DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared for the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ATLAS OF MARS
1:5,000,000 GEOLOGIC SERIES
MARE BOREUM AREA
M SM 90/0 G, 1984
I-1640 (MC-1)

# GEOLOGIC MAP OF THE MARE BOREUM AREA OF MARS

By
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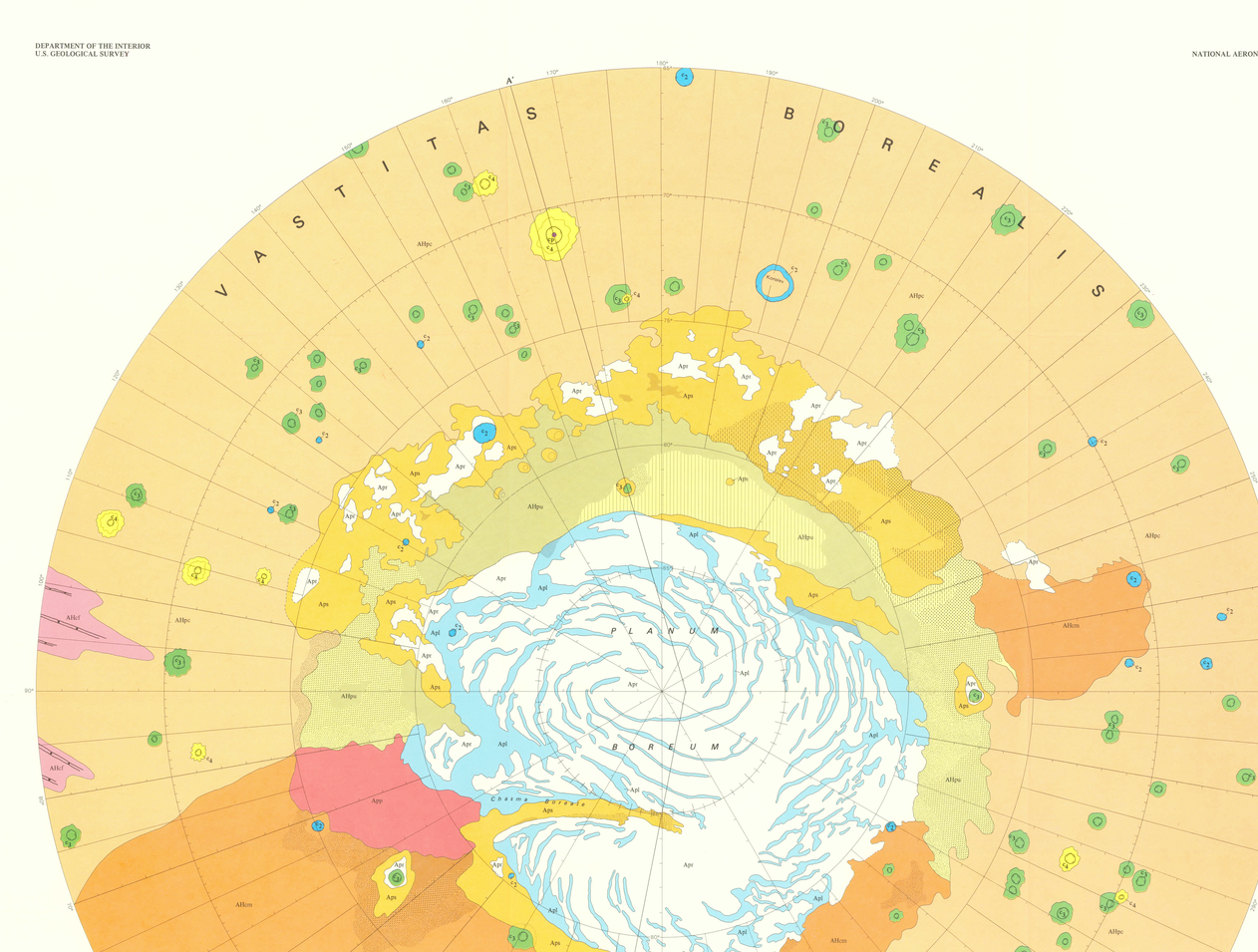
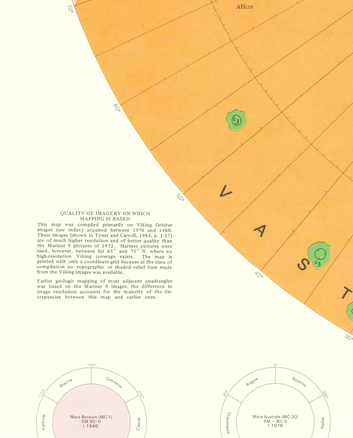
1984




