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

Prepared for the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ATLAS OF MARS
1:500,000 GEOLOGIC SERIES
CHASMA BOREALE REGION
M 500 K 81/40 G, 1994
I-2357

## CORRELATION OF MAP UNITS

| SYSTEM | EOLIAN MATERIALS | POLAR ICE MATERIALS | POLAR PLAINS MATERIALS | CRATER DENSITY (Number of craters >5 km in diameter per $10^6$ km$^2$)* |
|---|---|---|---|---|
| AMAZONIAN | Aeb, Aet, Ael | Apr, Apl | Ab, Am | |
| HESPERIAN | | | GROOVED MEMBER OF VASITIUS BOREALIS FORMATION: Hvg | 50, 75, 100, 150 |

*Tanaka (1986)

## DESCRIPTION OF MAP UNITS

### EOLIAN (DUNE) MATERIALS

**Aeb** — **Isolated barchan and barchan chain material**—Occurs within and south of Chasma Boreale. Includes isolated barchans as large as 1 km wide and lee-to-stoss wavelength as large as 1 km wide and 4 km long; slip faces are perpendicular to wind direction and horns point in direction of air flow. *Interpretation:* Isolated barchans form where sand is sparse on edges of ergs, may develop into barchanoid chains where winds are bidirectional. Chains indicate moderate sand accumulation. Dune ripples are least mature in map area and appear to be currently active

**Aet** — **Transverse dune material**—One deposit at south map border; characterized by braided appearance and two perpendicular slip faces. *Interpretation:* Slip faces formed by winds of equal strength from two directions

**Ael** — **Linear dune material**—Located within two parts of dune field. Smaller deposit, located along east edge of Chasma Boreale, is as much as 75 km long and almost 5 km wide. Larger deposit radiates southward in southern Chasma Boreale, is as much as 77 km wide and 180 km long. Dunes characterized by parallel ridges about 100 km long, about 10 to 30 m high, spaced 300 to 800 m apart. *Interpretation:* Dunes formed by bidirectional winds. These dunes indicate increased sand supply and are most mature type in map area

### POLAR ICE MATERIALS

**Apr** — **Polar residual ice cap**—Very high albedo patches throughout map area. Some disappear in spring; remainder have moderate to high albedo during summer. Rough surface due to impact craters. *Interpretation:* Composed mostly of water ice and silicate dust; thin mantle of $CO_2$ seasonal frost extends beyond Planum Boreum during summer

**Apl** — **Layered polar plains material**—Moderate albedo. Alternating light and dark layers tens of meters thick exposed in troughs as much as 25 km wide and 10 to hundreds of kilometers long; troughs cut Planum Boreum to form counterclockwise swirl pattern. *Interpretation:* Mostly water ice and minor alternating layers of windblown volcanic ash and silicate dust

### POLAR PLAINS MATERIALS

**Ab** — **Blocky material**—Near west edge of region in semicircular area that forms part of erosional scarp. Blocks are as much as 4 km wide. *Interpretation:* Slump material derived from mantle unit and possibly from underlying grooved member of Vastitas Borealis Formation

**Am** — **Mantle material**—Covers moderately cratered material (craters as large as 20 km in diameter; fig. 3). Near west edge of region (fig. 2) unit characterized by subdued grooves, irregular depressions, and pits (Hyperborei Cavi) at extreme southern edge as much as 150 m deep. *Interpretation:* Mixture of brecciated material and ice that overlies grooved member of Vastitas Borealis Formation

**Hvg** — **Grooved member of the Vastitas Borealis Formation**—In southwestern part of map area. Forms Hyperborean Labyrinthus, which is polygonally patterned ground characterized by grooves as much as 300 m deep; some have upturned edges 10 to 30 m high. *Interpretation:* Material composed of eolian, volcanic, or sedimentary deposits mixed with ice. Polygonal pattern formed by one or more fracturing mechanisms. (See text.)

