-rich deposits

As — **Slide material**—Irregular, lobate deposits; some at base of curvilinear slopes. *Interpretation*: Plains materials wetted during outflow events moved downslope as viscous mass into channels

CHANNEL AND VALLIS MATERIALS

AHv — **Vallis floor material**—Smooth surfaces on floors of steep-walled outflow channels. *Interpretation*: Sediments deposited and smoothed by water during times of outflow in valles

AHk — **Knobby vallis floor material**—Hummocky surfaces on steep-walled vallis floors. *Interpretation*: Plains materials modified by fluvial processes. Knobs probably partially eroded remnants that collapsed into vallis

AHvi — **Irregular vallis floor material**—Large, smooth, irregularly shaped blocks of low relief dissected by small channels and small to large fractures. Located at heads and margins of valles. *Interpretation*: Plains materials modified by fluvial erosion in initial stages of collapse

AHch — **Channel floor material**—Smooth surfaces in elongate, sinuous channels; linear and curvilinear features parallel channel margins. *Interpretation*: Channel deposits containing fluvial erosional and depositional features

AHv_2 — **Younger cut-off vallis floor material**—Smooth materials in elongate, sinuous channels; crosscut by unit AHv. *Interpretation*: Channel deposits in younger cut-off channel segments of Dao Vallis

AHv_1 — **Older cut-off vallis floor material**—Smooth surfaces in elongate, sinuous channels; similar to materials in unit AHv_2; crosscut by younger channels (units AHv and AHv_2). *Interpretation*: Channel deposits in older cut-off channel segments of Dao Vallis

PLAINS MATERIALS

AHpp — **Pitted plains material**—Smooth material with regularly spaced, shallow, circular depressions. *Interpretation*: Partially collapsed water- or ice-rich deposits or materials modified by deflation

AHm — **Mesa material**—Smooth, flat-topped features bounded by irregular scarps; topographically higher than surrounding plains. *Interpretation*: Erosional remnants of sedimentary mantle

Hps — **Smooth plains material**—Forms plains of slight to moderate relief cut by narrow, sinuous channels; forms low plateau south of Harmakhis and Reull Valles. Moderate albedo. No primary volcanic features visible. Modified to form giant regularly spaced ridges in western third of map area. Raised sinuous features (stipple) are smooth and topographically equal to or just higher than the plains on which they rest. Younger channels etch the margins of these raised, sinuous features in some places. *Interpretation*: Sedimentary deposits modified by fluvial and possibly by periglacial and eolian processes. Large irregular blocks in initial stages of collapse from sapping and dissection. Raised sinuous features may be paleochannels filled with material slightly more resistant than surrounding plains. Together with the larger channel deposits (unit AHch), the smooth plains material defines paleodrainage networks that flowed south and later were crosscut by Harmakhis Vallis. Giant ridges may have resulted from solifluction

HNh — **Hummocky plains material**—Forms irregular to highly irregular surfaces of moderate relief cut by channels; mottled appearance, especially in southwestern part of map area; lower albedo than smooth plains material (unit Hps). In places bordered by infacing escarpments forming windows in smooth plains material. *Interpretation*: Volcanic or sedimentary deposits underlying smooth plains material (unit Hps). Irregular texture and mottling may represent relict topography or reworking of old (or exhumed) surface materials. Probable causes for irregular surface texture, whether contemporaneous with unit formation or more recent, include eolian (deflation or deposition) or partial collapse of water- or ice-rich deposits

MOUNTAIN AND UPLAND MATERIALS

Nh_1 — **Hellas basin-rim materials**—Rugged, cratered uplands modified by erosional processes. *Interpretation*: Ancient crustal material faulted and uplifted during periods of heavy impact cratering; modified by erosional processes to form topography less angular than blocks of mountainous material (unit Nm)

Nm — **Mountainous material**—Forms steep, sharp-crested, rugged, isolated blocks from 3 to 45 km long; also forms semicircular ridges. *Interpretation*: Ancient crustal material faulted and uplifted during periods of heavy impact cratering; forms old crater rims in places

CRATER MATERIALS

[Materials associated with craters are interpreted to be of impact origin and have been subdivided into three groups based on their relative ages as determined from morphology and superposition. Craters with diameters smaller than 5 km are not mapped except where they have stratigraphic significance]

cf — **Crater-filling material**—Smooth, relatively featureless deposits partly filling some craters. *Interpretation*: Sedimentary fill; probably eolian

c_3 — **Material of well-preserved craters**—Fresh-appearing craters having sharp, continuous rim crest, steep inner wall, and well-defined, continuous, often lobate ejecta blanket extending one crater diameter or more beyond rim crest. Commonly superposed on materials of Amazonian to Hesperian age. Ejecta blankets not mapped where poorly resolved on images. *Interpretation*: Youngest craters in map area

c_2 — **Material of moderately degraded craters**—Partly eroded, rounded rim crest; ejecta deposits extend around crater less than one crater diameter where mappable. *Interpretation*: Moderately old craters

c_1 — **Material of highly degraded craters**—Subdued and discontinuous rim crest; ejecta deposits not recognizable or form narrow outer rim. Embayed or partly buried by younger units. *Interpretation*: Oldest crater materials in map area; some may be Noachian age