## QUALITY OF IMAGERY ON WHICH MAPPING IS BASED

This map was compiled primarily on Viking Orbiter images (see index) acquired between 1976 and 1980. Coverage is complete at resolutions of 232 m/pixel (1:1 M) or finer, and at much higher resolution and of better quality than the Mariner 9 pictures of 1972. Mariner pictures were used, however, between lat 65° and 75° N. where no high-resolution Viking coverage exists. The map is compilation at 1:5 000 000 scale and is not to be regarded as a compilation to topographic or shaded-relief base made from the Viking images was available.

Earlier geologic mapping of most adjacent quadrangles was based on the Mariner 9 images; the difference in image resolution accounts for the majority of the discrepancies between this map and earlier ones.




Albedo features from International Planetary Patrol photographs, Lowell Observatory, Flagstaff, Ariz.

## QUADRANGLE LOCATION

Number preceded by I refers to published geologic quadrangle. Number preceded by MC refers to sector map bounded by revised version.

## CORRELATION OF MAP UNITS

| EOLIAN MATERIALS | POLAR MATERIALS | MANTLED PLAINS MATERIALS | CRATERED PLAINS MATERIALS | CRATER MATERIALS | SYSTEM |
|---|---|---|---|---|---|
| | Apr | Aps<br>Apl | | | AMAZONIAN |
| | Apl | Apm | | | |
| | | Alfpc | Alfpu | Alfcm | HESPERIAN |
| | | | | Alfcf | |
| | | | | c5<br>c4<br>c3<br>c2 | NOACHIAN |

0 30 60 90 km
DIAMETER

## DESCRIPTION OF MAP UNITS

### EOLIAN MATERIALS

During the Martian summer, extreme temperature contrasts between the north polar region between the cooler polar residual ice cap and the warmer mottled cratered plains produce strong winds. These winds exhume material for the massive polar dune fields (fig. 3). Sources of the material are westerly-trending sand seas, volcanic ash, and silicic dunes that issue from the mottled and mantled plains materials and remnants of the residual ice cap.

#### Barchan dune materials

ISOLATED BARCHAN MATERIAL.—Occurs throughout dune field, but areas of sufficient size to map mostly absent from long 150° to 360°. Forms isolated barchans whose slip faces are perpendicular to wind direction and whose horns point in direction of air flow. Dunes range in width from a few to 500 m. *Interpretation:* Formed where sand sparse and winds from variable directions.

MEGABARCHANS.—Occupy areas between lat 75° and 80° N. long 270° and 360°. Dunes are as much as 3 km wide and 4 km long (Viking image 1916S67); many have symmetric crescentic dunes whose slip faces are oriented in same direction as main slip face are developed on gentle slopes of major megabarchan dunes. Megabarchans are also superposed on crescentic dunes by Breed and others (1979) and as megabarchans by Tsoar and others (1979); formed by secondary winds of relatively low frequency and moderate magnitude. Dominant winds from northeast; secondary winds blow toward ice cap from south.

These dunes are in early stages of evolving into more mature barchan dunes

BARCHAN CHAINS.—North of lat 75° N., long between long 60° and 120°, and third between long 250° and 300°. Forms individual barchans or linked crescentic dunes (Viking images 59B61 to 59B70); some barchans as large as 1 km wide and 2 km long. *Interpretation:* Barchan chains formed by relatively unidirectional strong winds

BARCHANOID RIDGE MATERIAL.—North of lat 75° N. between long 190° and 255°; characterized by light and dark, fine, wavy lineations. Viking images 1S85H, 62B29–31, 5611B31, and 5611B32 show sharp, bifurcate ridges 3 to 20 km long. *Interpretation:* Formed by coalescence of crescentic dunes to form transverse ridges that may in turn evolve into transverse dunes. Interpreted as "sabre" dunes by Breed and others (1979). Most mature barchan material in map area

#### Transverse dune materials

BRAIDED DUNE MATERIAL.—Between lat 80° and 80° N. and long 155° and 235°; characterized by two perpendicular slip faces. Erosional remnants of braided dunes. *Interpretation:* Formed by migration of dunes from nearly opposite directions; less mature than transverse dunes, but more advanced geomorphically than barchans