**Contact**—Dashed where approximately located

**Scarp**—Dashed where approximately located. Line at base; barb points downslope. Forms contact in places.

**Groove**—Dashed where subdued. Forms contact in places

**Crater rim crest**

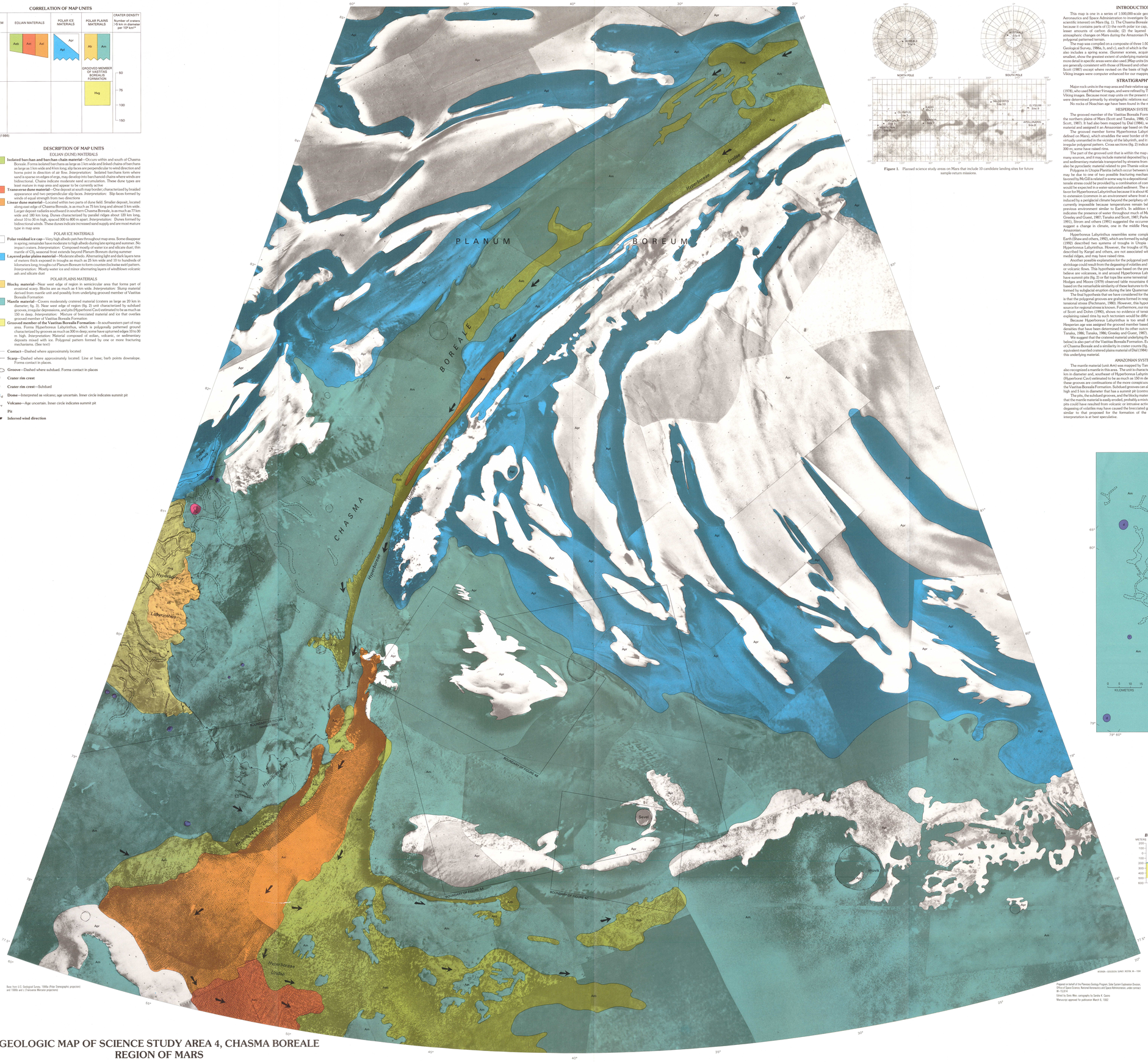
**Crater rim crest**—Subdued

**Dome**—Interpreted as volcano; age uncertain. Inner circle indicates summit pit

**Volcano**—Age uncertain. Inner circle indicates summit pit

**Pit**

**Inferred wind direction**




# GEOLOGIC MAP OF SCIENCE STUDY AREA 4, CHASMA BOREALE REGION OF MARS

By
Arthur L. Dial, Jr., and James M. Dohm

1994

SCALE 1:502 000 (1 mm = 502 m) AT 30° AND 50° LONGITUDE
TRANSVERSE MERCATOR PROJECTION

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




**Figure 1.** Planned science study areas on Mars that include 10 candidate landing sites for future sample-return missions

## INTRODUCTION

This map is one in a series of 1:500,000-scale geologic maps initiated by the National Aeronautics and Space Administration to investigate Science Study Areas (selected areas of scientific interest) on Mars (fig. 1). The Chasma Boreale region merits detailed geologic study because it contains parts of (1) the north polar ice cap, which is composed of water ice with lesser amounts of carbon dioxide; (2) the layered terrain that recorded climatic and atmospheric changes on Mars during the Amazonian Period; and (3) the enigmatic low-lying, polygonal patterned terrain.