Contact—Dashed where approximately located

Ridge crest—Dashed where approximately located

Scarp top—Hachures point downslope; dashed where approximately located

Depression

Dome or circular scarp—Hachures point downslope

Narrow channel

Crater rim—Showing crest; dotted where buried

Central peak of crater

INTRODUCTION

The geology for this map was compiled using Viking Orbiter images on 1:500,000-scale photomosaics of the Mars Transverse Mercator quadrangles –40262, –40267, and –40272. This map represents a detailed extension of regional geologic mapping of the east Hellas rim (Crown and others 1990, 1992) and is published at 1:1,000,000 scale. The map area is on the east rim of one of the largest impact structures in the Solar System, the ~2,000-km-diameter Hellas basin (fig. 1). Channeled plains, with Dao, Harmakhis, and Reull Valles as the primary drainage features, dominate much of the surface within the map area. Dao Vallis is the downstream extension of Niger Vallis, which originates on the south flank of Hadriaca Patera, north of the map area. Harmakhis Vallis and Reull Vallis appear to intersect near latitutude 38°30' S., longitude 264°30'; Harmakhis Vallis trends southwest and Reull Vallis trends southeast from the area of intersection. The source area for these major outflow channels is at the intersection of two principal rings of multiring impact basins (Potter, 1976; Schultz and Frey, 1990; fig. 1). Hellas basin is centered southwest of the map area, and the proposed Hesperia basin is centered northeast of the map area (Schultz and Frey, 1990).

The eastern part of the map area contains extensive remnants of ancient mountains and crater rim materials, along with large mesa-like features. Landforms over the entire map area appear to have been modified by multiple erosional events including downslope movement, eolian, and fluvial processes.

The purpose of mapping the geology of the Dao, Harmakhis, and Reull Valles region of Mars is to refine stratigraphic and geomorphologic relations among the geologic units in the area in order to better understand the nature of, relative timing of, and interactions among martian highland surface processes.

STRATIGRAPHY AND GEOMORPHOLOGY

Map units are defined based on their geomorphologic properties, which are interpreted to reflect the mode of formation and degradational history. The map units are classified as mountain and upland materials, plains materials, channel and vallis materials, surface materials, and crater materials. Generally, and where feasible, map units follow the formal terminology proposed by Greeley and Guest (1987). However, over most of the map area geologic units have been subdivided and the contacts modified following detailed examination of Viking Orbiter images. The area mapped on these quadrangles displays significant modification of the original topography created by the Hellas impact. Surficial modification has been accomplished by regional deposition of several plains material units, by downslope movement of steeply inclined materials, and by channel erosion.

NOACHIAN SYSTEM

Among the oldest units in the map area is the Noachian mountainous material (unit Nm), which forms large, rugged, isolated blocks that rise above the surrounding plains. This unit is found in the northeastern part of the map area. Greeley and Guest (1987) interpreted this unit to be ancient crust that was uplifted during the Hellas and other impact event. Some of the mountainous blocks apparently were modified by more recent impact events, as they now display smaller, more clearly defined crater rim morphology.

Hellas basin-rim material (unit Nh_1) (Greeley and Guest, 1987) is more continuous than but not as rugged as the mountainous material (unit Nm). The basin-rim material is more extensive on the east side of the Hellas impact site than on the west side, which has been interpreted as evidence that the Hellas structure was created by an oblique impact from the west (Leonard and Tanaka, 1993). Some of the Noachian materials may have been uplifted and deformed during the postulated Hesperia basin multiring structure event (Schultz and Frey, 1990). Greeley and Guest (1987) mapped these same Noachian units as rugged and heavily cratered materials of the Hellas basin rim.

