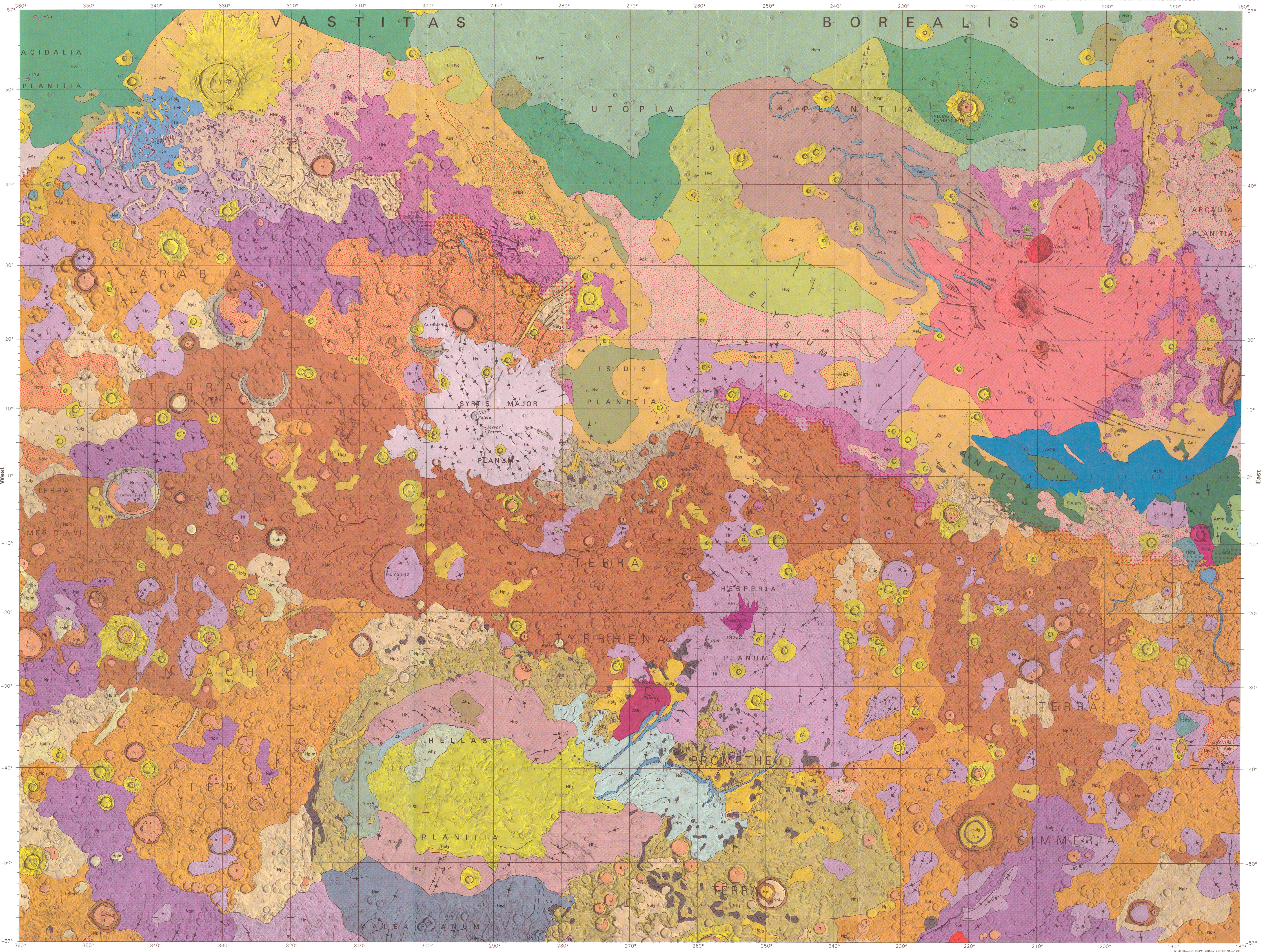
ATLAS OF MARS
1:15,000,000 GEOLOGIC SERIES
EASTERN REGION
M 15M, 0/270 G, 1987
I–1802–B



Compiled in 1984

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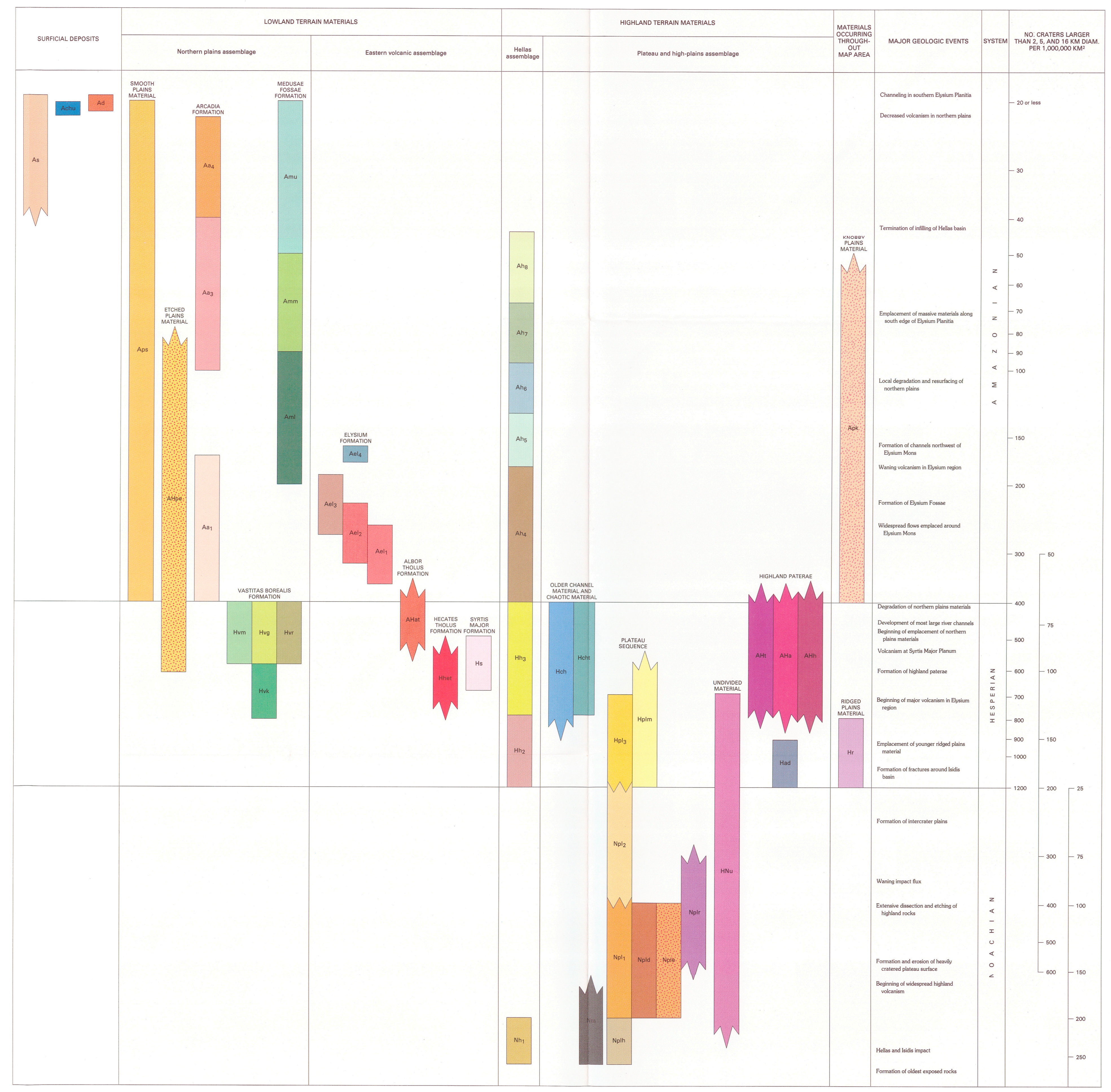
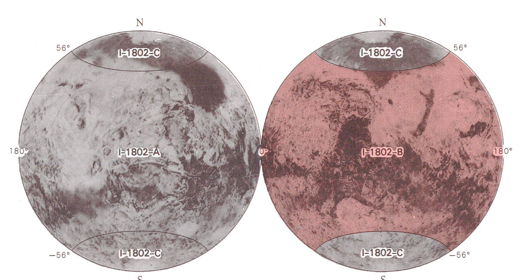
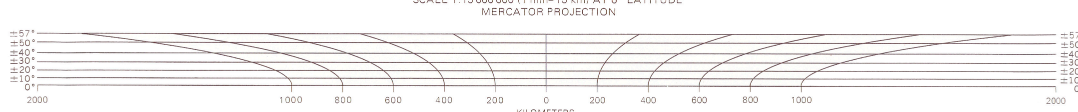
CORRELATION OF MAP UNITS, GEOLOGIC EVENTS, AND CRATER DENSITIES IN THE EASTERN EQUATORIAL REGION OF MARS





