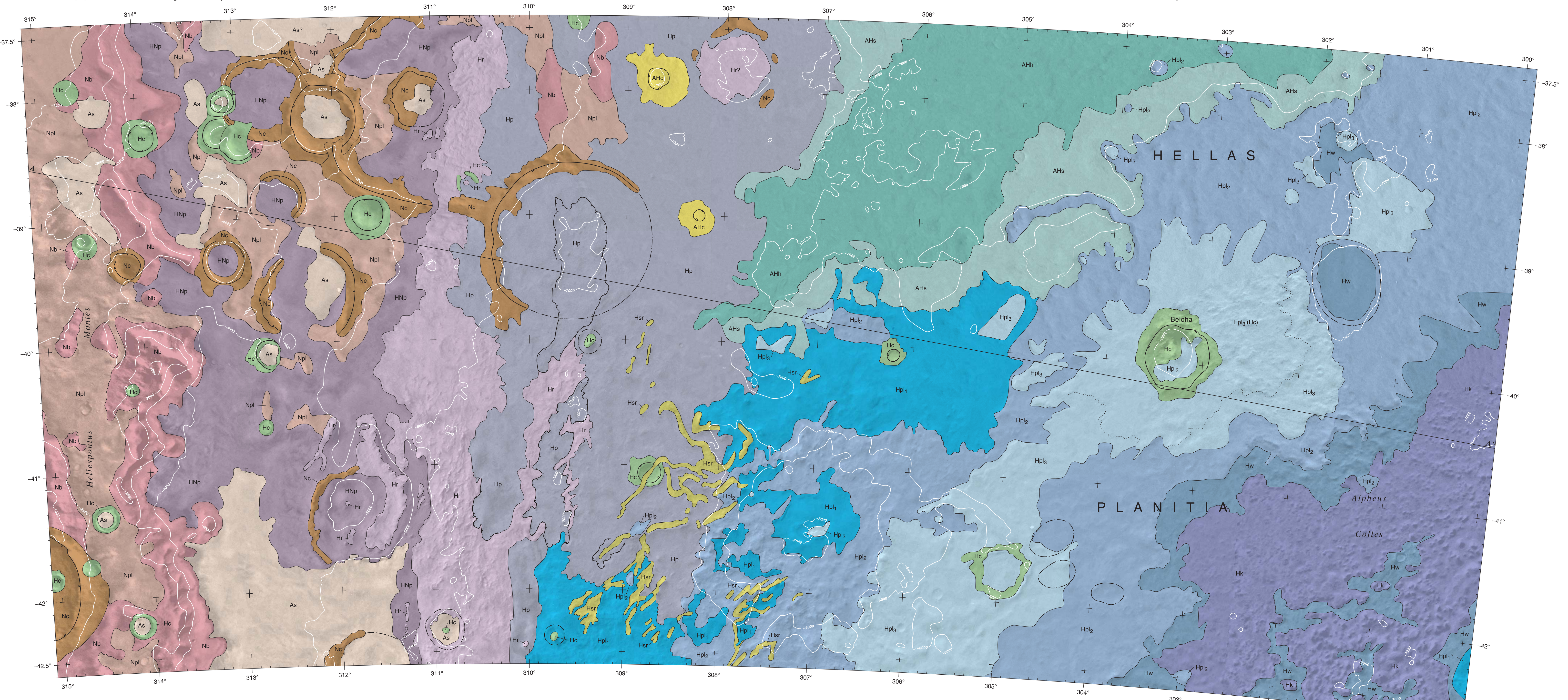

Descriptions of nomenclature used on map are listed at http://planetarynames.wr.usgs.gov/

SCALE 1:1 004 000 (1 mm = 1.004 km) AT 300° LONGITUDE
TRANSVERSE MERCATOR PROJECTION
CONTOUR INTERVAL 1,000 KILOMETERS
Planetographic latitude and west longitude coordinate system