LINEAR DUNE MATERIAL.—All dune fields near lat 80° N.; main field between long 118° and 270°, smaller fields near long 90° and 50°. Parallel ridges about 120 km long by 200 m high, spaced 0.3 to 3 km apart; like terrestrial sand dunes, these are aligned with the wind. Viking image 1S85H shows that dunes are asymmetrical in cross section, with slip faces on lee side. Dunes are formed by mobile barchanoid ridges and transverse dunes (Tsoar and others, 1979). Symmetrical profiles of dunes in western part of main field indicate counterclockwise wind direction. Dunes in eastern part of this field, between 210° and 260°, indicate clockwise circulation. Shape of small field west of Chasma Boreale shows dominant wind from south. These linear dunes are most mature in map area

### POLAR MATERIALS

POLAR RESIDUAL ICE CAP.—A kidney-shaped ice cap centered near north geographic pole. Estimated thickness less than 1 km (Farmer and Doms, 1979). Mostly covered by layered deposits. Morphology reflects asymmetric pattern of winds: to 62° N. to minimum near lat 68° N.; here mapped near minimum about half a Martian month after summer solstice ($L_s$=96°; see figure 1); minimum diameter about 1,000 km. Erosional remnants of layered deposits (Apl) form isolated patches and erosional remnants. Unit characterized by high albedo and undulating surface (Curtis and others, 1979); dark and light parallel banding visible in troughs and south-facing escarpments that form some of the steepest slopes on the residual ice cap to 600 km southward (east of 80° N. lineations distributed in arc between lat 74° and 80° N., long 70° and 255° (Viking image 61B32). Fresh impact craters absent. *Interpretation:* Composed largely of water ice and silicate dust

Apl LAYERED POLAR PLAINS MATERIAL.—Extends from north pole to lat 78° N. Forms stratified plains associated with polar residual ice cap. In troughs and south-facing escarpments, deposits are 11 to 600 km long and 8 to 20 km wide. Thickness of layers relatively uniform, about 30 m (Blasius and others, 1982); 30 to 40 layers visible in places, but accumulated thickness of layers can be as much as 1 km (Dzurisin and Blasius, 1975). Fresh impact craters absent. *Interpretation:* Mostly water ice, minor alternating layers of windblown volcanic ash and silicic dust (Sharp, 1973; Kieffer and others, 1976)

### MANTLED PLAINS MATERIALS

The three map units described below are almost everywhere covered by a mantle of indurated silicic dust and volcanic ash deposited from atmospheric suspension and subsequently reworked by global winds. This material was probably eroded from other north polar units (Soderblom and others, 1973a, b; Squyres, 1979). Maximum thickness of mantle estimated as less than 200 m (Soderblom and others, 1974). Mantle is relatively thin in the north polar area were subjacent units have been stripped from the mantled polygonal plains unit by wind at mouth of Chasma Boreale (Squyres, 1979).

Aps MANTLED SMOOTH PLAINS MATERIAL.—As far 71° to 80° N. and long 0° to 275°. Medium albedo. Relatively flat at medium resolution, but high-resolution Viking images (1480J and 1480A) show pedestal craters with diameters of 0.4 to 1.6 km and rocks and ridges with summit pits. Fresh impact craters very rare; diameters <5 km (Viking images 71B49 and 5448B30). *Interpretation:* Rocks and dunes may be either small volcanoes or remnants of mottled cratered plains unit; plains material possibly originated from small volcanoes or other sources now buried

Apm MANTLED POLYGONAL PLAINS MATERIAL.—Extends from Chasma Boreale (at 81° N., long 60°) southward to 74° N., long 355°. Characterized by polygonally fractured surface. Polygons are bounded by well-defined troughs with outermost ridges and flat floors (Viking image 5608J42); some mesas and cratered cones (Viking images 71B11 and 71B27). Superposed craters rare; diameters <5 km (Viking image 71B49). Fresh impact craters absent. Crater diameter observed in places (Viking images 1580A and 1580J). *Interpretation:* Volcanic lava. Polygonal pattern formed by contraction during cooling of lava or by ice wedging (Carr and Schaber, 1977), or by tensional tectonics (Pechmann, 1980)

Alfpc MANTLED CRATERED PLAINS MATERIAL.—Characterized by subdued irregular ridged patterns of polygons 5 to 15 km across; hummocky and knobby in places; northwest-trending lineaments visible in Viking images 627B10–24 and 676B08–24. Crater densities for craters ≥ 5, 10, and 20 km in diameter are 78, 20, and 5 per 10⁶ km², respectively (table 1). *Interpretation:* Material underlying mantle is permeable crust of water ice and highly altered volcanic material that probably contains palagonite. Pervasive ice and locally warm temperatures may have stripped the mantle from this unit