INDEX OF THE 1:15,000,000 GEOLOGIC SERIES

SCALE 1:15 000 000 (1 mm = 15 km) AT 0° LATITUDE
MERCATOR PROJECTION



NOTES ON BASE

This map sheet is one of a series covering the entire surface of Mars at a scale of 1:15,000,000. Sources for the map base were 1:5,000,000-scale shaded relief maps described by Batson and others (1979). Data used in the map portrayal were obtained from Viking Orbiter images.

ADOPTED FIGURE

The figure of Mars used for computing the map projections is an oblate spheroid (flattening of 1/192) with an equatorial radius of 3,393.4 km and a polar radius of 3,375.7 km.

PROJECTIONS

The Mercator projection is used between the 57° parallels; the Polar Stereographic projection is used for the polar regions north and south of the 55° parallels. Scales are 1:15,000,000 at the equator and 1:9,203,425 at the poles. The projections have a common scale of 1:8,418,000 at lat ±56°. Longitude increases to the west in accordance with astronomical convention for Mars. Latitudes are areographic.

CONTROL

Planimetric control for the 1:5,000,000-scale maps used to compile the bases for these sheets was derived from photogrammetric triangulations by use of Mariner 9 pictures (Davies, 1973). This control net was upgraded through the use of Viking data (Davies and others, 1978). At least 85 percent of the image control points lie within 0.5 mm of the positions published in 1978.

MAPPING TECHNIQUE

The mapping bases for this series were assembled from 1:5,000,000-scale shaded relief maps reduced and digitally transformed where necessary to fit the projections. During shaded relief portrayal, features on these bases were used to position details taken from Viking Orbiter pictures. Features were drawn as if illuminated uniformly from the west through use of airbrush techniques described by Inge (1972) and photointerpretive methods described by Inge and Bridges (1976). The shading is not generalized and accurately represents the character of surface features.

Shaded relief analysis and portrayal were made by Barbara J. Hall.

NOMENCLATURE

All names on this sheet are approved by the International Astronomical Union (IAU, 1974, 1977, 1980, 1983, and 1986). Named features and their positions are taken from published maps of Mars that have scales of 1:2,000,000, 1:5,000,000, and 1:25,000,000.

M 15M 0/270 G — Abbreviation for Mars 1:15,000,000 series; center of map, lat 0°, long 270°; geologic map, (G).

REFERENCES

Batson, R.M., Bridges, P.M., and Inge, J.L., 1979, Atlas of Mars, The 1:5,000,000 map series: National Aeronautics and Space Administration Special Publication 438, 146 p.
Davies, M.E., 1973, Mariner 9: Primary control net: Photogrammetric Engineering, v. 39, no. 12, p. 1297–1302.
Davies, M.E., Katayama, F.Y., and Roth, J.A., 1978, Control net of Mars: February 1978: The Rand Corporation, R-2309-NASA, 91 p.
Inge, J.L., 1972, Principles of lunar illustration: Aeronautical Chart and Information Center Reference Publication 72-1, 60 p.
Inge, J.L., and Bridges, P.M., 1976, Applied photointerpretation for airbrush cartography: Photogrammetric Engineering and Remote Sensing, v. 42, no. 6, p. 749–760.
International Astronomical Union, 1974, Commission 16: Physical study of planets and satellites, *and* Lunar and martian nomenclature, *in* 15th General Assembly, Sydney, 1973, Proceedings: International Astronomical Union Transactions, v. 15B, p. 105–108, 271–221.
_____ 1977, Working Group for Planetary System Nomenclature, *in* 16th General Assembly, Grenoble, 1976, Proceedings: International Astronomical Union Transactions, v. 16B, p. 321–325, 331–336, 355–362.
_____ 1980, Working Group for Planetary System Nomenclature, *in* 17th General Assembly, Montreal, 1979, Proceedings: International Astronomical Union Transactions, v. 17B, p. 293–297.
_____ 1983, Working Group for Planetary System Nomenclature, *in* 18th General Assembly, Patras, 1982, Proceedings: International Astronomical Union Transactions, v. 18B, p. 334–336.
_____ 1986, Working Group for Planetary System Nomenclature, *in* 19th General Assembly, New Delhi, 1985, Proceedings: International Astronomical Union Transactions, v. 19B, p. 347–350.

INTRODUCTION

The Mariner 9 mission in the early 1970's provided the first comprehensive view of the geology of Mars (McCauley and others, 1972; Masursky, 1973) and led to the derivation of the first global geologic map (Carr and others, 1973). These preliminary studies were followed by more comprehensive geologic mapping coordinated by the U.S. Geological Survey. Thirty quadrangles at a scale of 1:5,000,000 were produced in this map series, from which Scott and Carr (1978) compiled a single geologic map at a scale of 1:25,000,000. The reliability of these maps, however, is varied because of the uneven quality of the Mariner 9 data.

Viking Orbiter images fill important gaps in the Mariner data and provide substantially better coverage at both moderate (300 to 130 m/pixel) and high (25 m/pixel) resolutions. The increased quality of the images results from a better camera system, improved image processing, and clearer atmospheric conditions than those of the Mariner 9 mission. These factors, along with the higher resolution obtained by the Viking Orbiter cameras, have enabled the discovery of geologic relations previously unknown. Photogeologic results based on the Viking images, together with results from other remote-sensing experiments such as the Infrared Thermal Mapper flown on Viking Orbiter (Kieffer and others, 1977), provide the basis for compilation (at 1:15,000,000 scale) of the three map sheets in the present series: the geologic map of the western equatorial region of Mars (Scott and Tanaka, 1986), the geologic maps of the polar regions of Mars (Tanaka and Scott, 1987), and this sheet.

Photogeologic mapping techniques employed here follow principles defined by Shoemaker and Hackman (1962) for the Moon and refined by Wilhelms (in press). Initial mapping was compiled on uncontrolled mosaics prepared during Viking mission operations. Although these mosaics were produced at a wide range of scales, were not uniform in format, and did not cover the entire area of interest, this preliminary mapping provided insight into local geologic relations. Results were then compiled on 1:2,000,000-scale photomosaics of moderate-resolution photographs (~300 to 130 m/pixel). The final step involved recompilation from the 1:2,000,000-scale photomosaics onto the shaded relief 1:15,000,000-scale map base (U.S. Geological Survey, 1982).

The map portrays inferred rock units, stratigraphic relations, and other features such as faults. From this mapping, the major impact, tectonic, and volcanic events that have shaped the surface of Mars are interpreted, as are modifications produced by wind, water, and other agents of gradation. Definition of possible rock units is based on assessment of their geomorphology, albedo, spectral properties, and thermal characteristics. As discussed by Milton (1974), some units on Mars are characterized principally by their geomorphic expression, which locally may be due more to secondary modification than to their primary nature. Mapped units are assigned to time-stratigraphic systems formulated from Mariner 9 mapping (Scott and Carr, 1978), which were adapted for the map of the western equatorial region (Scott and Tanaka, 1986) and refined by Tanaka (1986).