Prepared on behalf of the Planetary Geology and Geophysics Program, Solar System Exploration Division, Office of Space Science, National Aeronautics and Space Administration
Edited by Jan L. Zigler; cartography by Darlene A. Ryan
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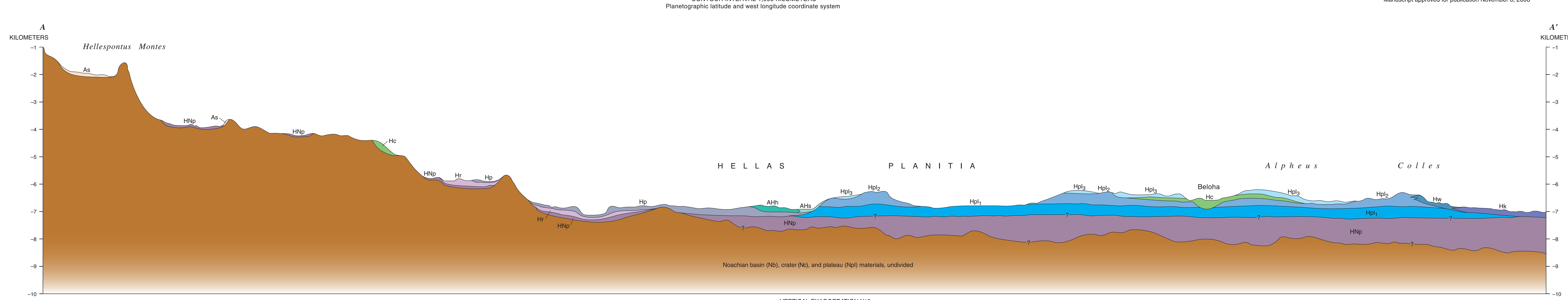
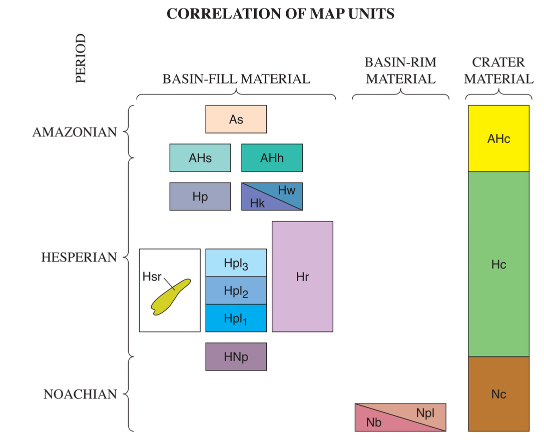


VERTICAL EXAGGERATION X13

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

BASIN-FILL MATERIAL

As — **Younger smooth material (Amazonian)**—Smooth, featureless, almost uncratered. On elevated terrain in western map area. *Interpretation*: Aeolian deposits of sand and indurated dust, as deduced from variable, high elevations where less subject to erosion than in Hellas Planitia

AHs — **Older smooth material (Amazonian or Hesperian)**—Smooth, wavy, or lobate. Marginal to unit AHh. *Interpretation*: Apparently related to unit AHh, therefore probably additional lacustrine deposit, modified by flowage

AHh — **Honeycomb material (Amazonian or Hesperian)**—Subplanar overall, with distinctive cell-like, closely packed, subequal elliptical or polygonal rimmed pits a few kilometers across producing honeycomblike appearance; more elongate, less regular near unit edges (fig. 6). In depression in north-central map area. Dated as Amazonian by Leonard and Tanaka (2001). *Interpretation*: Collection in depression indicates lacustrine origin, probably deformed while still wet by grounding of ice blocks as lake level dropped, resulting in soft-sediment deformation textures and morphology (figs. 2, 7)

Hp — **Younger plains material (Hesperian)**—Expansive, sparsely cratered, smooth to wavy. Locally incised, forming scarp-bounded enclosures. *Interpretation*: Scarps and smoothness indicate thickness sufficient to bury or mantle pre-existing topography over extensive area; therefore, probably water-laid, not aeolian. Possibly volcanic in part

Hw — **Wavy material (Hesperian)**—Smooth, flat to undulatory, sparsely dotted with small (~1 km) knobs; flow structure visible at high resolution. Gradational with knobby material (Hk) and Alpheus plateau materials (Hpl_3, Hpl_2, Hpl_1). *Interpretation*: Debris flows and plateau remnants, probably created by chaotic ground collapse caused by ice loss

Hk — **Knobby material (Hesperian)**—Closely spaced, roughly equidimensional knob-like hills typically a few kilometers across and possibly a few hundred meters high; some knobs elongate, some trend northeast. Occupies deep depression in southeastern map area. *Interpretation*: Broken from plateau materials during erosional retreat of plateau, probably through chaotic ground collapse caused by loss of ice matrix or substrate; elongate knobs possibly aeolian yardangs

Hr — **Reticulate material (Hesperian)**—Rough overall appearance from many short, sharp interconnected ridges connected into a net-like pattern of cells typically 1–2 km across (figs. 4, 5). Ridges generally tangential or normal to Hellas basin rim, enclosing rectangular or elliptical depressions. Main exposure lies along –5.8 km contour and concentric with basin rim. *Interpretation*: Deposited along periphery of ice-covered lake

Hsr — **Sinuous ridge material (Hesperian)**—Sinuous ridges typically a few tens to ~75 km long and a few kilometers wide. Peripheral to Alpheus Colles plateau or superposed on units Hpl_1 or Hpl_2 (fig. 3). *Interpretation*: Similarity to terrestrial eskers suggests origin by flow of sediment-laden water under ice layer or icy sediment

Hpl_3 — **Upper Alpheus plateau material (Hesperian)**—Uppermost layers of plateau studded by Alpheus Colles hills. Relatively smooth or wavy; partially bounded by irregular scarps. *Interpretation*: All three Alpheus plateau units probably originated as water-laid sediment then were degraded by loss of ice matrix derived from the water medium (see discussion regarding degradation style and water sources)

Hpl_2 — **Intermediate Alpheus plateau material (Hesperian)**—Intermediate layers forming plateau. Rough, uneven, hilly or hummocky, bounded by irregular scarps

Hpl_1 — **Lower Alpheus plateau material (Hesperian)**—Lowermost layers of plateau. Irregular, rough hills and lumps of all sizes and distributions bounded by irregular scarps