### CRATERED PLAINS MATERIALS

Alfpu PLAINS MATERIAL, UNDIVIDED.—Characterized on Mariner 9 images on resolutions 667 and 668 (DAS 13317500 and DAS 13333320). Unit partly surrounds residual ice cap on these same summer images, has very few albedo. Crater rims 10 to 30 km in diameter are rounded and subdued. Fresh impact craters rare; diameters <5 km (Viking images 71B49 and 5448B30). Unit here subdivided by extensive circumpolar sand sea and younger mantled plains materials, unit represents buried craters of mantled and mottled cratered plains and mantled polygonal plains units

Alfcm MOTTLED CRATERED PLAINS MATERIAL.—Similar in appearance to mantled cratered plains unit but albedo and relief moderate. Typical area is 180° to 240° and 70° to 80° N. Mariner 9 images 0268J and 0268J1. Crater densities for craters ≥ 5, 10, and 20 km in diameter are 190, 76, and 6 per 10⁶ km², respectively (table 1). *Interpretation:* Same as mantled cratered plains unit. Albedo contrasts with Alba Patera, which extends northward from lat 50° N., and with other parts of Olympus Tharsis Province. Intensely fractured by regional uplift. Crater densities suggest unit is oldest in map area (except for crater materials)

Alfcf CRATERED AND FRACTURED PLAINS MATERIAL.—Found in map area only south of lat 70° N. between long 80° and 120°; intermediate albedo. Irregularly fractured and shallow depressed. Crater densities for craters ≥ 5, 10, and 20 km in diameter are 280, 71, and 17 per 10⁶ km², respectively (table 1). *Interpretation:* Extension of volcanic flows associated with Alba Patera, which extends northward from lat 50° N., and with other parts of Olympus Tharsis Province. Intensely fractured by regional uplift. Crater densities suggest unit is oldest in map area (except for crater materials)

### CRATER MATERIALS

Viking Orbiter high resolution images of the north polar area show craters as small as 300 m across. As would be expected, small craters (<3 km across) are affected more than larger ones by eolian degradation and infilling—processes that have been particularly active in this area. Craters of diameters greater than 3 km are relatively unaffected by eolian processes; they are susceptible to degradation by impact cratering and subparallel fracture patterns (Plescia and Saunders, 1979, 1980). Subscripts refer to degradation sequence from $c_5$ (moderately degraded) to $c_4$ (well preserved). All craters of $c_1$ age (highly degraded craters) in the map area are deeply buried.

$c_4$ MATERIAL OF WELL PRESERVED CRATERS.—Craters are bowl shaped, relatively deep; complexly lobed ejecta blanket extends radially one or more crater diameters from crater rim; some craters have two layers of ejecta flow lobes (edge of upper layer shown by thin line); central peaks common. Type craters at lat 67° N., long 322° (Viking image 672B23) and at lat 71° N., long 187° (Viking image 70B06); this second crater shown on cross section. *Interpretation:* Young fresh craters; ejecta patterns formed by fluidization of material during impact

$c_{3-5}$ CENTRAL PEAK MATERIAL.—Occurs in some $c_4$ and $c_5$ craters. *Interpretation:* Brecciated crater-floor material formed by rebound following impact

$c_{3-5}$ MATERIAL OF MODERATELY DEGRADED CRATERS.—Craters shallow, flat, smooth floored; discontinuous ejecta blankets and hummocky rims. Type crater Korolev at 73° N., long 196°. *Interpretation:* Older craters degraded and partly filled with windblown material

CONTACT.—Queried where uncertain; dotted where concealed. Contacts of nonpolar units dashed where ephemeral. (Contacts of all polar units are ephemeral)

NARROW DEPRESSION OR GRABEN

CRATER RIM CREST.—Dotted where buried. Used as contact in places

## PHYSIOGRAPHIC SETTING

The Mare Boreum geologic map portrays the north polar area of Mars above lat 65° N. The area contains five physiographic provinces: (1) a residual ice cap characterized by troughs with a counterclockwise outward spiral pattern (Mariner 9 frames DAS 13317500 and DAS 13333320); (2) layered terrain adjacent to the ice cap, exposed within the spiral troughs; (3) a circumpolar band of low-albedo mantle material extending roughly from lat 70° to 80° N.; (4) isolated patches of high-albedo perennial ice near lat 75° N. with a semicircumpolar trend between long 180° and 270°; and (5) circumpolar cratered plains of mottled albedo south of lat 70° N.

