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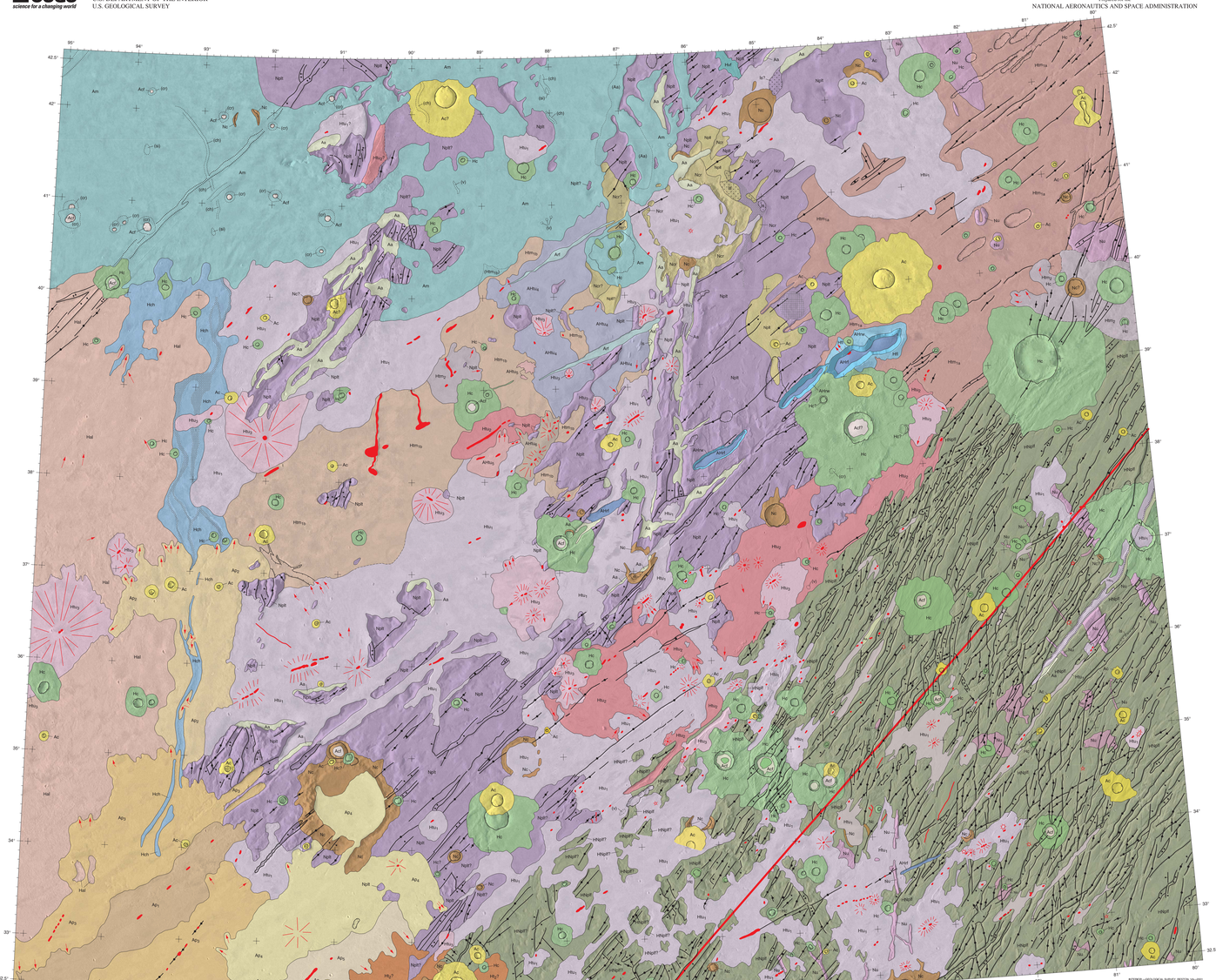
GEOLOGIC INVESTIGATIONS SERIES I–2727
ATLAS OF MARS: TEMPE-MAREOTIS REGION
Pamphlet accompanies map



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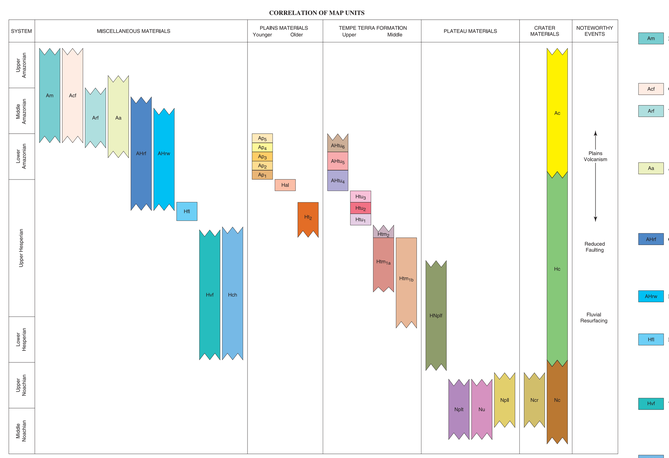
CORRELATION OF MAP UNITS



GEOLOGIC MAP OF THE TEMPE-MAREOTIS REGION OF MARS

By
Henry J. Moore
2001

DESCRIPTION OF MAP UNITS

MISCELLANEOUS MATERIALS

Am — **Mottled material**—Generally mottled; occurs at variable elevations with variable topography; depressions in northwest corner of map. Subdued and obscures grabens, channels, craters, and other landforms and unit **Aa**; craters surrounded by unit have shallow, flat floors. Forms north-trending ridges as long as 20 km that completely obscure channels and other landforms at lat 40.5° N., long 91.7° W. *Interpretation*: Superposed on apron materials (unit **Aa**) and other adjacent units. Eolian mantle with variable thickness. Ridges may be yardangs