Relative ages of the rock units are established by stratigraphic relations, cross-cutting relations of structural features, and size-frequency distributions of impact craters. Ages based on crater frequency must be employed with caution, however, especially in areas where wind and water have modified the surface and where sedimentary deposits may have partly buried other units. As discussed by Condit (1978), craters 4 to 10 km in diameter are important for use in broad relative-age dating of Martian surfaces; smaller craters may have been buried, eroded, or extensively modified, whereas larger craters are too scarce to produce statistically meaningful results. Crater-density numbers on the correlation chart were derived according to the convention established by Scott and Tanaka (1986). Because small craters are better preserved on the relatively smooth, younger geologic units than on the rough, uneven, or highly faulted older materials, different sizes of craters were counted for rock units in each system: greater than 2 km for the Amazonian, greater than 2 and 5 km for the Hesperian, and greater than 5 and 16 km for the Noachian.

Rock-stratigraphic classifications of different ranks (formations and members) are used to minimize cumbersome adjectival descriptions. The term "assemblage" (Scott and Tanaka, 1986) is employed for sets of units that share common attributes; for example, the Hellas assemblage encompasses those units associated with the formation and modification of the Hellas basin. Many of the units appear to intergrade, and some contacts are drawn primarily on the basis of secondary characteristics such as discontinuities in impact-crater density; these contacts are dashed.

Impact craters that are superposed on the surrounding terrain and have well-preserved, extensive rim units (inferred to be ejecta deposits) are shown in yellow; only those craters having material units larger than 100 km across are mapped. Craters whose various rim units appear to be buried or partly buried are shown in brown; only those craters having rim diameters larger than 150 km are mapped. Craters are not otherwise classified by type or age.

PHYSIOGRAPHIC SETTING

Mars' surface can be divided into two major physiographic provinces, the northern lowlands (which include the north polar region) and the southern cratered highlands. The boundary between the two provinces forms an approximate great circle inclined to the equator by about 28°. Both provinces are exposed in the map area, although the cratered highlands are the prevailing terrain. The boundary between the two provinces in the western part of the map area is marked by a scarp as high as several kilometers. The terrain on the upland side of this scarp displays grabens and fractures, many of which may have been modified by channels that are presumably of fluvial or sapping origin. This surface was termed "fretted terrain" by Sharp (1973). Valleys between high-standing remnants of uplands in the fretted terrain are floored by channel deposits, debris aprons, and sediments inferred to be eolian. The upland-lowland boundary in the eastern part of the map area is more gradational and lacks a conspicuous scarp and fracture system. In the middle of the map area, the boundary is embayed from the northeast by younger lowland plains that fill what is probably a degraded impact basin, Isidis.

Although materials of the northern lowlands are generally younger than those of the southern cratered uplands, younger intercrater plains material also occurs in the southern province. These deposits appear to be diverse and may include eolian and fluvial sediments as well as volcanic materials (Greeley and Spudis, 1978). The dominant feature in the southern province is the Hellas basin, interpreted as an impact scar, whose rim diameter is about 1,800 km.

The Elysium region, one of the major volcanic provinces on Mars, lies within the northern lowlands. Containing several volcanoes and multiple lava flows derived from central vents and probably from fissures, the Elysium region appears to be a smaller and generally older version of the Tharsis volcanic province in the western hemisphere.

Large impact basins are not as obvious on Mars as on the Moon and Mercury. Although their scarcity may represent a difference in impact flux, a more likely explanation is that erosion and resurfacing have obliterated much of the early Martian crustal record. Features representing the remnants of possible basins other than Hellas and Isidis (such as Aram Chaos and the "Ladon basin") have been described by Wood and Head (1976) and Schultz and others (1982).

STRATIGRAPHY AND HISTORY

Noachian System

The Noachian System comprises the oldest rocks discernible on Mars (Scott and Carr, 1978). Size frequencies of craters larger than 16 km in diameter on Noachian units correlate with those of the Nectarian System on the Moon and may represent a similar period of impact cratering (Tanaka, 1986).

Two of the oldest rock units on Mars are *basin-rim material* (unit Nh$_1$) and *hilly material* (unit Nplh), which form rugged, mountainous terrain associated with the Hellas and Isidis basins, respectively; a third ancient unit, *mountainous material* (unit Nm), forms isolated patches of more rugged terrain. This third unit does not everywhere appear to be associated with a clearly recognizable basin, but it is considered to represent parts of basins now mostly destroyed.

Overlying these rugged and intensely cratered terrains are old plateau units, including *cratered material* (unit Npl$_1$) and *subdued crater material* (unit Npl$_2$) that may in part represent early-stage, flood-style volcanism (Greeley and Spudis, 1981); such a volcanic origin is indicated by the presence of large mare-type (wrinkle) ridges in the *ridged material* (unit Nplr). The *dissected material* (unit Npld) has been cut by extensive channels that are presumably of fluvial origin; the *etched material* (unit Nple) appears to be mantled by sediments of possible eolian origin that, in turn, have been partly eroded to produce an etched appearance.

Undivided material (unit HNu) consists of rock units in the highlands and lowlands that cannot be distinguished morphologically or placed precisely in a stratigraphic position in the Hesperian or Noachian Systems.

Rock units of Noachian age are considered to result from the final stages of planetary accretion and the waning period of heavy bombardment. In the middle to late Noachian Period, we infer the extrusion of extensive flood lavas and contemporaneous surface modifications by eolian, fluvial, and other surface processes that continued into the Hesperian Period.

Hesperian System

As in the western hemisphere (Scott and Tanaka, 1986), many highland areas are interpreted to have been smoothed and resurfaced by lava flows and eolian deposits, representing a continuation of activity that began during the Noachian. Units of Hesperian age are distinguished by having 67 to 200 craters larger than 5 km in diameter per 10^6 km^2.

The most extensive plains unit in the Hesperian System is the *ridged plains material* (unit Hr), which has sinuous ridges resembling those of the lunar maria and is inferred to be lava flows. It forms the basal unit of the Hesperian System (Scott and Carr, 1978). The largest concentration of ridged plains material in the map area is in Hesperia Planum northeast of the Hellas basin. In Syrtis Major Planum, a widespread occurrence of apparently younger material is designated the *Syrtis Major Formation* (unit Hs); unlike the ridged plains material (unit Hr), flow units of the Syrtis Major Formation have clearly distinguishable flow fronts and margins, and they appear to have originated from at least two central features resembling calderas (Schaber, 1982). Although these flows display many ridges, the ridges are generally narrower and shorter than those of the ridged plains northeast of Hellas.

In addition to eruptions in Syrtis Major, the middle Hesperian Period was marked by the initiation of central-vent volcanism in the Elysium region: lavas were extruded to form the *Hecates Tholus Formation* (unit Hhet) and the older flows of the *Albor Tholus Formation* (unit AHat). Eruptions also occurred in the southern hemisphere to form the *dissected member* of the *Amphitrites Formation* (unit Had) and most of the *Tyrrhena Patera Formation* (unit AHt), the *Apollinaris Patera Formation* (unit AHa), and the *Hadriaca Patera Formation* (unit AHh). These eruptions may be associated with crustal adjustments following the formation of the Hellas basin (Peterson, 1978). On the basis of photogeologic analysis, Greeley and Spudis (1981) postulated that Tyrrhena Patera was formed by magmas erupted through impact-generated regolith that contained ground water. This process may have resulted in phreatomagmatic explosions that produced an early-stage ash shield, which was later degraded by surficial processes and which was the site of late-stage effusion of lavas. Although images of Amphitrites (lat 61° S., long 299°), Apollinaris, and Hadriaca Paterae are inadequate for detailed analysis, a similar history is proposed for these eruptive centers.