## EARLY OBSERVATIONS

The studies of early workers noted below have been summarized by Glenzinne (1968). The polar regions of Mars were first observed and sketched as white spots by Giovanni D. Cassini in 1666. In 1784, Sir William Herschel hypothesized that the bright polar caps consist of snow and ice and are probably thin because they almost disappear during the Martian summer, presumably as a result of melting and evaporation. Wilhelm Beer and Johann H. von Mädler produced in 1840 a map of Mars that shows dark bands adjacent to the cap in both the south and north polar regions. These dark bands were thought by some astronomers to be an optical illusion resulting from the contrast between the high albedo polar caps and the darker areas around them. In 1890, A. C. Ranyard and G. J. Stoney suggested that the polar caps might be composed of solid carbon dioxide. Percival Lowell in 1892 suggested that water in the Martian polar caps was deposited as hoarfrost; in 1906, he described the dark band around the north polar cap as a "badge of blue ribbon about a rotting cap."

In those early years, most scientists thought that the caps were composed of only water ice, similar to that in the Earth's polar regions. Leighton and Murray (1966), however, discovered from Earth-based measurements that low temperatures (about 130 K) exist at the polar caps; they proposed that the caps are mostly solid $CO_2$. They also predicted the seasonal recession rates of the caps, which would later be confirmed by the Mariner 9 and Viking missions.

## PREVIOUS WORK

### Mariner 9 results

Winter darkness and the white polar hood concealed the north polar area as Mariner 9 orbited Mars during its standard mission from November 1971 to December 1972. Not until the beginning of the extended mission in June 1972 was a small number of images of good quality (A frames with a resolution of 3 to 6 km and B frames with a resolution of about 500 m).

Several differences were observed between the north and south polar areas. In the north, the residual ice cap is more extensive and its swirled cyclonic pattern is more pronounced. A band of very low albedo material surrounds the northern cap and its adjacent layered material, but is absent in the south. Wind streaks that are counterclockwise around the pole are observed in the northern cap, indicating that strong winds are active (Hartmann and Raper, 1974; Murch and others, 1976); these streaks are less evident in the south. Also, significant differences in crater density were found between the oldest cratered units of the two polar areas (Condit and Soderblom, 1978): in the south, the most densely cratered unit is the moderately cratered plains material; material of intermediate age, which is widespread between lat 55° and 75° N.; no craters of $c_1$ age are exposed. However, in the south, the oldest unit consists of large $c_1$ craters that have undergone advanced erosion and burial. The evidence for this unit is the exposed crater rim material that protrudes through overlying smooth intercrater plains material. The mottling in the north is evidently caused by high-albedo material trapped around the ejecta blankets of craters (Soderblom and others, 1973a, b).

In both polar areas, deposits of intermediate age were thought to overlie the cratered plains. In the northern area, these deposits include a bright, debris mantle, rippled plains, and etch-pitted plains material (Soderblom and others, 1973b); intermediate-age deposits of the southern area include smooth plains, ridged plains, and smooth intercrater plains materials (Carr and others, 1976; Howard, 1978; Squyres, 1979; Botts, 1980). Squyres (1979) defined five principal geologic units: (1) cratered plains material, characterized by many impact craters and a pattern of polygonal fractures; (2) mantled deposits, forming a thick sequence of thin layers of material with a spiral pattern of grooves caused by deflation; (3) a debris mantle, defined as a seasonally blanketed material of fine-grained material that surrounds and interfingers with the laminated deposits; (4) dune material; and (5) perennial ice. The last three units overlie the other two.

A stratigraphic sequence of four volcanic and sedimentary units has been proposed by Botts (1980) for the area north of lat 70° N.: (1) hulbous plains, (2) mantled plains, (3) dune deposits, and (4) layered deposits and perennial ice. The oldest unit, hulbous plains, is a subunit of the mottled cratered plains unit of Soderblom and others (1973b). Crater densities determined by Neukum and Wise (1976) suggest that this unit is equivalent in age to the old cratered plains unit of Tempe Terra (lat 30° N., long 90°).