LATE NOACHIAN, HESPERIAN, AND AMAZONIAN SYSTEMS

Plains units in the map area embay older mountain material and are eroded by younger channels. In this region, the plains were mapped as the channeled plains rim material (unit AH_5) by Greeley and Guest (1987) but are separated into four units (units HNh, Hps, AHm, and AHpp) in this study. These widespread plains materials were emplaced from Late Noachian through Amazonian time, as determined by crater counts in this study (fig. 2) and by Crown and others (1990, 1992). The oldest mapped plains unit is hummocky plains material (unit HNh), generally located in the southwestern and south-central part of the map area. The irregular topographic appearance of this unit may be attributed to lava flow morphology or, more likely, to thermokarst modification of the surface material that overlies an ice-rich substrate. Thermokarst topography is generated from softening and partial collapse of ice-rich surface materials, generating a hummocky, irregular surface. These surface materials may consist of sediments shed from nearby Noachian highlands, or they may be eolian deposits derived from a combination of local and more distant terrain. Alternatively, the surface materials may be lavas that were erupted from local fissures or from Hadriaca or Tyrrhena Paterae to the north (Crown and Greeley, 1993). Whatever the nature of the surface materials, partial melting of subsurface ice probably generated the observed thermokarst appearance of the hummocky plains material. The thermokarst topography may be interpreted as a relict landform because it seems to be most prominently displayed on the oldest plains unit (unit HNh).

Smooth plains material (unit Hps), which may be either interbedded volcanics or a sedimentary mantle or a combination of both, locally overlies the hummocky plains material. Most likely the smooth plains material is sedimentary because it lacks visible lava flow structures, such as lobate flow margins. At three places near the center of the map area, in-facing scarps of the younger smooth plains material form windows through which the underlying hummocky plains material is exposed (fig. 3). Sinuous features, having positive relief and lobate margins in places, are also seen in the smooth plains unit (fig. 3). These features are interpreted as former channels that were filled with material which is now more resistant to erosion than the surrounding plains materials, and they are topographically inverted. These resistant materials may have originated as lava that issued from fissures, though sources for the lava flows are not evident in the near vicinity. A sedimentary origin is more likely, as mudflows or sediment-laden water from the release of ground water under pressure might have filled the preexisting valleys. In order for the resulting sedimentary materials to be more resistant than surrounding materials, they must have been cemented or laden with large clasts. Proposed catastrophic release of ground water (Carr, 1979; Baker and others, 1992; Clifford, 1993) would have had the capacity and competence to transport such a sediment load.

In places along the margins of the valleys and at the head of Harmakhis Vallis, both smooth and hummocky plains materials (units Hps and HNh) collapsed during vallis formation and were modified to form large, smooth, irregularly shaped blocks. The collapse of these materials—mapped as irregular vallis floor material (unit AHvi; figs. 4, 5)—probably occurred following saturation of the plains materials due to melting ground ice at the time of vallis formation.

Along the walls of Reull Vallis, the layered nature of at least two plains units (probably units HNh and Hps) can be observed (fig. 5). The layered appearance is probably a result of differential weathering and erosion, which is due to the units possessing slightly different resistances to weathering and erosion processes and which may or may not follow formational contacts.

North of Dao Vallis, the smooth plains material (unit Hps) has a ridged appearance (fig. 6). The ridges are large-scale, gently arcuate, parallel features that trend nearly east-west and that occupy more than 2,000 square km. The rhythmic spacing between ridge crests ranges from 5 to 15 km (fig. 6). The ridged topography is crosscut by Dao Vallis, though south of Dao Vallis these features are less aerially extensive. The large ridges may have formed as glacial moraines; periglacial features associated with permafrost; giant eolian, fluvial, or lacustrian ripple marks; or volcanic or tectonic features. The magnitude of the rhythmic features suggests that the ridges probably formed by solifluction—the slow downslope movement of permafrost terrain. If so, a regional paleoslope that was nearly due south (about 45 degrees from the slope radial to Hellas along which Dao Vallis flowed) is suggested by the nearly east-west ridge trend. The existence of a more southerly paleoslope is also supported by the presence of a channel network near Harmakhis Vallis (discussed below with other channel features). Just south of the large-scale ridges is a line of similarly sized cuspate ridges, with cusps ~50 km long trending generally north-northeast to south-southwest across the west-central part of the map area (fig. 6). This line of ridges does not have the same morphology as the large-scale ridges and so is likely of a different origin—probably either glacial moraines or old, degraded wrinkle ridges.

Two other plains units are mapped in the east half of the map area. Mesa material (unit AHm) forms smooth, raised, flat-topped features with irregular escarpment margins in the southeastern part of the map area. The larger isolated mesas extend over areas of ~300 km^2. Shadow measurements (fig. 7) show the mesa escarpments to be ~350 meters high. The escarpments appear to be erosional remnants of a former wide-spread mantle, most likely eolian material, which rests on the older smooth plains material (unit Hps). Pitted plains material (unit AHpp) is associated with mountainous terrain and debris aprons and is situated north of Reull Vallis (fig. 5). Pitted plains are interpreted to be partially collapsed water- or ice-rich materials—either lava flows or, more likely, sedimentary deposits (Squyres, 1979; Squyres and Carr, 1986; Crown and others, 1992; Squyres and others, 1992).