The map was compiled on a composite of three 1:500,000-scale photomosaic bases (U.S. Geological Survey, 1986a, b, and c), each of which is the summer scene of a two-sheet set that also includes a spring scene. (Summer scenes, acquired when the north polar ice cap is smallest, show the greatest extent of underlying materials. However, spring scenes that show more detail in specific areas were also used.) Map units (including crater materials) and contacts are generally consistent with those of Howard and others (1982), Dial (1984), and Tanaka and Scott (1987) except where revised on the basis of higher resolution Viking images. Several Viking images were computer enhanced for our mapping.

## STRATIGRAPHY

Major rock units in the map area and their relative ages were established by Scott and Carr (1978), who used Mariner 9 images, and were refined by Tanaka and Scott (1987) on the basis of Viking images. Because most map units on the present map lack impact craters, relative ages were determined primarily by stratigraphic relations such as superposition and embayment.

No rocks of Noachian age have been found in the map area.

### HESPERIAN SYSTEM

The grooved member of the Vastitas Borealis Formation (unit Hvg) has been mapped in the northern plains of Mars (Scott and Tanaka, 1986; Greeley and Guest, 1987; Tanaka and Scott, 1987). It had also been mapped by Dial (1984), who called it mantled polygonal plains material and assigned it an Amazonian age based on the age of its almost ubiquitous mantle.

The grooved member forms Hyperborean Labyrinthus (one of only three labyrinths defined on Mars), which straddles the west border of the map area. The grooved member is virtually unmarked in the vicinity of the labyrinth, and it is transected by grooves that form an irregular polygonal pattern. Cross sections (fig. 2) indicate that the grooves may be as deep as 300 m; some have raised rims.

The part of the grooved unit that is within the map area probably contains material from many sources, and it may include material deposited by global winds and a mixture of volcanic and sedimentary materials transported by streams from the cratered highlands. The unit may also be pyroclastic material related to pre-Tharsis volcanism (McGill, 1986).

Polygons in Utopia Planitia (which occur between lat 25° and 55° N., long 220° and 300°) may be due to one of two possible fracturing mechanisms (McGill, 1985, 1986). The type favored by McGill is related in some way to a depositional process. He indicated that the needed tensile stress could be provided by a combination of compaction and dehydration, both of which would be expected in a water-saturated sediment. The other fracturing mechanism, which we favor for Hyperborean Labyrinthus because it is about 60° farther north than Utopia, is related to extension (common in an environment where frost action is dominant) or to phenomena induced by a peripheral chasma beyond the periphery of the ice. Although peripheral activity is currently impossible because temperatures remain below freezing, Mars may have had a previous environment similar to Earth's. In addition to morphologic evidence that indicates the presence of water throughout much of Mars' history (Scott and Tanaka, 1986; Greeley and Guest, 1987; Tanaka and Scott, 1987; Parker and others, 1989; Scott and others, 1991), Strom and others (1991) suggested the occurrence of two glacial epochs that would suggest a change in climate, one in the middle Hesperian and the other in the middle Amazonian.

Hyperborean Labyrinthus resembles some complex systems of "tunnel channels" on Earth (Shaw and others, 1992), which are formed by subglacial fluvial erosion. Kargel and others (1992) described two systems of troughs in Utopia as Arcadia Planitia that resembled Hyperborean Labyrinthus. However, the troughs of Hyperborean Labyrinthus, unlike those described by Kargel and others, are not associated with thumbprint terrain, do not exhibit medial ridges, and may have raised rims.

Another possible explanation for the polygonal patterned ground is that compaction and shrinkage could result from the degassing of volatiles and the melting of ground ice by intrusions or volcanic flows. This hypothesis was based on the presence of domal structures, which we believe are volcanoes, in and around Hyperborean Labyrinthus. Several of these structures have summit pits (fig. 2) or flat tops like some terrestrial table mountains. In Chasma Boreale, Hodges and Moore (1979) observed table mountains that they interpreted to be volcanoes based on the remarkable similarity of these features to the table mountains of Iceland that were formed by subglacial eruption during the late Quaternary.