HNp — **Older plains material (Hesperian to Noachian)**—Not distinctive at Viking mapping scale; intermediate in roughness between adjacent units Npl and As. Located on Hellas basin wall beneath –3.1 km contour. *Interpretation*: Ambiguous but consistent with deposition in ice-covered water body reaching –3.1 km contour

BASIN-RIM MATERIAL

Npl — **Older plateau material (Noachian)**—Moderate roughness on slopes or level parts of Hellas basin rim and wall. *Interpretation*: Probably mixed materials including basin ejecta, mass-wasted debris, and later aeolian deposits

Nb — **Basin material (Noachian)**—Forms mountainous massifs and other topographic prominences of Hellas basin rim and wall. *Interpretation*: Uplifted during basin-forming impact and covered by unknown thickness of basin ejecta

CRATER MATERIAL

AHc — **Younger crater material (Amazonian or Hesperian)**—Rims, flanks, floors, and outer ejecta of relatively fresh-appearing craters. Pedestal-like ejecta where exposed, terminating at steep scarp. *Interpretation*: Impact crater materials including ejecta blankets of a type characteristic of derivation from volatile-rich targets

Hc — **Middle crater material (Hesperian)**—Rims, flanks, floors, and outer ejecta of slightly degraded craters or small rings without visible ejecta. *Interpretation*: Materials of impact craters, eroded or nearly obscured by later deposits

Nc — **Older crater material (Noachian)**—Forms degraded rims or central peaks of large craters. *Interpretation*: Ancient impact crater materials

Contact—Dotted where concealed (Hc/Hpl_3 contact). Queried in cross section where hypothetical

Interfingering contact (cross section)

Irregular depression—Hachures point downslope

Crater rim crest

Buried crater rim crest

–6000 **Topographic contour**—Negative value denotes depth in kilometers below MOLA-derived Mars datum

INTRODUCTION

Rock units were deposited on Mars by meteorite impact, volcanism, wind, flowing water, standing water, and ice, acting separately or in concert. Hellas Planitia, the deepest tract on Mars, is a broad depression lying within the high-rimmed, approximately 2,300-km-wide Hellas impact basin. The basin and the planitia are centered about 250 km east of the southeast corner of the map area. Like other stratigraphy-based planetary mapping (Wilhelms, 1990), we suggest the most likely origins for age relations and morphologies visible in the map area.

Western Hellas Planitia was first mapped geologically by Peterson (1977) using Mariner 9 images that barely disclosed surface detail. Greeley and Guest (1987), mapping from better Viking images but at the small scale of 1:15,000,000, proposed that lava flows underlie and partly constitute the deposits of Hellas Planitia, but that deposits exposed in the map area are sediments dissected by winds and minor fluvial activity. Kargel and Strom (1992) suggested deposits originating from continental glaciers and proglacial lakes. Moore and Edgett (1993) interpreted Viking and Earth-based remote-sensing data as more consistent with fine-grained surface material than with coarse glacial deposits or blocky volcanics. Tanaka and Leonard (1995) favored wind as the main agent of both deposition and erosion, which they reiterate in their 1:5,000,000-scale mapping of the entire Hellas region (Leonard and Tanaka, 2001). Studies of areas around Hellas Planitia disclosed undoubted volcanic landforms (Potter, 1976; Peterson, 1977; Greeley and Guest, 1987; Tanaka and Leonard, 1995; Leonard and Tanaka, 2001). An idea of particular interest for our map is that water, released by volcanism or geothermal heat from subsurface ice, carried sediment into Hellas Planitia along the large channels called Dao and Harmakhis Valles east of the map area (Squyres and others, 1987; Crown and others, 1992; Price, 1998), as well as in smaller but numerous channels along much of the basin periphery. Similarly, magmatic intrusions into erosion-prone, volatile-rich terrain now occupied by Malea and Hesperia Plana (east of the map area) may have triggered flows of debris into Hellas Planitia (Tanaka and others, 2002).

Our map is based primarily on Viking orbital images of uneven quality obtained from 1976 to 1980. This basic mapping was completed when, in 1999, Mars Global Surveyor (MGS) began transmitting elevation data from the Mars Orbiter Laser Altimeter (MOLA; Smith and others, 1999) and high-resolution images from the Mars Orbiter Camera (MOC; for example, Malin and Edgett, 2000). These valuable new data clarified geologic relations and revealed diagnostic morphologies of the already mapped units. The Viking and MGS data are combined here and in a report that extends the study to the rest of Hellas Planitia (Moore and Wilhelms, 2001). As that report explains more fully, we maintain that the geologic relations and characteristics of most mapped rock units are the result of sedimentation from ice-covered bodies of water.

STRATIGRAPHY

The rim and wall of the Hellas impact basin rise above Hellas Planitia in the west quarter of the map area and culminate along the map edge as the classical feature Hellespontus Montes. The rock composing the more rugged, massif-like topography probably shaped by the impact is mapped as basin material (unit Nb) and the intervening less-rugged terrain of uncertain origin is mapped as older plateau material (unit Npl). Both units appear smooth at fine scale on available images. This mountainous terrain is pocked by so many large Noachian craters (unit Nc) that the basin must have been created very early in Martian history and be Noachian in age. Similar terrain must extend beneath the exposed rocks of Hellas Planitia.