HESPERIAN AND AMAZONIAN SYSTEMS

Channels within the map area show two distinct morphologies. Younger outflow channels are predominant and form features called valles—somewhat degraded trough-shaped valleys that head in large semicircular depressions and that have a fairly consistent downstream width of ~10 km. Shadow measurements show that the vallis walls stand between 0.75 and 3.5 km above the channel floor. Three units are mapped associated with the outflow channels. The channel floors consist primarily of vallis floor material (unit AHv), which appear to be sedimentary deposits that have been smoothed by fluvial erosion. Irregular vallis floor material (unit AHvi), most abundant at the heads of Harmakhis and Dao Valles, is bank material that collapsed during fluvial erosion. Knobby vallis floor material (unit AHk) is mapped where previously irregular vallis floor material has been partially smoothed by fluvial processes (fig. 8). Proposed mechanisms for the formation of the large outflow channels, including erosion by wind, lava flows, liquid hydrocarbons, glaciers or ice streams, debris or mud flows, and water floods, are summarized by Baker and others (1992). Channel morphology suggests that valles formed, and were enlarged and modified by sapping—the erosion of surface materials by ground water outflow. This conclusion is supported by numerous field and laboratory studies summarized by Baker and others (1992).

Two probable cut-off outflow channel segments are on the north side of Dao Vallis near the west-central edge of the map area (units AHv_1 and AHv_2) (fig. 6). Such channel migrations can occur with high-magnitude discharges, which are infrequent and episodic. Crosscutting relations displayed by these channels suggest at least two changes in the course of the Dao Vallis channel that probably occurred over a relatively short interval of geologic time.

Researchers presume that a global ground water system that included water and ice stored in the fractured megaregolith existed (and may still exist) on Mars (for example, Squyres and others, 1992; Clifford, 1993). At the source areas for Dao, Harmakhis, and Reull Valles, the megaregolith is probably more highly fractured and, therefore, more porous and permeable than usual for Mars. One explanation for the highly fractured megaregolith may be that these areas are located at the intersection of two proposed primary rings of multiring impact basins—Hellas and South Hesperia basins (Schultz and Frey, 1990). If this highly fractured region was saturated, more water and ice would have been available for release from these areas. The release of ground water to form outflow channels at the surface may have been triggered either by subsurface rupture caused by impact or, more likely, by pore pressure reaching the confining lithostatic pressure (Carr, 1979). Near-surface water, if still present at mid-latitudes on Mars, is probably partially or entirely frozen. Melting could have been facilitated in the past by the near-surface migration of magma associated with the nearby Hadriaca Patera eruption.

Other channels are shallower than the outflow channels, are in some places crosscut by the valles, are dendritic in places, and individually are of fairly uniform width along their courses, with widths ranging from 1 to 10 km. Associated channel floor material is mapped as unit AHch. Sources for these channels are in some places the sites of impact craters where ground ice was probably melted on impact, and in other places appear to be surface runoff, either from precipitation, from springs, melting of ground ice by volcanic eruption, or associated with debris apron formation (fig. 4). Dendritic channel morphology, as seen near latitude 39°45' S., longitude 265°, suggests overland flow, which implies precipitation as a water source. Precipitation is a process invoked by many researchers and summarized by Baker and others (1992), Clifford (1993), and Craddock and Maxwell (1993).

Some of the channels appear to have ponded in crater floors, forming lakes that probably froze quickly upon filling. Geologic evidence for this is the uninterrupted extension of smooth channel deposits onto the crater floor. The best example of such a lake is at latitude 39°38' S., longitude 261°45'. Resolution on the Viking Orbiter images is not high enough to discern shoreline features at this site, therefore, the likely lacustrian materials are mapped as channel floor material (unit AHch).

A paleochannel network and perhaps a more southerly paleoslope is suggested by the channel that is crosscut by the head of Harmakhis Vallis and that extends south of Harmakhis in the form of inverted topography (fig. 9).

AMAZONIAN SYSTEM

The youngest units in the map area are lobate debris apron material (unit Ada) shed from mountains and slide material (unit As) along the margins of the channels. Slide deposits were likely formed when the channel walls were water-saturated during periods of outflow. Debris apron material has been described as analogous to terrestrial rock glaciers, where surface and near-surface materials mix with annual ice deposits and downslope movement is facilitated by interstitial ice creep (Squyres, 1979; Squyres and Carr, 1986; Squyres and others, 1992).