The final hypothesis that we have considered for the origin of polygonal patterned ground is that the polygonal grooves are grabens formed in response to a nearly isotropic, horizontal tensional stress (Pechmann, 1980). However, this hypothesis is difficult to prove because no source for regional stress is known. Furthermore, our mapping, as well as the global fault maps of Scott and Dohm (1990), shows no evidence of tensional tectonism in the region. Finally, explaining raised rims by such tectonism would be difficult.

Because Hyperborean Labyrinthus is too small for significant crater counts, a Late Hesperian age was assigned the grooved member based on stratigraphic relations and crater densities that have been determined for its other outcrops in the northern plains (Scott and Tanaka, 1986; Tanaka, 1986; Greeley and Guest, 1987).

We suggest that the cratered material underlying the mantle material (unit Am, described below) is also part of the Vastitas Borealis Formation. Evidence includes the subdued grooves of Chasma Boreale and a similarity in crater counts (fig. 3) to the unit and that for the nearly equivalent mantled cratered plains material of Dial (1984) both indicate a Late Hesperian age for this underlying material.

### AMAZONIAN SYSTEM

The mantle material (unit Am) was mapped by Tanaka and Scott (1987); Dial (1984) had also recognized a mantle in this area. The unit is characterized by buried impact craters 5 to 20 km in diameter and, southeast of Hyperborean Labyrinthus, by irregular depressions or pits (Hyperborei Cavi) estimated to be as much as 100 m deep and by subdued grooves. Many of these grooves are continuations of the more conspicuous grooves of the grooved member of the Vastitas Borealis Formation. Subdued grooves can also be traced to a volcano about 120 m high and 5 km in diameter that has a summit pit (control point 5 in fig. 2).

The pits, the subdued grooves, and the blocky material (unit Ab, described below) indicate that the mantle material is easily eroded, probably a mixture of brecciated material and ice. The pits could have resulted from volcanic or intrusive activity; the melting of ground ice and the degassing of volatiles may have caused the brecciated ground to collapse. This mechanism is similar to that proposed for the formation of the Hesperian grooves. However, this interpretation is at best speculative.

Blocky material (unit Ab) occurs in a semicircular area near the west map border; the blocks are as much as 4 km long. The material is interpreted to be a large slump that was shed from the mantle unit and possibly from the underlying material along an erosional scarp to the east.

The layered polar plains material (unit Apl) consists of alternating light and dark layers exposed within immense, long troughs that form a counterclockwise swirl pattern in Planum Boreum. The layered material and troughs have been described extensively by several investigators, including Blasius and others (1982) and Howard and others (1982). The thickness of the individual layers is estimated to range from 14 to 46 m, although thinner beds may be present (Blasius and others, 1982). The composition of the layered polar plains material has been suggested to be mostly water ice and minor siliceous dust and volcanic ash (Murray and others, 1972; Cutts, 1973; Howard, 1978).

The origin of the swirl-patterned troughs is enigmatic. Because these large troughs occur only in the layered polar material, they are thought to be roughly contemporaneous with it. Howard (1978) suggested that the spiral pattern is probably due to a more rapid retreat of scarps facing the direction of greatest solar and atmospheric warming. Cutts and others (1979) suggested that the troughs appear to record lateral migration, expansion, and contraction of perennial ice caps through the geologic history of Mars. However, Carr (1982) stated that the amounts of erosion are difficult to explain by either of these hypotheses. He suggested that erosion and deposition could be occurring at almost the same time, alternating on relatively short time scales such as the seasons or the precessional cycle.

The young age (Late Amazonian) assigned the layered polar plains material of our map area is based largely on the absence of superposed impact craters. Cutts and others (1976) noted that in an area of 8×10$^6$ km$^2$ of "layered deposits" (layered polar plains material) in the north polar region, not one fresh impact crater as large as 300 m in diameter was observed.

The polar residual ice cap (unit Apr) overlies most of the layered polar plains material and extends onto the mantle material around its periphery. The ice cap is composed of water ice and dust (Kieffer and others, 1976; Kieffer, 1990), and small amounts of carbon dioxide are present during the Martian winter. Viking images clearly show outliers of seasonal frost from the ice cap (fig. 4*B*,*C*). Cap materials are either bright or dark. In midsummer the bright material has an albedo near 0.41 and a temperature near 210 K, and the dark material has an albedo near 0.24 and a temperature near 235 K (Kieffer and others, 1976; Kieffer, 1990). Kieffer (1990) suggested that is the late summer the bright areas are accumulating frost while the dark areas are losing water vapor. He further suggested that dust is a minor component of the cap, which implies that the material now at the cap surface formed in an atmosphere far cleaner than the present one.