Acf — **Crater floor material**—Forms smooth level surfaces on floors of craters; map span entire crater from rim crest to rim crest. *Interpretation*: Eolian materials deposited on floors of impact craters

Arf — **Younger rima floor material**—Forms smooth level surfaces on floors of two rimae that trend N. 50° E. and N. 66° E., respectively. Occurs at lat 40.4° N., long 88.0° W. and at lat 39.4° N., long 87.3° W. Rimae truncate units $AHhu_1$, $AHhu_2$, and $AHhu_3$ and unit **Aa**, except for one small lobe of unit **Aa**. *Interpretation*: Materials deposited after adjacent faces of upper member of Tempe Terra Formation (units $AHhu_1$, $AHhu_2$, and $AHhu_3$) and some apron materials (unit **Aa**). Lava and eolian materials that partly fill rimae formed by collapse of adjacent materials. Collapse caused by magma withdrawal at depth

Aa — **Apron material**—Forms smooth lobate aprons at the bases of cliffs and smooth surfaces of some valley floors. Generally level near cliff, but outer margins are convex upward; level in valleys. Outer margins are deflected by hills and craters; crater rims and topographic grains of adjacent surfaces terminate at this unit. Common and well developed northward of lat 39° N. between long 85° and 92° W. Locally (at lat 39.6° N., long 86.6° W.) this unit is truncated by one rima, but contact between units **Arf** and $AHhu_3$ terminates against a small lobe of this unit. *Interpretation*: Superposed on adjacent materials, except mottled material (unit **Am**) and, locally, rima floor material (unit **Arf**). Ice-laden clastic debris that flowed onto adjacent materials.

AHrf — **Older rima floor material**—Forms smooth level surfaces on floors of northeast-trending rimae that truncate units Hhu_1, $HHhu_4$, **Hh**, **Hc**, **NpH**, and **HNpH**. *Interpretation*: Material deposited after faces 1 of the upper member and faces 1a of middle member of Tempe Terra Formation and rima flank, slightly degraded crater, and terrraced plateau, and fractured plateau materials (units $HHhu_4$, $HHhu_3$, **Hh**, **Hc**, **NpH**, and **HNpH**, respectively). Lava and eolian materials that partly fill rimae formed by collapse of adjacent materials. Collapse caused by magma withdrawal at depth

AHrhu — **Rima wall material**—Forms steep walls of large, northeast-trending rimae that truncate units $HHhu_4$, **Hh**, **Hc**, **NpH**; embayed by unit **AHrf**. *Interpretation*: Talus and wall exposures that formed before rima floor material (unit **AHrf**) and after faces 1a of middle member of Tempe Terra Formation and rima flank, slightly degraded crater, and terraced plateau, and fractured plateau materials (units $HHhu_4$, **Hh**, **Hc**, and **NpH**, respectively). Same as surround material, but disturbed

Hrf — **Rima flank material**—Forms deposits on flanks of two northeastern links of Bagbratyn Catena (near lat 39.2° N., long 83.5° W.) with sinuous ridges separated by smooth surfaces; absent around southwest link. Sinuous ridges at contact rise above adjacent plains (unit $HHhu_4$); topographic expression locally obscured by materials of Charlieu (unit **Hc**). *Interpretation*: Superposed on faces 1a of middle member of Tempe Terra Formation (unit $HHhu_4$); superposed by slightly degraded crater material of Charlieu (unit **Hc**). Lava and ejecta from volcanoes or possibly, ejecta from craters produced by impact of bolide on oblique trajectory that pre-date collapse that formed caterra

Hvf — **Valley floor material**—Forms ridged and grooved surface on floor of northwest-trending valley (near lat 42.5° N., long 85.4° W.); ridges and grooves are subparallel to valley walls. Ridges and grooves terminate against unit Hhu_2; northeast-trending grabens of unit **NpH** terminate against this unit; fracture patterns of nearby plateaus (unit **NpH**) are absent. *Interpretation*: Superposed on terraced plateau material (unit **NpH**) and by faces 1 of upper member of Tempe Terra Formation (unit Hhu_2). Younger than fractures in terraced plateau material (unit **NpH**). Ridges and grooves suggest that the material flowed, perhaps by solifluction

Hch — **Channel material**—Forms smooth to rough, level surfaces in and around channels of Eniposo Vallis between lat 34.0° N. long 93.4° W. and lat 40.0° N., long 92.7° W.; exposures 375 km long. Channel levels locally rise above surrounding plains (unit **Apy**) and segments of channel flows in the south. Multiple channels without levees form mosaic pattern in central part. Channels locally widen; small, irregular to diamond-shaped non-channel islands (unit **Ac**) occur in upper flat surface in north. Channels are truncated by most adjacent materials (units **Am**, Hhu_2, and **Hdf**); contact with unit Hhu_2 is indistinct; fracture patterns that rise above surfaces of this unit (unit **NpH**) are absent. *Interpretation*: Superposed by mottled material, faces 1 of upper member of Tempe Terra Formation, and lower member of Alba Patera Formation (units **Am**, Hhu_2, and **Hdf**, respectively). Younger than fractures in terraced plateau material (unit **NpH**). Channels extend northward beneath mottled material (unit **Am**). Channel lengths, meanders, and streamlined islands suggest that a low viscosity fluid, perhaps water, flowed in channels; levees suggest that fluids overflowed channels and deposited materials