Hellas Planitia may be underlain by postbasin materials deposited in the Noachian Period, but the exposed units are probably Hesperian or perhaps early Amazonian in age (Greeley and Guest, 1987; Tanaka and Leonard, 1995; Leonard and Tanaka, 2001). Age assignments of individual map units are based on crater statistics given by Leonard and Tanaka (2001) for units identifiable as roughly conterminous with our units (although differently named). Extensive and differential erosion precludes more precise dating from crater statistics in the map area. Relative ages of adjacent units are determined from superposition and cross-cutting relations.

The oldest postbasin geologic map unit is older plains material (unit HNp), which is equivalent to the mantling material of Moore and Wilhelms (2001, unit m). Its presence is revealed by faint textural elements and a partial blanketing of craters and the basin wall as high as –3.1 km elevation (fig. 1; Moore and Wilhelms, 2001). Because it reached so high, we assume that this unit also filled low elevations and interpret it on the cross section as the oldest postbasin unit in Hellas Planitia. It presumably would level out the irregular basin floor. However, other units not exposed in this map area very likely underlie the older plains material.

A plateau, studded by the hills called Alpheus Colles, dominates the east half of the map area and is the western part of a broad plateau in Hellas Planitia's interior (Leonard and Tanaka, 2001). The beds composing it are seen in MGS images and in the best Viking images to be finely stratified (fig. 2) but can be divided consistently into only three map units, lower, intermediate, and upper Alpheus plateau materials (Hpl_1, Hpl_2, Hpl_3, respectively). The many strata form a bench-and-scarp topography that implies moderate coherence that holds up the scarps alternating with moderate erodability that creates the benches. All three map units and the entire plateau are bounded by irregular scarps that demonstrate postdepositional erosion. Small hills beyond the scarps are probably erosional outliers of once-continuous beds. Plateau materials are protected from erosion by the ejecta of some craters, for example the large (23 km) Hesperian-age Beloha crater intersected by the cross section, that may have formed between the intermediate and upper Alpheus plateau materials. The cross section derived from MOLA data confirms the superposition relations among the three plateau units but shows that parts of the intermediate unit (Hpl_2) rise higher than parts of the upper unit. This irregular surface of the intermediate unit and the sandwiching of Beloha and its associated ejecta suggest that erosion cut into the intermediate layer before the upper layer was deposited; other alternations between deposition and erosion are expected within the plateau stack. Thicknesses are estimated from the elevations at which the mapped units intersect the surface of the cross section: approximately 350 m each for the lower and intermediate plateau units and less than 150 m for the preserved outcrops of the upper unit. Future imaging will undoubtedly reveal new details of depositional and erosional history.

Lying upon and extending beyond the lower plateau units are sinuous ridges (fig. 3) believed to consist of a material deposit, sinuous ridge material (unit Hsr), rather than a structural modification of other units. The ridges seem to have formed during or after the growth of the plateau and were later exhumed, suggesting an esker-like origin.

Reticulate material (unit Hr) is more regularly textured than the plateau materials and forms north-south bands (and one questionable circular patch) in the western map area. The unit name is derived from roughly rectangular or elliptical depressions separated by interconnected bounding ridges that are generally tangential or normal to the basin wall (figs. 4, 5). The MOLA altimetry reveals that this interesting unit varies in elevation. Where intersected by the cross section, the main exposure lies at –5.8 km elevation. Farther south, this unit is exposed below –6.0 km elevation. On the map, a branch of unit Hr extends northward from the main exposure between long 309.5° and 310° W. and continues in the subsurface—revealed by subdued traces of its characteristic texture—beneath a trough filled as high as –6.9 km elevation by younger plains material (unit Hp). The exposures at –5.8 km are higher than any plateau surface, so the reticulate material is probably at least partly younger than the preserved plateau beds. Less erosion also suggests this relative youth. However, the lower exposures and buried extensions of reticulate material are level with the lower units of the plateau and could be contemporaneous with them. We suggest that this unit is a marginal facies of the plateau strata that is now isolated from them.

The most extensive unit west of the plateau is younger plains material (unit Hp), which encroaches on and visibly blankets the plateau and reticulate units. The term "plains" only means level and smooth relative to other units; its surface is, in fact, largely wavy or bumpy. Available images do not reveal features diagnostic of origin other than the capacity to cover, but not totally obscure, subjacent topography. Elevations of the younger plains material along the cross section vary from –5.8 to –6.9 km.

In the southeastern map area, two units formed at the expense of the plateau and, within broad limits, in the same epoch as the younger plains material. The better defined unit is knobby material (unit Hk), which consists of small, roughly equidimensional hills scattered across a planar surface (perhaps younger plains material). The knobs are pieces of the plateau that were clearly created by its breakup; they may be considered extreme forms of the erosional outliers on the plateau. Wavy material (unit Hw), between the knobs and the plateau and between patches of knobs, is a transitional unit that appears to be less altered than the knobby material and may represent viscous debris flows. The loss of coherence of the plateau sediments manifested in the wavy and knobby materials suggests weathering of the cementing material. Knobby material lies at or below –6.9 km elevation, one of the lowest spots in Hellas Planitia and, therefore, on Mars.