Further resurfacing of the southern highlands is represented by the youngest units of the plateau sequence, which subdue the underlying terrain. These units are characterized by smooth surfaces and are separated on the basis of albedo patterns into *smooth material* (unit Hpl$_3$) and *mottled plains material* (unit Hplm). Both units may consist of interbedded lava flows and sedimentary deposits; the mottling of the mottled plains unit may be caused by wind-sorted sediments.

The *Hellas assemblage* consists of units in and around Hellas Planitia. Its lowermost unit, the Noachian basin-rim material noted above, is overlain by the *ridged plains floor unit* (unit Hh$_2$, presumed to be flood lavas contemporaneous with the ridged plains unit), which is in turn overlain by the *dissected floor unit* (unit Hh$_3$) that may consist of modified eolian, fluvial, and lava-flow materials.

Older channel material (unit Hch) was also emplaced during the Hesperian along the northern lowlands-southern highlands boundary and on the northeast margin of the Hellas basin. Channel formation along the boundary was concentrated near Deuteronilus Mensae and represents major modification of the scarp boundary. East of Deuteronilus, channels are not abundant; however, scarp modification or retreat is indicated by knobby material mapped as part of the undivided unit (unit HNu). Parts of the southern highlands were modified by erosion to produce *chaotic material* (unit Hcht).

The *Vastitas Borealis Formation* (Scott and Tanaka, 1986) occurs in the northern lowlands as part of the northern plains assemblage. It consists of four members representing various stages of degradation and modification: *knobby member* (unit Hvk), *mottled member* (unit Hvm), *grooved member* (unit Hvg), and *ridged member* (unit Hvr). The oldest and most widespread, the knobby member, is characterized by many closely spaced, conical hills that appear darker than the surrounding terrain. The mottled member forms an extensive zone that nearly encircles the planet between about lat 50° and 70° N.; although Mariner 9 images indicate only a blurred surface having high albedo contrast, Viking images show that the contrasting albedo is due to impact craters whose ejecta deposits are brighter than intercrater areas (Witbeck, 1984, p. 296). The grooved member is characterized by irregular to polygonal patterns formed by grooves and troughs as long as 20 km, which may have been produced by periglacial, tectonic, or compaction processes (Carr and Schaber, 1977; Pechmann, 1980; McGill, 1985) enhanced by erosion. The ridged member is distinguished by whorl-like patterns of ridges resembling fingerprints. Stratigraphic relations between the Vastitas Borealis Formation and the younger Arcadia Formation are unclear except in eastern Acidalia Planitia, where the lowermost member (unit Aa$_1$) of the Arcadia Formation overlies the knobby member of the Vastitas Borealis Formation.

Contemporaneous with formation of the younger Vastitas Borealis members was the beginning of the development of the *etched plains material* (unit AHpe) in southern and western Elysium Planitia. This unit is characterized by irregular mesas and pits representing the erosion of a mantle, possibly by the wind.

Amazonian System

This system was defined by Scott and Carr (1978) to include the youngest units on Mars, most of which occur in the northern lowlands. As seen on Mariner 9 images, the units generally form sparsely cratered, featureless plains. However, Viking data reveal more complex terrains and suggest diverse origins and modification by a variety of processes. Amazonian units are subdivided by age on the basis of frequency distributions of craters larger than 2 km in diameter.

In addition to the northern plains units, the Amazonian System includes the Elysium Formation and materials formed during the modification of the Hellas basin. During the early part of the Amazonian, central-vent volcanism continued at Albor Tholus. Its flows, as well as those of the Hecates Tholus Formation, are overlain by plains-forming lava flows of *member 1* (unit Ael$_1$) of the *Elysium Formation*. These fresh-appearing flows are radial to the Elysium Mons edifice and are gradational with flows of *member 2* (unit Ael$_2$) that form the edifice; these younger flows also appear fresh and display channels and features interpreted as collapsed lava tubes. Northwest of Elysium Mons, in Utopia Planitia, *member 3* (unit Ael$_3$) forms rugged plains having hummocky surfaces and flow lobes; the member appears to interfinger with member 1. The plains have been extensively modified by processes inferred to be fluvial, eolian, and periglacial. Part of this modification may be related to channels that also cut member 1. The channel material, mapped as *member 4* (unit Ael$_4$), is considered volcanic, possibly derived from lahars of Elysium Mons (Christiansen and Greeley, 1981).

Partial filling, mantling, and modification of the Hellas basin continued through the middle of the Amazonian Period to produce the younger units of the Hellas assemblage. Most of these units occur near the basin rim and are considered to be mantling material, some of which is eroded. The *lineated floor unit* (unit Ah$_4$) and the *channeled plains rim unit* (unit Ah$_5$) have similar crater-count ages and may represent only slightly modified areas of a mantle. The lineated floor unit is characterized by straight and curvilinear lineaments within smooth plains material and may have formed by tectonic modification of mantling material. The channeled plains rim unit has a subdued appearance and low remnant mesas and narrow channels. The other younger Hellas units form plains distinguished by low-relief features that may reflect differential erosion of mantling material. These units are *reticulate floor material* (unit Ah$_6$) characterized by a reticulate pattern of ridges, a *rugged floor unit* (unit Ah$_7$) whose undulating surface is rugged on a kilometer scale, and a *knobby plains floor unit* (unit Ah$_8$) that forms low knobs a few kilometers across.

In the northern plains assemblage, the *Arcadia Formation* is inferred to consist of lava flows whose age range defines and spans the Amazonian Period (Scott and Carr, 1978). Of the five members present in the western equatorial region (Scott and Tanaka, 1986), only three occur in the eastern region: *member 1* (unit Aa$_1$), *member 3* (unit Aa$_3$), and *member 4* (unit Aa$_4$). Lobate flow fronts, crescentic flow-lava ridges, and features presumed to be lava channels are visible on high-resolution images and are considered to be evidence of volcanic origin.

The *Medusae Fossae Formation* (Scott and Tanaka, 1986) consists of three members distributed along an east-west border zone between the highland plateau and lowland plains of Amazonis Planitia in the eastern part of the map area. The *lower*, *middle*, and *upper members* (units Aml, Amm, and Amu, respectively) are distinguished on the basis of morphology, stratigraphic relations, and albedo. The materials are seen on high-resolution Viking images as massive horizontal sheets that may have a combined thickness in excess of 3 km. They have smooth and flat to gently rolling surfaces that in places are lineated in places where an upper member has been stripped by wind. Eolian erosion has also produced yardangs on the edges of some high-standing deposits of the upper member, which suggests that they are composed of friable materials (Ward, 1979). The deposits are less hilly and cratered than those of the highlands, but they have higher relief and a higher albedo than the plains materials. Although Scott and Tanaka (1982) preferred a volcanic origin for this formation, suggesting that it consists of ignimbrites and lava flows, it may be formed of vast accumulations of eolian deposits transported and trapped along the highland-lowland boundary (Lee and others, 1982; Thomas, 1982) or of materials related to ancient polar deposits (Schultz and Lutz-Garihan, 1981).

Resurfacing or modification of parts of the northern lowlands continued through the Amazonian Period to produce plains materials of diverse origins. These materials have been divided into a featureless *smooth plains unit* (unit Aps) and a *knobby plains unit* (unit Apk). In many places the smooth plains unit probably consists of eolian deposits. The knobby plains unit appears to be formed by the erosion of older units; surfaces between the knobs may be erosional or may consist of volcanic, mass-wasting, or eolian materials.