PLAINS MATERIALS

Younger plains materials—Form level surfaces with various textures; may include small, conical rises and broad ridges having elliptical bases, with and without summit depressions; contacts include lobes, scarps, indistinct rises, and embayments. *Interpretation*: Lava that issued from local vents and flowed onto adjacent materials

Apy — **Facies 5**—Forms surfaces having subtle ridges; unit includes large ridge with linear summit depression that trends N. 41° E. (at lat 32.6° N., long 91.3° W.); subtle, conical rise with a summit depression partly obscures northwest end of large ridge with summit depression. Contacts include elongate lobes that extend away from ridge; topographic grains of adjacent plains (units **Apy**, and Hp_2) are truncated by this unit. *Interpretation*: Superposed on facies 4 of plains materials and member 2 of Tharsis Montes Formation (units **Apy** and Hp_2, respectively). Lava erupted from a vent and ridge is loci of partly filled vents. Elevated, circular, smooth surface with summit depression is a low shield

Apy — **Facies 4**—Forms undulating surfaces; unit includes two conical rises and a wide, oval depression that trends N. 70° E.; occurrence in crater Gaudreau (at lat 34.8° N., long 90.0° W.) inferred from continuity of surfaces. Contacts include lobate scarps; topographic grains of adjacent plains (units **Apy** and Hp_2) are truncated by this unit; embays terrraced plateau material (unit **NpH**). *Interpretation*: Superposed on facies 3 of plains materials; facies 1 of upper member of Tempe Terra Formation, and terraced plateau materials (units **Apy**, Hhu_2, and **NpH**, respectively). Conical rises are low shields; oval depression is a collapse pit caused by magma withdrawal at depth

Apy — **Facies 3**—Forms smooth surfaces. At lat 33.0° N., long 94.6° W., unit contains a chain of narrow, elongate depressions trends N. 26° E., and channel levees, which are locally absent, rise above this surface; and near lat 32.7° N., long 93.0° W., depressions along grabens trend N.-40° E. Knobs and ridges (unit **Apy**, lineations of unit **NpH**, and contacts between adjacent materials (units **Apy**-**Hdf**, **Apy**-**NpH**, and **Apy**-Hhu_2) are truncated by this unit. *Interpretation*: Superposed on facies 1 and 2 of younger plains (units **Apy** and **Apy**), channel (unit **NpH**), and terraced plateau (**NpH**) materials. Lava issued from rimae

Apy — **Facies 2**—Forms conical rises and broad ridges having elliptical bases as much as 60 km across; rises and ridges commonly have circular to elongate summit depressions and faint ridges and valleys that extend radially from summits; rises occur singly or in clusters; depressions are crisp to subdued. Contacts are commonly outward-facing scarps and lobes, but some are subtle to gradational. Truncates contacts between units $HHhu_3$, $HHhu_2$, and Hhu_2, embays and truncates lineations in units **HNpH** and **NpH**, and embays some crater materials. Some materials (units **Apy**, $AHhu_4$, and **Hdi**) truncate radial patterns of this unit. *Interpretation*: Superposed on most adjacent units of Tempe Terra Formation (units $HHhu_3$, $HHhu_2$, and Hhu_2). Fractured and lineated plateau materials (units **HNpH** and **NpH**), and some slightly degraded crater material (unit **Hc**); superposed by younger plains materials (units **Apy**, **Apy**, **Apy**, and **Apy**); facies 4 of upper member of Tempe Terra Formation (unit $AHhu_4$), and lower member of Alba Patera Formation (unit **Hdf**). Faint edges are lava tube ridges and flows on flanks of low shields

Apy — **Facies 1**—Forms level, smooth to ridged plains that are typically bounded by outward-facing scarps; may include some small conical rises having summit depressions and northeast-trending fissures and grabens. Materials in box canyon at lat 34.8° N., long 86.8° W. and at lat 41.5° N., long 90.5° W. included in this unit. Contacts are typically scarps and lobes. This unit crosses contacts between units Hhu_2 and **NpH** and embays and truncates lineations in units **HNpH** and **NpH**. *Interpretation*: Superposed on facies 1 of upper member of Tempe Terra Formation (unit Hhu_2) and fractured and terraced plateau materials (units **HNpH** and **NpH**). Lava issued from fissures as well as low shields

Hhu_2 — **Facies 1**—Forms level, smooth plains in western and northeastern parts of map area, in Ascuris Planum, and in valleys in southeastern part of map area; some occurrences are perched atop mesas and plateaus. Small conical rises having summit depressions and smooth-supporting flanks are common. Embays plateaus and some craters (units **NpH**, **HNpH**, **Hc**, and **Hc**); truncates channels (in unit **Hch**), rimae and lineations of plateau materials (units $HHhu_3$ and $HHhu_2$), and lineations (in units **NpH** and **HNpH**). Contacts include lobate scarps that rise above adjacent units and lobate scarps of other units (modified from Hodges and Moore, 1994); see also Mouginis-Mark and others, 1982). Lava issued from fissures and vents (unit **Hdi**). Channels extend northward beneath mottled material (unit **Am**). Channel lengths, meanders, and streamlined islands suggest that a low viscosity fluid, perhaps water, flowed in channels; levees suggest that fluids overflowed channels and deposited materials