Farmer and others (1976) measured relatively large amounts (by Martian standards) of water vapor (60-80 pr µm) in the atmosphere over the ice cap during the Martian summer of 1976, while temperatures of about 205 K were measured on the surface of the seasonal frost (Kieffer and others, 1976). These temperatures are close to the frost point of water in an atmosphere containing a few tens of precipitable microns of water (Kieffer and others, 1976). During this same summer of 1976, a patch of seasonal frost partly covered crater Seyd (8 km in diameter; fig. 4*C*); the patch was largely gone by the following spring (fig. 4*A*). Similarly, a pronounced zonation of albedo present in the Martian summer of 1976 (fig. 4*B*) had disappeared by the following spring (fig. 4*A*). Kieffer (1990) suggested that the disappearance of a deposit of old polar-cap volatiles was unlikely to have been observed by coincidence. Rather, he thought that the frost observed in the summer of 1976 was probably the residue of the past few Martian years.

## THE DUNE FIELD

Viking images have revealed the existence of an enormous circumpolar sand sea covering an area of about 7×10$^6$ to 8×10$^6$ km$^2$ around the residual ice cap (Tsoar and others, 1979). Linear, transverse, and barchan dunes have been mapped in this sand sea (Breed and others, 1979; Tsoar and others, 1979; Mainguet and Moreau, 1982; Dial, 1984). Separate parts of a dune field (Hyperborean Undae) in the map area cover a total area of about 2×10$^5$ km$^2$ and include the three dune types. The dune field is caused by extreme temperature variations in the north polar region between the cooler ice cap and the warmer plains of the Vastitas Borealis Formation. During the Martian summer, these temperature variations produce strong winds that entrain materials from many sources that may include weathered lava, volcanic ash, and silicic dust from the Vastitas Borealis Formation and the layered polar unit.

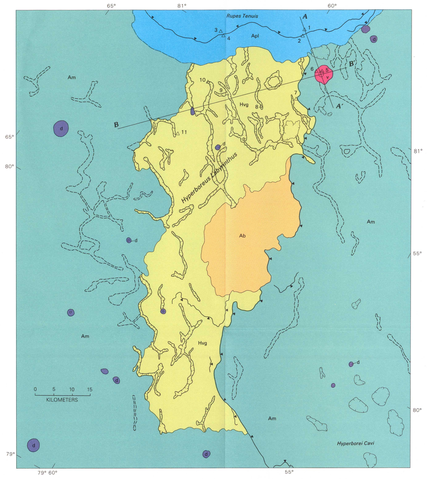
Within Chasma Boreale, a major southwestward wind direction has been identified by the authors listed above; winds flowing through the chasma are joined by minor counterclockwise winds from the residual ice cap (Dial, 1984). Where these two wind patterns intersect, a transition is seen from isolated barchans to collective barchan chains forming barchanoid ridges, as described by Bagnold (1941).

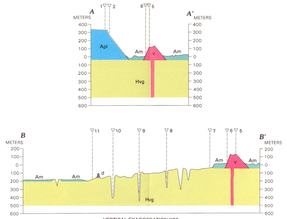
At the mouth of Chasma Boreale, part of the dune field lies within a shallow depression where both linear and barchan dunes are present. The dune field extends southward from the depression on level terrain. Here, isolated barchan dunes form barchanoid ridges on both the east and west edges of the linear dunes. Transverse dunes south of the linear dunes have two perpendicular slipfaces, indicating the collision of two wind regimes of equal strength (Tsoar and others, 1979). Bagnold (1941) suggested that barchan ridges and linear (seif) dunes are the result of a positive maximum sand supply and indicate bidirectional winds. Although Breed and others (1979) suggested that eolian activity on Mars may have taken place early in its history, we believe that the dune field within our map area is relatively young and active. This belief is consistent with ideas of Tsoar and others (1979) and Mainguet and Moreau (1982), who suggested that the entire circumpolar sand sea is relatively young and active.