GEOLOGIC HISTORY

The geologic history of the Dao, Harmakhis, and Reull Valles region is interpreted here from superposition, crosscutting relations, crater counts, and the morphology of geologic units, all of which were derived from the photogeologic analysis of Viking Orbiter images. The following sequence of events is suggested from these analyses.

1. The Hellas impact and possibly an impact associated with the postulated South Hesperia basin faulted and uplifted mountainous materials during the Noachian period. These materials are preserved as rugged isolated mountains and basin rims (units Nm and Nh_1).
2. Erosion of Noachian highlands formed two of the four plains material units (units HNh and Hps). These units may be sedimentary deposits or sedimentary deposits interbedded with lava flows that originated from Hadriaca or Tyrrhena Paterae, north of the map area.
3. Water eroded small channels in upland plains surfaces, thus forming shoestring deposits of unit AHch. Water was probably mobilized, as springs, by the melting of ground ice during meteorite impact or from the intersection of the ground ice/water table with the surface.
4. Deposition and subsequent erosion of a surface mantle, probably eolian, formed mesas (unit AHm) in the southeastern part of the map area.
5. Ground ice melting or partial melting softened surface deposits and modified the smooth plains, forming ridged topography and thermokarst pitted plains (unit AHpp). These landforms may represent events in the transition between an earlier warm climate and the present frozen state. Meteorite impacts generated crater materials, which are superimposed on preexisting units.
6. Dao, Harmakhis, and Reull Valles outflow systems (units AHv, AHk, and AHvi) formed by ground water sapping, which was triggered by the melting of near-surface ground ice.
7. Lobate slide deposits and debris aprons (units As and Ada) formed along channel margins and at the base of mountains.

REFERENCES CITED

Baker, V.R., Carr, M.H., Gulick, V.C., Williams, C.R., and Marley, M.S., 1992, Channels and valley networks, *in* Kieffer, H.H., Jakosky, B.M., Snyder, C.W., and Matthews, M.S., eds., Mars: Tuscon, University of Arizona Press, p. 493–522.

Carr, M.H., 1979, Formation of Martian flood features by release of water from confined aquifers: Journal of Geophysical Research, v. 84, p. 2995–3007.

Clifford, S.M., 1993, A model for the hydrologic and climatic behavior of water on Mars: Journal of Geophysical Research, v. 98, p. 10,973–11,016.

Craddock, R.A., and Maxwell, T.A., 1993, Geomorphic evolution of the Martian highlands through ancient fluvial processes: Journal of Geophysical Research, v. 98, p. 3453–3468.

Crown, D.A., and Greeley, Ronald, 1993, Volcanic geology of Hadriaca Patera and the eastern Hellas region of Mars: Journal of Geophysical Research, v. 98, p. 3431–3451.

Crown, D.A., Price, K.H., and Greeley, Ronald, 1990, Evolution of the east rim of the Hellas basin, Mars, *in* Abstracts of papers submitted to the 21st Lunar and Planetary Science Conference, Houston, March 12–16, 1990: Houston, Lunar and Planetary Institute, p. 252–253.

———1992, Geologic evolution of the east rim of the Hellas Basin, Mars: Icarus, v. 100, p. 1–25.

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.

Knighton, D., 1987, Fluvial forms and processes: Maryland, Edward Arnold, p. 169.

Leonard, G.J., and Tanaka, K.L., 1993, Hellas Basin, Mars: Formation by oblique impact, *in* Abstracts of papers submitted to the 24th Lunar and Planetary Science Conference, Houston, March 15–19, 1993: Houston, Lunar and Planetary Institute, p. 867–868.

Potter, D.B., 1976, Geologic map of the Hellas quadrangle of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–941, scale 1:5,000,000.

Schultz, R.A., and Frey, H.V., 1990, A new survey of multiring impact basins on Mars: Journal of Geophysical Research, v. 95, p. 14,175–14,189.

Squyres, S.W., 1979, The distribution of lobate debris aprons and similar flows on Mars: Journal of Geophysical Research, v. 84, p. 8087–8096.

Squyres, S.W., and Carr, M.H., 1986, Geomorphic evidence for the distribution of ground ice on Mars: Science, v. 231, p. 249–252.

Squyres, S.W., Clifford, S.M., Kuzmin, R.O., Zimbleman, J.R., and Costard, F.M., 1992, Ice in the Martian regolith, *in* Kieffer, H.H., Jakosky, B.M., Snyder, C.W., and Matthews, M.S., eds., Mars: Tucson, University of Arizona Press, p. 523–554.

U.S. Geological Survey, 1990a, Controlled photomosaic of part of the Hadriaca region of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–2045, scale 1:500,000.

———1990b, Controlled photomosaic of part of the Hadriaca region of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–2043, scale 1:500,000.