TEMPE TERRA FORMATION

Upper member—Forms small, conical rises and broad ridges having elliptical bases, with summit depressions, elongated patches with marginal lobes, plains at margins of rimae, and broad smooth plains. *Interpretation*: Conical and broad ridges with elliptical bases are low shields formed by extrusions of lava from vents; elevated patches are thick lava flows that issued from local fissures; plains are lava flows that issued from rimae or from local vents and fissures

$AHHu_4$ — **Facies 6**—Forms a small group of conical rises, as much as 15 km across, with elongate summit depressions (near lat 38.3° N., long 88.2° W.); includes pits in northeast part; one conical rise has faint radial ridges and valleys that extend from fresh-appearing summit depression, but most rises appear subdued. Summit depressions aligned along N. 32° E., but alignment of pits varies from N. 46° E. to N. 70° E. Contacts are commonly lobate scarps, but some are subtle to gradational; lobes cross adjacent materials (units $HHhu_3$, $HHhu_2$, $AHHu_4$, and $AHHu_3$); embays slightly degraded crater material (unit **Hc**). *Interpretation*: Superposed on facies 1, 2, 4, and 5 of upper member of Tempe Terra Formation (units $HHhu_3$, $HHhu_2$, $AHHu_4$, and $AHHu_3$); facies 1b of middle member of Tempe Terra Formation (unit $HHhu_4$), and slightly degraded crater material (unit **Hc**). Faint ridges are lava tube ridges and lava flows on flanks of low shield

$AHHu_3$ — **Facies 5**—Forms three small patches (two near lat 39.2° N., long 88.3° W. and one at lat 38.3° N., long 88.9° W.) that have smooth level surfaces; southern patch includes elongate trough and pits aligned N. 63°-69° E. Contacts are lobes and scarps that rise above adjacent materials; these lobes and scarps cross contacts between units Hhu_2 and Hhu_2 and between $AHHu_4$ and $HHhu_2$); lobes of one isolated patch rest on $HHhu_2$. *Interpretation*: Superposed on various facies of adjacent members of Tempe Terra Formation (units $HHhu_3$, $HHhu_2$, and $AHHu_4$). Troughs and pits are volcanic vents; fissures and vents of northern patches may be too small to see

$AHHu_4$ — **Facies 4**—Forms flanks of two large rimae (at lat 39.4° N., long 87.3° W. and at lat 40.4° N., long 87.9° W. Contacts are commonly lobate scarps, but some are embayments, and others are indistinct. Lobes and scarps interrupt textural patterns of unit $HHhu_3$; embayments truncate lineations in unit **NpH**; truncates contacts between units $HHhu_3$-**NpH** and $HHhu_2$-**NpH**. *Interpretation*: Superposed on facies 1 of upper member and facies 1b of middle member of Tempe Terra Formation (units $HHhu_3$ and $HHhu_2$, respectively) and terraced plateau (unit **NpH**) and lineated plateau (**NpH**) materials. Lava issued from rimae

Hhu_2 — **Facies 3**—Forms conical rises and broad ridges having elliptical bases as much as 60 km across; rises and ridges commonly have circular to elongate summit depressions and faint ridges and valleys that extend radially from summits; rises occur singly or in clusters; depressions are crisp to subdued. Contacts are commonly outward-facing scarps and lobes, but some are subtle to gradational. Truncates contacts between units $HHhu_3$, $HHhu_2$, and Hhu_2, embays and truncates lineations in units **HNpH** and **NpH**, and embays some crater materials. Some materials (units Apy, $AHHu_4$, and **Hdi**) truncate radial patterns of this unit. *Interpretation*: Superposed on most adjacent units of Tempe Terra Formation (units $HHhu_3$, $HHhu_2$, and Hhu_2). Fractured and lineated plateau materials (units **HNpH** and **NpH**), and some slightly degraded crater material (unit **Hc**); superposed by younger plains materials (units **Apy**, **Apy**, **Apy**, and **Apy**); facies 4 of upper member of Tempe Terra Formation (unit $AHHu_4$), and lower member of Alba Patera Formation (unit **Hdf**). Faint edges are lava tube ridges and flows on flanks of low shields

Hhu_2 — **Facies 2**—Forms level, smooth to ridged plains that are typically bounded by outward-facing scarps; may include some small conical rises having summit depressions and northeast-trending fissures and grabens. Materials in box canyon at lat 34.8° N., long 86.8° W. and at lat 41.5° N., long 90.5° W. included in this unit. Contacts are typically scarps and lobes. This unit crosses contacts between units Hhu_2 and **NpH** and embays and truncates lineations in units **HNpH** and **NpH**. *Interpretation*: Superposed on facies 1 of upper member of Tempe Terra Formation (unit Hhu_2) and fractured and terraced plateau materials (units **HNpH** and **NpH**). Lava issued from fissures as well as low shields

Hhu_2 — **Facies 1**—Forms level, smooth plains in western and northeastern parts of map area, in Ascuris Planum, and in valleys in southeastern part of map area; some occurrences are perched atop mesas and plateaus. Small conical rises having summit depressions and smooth-supporting flanks are common. Embays plateaus and some craters (units **NpH**, **HNpH**, **Hc**, and **Hc**); truncates channels (in unit **Hch**), rimae and lineations of plateau materials (units $HHhu_3$ and $HHhu_2$), and lineations (in units **NpH** and **HNpH**). Contacts include lobate scarps that rise above adjacent units and lobate scarps of other units (modified from Hodges and Moore, 1994); see also Mouginis-Mark and others, 1982).