North of the plateau in the deepest Mars depression (Smith and others, 1999), a generally planar but morphologically distinctive unit is characterized by closely packed, cell-like structures that are appropriately called honeycomb material (unit AHh; figs. 2, 6, 7). This young deposit is part of an arcuate belt circumferential to the plateau. The honeycomb material and an adjacent probably gradational unit, which lacks distinctive features and is simply called older smooth material (unit AHs), encroach on the obviously older plateau beds.

Another indistinct unit completes the stratigraphic column, excluding the well-understood crater materials. This randomly scattered younger smooth material (unit As), which coats both high and low landforms, apparently is a minor depositional product of the wind.

ICE-COVERED LAKES

Unit boundaries at consistent elevations of –3.1, –5.4, –5.8, and –6.9 km in Hellas basin, such as older plains material extending to –3.1, indicate deposition from lakes (Moore and Wilhelms, 2001). Deposition by volcanic air fall or wind presumably would scatter materials more randomly, similar to younger smooth material (unit As). The riverlike channels called Dao and Harmakhis Valles east of the map area, and smaller channels entering the basin are likely sources of the water. Groundwater seepage from the walls of Hellas basin, would also be expected in such a broad and deep catchment (Clifford, 1993).

The unit boundary at –5.8 km is particularly conspicuous (Moore and Wilhelms, 2001). At that depth, the sharply defined and exposed channels, Dao and Harmakhis Valles, that evidently fed sediment-laden water into Hellas Planitia are succeeded westward by muted, meandering forms, probably because they are partly buried by the sediment they deposited (Hesperian smooth plains material of Price, 1998). Similarly, sediments gradually obscure channels at the mouths of terrestrial streams (Kargel and Strom, 1992). Plains at the north and south edges of Hellas Planitia also meet the basin wall at –5.8 km (Moore and Wilhelms, 2001). Along the cross section, the –5.8-km elevation grazes the surface of the uppermost exposures of reticulate material (unit Hr) and of the overlying younger plains material (unit Hp), which resembles the smooth plains material deposited from Dao and Harmakhis Valles. As noted, other exposures of the reticulate and younger plains units lie lower than –5.8 km. The highest plateau beds lie about 350 to 1,100 m below the –5.8-km elevation. A water level at –5.8 km could, therefore, account for all of the sedimentation of Alpheus plateau and the reticulate and younger plains materials. However, the multiple layering of the plateau and the varying elevations of units Hr and Hp suggest episodic cycles of deposition in a regime of fluctuating water levels.

We infer from likely Martian climates that the lake surfaces froze quickly (Haberle, 1998). Morphologies of some geologic units probably reflect the effects of ice: (1) Plateau and knobby materials—The plateau's susceptibility to erosion, indicated by benchlike topography, layers truncated by scarps, and isolated erosional hills, suggests sedimentary rather than volcanic composition. Because the erosion that created the knobby material was so pervasive, its primary mechanism was less likely to have been wind than decay of an icy matrix caused by sublimation or geothermal heating, although wind probably helped erode and remove the material. (2) Reticulate material—Location at the periphery of the Hellas Planitia stratigraphic stack, high elevation, and alignment of ridges parallel to the enclosing basin wall all suggest shaping by ice-marginal processes including sedimentation along the periphery of an ice-covered lake, reworking by large jostling blocks from the icy carapace, and deposition of locally reworked material (Moore and Wilhelms, 2001). (3) Honeycomb material—Except for their large size (a few kilometers), the distinctive cell-like pits in this unit have been compared to those of terrestrial kame-and-kettle terrain created by the stagnation of ice (Kargel and Strom, 1992). We suggest that the pits were created by the settling of ice blocks into soft lacustrine mud as the lake level dropped (Moore and Wilhelms, 2001); the bounding ridges represent soft mud forced up between the ice blocks. At a few places, this unit surface is textured with strongly angular, hectometer-sized, ridge-bounded polygons (fig. 7), which we interpret as casts of cracks that were on the undersurface of the grounding ice. Aeolian dune origins favored by Tanaka and Leonard (1995) are refuted by the high-resolution MGS images, which show the pit walls or septa to be complete and sharply defined by flat tops (fig. 7). Older smooth material seems to grade into honeycomb material and may be additional sediment from a late lake.

Formation of the sinuous ridge material may also result from the icy history of the plateau. Similar ridges in Argyre Planitia were attributed to a process that is responsible for forming terrestrial eskers (Kargel and Strom, 1992). Eskers are accumulations of sediment deposited from water flowing in tunnels in or beneath ice or ice-rich material (Price, 1973; Sugden and John, 1976). They survive when the enclosing ice melts or when the level of a subjacent lake is lowered. This origin is compatible with the location of sinuous ridge material in the map area, formerly sandwiched between ice-rich plateau beds that were subsequently removed. Braided bed morphologies revealed by high-resolution MGS images support an esker-like origin (fig. 3).

GEOLOGIC HISTORY

Although other interpretations are possible, we present the simplest geologic history that can be inferred from stratigraphic relations visible in the map area.