Surficial materials of inferred mass-wasting, fluvial, and eolian origin occur locally throughout the eastern hemisphere of Mars. However, in only a few places are deposits extensive or continuous enough to be mapped as separate units. *Slide material* (unit As) forms aprons around knobs and fills channels in the fretted terrain of Deuteronilus Mensae and eastward. This material, interpreted to result from mass wasting, clearly overlies both the older channel material (unit Hch) and crater ejecta on the channel floors. *Younger channel and flood-plain material, undivided* (unit Achu), located south of the Elysium region, is characterized by albedo patterns that appear to represent channels and bars formed by fluid flow. The paucity of superposed craters on this material indicates that channel formation may have occurred late in the Amazonian Period. Eolian processes also were significant during Amazonian time. In addition to the eolian deposits that mantle underlying terrain and probably make up at least part of the smooth plains material of the northern plains assemblage, evidence of eolian activity includes *dune material* (unit Ad) and wind streaks that form albedo patterns in the lee of obstacles. In some areas the streaks are dark and may represent patches of older rocks exposed by erosion.

Unassigned Materials

Mantling deposits form smooth plains on the floors of many craters. In some places the materials may consist of lava flows extruded from fractures in crater floors (as on the Moon and probably on Mercury); in other areas they may be eolian and alluvial deposits. The mantling deposits are shown in orange and designated by the symbol "s".

One mountain, interpreted as volcanic, straddles the south boundary of the map area at long 220°–224°.

STRUCTURE

The major tectonic features on Mars fall into four broad categories: (a) the northern lowlands-southern highlands boundary, (b) the Tharsis and Elysium rises, (c) Valles Marineris, and (d) crustal deformation associated with large impact structures. Of these features, part of the northern lowlands-southern highlands boundary, the Elysium rise, and some large-impact crustal deformation occur within the map area. Several hypotheses have been proposed to explain the northern-southern dichotomy, including origins related to global expansion (Mutch and others, 1976, p. 233), thinning of the lithosphere due to first-order mantle convection early in Martian history (Wise and others, 1979), and impact-basin formation (Wilhelms and Squyres, 1984). However, compelling evidence to support or refute these ideas has not been advanced and the problem remains enigmatic.

Gravity data (Sjogren, 1979) reveal large positive anomalies over the Tharsis rise and the Elysium volcanic field. Several interpretations have been offered to explain these anomalies. For example, Solomon and Head (1979, 1982) proposed a model that involves crustal thickening by the accumulation of lava flows and other volcanic products on a lithosphere whose thickness has varied with location and time. This model is consistent with analyses of concentric fractures surrounding Elysium Mons generated by mass loading (Comer and others, 1985) and with the gravity data (Janle and Ropers, 1983). Although applied principally to the Tharsis rise, the model may apply also to the Elysium region (Solomon and Head, 1982; Hall and others, 1983).

Basin-forming impacts have had major effects on planetary surfaces. They have deposited ejecta that may mantle thousands of square kilometers, and they have generated seismic waves that may have been felt planet-wide. They have also extensively fractured the lithosphere: the structural imprint of a basin may be imposed over a large area. Adjustments of the crust and subsequent volcanism also are common postimpact effects. As noted above, many of the volcanic paterae on Mars may have formed over ring fractures around the Hellas basin (Peterson, 1978). Similarly, the eruption of the Syrtis Major flows may represent volcanism associated with the Isidis basin, as the probable source vents are positioned over extrapolated ring fractures around the basin (Comer and others, 1985).

ACKNOWLEDGMENTS

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REFERENCES CITED

Carr, M.H., Masursky, Harold, and Saunders, R.S., 1973, A generalized geologic map of Mars: Journal of Geophysical Research, v. 78, no. 20, p. 4031–4036.
Carr, M.H., and Schaber, G.G., 1977, Martian permafrost features: Journal of Geophysical Research, v. 82, no. 28, p. 4039–4054.
Christiansen, E.H., and Greeley, Ronald, 1981, Mega-lahars(?) in the Elysium region, Mars, *in* Abstracts of papers submitted to the Twelfth Lunar and Planetary Science Conference, Houston, March 16–20, 1981: Lunar and Planetary Institute, p. 138–140.
Comer, R.P., Solomon, S.C., and Head, J.W., 1985, Mars: Thickness of the lithosphere from the tectonic response to volcanic loads: Reviews of Geophysics, v. 23, no. 1, p. 61–92.
Condit, C.D., 1978, Distribution and relations of 4- to 10-km-diameter craters to global geologic units of Mars: Icarus, v. 34, no. 3, p. 465–478.
Greeley, Ronald, and Guest, J.E., 1978, Geologic map of the Casius quadrangle of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1038, scale 1:5,000,000.
Greeley, Ronald, and Spudis, P.D., 1978, Volcanism in the cratered terrain hemisphere of Mars: Geophysical Research Letters, v. 5, no. 6, p. 453–455.
_____ 1981, Volcanism on Mars: Reviews of Geophysics and Space Physics, v. 19, no. 1, p. 13–41.
Hall, J.L., Solomon, S.C., Head, J.W., and Mouginis-Mark, P.J., 1983, Elysium region, Mars: Characterization of tectonic features, *in* Abstracts of papers submitted to the Fourteenth Lunar and Planetary Science Conference, Houston, March 14–18, 1983: Lunar and Planetary Institute, p. 275–276.
Janle, Peter, and Ropers, Jan, 1983, Investigation of the end isostatic state of the Elysium dome on Mars by gravity models: Physics of the Earth and Planetary Interiors, v. 32, no. 2, p. 132–145.
Kieffer, H.H., Martin, T.Z., Peterfreund, A.R., Jakosky, B.M., Miner, E.D., and Palluconi, F.D., 1977, Thermal and albedo mapping of Mars during the Viking primary mission: Journal of Geophysical Research, v. 82, no. 28, p. 4249–4291.
Lee, S.W., Thomas, P.C., and Veverka, Joseph, 1982, Wind streaks in Tharsis and Elysium: Implications for sediment transport by slope winds: Journal of Geophysical Research, v. 87, no. B12, p. 10025–10041.
Masursky, Harold, 1973, An overview of geological results from Mariner 9: Journal of Geophysical Research, v. 78, no. 20, p. 4009–4030.
McCauley, J.F., Carr, M.H., Cutts, J.A., Hartmann, W.K., Masursky, Harold, Milton, D.J., Sharp, R.P., and Wilhelms, D.E., 1972, Preliminary Mariner 9 report on the geology of Mars: Icarus, v. 17, no. 2, p. 289–327.
McGill, G.E., 1985, Age and origin of large Martian polygons, *in* Abstracts of papers submitted to the Sixteenth Lunar and Planetary Science Conference, Houston, March 11–15, 1985: Lunar and Planetary Institute, p. 534–535.
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.
Mutch, T.A., Arvidson, R.E., Head, J.W., III, Jones, K.L., and Saunders, R.S., 1976, The geology of Mars: Princeton, N.J., Princeton University Press, 400 p.
Pechmann, J.C., 1980, The origin of polygonal troughs on the northern plains of Mars: Icarus, v. 42, no. 2, p. 185–210.
Peterson, J.E., 1978, Volcanism in the Noachis-Hellas region of Mars, 2: Lunar and Planetary Science Conference, 9th, Houston, March 13–17, 1978, Proceedings, p. 3411–3432.
Schaber, G.G., 1982, Syrtis Major: A low-relief volcanic shield: Journal of Geophysical Research, v. 87, no. B12, p. 9852–9866.
Schultz, P.H., and Lutz-Garihan, A.B., 1981, Equatorial paleo-poles on Mars, *in* Abstracts of papers submitted to the Twelfth Lunar and Planetary Science Conference, Houston, March 16–20, 1981: Lunar and Planetary Institute, p. 946–948.
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.
Scott, D.H., 1979, Geologic problems in the northern plains of Mars: Lunar and Planetary Science Conference, 10th, Houston, March 19–23, 1979, Proceedings, p. 3039–3054.
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 Tanaka, K.L., 1982, Ignimbrites of Amazonis Planitia region of Mars: Journal of Geophysical Research, v. 87, no. B2, p. 1179–1190.
_____ 1986, Geologic map of the western equatorial region of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1802–A, scale 1:15,000,000.
Sharp, R.P., 1973, Mars: Fretted and chaotic terrains: Journal of Geophysical Research, v. 78, no. 20, p. 4073–4083.
Shoemaker, E.M., and Hackman, R.J., 1962, Stratigraphic basis for a lunar time scale, *in* Kopal, Zdenek, and Mikhailov, Z.K., eds., The Moon: London, Academic Press, p. 289–300.
Sjogren, W.L., 1979, Mars gravity: High-resolution results from Viking Orbiter 2: Science, v. 203, no. 4384, p. 1006–1010.
Solomon, S.C., and Head, J.W., 1979, Vertical movement in mare basins: Relation to mare emplacement, basin tectonics, and lunar thermal history: Journal of Geophysical Research, v. 84, no. B4, p. 1667–1682.
_____ 1982, Evolution of the Tharsis province of Mars: The importance of heterogeneous lithospheric thickness and volcanic construction: Journal of Geophysical Research, v. 87, no. B12, p. 9755–9774.
Tanaka, K.L., 1986, The stratigraphy of Mars: Lunar and Planetary Science Conference, 17th, Houston, March 17–21, 1986, Proceedings, *in* Journal of Geophysical Research, v. 91, no. B13, p. E139–E158.
Tanaka, K.L., and Scott, D.H., 1987, Geologic maps of the polar regions of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1802–C, scale 1:15,000,000.
Thomas, Peter, 1982, Present wind activity on Mars: Relation to large latitudinally zoned sediment deposits: Journal of Geophysical Research, v. 87, no. B12, p. 9999–10008.
U.S. Geological Survey, 1982, Shaded relief map of the eastern region of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1321, scale 1:15,000,000.
Ward, A.W., 1979, Yardangs on Mars: Evidence of recent wind erosion: Journal of Geophysical Research, v. 84, no. B14, p. 8147–8166.
Wilhelms, D.E., in press, Geologic mapping, *in* Greeley, Ronald, and Batson, R.M., eds., Planetary Mapping: Cambridge, England, Cambridge University Press.
Wilhelms, D.E., and Squyres, S.W., 1984, The martian hemispheric dichotomy may be due to a giant impact: Nature, v. 309, no. 5964, p. 138–140.
Wise, D.U., Golombek, M.P., and McGill, G.E., 1979, Tharsis province of Mars: Geologic sequence, geometry, and a deformation mechanism: Icarus, v. 38, no. 3, p. 456–472.
Witbeck, N.E., 1984, The geology of Mare Acidalium quadrangle, Mars, *in* Advances in planetary geology: National Aeronautics and Space Administration Technical Memorandum 86247, p. 219–419.
Wood, C.A., and Head, J.W., 1976, Comparison of impact basins on Mercury, Mars and the Moon: Lunar Science Conference, 7th, Houston, March 15–19, 1976, Proceedings, p. 3629–3651.