PLATEAU MATERIALS

HNpH — **Fractured plateau material**—Forms polygonal mesas separated by flat-floored valleys in southeastern part of map area; largest valleys, about 2–7 km wide and as much as 100 km long, trend N. 20° E. to N. 45° E., but comprise scalp segments having more northerly and easterly trends. Mesa surfaces are level, smooth, and at same elevation. Detached hills (1 km across), several irregular hills (about 2 km across), slender ridges (0.5 to 5 km wide), and small irregular mesas are perched atop the polygonal mesas. Valleys and lineations within this unit terminate at contacts with units Hhu_2, Hhu_2, and Hhu_2; contact with unit $HHhu_4$ is indistinct; most craters appear pristine. *Interpretation*: May be coeval with facies 1a of middle member of Tempe Terra Formation (unit $HHhu_4$). Superposed by facies 2 of middle member and facies 1 and 2 of upper member of Tempe Terra Formation (units $HHhu_3$, Hhu_2, and Hhu_2, respectively). Lava plains and older rocks displaced by faulting during northwest-southeast extension; overall pattern suggests reactivation of preexisting faults, conjugate shearing, or both. Many valleys probably contain mass-wasting and eolian deposits. Some ridges may be volcanic dikes exposed by erosion. Small hills may be volcanic domes and shields, whereas other ridges, irregular hills, and irregular mesas (mapped as unit **Mu**) may be erosional remnants

NpH — **Lineated plateau material**—Forms patches having ridges, troughs, and elongate pits that radiate from center of crater Reykholt; best exposed around lat 39.5° N., long 85.0° W., where western contact is a west-facing scarp that separates this unit from smooth surfaces that are aligned with channel to north (see unit **NpH**); elsewhere, contacts are diffuse. *Interpretation*: Superposed on terraced plateau material (unit **NpH**); coeval with Reykholt crater material (unit **Nr**). Ejecta and local materials scoured by ejecta from Reykholt; in many places, these materials have been removed by fluvial erosion and, in others, they lie below the ejecta from Reykholt

NpH — **Terraced plateau material**—Forms terraced plateaus and mountains; terraces well illustrated from lat 37.5° to 40° N., long 86.0° and in a cratorform at lat 38.8° N., long 84.6° W.; terraces and channel are present from lat 40.0° to 41.0° N., long 85.3° W. Margins of western and northern occurrences tend to have large, abrupt relief (about 1 km), but those to the east tend to have small, gradual relief. Contacts include (1) cirquelike embayments that contain other units, (2) scarps of peninsulas, hills, and plateaus that contain this unit, and (3) gentle rises that elevate this unit above surrounding units. Lineations in plateau materials typically terminate at contacts with adjacent units. *Interpretation*: All adjacent materials are superposed on this unit. Old crater, basin ejecta, volcanic, and sedimentary materials eroded chiefly by fluvial processes. Fluvial erosion produced terraces which suggests that materials are layered; materials at lower elevations are older than those at higher elevations

Nu — **Undivided material**—Forms isolated mesas, hills, and ridges that rise above unit **HNpH**; some fractures terminate at contacts with unit **HNpH** and other units. *Interpretation*: Old material of indefinite origin, but probably includes basin ejecta and lava flows

CRATER MATERIALS

Ac — **Well-preserved crater material**—Forms craters with raised rims, large depth to diameter ratios, and hummocky flanks; includes central peaks and undulatory to hummocky floors of large craters. Smooth, flat floors, if present, are relatively small. *Interpretation*: Amazonian-age material of impact craters

Hc — **Slightly degraded crater material**—Forms craters with raised rims, moderate depth to diameter ratios, and, commonly, hummocky flanks; includes central peaks and undulatory to hummocky parts of floors of large craters. Floors of smaller craters contain smooth, flat floors of crater floor material (unit **Acf**); floors of large crater may contain only patches of crater floor material. Material on crater flanks of some craters embayed by facies of upper Tempe Terra Formation (units Hhu_2 through $AHhu_4$) and material of rims, walls, and flanks of some craters are transected by faults. *Interpretation*: Hesperian-age material of impact craters

Hc — **Degraded crater material**—Forms degraded craters, arcuate crater rim segments, and circular rims of ringed plains; embayment of craters by various facies of members of Tempe Terra Formation, plains material (unit **Apy**), and other materials form interior and exterior plains; commonly transected by faults and fractures; may include material of undulatory to hummocky floors. *Interpretation*: Superposed by most adjacent units. Noachian-age material of old and degraded impact craters

Nr — **Reykholt crater material**—Forms hummocky flanks, walls, and central peak of crater Reykholt and isolated patches around crater. Embayed by unit Hhu_2. Isolated patches are elevated above surroundings (unit **NpH**). *Interpretation*: Superposed on terraced plateau material (unit **NpH**). Ejecta deposits and other materials of impact crater Reykholt; locally eroded by fluvial processes (see unit **NpH**)

BLACK MAP SYMBOLS

Contact—Dashed where approximately located; dotted where buried or subsaed

Fault—Ball on downthrown side, dotted where buried. Forms contact in places

Narrow Graben—Dotted where buried; forms contact in places

Closed depression—Interpreted to be collapse depression

Partly closed depression—Interpreted to be breached collapse depression

Circular depression having concentric interior terraces and two central circular ridge segments—Interpreted to be deeply eroded complex or peak-ring impact crater