After Hellas basin was created by a giant impact early in the history of Mars, it began to fill with various deposits. The blanketing, older plains material is the earliest deposit. This and most subsequent strata of Hellas Planitia were deposited from lakes that filled the basin to varying elevations marked by stillstands at –3.1, –5.4, –5.8, and –6.9 km. These strata include multiple beds of a once-larger plateau within Hellas Planitia, a marginal facies called reticulate material, and quasi-planar deposits that decreased in volume through time. Reticulate material, characterized by a structure of ridges both tangential and normal to the basin wall, suggests reworking by the ice that we believe covered exposed water in Martian climates. Continental glaciers scouring the substrate while entering Hellas Planitia from the south (Kargel and Strom, 1992) would produce much the same features that we observe but probably not the fine grain size inferred from fine layering and remote-sensing data or the type of grooves and ridges observed by MOC images in the putative approach path south of the map area (Moore and Wilhelms, 2001). Massive debris flows (Tanaka and others, 2002) would fill the basin but probably not to such regular levels.

Erosional episodes probably intervened frequently while deposition was most active. The edges of the plateau sediments eroded, and parts of the plateau were broken up by decay of the ice matrix to create wavy and knobby materials. Escaping meltwater formed esker-like deposits. Erosion apparently removed material from the top of the plateau, judging from the high level of parts of the probable marginal reticulate material. The result was an island-like plateau that was surrounded later by more water and sediment.

Small lakes filled the remaining lowest depressions, creating a honeycomblike structure as blocks from the ice carapace sank into muddy sediment. Older smooth material may represent additional sedimentation. Winds deposited some coatings on the wall of Hellas basin and, no doubt, many other places where they remain unmapped. The wind has certainly been an agent of erosion for all mapped units, and aeolian (and pyroclastic) material may have added to the load of sediment that settled out of the water. But consistent deposition levels around the basin preclude aeolian deposition for the bulk of the mapped units.

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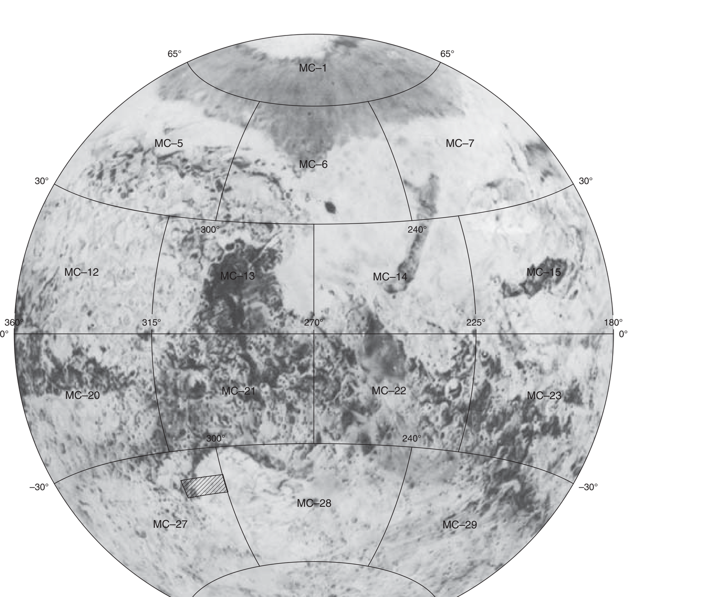

QUADRANGLE LOCATION
Photomosaic showing location of map area. An outline of 1:5,000,000-scale quadrangles is provided for reference.

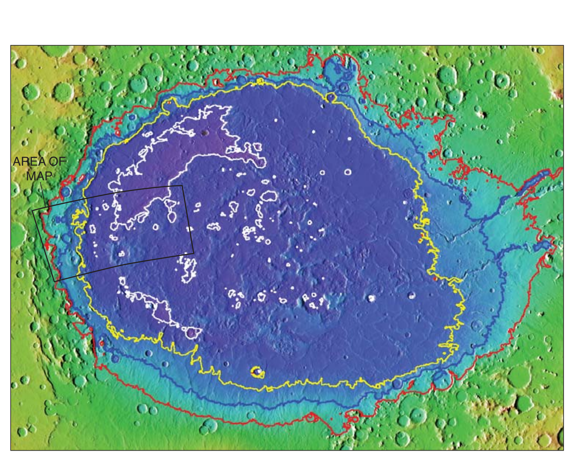

Figure 1. Shaded-relief map of the Hellas Planitia region color-coded by elevation measured by the Mars Orbiter Laser Altimeter (MOLA) and binned at 1/16°. Elevation scale in 1-km increments, +4 km to –8 km relative to the MOLA-derived Mars datum. Contours at –3.1 km (red), –5.4 km (blue), –5.8 km (yellow), and –6.9 km (white) mark putative water stillstands (Moore and Wilhelms, 2001).