———1990c, Controlled photomosaic of part of the Hadriaca region of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–2044, scale 1:500,000.

———1991, Topographic maps of the polar, western, and eastern regions of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–2160, 3 sheets, scale 1:15,000,000.

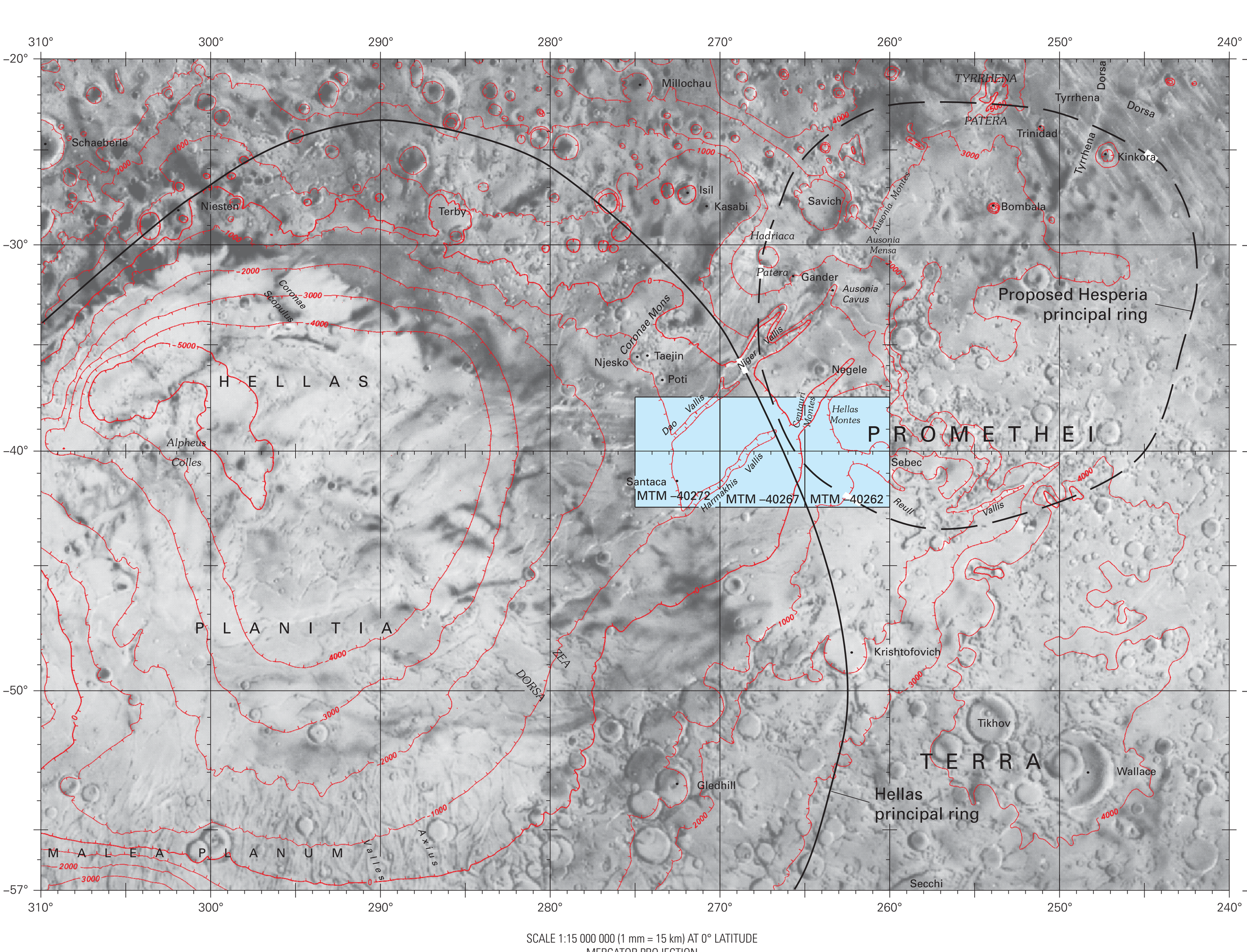


Figure 1. Index map of Hellas region showing major physiographic features and MTM quadrangles –40262, –40267, and –40272. Principal rings for Hellas and South Hesperia multiring impact basins are outlined (from Schultz and Frey, 1990). Base from U.S. Geological Survey (1991, scale 1:15,000,000).