Crater rim crest—Forms contact in places

Channel—Interpreted to be fluvial channel

(a) **Landslide**—Interpreted to be result of mass movement

(ch) **Subdued trough**—Interpreted to be mantled channel

(ch) **Subdued rise**—Interpreted to be mantled streamlined island

(v) **Subdued closed depression**—Interpreted to be mantled vent

(cr) **Subdued crater flank**—Interpreted to be mantled crater material

RED MAP SYMBOLS

Small closed depression—Interpreted to be volcanic vent or summit pit

Small conical rise and broad ridge having summit depression—Faint radial texture suggests; interpreted to be low shields

Small conical rise and broad ridge having no summit depression—May have summit knob; interpreted to be low shield

Small domical rise—Interpreted to be extrusive lava dome or laccolith

Ridge—Interpreted to be dike (d) or lava tube (l)

Paleoflow direction of lava—Inferred from lob ex

Rima and associated collapse pit

Great circle that passes through caldera centers of Pavonis Mons and Uranius Patera

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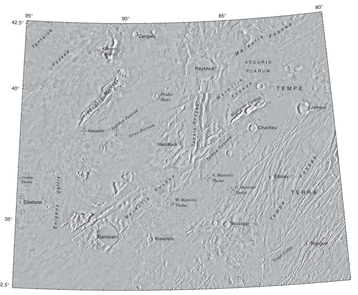

Figure 2. Map showing selected features. Contrast in reduced base mosaic was purposely suppressed to emphasize nomenclature.

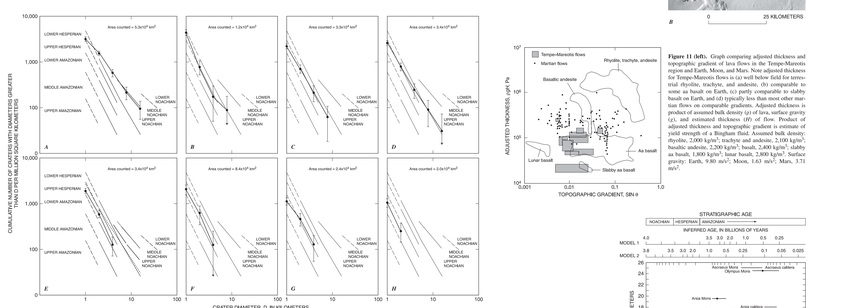

Figure 3. Crater size-frequency distributions for selected surfaces in Tempe-Mareotis region. **A**, All craters of terraced plateau material (unit **NpH**) record age of unit. **B**, Craters superposed on terraced plateau material (unit **NpH**) record relative age of fluvial resurfacing. **C**, Faulted and unfaulted craters superposed on fractured plateau material (unit **HNpH**). Note that all frequencies suggest Hesperian age. **D**, Second measurement of faulted and unfaulted craters superposed on fractured plateau material (unit **HNpH**). Note that frequencies at smallest diameters suggest mid-Hesperian age and largest diameters suggest Upper Noachian age. **E**, Unfaulted craters superposed on fractured plateau material (unit **HNpH**). Faulted craters have notched rims and walls, as well as linear valleys on flanks. Dotted lines are curve in part **D**, above. **F**, Craters superposed on three facies of upper member of Tempe Terra Formation (units Hhu_2, Hhu_2, and Hhu_2) in Ascaris Planum. **G**, Craters superposed on lower member of Alba Patera Formation (unit **Hdf**). **H**, Craters superposed on young plains materials (units Apy-Apy).

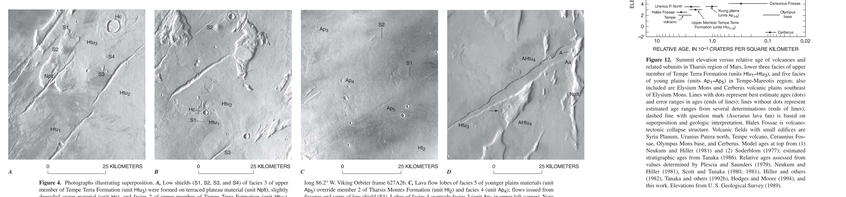

Figure 4. Photographs illustrating superposition. **A**, Low shields (S1, S2, S3, and S4) of facies 3 of upper member of Tempe Terra Formation (unit Hhu_2) were formed on terraced plateau material (unit **NpH**), slightly degraded crater material (unit **Hc**), and facies 2 of upper member of Tempe Terra Formation (unit Hhu_2). Lobes of facies 2b are overridden facies 1 of upper member of Tempe Terra Formation (unit Hhu_2). Relief of shields S1, S2, S3, and S4 are 39 m, 158 m, 90 m, and 52 m, respectively (see table 1). Note smooth flanks of S1 and S2; radial vectors of flanks of S3; and hummocky flanks and summit knob of S4. Sun to left; sun elevation angle about 18°; centered at lat 35.8° N., long 88.0° W. Viking Orbiter frame 625A41. **B**, Low shield (S1) (no small to map as unit **Hhu**) and facies 1 of upper member of Tempe Terra Formation (unit Hhu_2) overlie slightly degraded crater material (unit **Hc**); but, slightly degraded crater material is superposed on lobes 1 (unit Hhu_2). Shield S2, 134-138 m high, has smooth flanks; shield S3, 52 m high, has hummocky flanks and summit knob (see table 1). Sun to left; sun elevation angle about 25°; centered at lat 36.2° N., long 86.2° W. Viking Orbiter frame 627A26. **C**, Lava flow lobes of facies 5 of younger plains materials (unit **Apy**) override member 2 of Tharsis Montes Formation (unit **Hp**) and facies 4 (unit **Apy**); flows issued from fissures and vents of low shield (S1). Lobes of facies 4 overrode facies 3 (unit **Apy** in upper left corner). Note low shields at S1 and S2; S1 has subtle central depression and S2 has no central depression. Sun to left; sun elevation angle about 18°; centered at lat 32.8° N., long 91.6° W. Viking Orbiter frame 224A27. **D**, Small apron at "A" rests upon larger apron of apron material (unit **Aa**) and younger rima floor material (not labeled), but large apron is truncated by rima wall. Facies 4 of upper member of Tempe Terra Formation (unit $AHhu_4$) comprises flanks of rimae in most places. Note low shield (unit **Hhu**) that is partly buried by lava flow (unit $AHhu_4$) and flow lobe (arrows) in crater in terraced plateau material (unit **NpH**). North-south ridge and valley at right are part of Tanais Fossae. Sun to left; sun elevation angle about 25°; centered at lat 39.5° N., long 88.3° W. Viking Orbiter frame 627A03.