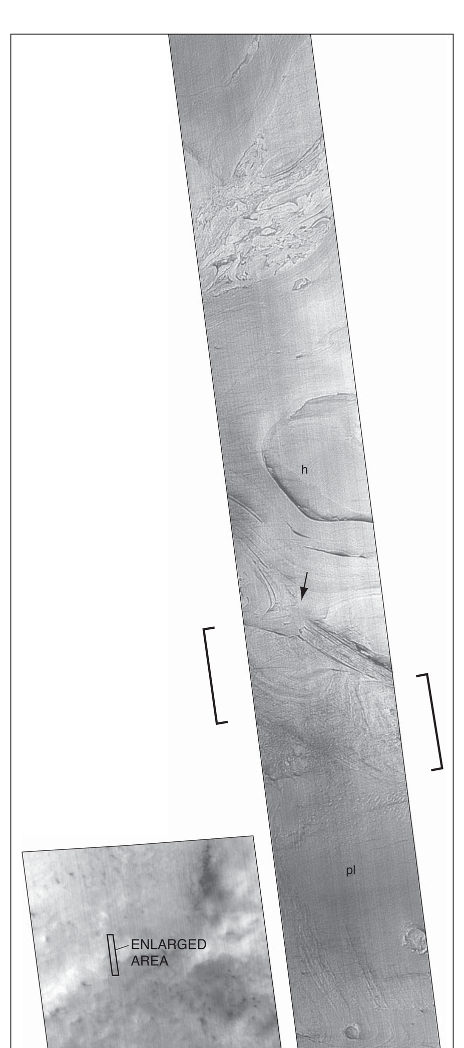

Figure 2. Detailed image showing stratified plateau beds (pl) bounded by scarp (brackets) and onlapped (arrow) by honeycomb material (h). Mars Orbiter Camera (MOC) narrow-angle image M10-01313, centered at lat 37.9° S., long 303.3° W. North at top. Illumination from left. Original resolution 2.9 m/pixel. MOC wide-angle context image M10-01314 at lower left. Image processing courtesy of Malin Space Science Systems.

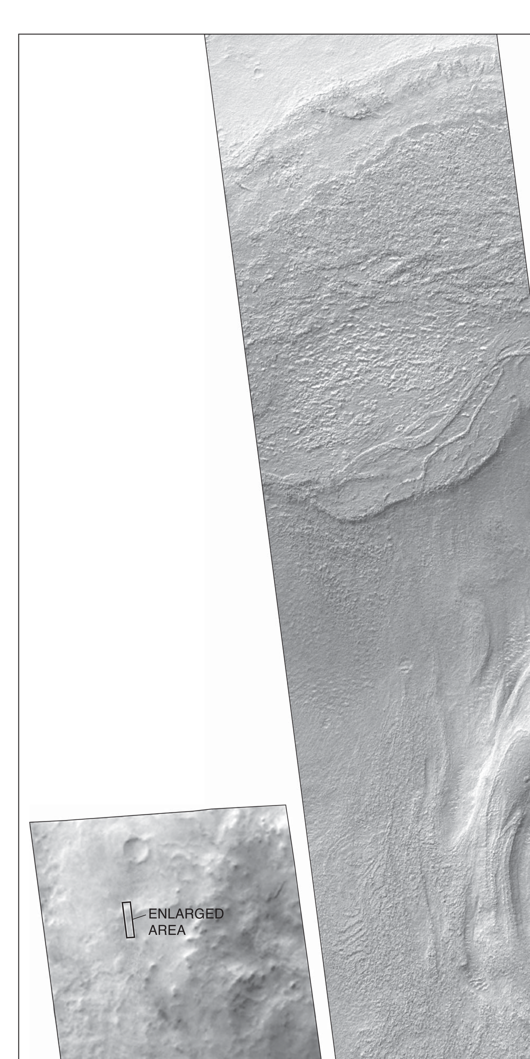

Figure 3. Detailed image showing sinuous ridges interpreted to be eskers atop a plateau outlier, top of image. MOC narrow-angle image M19-01067, centered at lat 41.8° S., long 308.4° W. North at top. Illumination from left. Original resolution 5.5 m/pixel. MOC wide-angle context image M19-01068 at lower left (compare with geologic map). Image processing courtesy of Malin Space Science Systems.

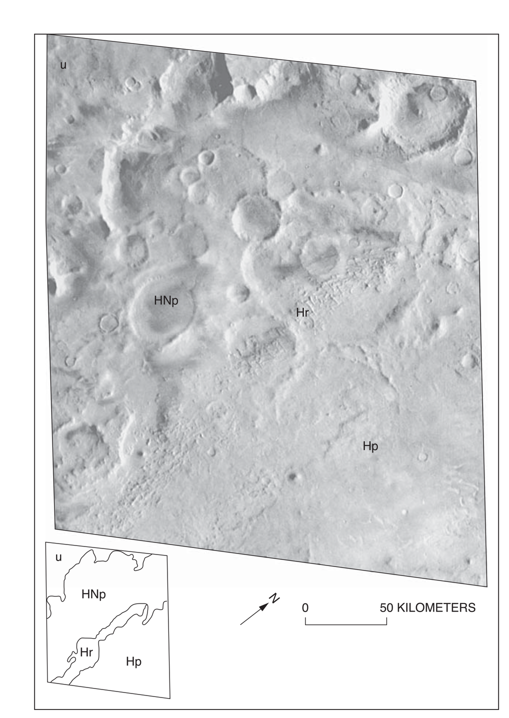

Figure 4. Detailed image showing northwest periphery of Hellas Planitia including reticulate material (unit Hr) and younger plains material (unit Hp). These Hellas Planitia deposits abut and rest on the heavily cratered wall and rim of the basin (u, undivided units), which is partly blanketed by mantling material (unit HNp; Moore and Wilhelms, 2001). Viking Orbiter image 620A43, centered at lat 38.1° S., long 311.3° W., orthographically projected. Illumination from right.