DESCRIPTION OF MAP UNITS

Unit descriptions are based on characteristics observed primarily on Viking Orbiter images, supplemented by data from Mariner 9 and other remote-sensing instruments such as the Viking Infrared Thermal Mapper. Most units are grouped by geologic assemblages, according to the convention of Scott and Tanaka (1986).

SURFICIAL DEPOSITS

As SLIDE MATERIAL—Smooth to lobate flow material associated with some scarps and crater rims; especially well developed along channel walls in Deuteronilus Mensae region. Forms aprons along scarps and around knobs and mesas; may completely cover channel floors. Primarily equivalent to third type of slide material mapped by Scott and Tanaka (1986). No specific type area. *Interpretation:* Unconsolidated material, such as debris flows, resulting from mass wasting

Achu YOUNGER CHANNEL AND FLOOD-PLAIN MATERIAL, UNDIVIDED—In eastern equatorial part of map area; forms plain as wide as 600 km marked by dark, sinuous, intertwining albedo patterns; appears more mottled westward. Type areas (Scott and Tanaka, 1986): lat 15° N., long 177° (younger channel material) and lat 22° N., long 171° (flood-plain material). *Interpretation:* Fluvial deposits; distinct albedo patterns probably represent channels with bars and islands; mottled zones in western part may represent deposition from ponded terminus of fluvial system

Ad DUNE MATERIAL—Patches of barchan and other types of dunes on crater floors. Makes up part of dunes and dune-capped material (unit Ad) of south polar region (Tanaka and Scott, 1987). Type area: lat 48° S., long 329°. *Interpretation:* Sand deposited in areas of low wind strength

LOWLAND TERRAIN MATERIALS

Consist of all plains-forming units between highland-lowland boundary scarp and north edge of map area, as well as materials of eastern volcanic assemblage.

Northern plains assemblage

Materials deposited in widespread sheets on northern plains. Within each formation, members mapped on basis of morphology, albedo, and crater size-frequency distribution; some contacts approximately located. This assemblage postdates formation of highland-lowland boundary scarp (Scott, 1979).

Aps SMOOTH PLAINS MATERIAL—Forms patches and regions of flat, featureless plains; lightly cratered. Type area: lat 9° N., long 222°. *Interpretation:* Probably of diverse origin; many exposures probably consist of eolian deposits

AHpe ETCHED PLAINS MATERIAL—Occurs as patches in Elysium Planitia. Surface characterized by irregular mesas and pits. Type area: lat 15° N., long 238°. *Interpretation:* Plains deposits mantled by eolian material that has subsequently been eroded, possibly by wind

ARCADIA FORMATION—Forms low-lying plains (1) in Arcadia Planitia east of Phlegra Montes in east margin of map area and (2) in Acidalia Planitia as small patch in west margin. Common boundaries of older members mapped arbitrarily in places. Flows with lobate margins, ridges, and channels and small hills with summit craters visible in some areas. Members 2 and 5 as defined by Scott and Tanaka (1986) not present in map area. *Interpretation:* Mostly lava flows and small volcanoes

Aa$_4$ Member 4—In Arcadia Planitia; overlies member 3. Type area: lat 45° N., long 175° (Scott and Tanaka, 1986)

Aa$_3$ Member 3—In and north of Arcadia Planitia along east margin of map area. Flow fronts visible in places. Type area: lat 15° N., long 155° (Scott and Tanaka, 1986)

Aa$_1$ Member 1—Near west and east borders of map area. Type area: lat 30° N., long 40° (Scott and Tanaka, 1986)

MEDUSAE FOSSAE FORMATION—Occurs near equator in eastern part of map area. Consists of extensive, relatively flat sheets, generally smooth to grooved and gently undulating; albedo moderate (Scott and Tanaka, 1986). Locally, where upper or middle member stripped by wind, underlying member shows lineations

Amu Upper member—Surfaces smooth, flat to rolling, light in color; sculptured into ridges and grooves in places; broadly curved margins, locally eroded into serrated scarps. Type area: lat 0° N., long 160° (Scott and Tanaka, 1986). *Interpretation:* Thick deposits of eolian sediments or volcanic pyroclastic deposits; wind eroded, particularly along margins, to form yardangs

Amm Middle member—Similar to upper member but in places surface is more rugged and eroded. Type area: lat 10° N., long 160° (Scott and Tanaka, 1986). *Interpretation:* Poorly to moderately indurated eolian or pyroclastic deposits; wind eroded, particularly along margins

Aml Lower member—Most widespread member in map area. Surfaces smooth to rough and highly eroded, darker than those of other members. One area centered at lat 1° S., long 182° contains long, broad troughs. Type area: lat 0° N., long 174° (Scott and Tanaka, 1986). *Interpretation:* Lava flows interbedded with eolian or pyroclastic deposits, in places heavily eroded

VASTITAS BOREALIS FORMATION—Subpolar plains deposits of northern lowlands; members distinguished on basis of morphology and albedo contrast; placement of contacts locally arbitrary (Scott and Tanaka, 1986)