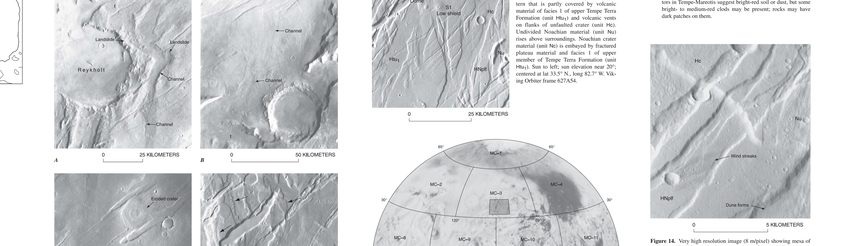

Figure 5. Histogram showing azimuths of faults of fractured plateau material (unit **HNpH**) and elongations and alignments of vents of upper member of Tempe Terra Formation (units Hhu_2, $AHhu_4$) and younger plains materials (units Apy). Note broad spectrum of azimuths and two modes near 7° and 40° for faults, narrow spectrum of azimuths and two modes near N. 42° E. and N. 62° E. for vents, and vents generally tend to be more easterly than fault azimuths. Azimuths of a great circle drawn through calderas of Pavonis Mons and Uranius Patera range from N. 42.4° E. to N. 50.5° E. at latitudes of this map area. Faults sampled are covered by Viking Orbiter frames 627A36, 51, and 54 (see figs. 7, 9).

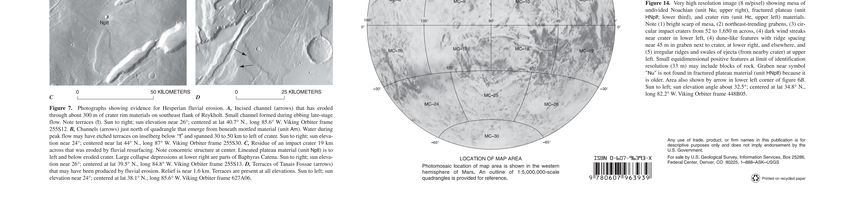

Figure 6. Photographs showing orientations of faults and fissures of fractured plateau material (unit **HNpH**). **A**, Mosaic of diamond-shaped blocks formed by small grabens and faults. Linear ridges, some of which intersect at large angles, may be dikes (arrows). If ridges are dikes, surface has been eroded and vertical fault planes are indicated. Note lobes 1 of upper member of Tempe Terra Formation (unit Hhu_2) is superposed on fractured plateau material (unit **HNpH**) in upper right. Sun to left; sun elevation near 20.7°; centered at lat 34.7° N.; long 83.8° W. Viking Orbiter frame 627A51. **B**, Large valleys made of segments and mosaic of diamond-shaped blocks formed by small grabens and faults in fractured plateau material (unit **HNpH**). Note that faults and grabens appear unrevealed and that mesas and ridges (unit **Hu**) rise above adjacent surfaces. Location of figure 14 at lower left edge (arrow). Sun to left; sun elevation near 19.5°; centered at lat 35.1° N., long 81.7° W. Viking Orbiter frame 627A36.

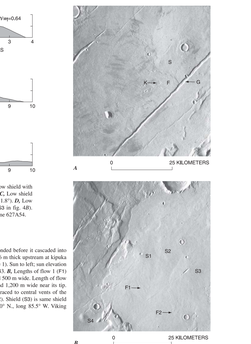

Figure 11 (left). Graph comparing adjusted thickness and topographic gradient of lava flows in the Tempe-Mareotis region and Earth, Moon, and Mars. Note adjusted thickness for Tempe-Mareotis flows is (a) well below field for terrestrial rhyolite, trachyte, and andesite, (b) comparable to some au basalt on Earth, (c) partly comparable to slabby basalt on Earth, and (d) typically less than most other martian flows on comparable gradients. Adjusted thickness is product of assumed bulk density (ρ) of lava, surface gravity (g), and estimated thickness (H) of flow. Product of adjusted thickness and topographic gradient is estimate of yield strength of a Bingham fluid. Assumed bulk density: rhyolite, 2,000 kg/m^3; trachyte and andesite, 2,100 kg/m^3; basaltic andesite, 2,200 kg/m^3; basalt, 2,400 kg/m^3; slabby au basalt, 1,800 kg/m^3; lunar basalt, 2,800 kg/m^3. Surface gravity: Earth, 9.80 m/s^2; Moon, 1.63 m/s^2; Mars, 3.71 m/s^2.