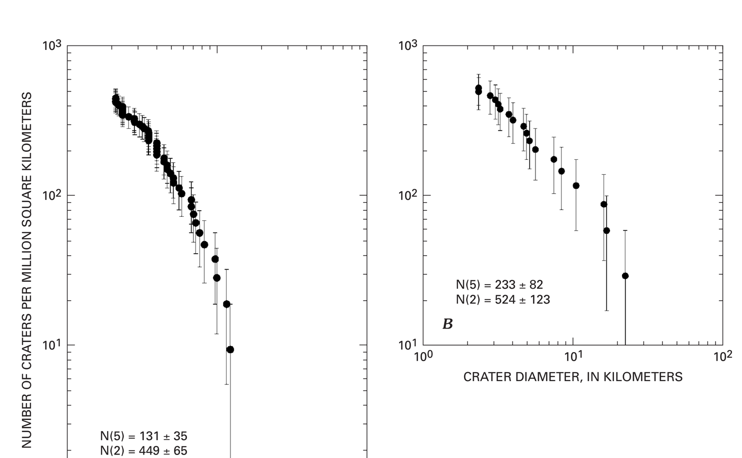


Figure 2. Crater counts for (*A*) smooth plains material (unit Hps; quadrangles –40262, –40267, –40272) and for (*B*) hummocky plains material (unit HNh; quadrangles –40267, –40272). N(2) and N(5) are the numbers of craters of width greater than 2 and 5 km, respectively. Vertical bars attached to each point are error bars and represent the range of one standard deviation. These units were mapped as one unit (unit AHh_5) by Crown and others (1992).

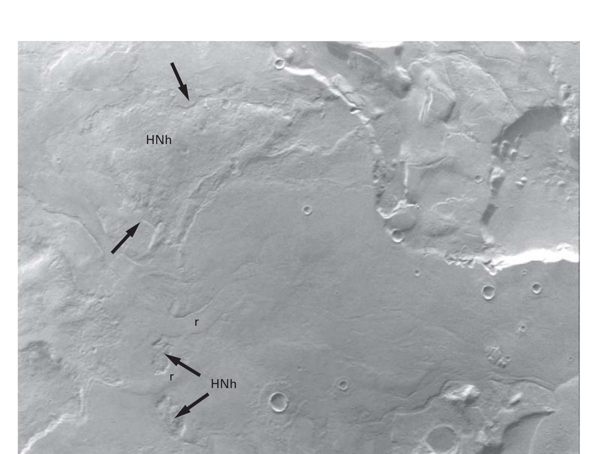


Figure 3. Sinuous raised features (labeled r) on smooth plains material (unit Hps). (Sinuous raised features shown on map as unit Hps with stipple.) In-facing escarpments (arrows) form windows on underlying hummocky plains material (unit HNh). Viking Orbiter image 408S76.

GEOLOGIC MAP OF THE DAO, HARMAKHIS, AND REULL VALLES REGION OF MARS

By
Katherine H. Price
1998

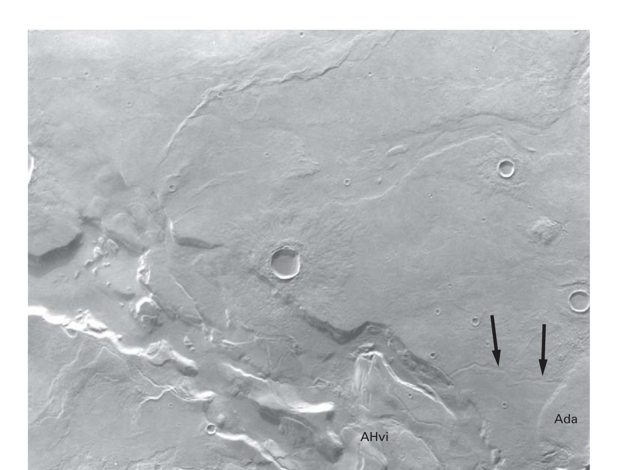


Figure 4. Partially collapsed smooth plains at the head of Harmakhis Vallis form irregular vallis floor material (unit AHvi). Partly buried channel on the upland surface (arrows) extends from under debris apron material (unit Ada) and is crosscut by Harmakhis Vallis. Viking Orbiter image 408S74.