Hvm Mottled member—Major occurrence north of map boundary (Tanaka and Scott, 1987); extends as far south as about lat 43° N. Crater-ejecta blankets have higher albedo than adjacent terrain, giving mottled appearance. In places, gently rolling, closely spaced hills averaging 5 km in diameter can be distinguished. Type area: lat 55° N., long 40° (Scott and Tanaka, 1986). *Interpretation:* Possibly lava flows erupted from fissures, or of alluvial or eolian origin

Hvg Grooved member—Occurs as isolated patches in several areas of lowland plains; similar to mottled member but marked by curvilinear and polygonal patterns of grooves and troughs; closed polygons as wide as 20 km. Ridges present in center of some grooves, as at lat 53° N., long 295°. Type area: lat 45° N., long 15° (Scott and Tanaka, 1986). *Interpretation:* Material same as mottled member; patterns may be due to compaction, tectonism, or periglacial processes

Hvr Ridged member—In isolated patches in northern plains. Characterized by concentric, low ridges about 1 to 2 km wide; northwest of Deuteronilus Mensae, many ridges are within depressions. In Isidis basin, member displays low mounds, many of which are aligned. Type area: lat 38° N., long 33° (Scott and Tanaka, 1986). *Interpretation:* Material same as mottled member; unit appears to develop from erosion of surrounding units. Origin of ridges unknown but they may result from periglacial or erosional processes. Low mounds in Isidis basin may represent spatter cones along lines of vents

Hvk Knobby member—Similar in appearance to mottled member but generally has higher albedo and abundant small, dark, knoblike hills, some with summit craters. Crater ejecta have albedo similar to that of surrounding terrain. Type area: lat 55° N., long 5° (Scott and Tanaka, 1986). *Interpretation:* Plains of diverse origins (volcanic flows, eolian mantles); hills may be small volcanoes, remnants of highland terrain or of crater rims, or pingos

Eastern volcanic assemblage

Volcanoes and lava flows in Elysium region (Greeley and Spudis, 1981).

ELYSIUM FORMATION—Units associated with Elysium Mons.

Ael$_4$ Member 4—Channel material. Type area: lat 36.9° N., long 220°. *Interpretation:* May be derived from lahars of members 1 and 3 (Christiansen and Greeley, 1981)

Ael$_3$ Member 3—Forms plains having rugged relief, hummocky surfaces; lobate deposits seen at high resolution. Type area: lat 43° N., long 230°. *Interpretation:* Of volcanic origin; flows possibly derived from Elysium Mons, possibly interfinger with member 1. Extensively modified by fluvial, eolian, and periglacial processes

Ael$_2$ Member 2—Lobate deposits, with rilles, composing Elysium Mons edifice. Gradational with member 1. Type area: lat 25° N., long 215°. *Interpretation:* Lava flows displaying channels and partly collapsed lava tubes

Ael$_1$ Member 1—Lobate, plains-forming deposits that radiate from Elysium Mons and overlie and embay Albor Tholus and Hecates Tholus Formations. Type area: lat 32.5° N., long 214°. *Interpretation:* Volcanic flows and related materials

AHat ALBOR THOLUS FORMATION—Material forming Albor Tholus; hummocky texture, more subdued near vent. Type area: lat 18° N., long 210°. *Interpretation:* Volcanic flows

Hhet HECATES THOLUS FORMATION—Forms Hecates Tholus; hummocky surface cut by many narrow, sinuous channels. Type area: lat 33° N., long 209°. *Interpretation:* Volcanic flows, some emplaced through lava channels

Hs SYRTIS MAJOR FORMATION—Plains-forming unit constituting Syrtis Major Planum. Characterized by many lobate deposits radiating generally from two irregular depressions (Nili Patera, centered at lat 9° N., long 293°, and Meroe Patera, centered at lat 7° N., long 291.5°); flow fronts and margins clearly recognizable; mare-type ridges trend north-northwest; many light and dark "wind" streaks on plains deposits. Type area: lat 11° N., long 295°. *Interpretation:* Lava flows erupted with low effective viscosity from central vents; rheological properties similar to those of basaltic magmas

HIGHLAND TERRAIN MATERIALS

Rock units of moderate to high relief; dominate southern and near-equatorial parts of map area.

Hellas assemblage

Consists of units in and near Hellas Planitia.

Ah$_8$ Knobby plains floor unit—Floor material characterized by low knobs a few kilometers across. Type locality: lat 35° S., long 295°. *Interpretation:* Possibly remnants of mantle that has been differentially eroded; knobs may be small cinder cones

Ah$_7$ Rugged floor unit—Forms undulating terrain of rugged relief on a kilometer scale in western Hellas Planitia; one occurrence mapped. Type area: lat 42° S., long 310°. *Interpretation:* Eroded mantle of possible eolian origin overlying ridged plains material (unit Hr)

Ah$_6$ Reticulate floor unit—Plains material characterized by reticulate pattern of ridges; one occurrence mapped. Type area: lat 36° S., long 301.5°. *Interpretation:* Plains material whose high-standing remnants result from differential erosion

Ah$_5$ Channeled plains rim unit—Plains material on east rim of Hellas basin characterized by narrow, sinuous channels and slight to moderate relief; includes widespread mesas having irregular margins and a few small knobs. Appears to fill some craters. Type area: lat 43° S., long 264°. *Interpretation:* Mantle of volcanic or eolian deposits eroded possibly by a combination of fluvial and eolian processes. Channels may be fluvial or volcanic

Ah$_4$ Lineated floor unit—Smooth plains material characterized by straight and curvilinear lineaments; one occurrence mapped. Type area: lat 34° S., long 295°. *Interpretation:* Possible mantle modified by local tectonic processes

Hh$_3$ Dissected floor unit—Smooth, rolling-plains material that has been deeply dissected to produce local rugged relief. Occurs in central part of Hellas Planitia. Type area: lat 40° S., long 289°. *Interpretation:* Sedimentary deposits modified by wind and minor fluvial activity; may include lava flows

Hh$_2$ Ridged plains floor unit—Forms rolling smooth plains having sinuous to linear mare-type (wrinkle) ridges; occupies outermost Hellas Planitia as discontinuous concentric band. Type locality: lat 50° S., long 280°. *Interpretation:* Lava flows erupted with low effective viscosity; composition possibly basaltic

Nh$_1$ Basin-rim unit—Material of the Hellas basin rim. Rugged, mountainous, heavily cratered, and modified by surficial processes, but intermontane patches have little relief. Type locality: lat 52° S., long 261°. *Interpretation:* Impact-generated unit of ancient Martian crust; consists of breccias and interbedded volcanic materials. Features normally associated with basins, such as radial troughs, not seen, probably covered by younger surficial deposits

Plateau and high-plains assemblage

Forms ancient highland terrain and local tracts of younger deposits.

OLDER CHANNEL MATERIAL AND CHAOTIC MATERIAL

Hch Older channel material—Occurs mainly along boundary of northern highlands of Deuteronilus Mensae but also in other highland locations, including margin of Hellas basin. Channels generally steep sided, smooth floored, and abruptly terminated on up-slope end. Type area: lat 25° N., long 60° (Scott and Tanaka, 1986). *Interpretation:* May be mixture of channel deposits and mass-wasted materials; channels may have formed by sapping

Hcht Chaotic material—Forms semicircular patches of closely spaced knobs of similar heights; mapped near west map border just south of lat 40° N. and near east border. Type area: lat 5° S., long 27° (Scott and Tanaka, 1986). *Interpretation:* Erosional remnants; not associated with channels within map area

Nm MOUNTAINOUS MATERIAL—Forms large, very rugged, isolated blocks. Scattered occurrences mostly around Hellas and Isidis basins. Equivalent in part to mountain material (mapped as "m") in south polar region (Tanaka and Scott, 1987). *Interpretation:* Mostly ancient crustal material uplifted during formation of impact basins

PLATEAU SEQUENCE—Forms rough, hilly, heavily cratered to relatively flat and smooth terrain covering most of highlands; occurs mostly in southern hemisphere.