Figure 10 (right). Photographs showing lava flows. **A**, Flow (F) nearly ponded before it cascaded into graben (G). Flow is 2b=30 m thick and 300 m wide near graben and 14=16 m thick upstream at kipukas (K). Note low shield with summit knob (S). Relief of shield is 32 m (see table 1). Sun to left; sun elevation near 24°; centered at lat 35.4° N., long 87.1° W. Viking Orbiter frame 627A43. **B**, Lengths of flow 1 (F1) and its neighbors are subdivided to low shield (S1); it is about 2=3 m thick and 500 m wide. Length of flow 2 (arrow F2) is subdivided to low shield 2 (S2); it is about 8=13 m thick and 1,200 m wide near its tip. Both lava flows may have issued from lava tubes because they cannot be traced to central vents of the shields. Relief of S1 and S2 are 25 m and 54 m, respectively (see table 1). Shield (S3) is same shield as S2 in figure 4B. Sun to left; sun elevation near 22°; centered at lat 37.0° N., long 85.5° W. Viking Orbiter frame 627A27.

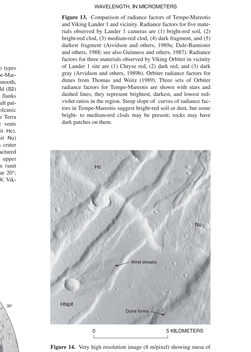

Figure 13. Comparison of radiance factors of Tempe-Mareotis and Viking Lander 1 and 2 visibility. Radiance factors for the materials observed by Lander 1 cameras are (1) bright-red soil, (2) bright-red clod, (3) medium-red clod, (4) dark fragment, and (5) darkest fragment (Arvidson and others, 1989a; Dale-Bannister and others, 1988; see also Guinness and others, 1987). Radiance factors for three materials observed by Viking Orbiter in vicinity of Lander 1 site are (1) Chryse red, (2) dark red, and (3) dark gray (Arvidson and others, 1989b). Orbiter radiance factors for dunes from Thomas and Weitz (1989). Radiance factors for radiance factors for Tempe-Mareotis are shown with stars and dashed lines; they represent brightest, flatest, and lowest red-violet ratios in the region. Steep slope of curves of radiance factors in Tempe-Mareotis suggest bright-red soil or dust, but some bright- to medium-red clods may be present; rocks may have dark patches on them.

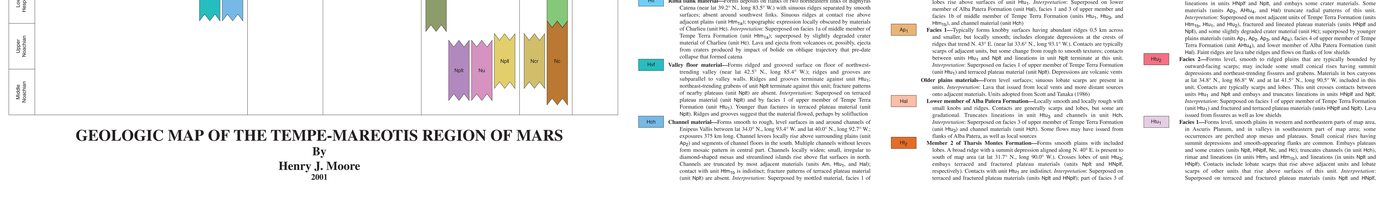

Figure 1. Sketch Map of Thaumasia region of Mars showing volcanoes, lava flows, and location of Tempe-Mareotis region (modified from Hodges and Moore, 1994); see also Mouginis-Mark and others, 1982). Mercator projection.

Figure 7. Photographs showing evidence for Hesperian fluvial erosion. **A**, Incised channel (arrows) that has eroded through about 300 m of crater rim materials on southeast flank of Reykholt. Small channel formed during ebbing late-stage flow. Note terraces (I). Sun to right; sun elevation near 26°; centered at lat 40.7° N., long 85.6° W. Viking Orbiter frame 255G12. **B**, Channels (arrows) just north of quadrangle that emerge from beneath mottled material (unit **Am**). Note during peak flow they have etched terraces on inselberg below "T" and spanned 30 to 50 km to left of crater. Sun to right; sun elevation near 24°; centered near lat 44° N., long 87° W. Viking Orbiter frame 255E10. **C**, Residue of an impact crater 19 km across that was eroded by fluvial resurfacing. Note concentric structure at center. Lineated plateau material (unit **NpH**) is to east (upper left). Channel and depressions at lower right are parts of quadrangle that emerge from beneath mottled material (unit **Am**). Note during peak flow they have etched terraces on inselberg below "T" and spanned 30 to 50 km to left of crater. Sun to right; sun elevation near 24°; centered near lat 44° N., long 87° W. Viking Orbiter frame 255E10. **C**, Residue of an impact crater 19 km across that was eroded by fluvial resurfacing. Note concentric structure at center. Lineated plateau material (unit **NpH**) is to east (upper left). Channel and depressions at lower right are parts of quadrangle that emerge from beneath mottled material (unit **Am**). Note during peak flow they have etched terraces on inselberg below "T" and spanned 30 to 50 km to left of crater. Sun to right; sun elevation angle about 18°; centered at lat 32.8° N., long 91.6° W. Viking Orbiter frame 224A27. **D**, Small apron at "A" rests upon larger apron of ap