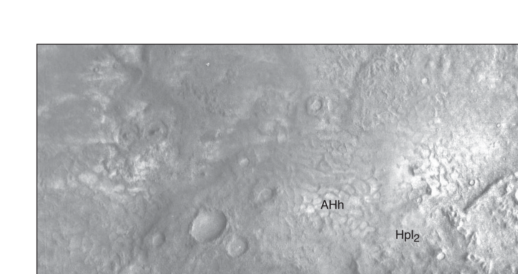

Figure 6. Synoptic view of north periphery of Hellas Planitia including intermediate Alpheus plateau material (Hpl_2) and younger honeycomb material (AHh). Part of Viking Orbiter image 620A47, centered at lat ~35.5° S., long ~303.5° W., oblique, rectilinear view. North to upper right. Illumination from right.

Figure 5. Detailed image showing reticulate material (Hr) perched at –5.8 km as seen in MOC narrow-angle image M08-03314, centered at 38.3° S., 310.9° W. Original resolution 4.2 m/pixel. North at top. Illumination from left. Ridges, outlined in sketch at left, may have been formed in spaces between jostling ice blocks at the margin of an ice-covered lake (Moore and Wilhelms, 2001). There is no MOC wide-angle context image for this narrow-angle observation. Image processing courtesy of Malin Space Science Systems.

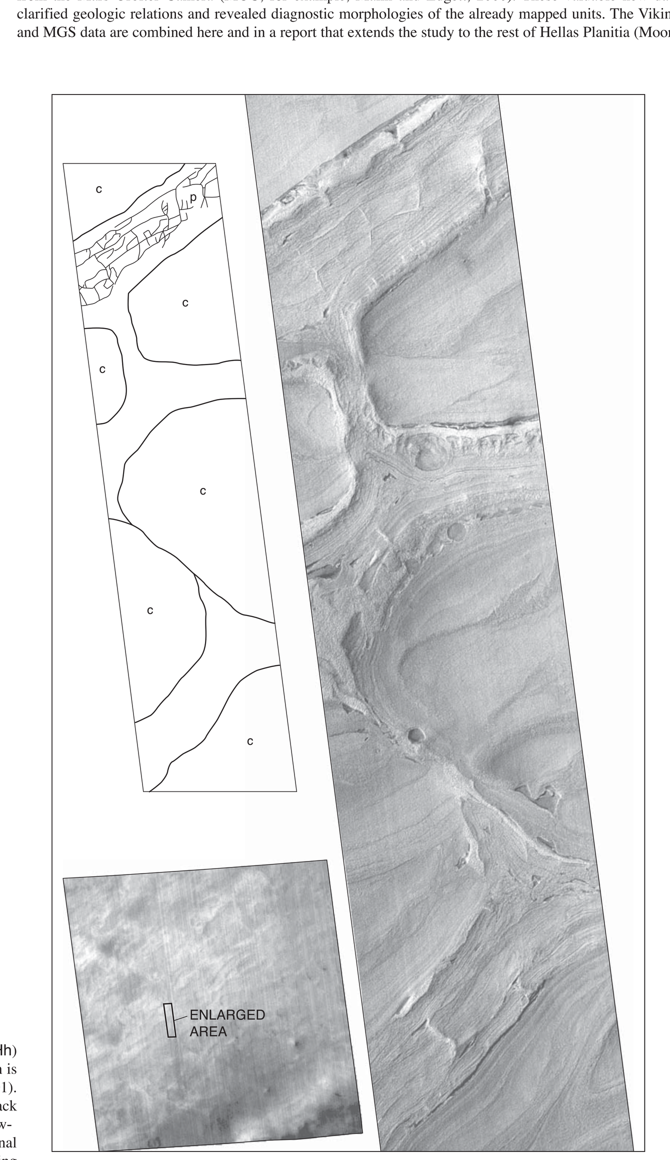

Figure 7 (right). High-resolution image of honeycomb material (unit AHh) showing individual cells with raised rims (c in sketch at left). Proposed origin is deformation of soft mud by settling ice blocks (Moore and Wilhelms, 2001). Hectometer-scale, ridge-edged polygons (p in sketch map) might be ice-crack casts. MOC wide-angle context image M07-05325 at lower left. MOC narrow-angle image M07-05324, centered at lat 37.4° S., long 305.1° W. Original resolution 2.8 m/pixel. North at top. Illumination from left. Image processing courtesy of Malin Space Science Systems.

Geologic Map of Part of Western Hellas Planitia, Mars

By

Jeffrey M. Moore[1] and Don E. Wilhelms[2]

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[1]NASA Ames Research Center, Moffett Field, CA 94035
[2]U.S. Geological Survey, Menlo Park, CA 94025

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