Hpl$_3$ Smooth unit—Forms flat, relatively featureless plains in southern highlands; locally embays other units of plateau sequence. Faults and flow fronts rare. Type area: lat 43° S., long 105° (Scott and Tanaka, 1986). *Interpretation:* Interbedded lava flows and sedimentary deposits of eolian or fluvial origin that bury most underlying rocks

Hplm Mottled smooth plains unit—Same as smooth unit but has mottled albedo patterns. Global occurrences only in southwestern part of map area. Type area: lat 38° S., long 358°. *Interpretation:* Same as smooth unit except that wind-sorted sediments have produced mottled appearance

Npl$_2$ Subdued cratered unit—Forms highland plains characterized by subdued and partly buried crater rims; fills some crater floors; flow fronts rare. Type area: lat 28° S., long 162° (Scott and Tanaka, 1986). *Interpretation:* Thin lava flows and sedimentary deposits that partly bury underlying rocks

Npl$_1$ Cratered unit—Widespread in southern highlands; highly cratered, uneven surfaces of generally moderate, locally high relief; fractures and channels common. Type area: lat 45° S., long 148° (Scott and Tanaka, 1986). *Interpretation:* Materials formed during period of high impact flux; probably a mixture of volcanic materials, erosional products, and impact breccia

Npld Dissected unit—Similar in occurrence and appearance to cratered unit but more highly dissected by small channels, channel networks, and troughs. Gradational with cratered unit; placement of contact based on abundance of channels. Type area: lat 45° S., long 70° (Scott and Tanaka, 1986). *Interpretation:* Origin same as that of cratered unit but material more highly eroded by fluvial processes

Nple Etched unit—Similar to cratered unit but deeply furrowed by sinuous, intersecting, curved to flat-bottomed grooves, producing an etched or sculptured surface; commonly forms small mesas having irregular margins; craters and other depressions filled with smooth deposits. Occurs in several places on cratered plateaus, but is most extensive and well developed northwest of Syrtis Major Planum. Type area: lat 45° N., long 55° (Scott and Tanaka, 1986). *Interpretation:* Cratered unit that has been partly mantled by deposits of possible eolian origin and dissected by eolian erosion, decay and collapse of ground ice, and minor fluvial activity

Nplr Ridged unit—Resembles and is locally gradational with ridged plains material (unit Hr) where units adjoin, but ridges generally larger and farther apart, intervening areas rougher and more densely cratered. Type area: lat 15° S., long 163° (Scott and Tanaka, 1986). *Interpretation:* Flood-lava flows; ridges due to faulting, folding, or volcanic processes

Nplh Hilly unit—Rough, hilly, fractured material of moderately high relief. Type area: lat 12° S., long 174° (Scott and Tanaka, 1986). Forms complete or partial rims of Isidis and some other ancient basins. *Interpretation:* Ancient highland rocks and impact breccia generated during period of heavy bombardment

HNu UNDIVIDED MATERIAL—Forms closely spaced, conical hills a few kilometers across whose distribution indicates that they are remnants of numerous craters. Unit also forms rugged terrain on margins of cratered plateaus and isolated remnants (as west of Orcus Patera near east map border). Gradational with knobby plains material (unit Apk) where units adjoin, but hills are more closely spaced, larger, and occupy more than about 30 percent of area. No specific type area. *Interpretation:* Most hills are eroded remnants of ancient cratered terrain produced by mass-wasting processes, possibly as result of removal of ground ice; some hills may be erosional remnants of intrusive bodies (Greeley and Guest, 1978). Material may include some units of plateau sequence

HIGHLAND PATERAE

AHt Tyrrhena Patera Formation—Material forming Tyrrhena Patera; seen on high-resolution images to consist of several members (Greeley and Spudis, 1981), including a highly dissected basal member. Type locality: lat 22° S., long 254°. *Interpretation:* Volcanic materials erupted serially, including early-stage pyroclastic material and later lava flows

AHa Apollinaris Patera Formation—Material composing Apollinaris Patera. Consists of several members including deposits dissected by channels, some of which flowed over a basal scarp; forms a large fanlike feature on southeast flank. Type area: lat 9° S., long 186°. *Interpretation:* Material of multiple-stage eruptions forming shield volcano (Greeley and Spudis, 1981)

AHh Hadriaca Patera Formation—Material of Hadriaca Patera. Consists of smooth floor material in central depression, locally ridged along margin, surrounded by material dissected radially to depression. Type area: lat 31° S., long 268°. *Interpretation:* Material of central-vent volcano formed by multiple eruptions; possible pyroclastic deposits indicate explosive activity (Greeley and Spudis, 1981)

Had Amphitrites Formation, dissected member—Forms shieldlike deposit along north edges of Malea Planum (near south map border). Consists of deeply etched, ridged, lobate deposits and superposed crater material; sinuous furrows, ridges, and scarps trend toward Hellas Planitia. Type area: northern Malea Planum. *Interpretation:* Ridged plains material (unit Hr) modified by fluvial channeling

MATERIALS OCCURRING THROUGHOUT MAP AREA

Apk KNOBBY PLAINS MATERIAL—Extensive in northern lowlands where it forms moderately to lightly cratered, generally smooth plains; several isolated occurrences in cratered highlands. Conical hills or knobs occur at irregular intervals; mare-type (wrinkle) ridges locally present. Where adjacent to undivided material (unit HNu), units are intergradational, but knobs in knobby plains unit are smaller and spaced farther apart. Type area: lat 22° N., long 263°. *Interpretation:* Probably of diverse origins but appears to have formed mainly by erosion of older units. Knobs are probably erosional remnants but some may be volcanic. Intervening plains may be erosional surfaces or may consist of eolian, mass-wasted, or volcanic materials

Hr RIDGED PLAINS MATERIAL—Characterized by broad planar surfaces, rare lobate deposits, and long, parallel, linear to sinuous mare-type (wrinkle) ridges about 30 to 70 km apart. Forms plains within and outside craters throughout plateau area and lowland plains north of Orcus Patera (near east map border). Locally gradational with ridged plateau material (unit Nplr) where units adjoin. Type area: Lunae Planum, lat 10° N., long 65° (Scott and Tanaka, 1986). *Interpretation:* Extensive lava flows erupted with low effective viscosity from many sources at high rates; ridges either volcanic constructs or compressional features

IMPACT-CRATER MATERIALS—Yellow indicates materials of superposed craters greater than about 100 km across; brown indicates materials of partly buried craters greater than about 150 km across. May include rim crest (hachured), central ring (inner circular feature, also hachured), and central peak. Hachures also denote impact-basin rims. Symbol "c" denotes crater-rim and ejecta material. Symbol "s" and orange color denote smooth floor material; within mapped crater material, only patches larger than 30 km across are shown; elsewhere, only patches larger than about 80 km across are shown. Linear dot pattern denotes secondary craters outside crater aprons. *Interpretation:* Units resulting from impact cratering, but smooth-floor material may be of volcanic, eolian, or fluvial origin

CONTACT—Dashed where approximately located or gradational, or where arbitrarily located based on crater densities of bounded map units

FAULT—Bar and ball on downthrown side

NARROW DEPRESSION—Fracture or graben

MARE-TYPE (WRINKLE) RIDGE—Symbol on ridge crest

SCARP—Line marks top of slope; barb points downslope

NARROW SINUOUS CHANNEL—Wide age range

INFERRED FLOW DIRECTION OF FLOW LOBE

DEPRESSION OR CALDERA

HIGHLAND-LOWLAND BOUNDARY SCARP—Diffuse zone of transition between highland and lowland physiographic provinces; not shown where buried or uncertain

VOLCANO—Age uncertain

GEOLOGIC MAP OF THE EASTERN EQUATORIAL REGION OF MARS

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