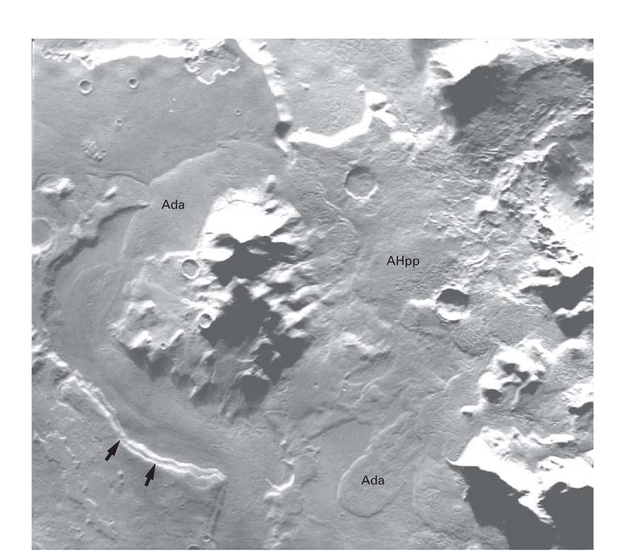


Figure 5. Layered deposits displayed in the wall of Reull Vallis (arrows) indicate multiple depositional events. Terrain softening evidence includes lobate deposits of debris apron material (unit Ada) and pitted plains material (unit AHpp). Viking Orbiter image 408S77.

Figure 6. Large-scale ridges (r) and cuspate features (c) in smooth plains material (unit Hps). Irregular vallis floor material (unit AHvi) along Dao Vallis shown with open arrows. Cut-off vallis floor materials (units AHv_1 and AHv_2) indicated with solid arrows. Viking Orbiter image 363S45.

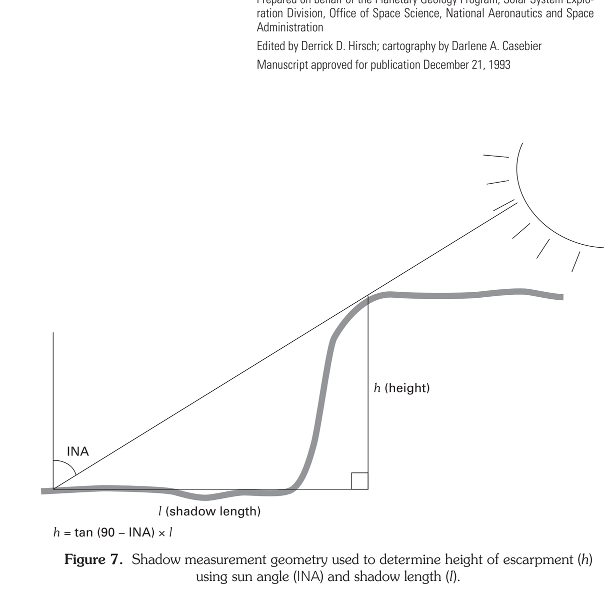


Figure 7. Shadow measurement geometry used to determine height of escarpment (h) using sun angle (INA) and shadow length (l).

Figure 8. Smooth vallis floor material (unit AHv) and fluvially modified knobby vallis floor material (unit AHk) in Harmakhis Vallis. Smaller channel heads at site of impact crater (open arrow). Viking Orbiter image 329S26.

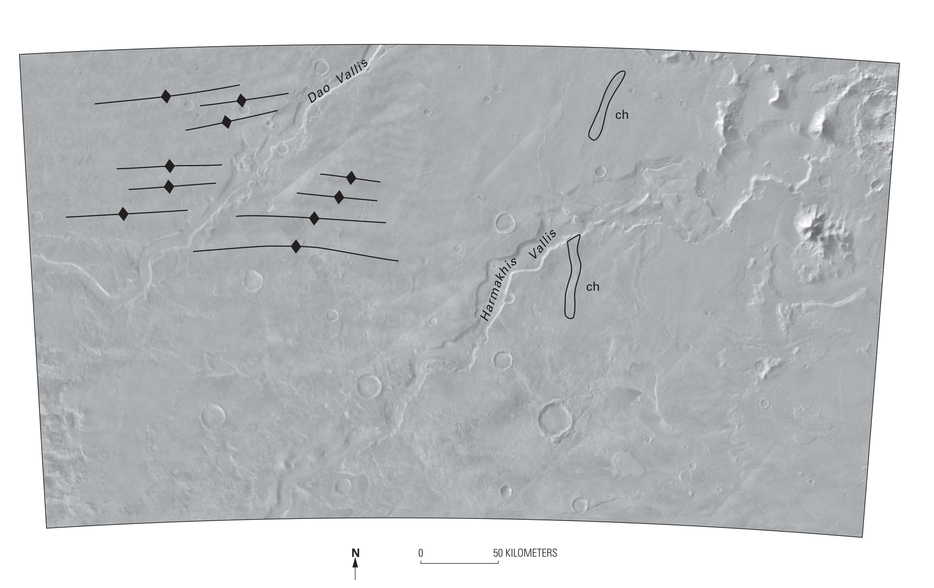


Figure 9. Sketch map showing relation between large-scale ridges (ridge crest symbol), older south-flowing channel (ch), and more recently formed Dao and Harmakhis Valles. This map covers the western three-quarters of index map (fig. 1).

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