## GEOLOGIC HISTORY

The earliest period recorded in the map area, that following heavy bombardment, is represented by the Upper Hesperian-grooved member of the Vastitas Borealis Formation. The large polygons of this member are thought to have developed at the time of its emplacement. If the climate was similar to Earth's polar climate, one of the most plausible fracturing mechanisms for polygon development is extension, which is common in a periglacial environment. If the Late Hesperian was a time of volcanism and intrusive activity, another possible explanation for polygon development is the degassing of volatiles and the melting of ground ice by intrusions and lava flows. In addition to the mapped volcano (near the west edge of the map), evidence of such volcanism may well be the domes, which we interpret as volcanoes, and possibly the table mountains, which are similar to volcanic features in Iceland. However, some of these structures could be remnants of older material. Because these features are associated with deposits of Amazonian as well as Hesperian age, their ages of formation are uncertain and volcanism may have occurred in both periods.

During the Amazonian Period, the mantle material was emplaced. Irregular pits, shallow troughs, and the large slump suggest that this material is an easily eroded mixture of brecciated material and ice. The layered polar plains material and its swirl-patterned troughs were also formed in Amazonian time. During the Late Amazonian, the polar residual ice cap and the Hyperborean Undae dune field were emplaced. Some barchan dunes seem to be currently active, and frost is evidently seasonal.




| CONTROL POINTS | ELEVATION (meters) | MAJOR FEATURE |
|---|---|---|
| 1 | 333 | Top of rupes |
| 2 | 260 | Base of upper scarp of rupes |
| 3 | 341 | Top of rupes |
| 4 | 339 | Base of upper scarp of rupes |
| 5 | 136 | Rim of volcano |
| 6 | 14 | Base of volcano |
| 7 | -37* | Top of grooved member, Vastitas Borealis Formation |
| 8 | -291* | Groove floors of grooved |
| 9 | -445* | member, Vastitas Borealis |
| 10 | -410* | Formation |
| 11 | -174* | Top of grooved member, Vastitas Borealis Formation |

*Elevation projected onto cross section *B*-*B'*

**Figure 2.** Geologic map and cross sections of Hyperborean Labyrinthus area based on Viking image 560B03 at $L_s$ 54°(spring). Map differs from main map because images used as bases were acquired at different seasons with different sun angles. (See Introduction.) Control points (numbered triangles) derived by stereophotogrammetry by F.J. Schaller, U.S. Geological Survey (Schaller, written commun., 1989).

Prepared on behalf of the Planetary Geology Program, Solar System Exploration Division, Office of Space Science, National Aeronautics and Space Administration, under contract W–15,914

Edited by Doris Wen; cartography by Sandra K. Cazins

Manuscript approved for publication March 6, 1992

MCNAIR—GEOLOGICAL SURVEY, RESTON, VA—1994

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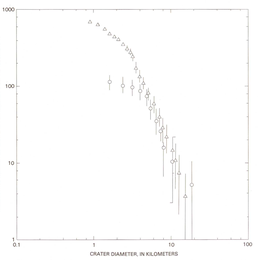
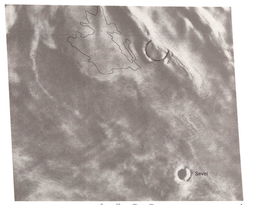
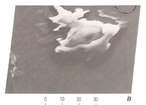



**Figure 3.** Cumulative crater size-frequency distribution curves for cratered material underlying mantle unit (circles) of our map area and mantled cratered plains material (triangles; Dial, 1984). Densities of craters larger than 5 km per one million square kilometers are 75±15 (our count) and 80±15 (Dial, 1984), both of which are in the Late Hesperian range (Tanaka, 1986). (Our count was made on spring scenes of U.S. Geological Survey maps (1986a–c) and on part of a semicontrolled mosaic (211–5869) of the Jet Propulsion Laboratory, which covers most of the map area.)



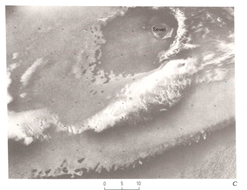




**Figure 4.** Images of south-central part of map area showing variations in seasonal frost. *A*, Spring 1977 image. Outline shows extent of seasonal frost absent here but apparent in *B*. Note well-defined rim and part of ejecta blanket of crater Sevel (8 km in diameter). Subdued impact crater is partly buried in this season by layered polar plains material. Viking image 560B66. *B*, Summer 1976 image of northeastern part of area shown in *A*. Note presence of seasonal frost. Viking image 588J34. *C*, Summer 1976 image including southeastern part of area shown in *A*, here at larger scale. Seasonal frost obscures rim and ejecta blanket of crater Sevel. Viking image 67B01.

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