Carr (1981) described two types of northern plains material as mottled and patterned plains units. They occur mostly above lat 50° N. but may be found as far south as lat 30° N. Where thin, both units commonly display a polygonal fractured pattern, and are protruded by remnants (hills or plateaus) of the old cratered terrain. The sharp contrast in albedo between the ejecta blankets of craters and the surrounding dark plains is characteristic of the mottled plains unit. Where mantling material is thicker than the mottled plains, was divided into a relatively smooth unit with gently rolling topography and a stippled unit characterized by a "thumb-print" texture (Guest and others, 1977). Carr (1981) suggested that the smooth unit may be what is meant by a highly eroded remnant or a thin mantling of the old cratered terrain. Carr and Schaber (1977) interpreted the stippled unit as a surface stripped of its mantle by wind erosion to reveal the underlying material. Carr (1981) also defined a plains unit with polygonal fractures that is dispersed throughout the region and mantles both the mottled and patterned plains materials.

Cutts and others (1976), Howard (1978), and Soderblom and others (1978) suggested that the sequence established (1978) and Cutts and others (1976), Howard (1978) [sic] some processes that may be responsible for topography at the Martian poles: erosion of the less resistant layers, erosion rates that are inversely proportional to slope gradient, basal sapping, and simultaneous but temporal rates of erosion. Howard (1978) suggested that the parallelism of the scarps would require that the scarp retreat on the south to southeast-dipping regional slope, and also that the spiral pattern of the scarps is due to the rapid retreat of scarps that face in the direction of greatest solar warming. Cutts and others (1979) suggested that the undulating landscape and trough complexes of the layered deposits indicate lateral migration as well as expansion and contraction of the perennial ice cap through geologic history.

## PICTURE QUALITY AND MAPPING TECHNIQUES

Mariner 9 and Viking Orbiter 2 spacecraft provided the data used to map the north polar area. Mariner 9 low-resolution (400 to 800 m/pixel) images were used only where no high-resolution Viking Orbiter 2 coverage exists between lat 65° and 75° N., long 135° and 255°. Viking Orbiter 2 images were obtained during the northern hemisphere spring and summer. Sunset ($L_s$=326° to 169°) Viking images with moderate (100 to 180 m/pixel) resolution were used from revolutions 56 to 122. Other Viking images obtained during the spring ($L_s$=0° to 90°) on revolutions 487 to 580 have high (40 to 80 m/pixel) resolution.

Cratering statistics have proven useful in determining relative ages for geologic units on Mars south of lat 45° N., but they must be used with care in the north polar area. Two factors may influence crater-density statistics: (1) erosional conditions, which affect a crater's life span; (2) composition of the impacted material, which affects crater morphology (Boyce, 1979; Croft and Soderblom, 1979). Both factors must be considered in the north polar area before crater statistics are applied.

In this study, crater-density statistics for units in the north polar area were collected from moderate and high-resolution Viking Orbiter 2 images. Crater counts on the same geologic unit from several localities were combined in order to produce a representative curve that includes craters ranging in diameter from 800 m to 20 km. Because craters less than 4 km across are in varied states of preservation (fresh, partly buried to obscured, and may not represent the true net accumulation on the surface, the diameters chosen for comparison are 5 km, 10 km, and 20 km (table 1).

Crater size-frequency distribution curves for three cratered units mapped in the northern plains are shown in figure 2. Curves for both the cratered and fractured plains unit and the mantled cratered plains unit exhibit a crater retention (power law) slope of -2.3 for crater diameters between 8 and 20 km. The curve for the mottled cratered plains unit has a crater-retention slope of -2.3 for crater diameters between 1 and 20 km.

A comparison of figure 2 and table 1, which shows that the mottled unit has a slightly higher crater density than the mantled unit, suggests that eolian or volcanic deposits have blanketed parts of both units. Where the cratered surface is not blanketed and the mottled unit is exposed, more craters are visible. Both figure 2 and table 1 show higher crater densities for the cratered and fractured plains unit, parts of which clearly predate both the mottled and mantled units.

## STRATIGRAPHY

### Cratered plains materials

Although the south polar area contains a densely cratered subcrustal deformation associated with the protocontinental hexus bombardment of Mars (Soderblom and others, 1973a; Condit and Soderblom, 1978), no equivalent cratered terrain is exposed in the north polar area. Remnants of an older cratered plain, however, may protrude through the layered deposits and dune fields (Cutts and others, 1976; Wise, 1979; Carr, 1981).

*The cratered and fractured plains unit* (unit Alfcf) is the oldest unit mapped, other than crater materials. It consists of volcanic material that has been intensely faulted, suggesting that it is a northern extension of flows from Alba Patera (Wise, 1979; Morris and Blasius, 1982) and from other sources in the Olympus Tharsis Province described by Scott (1982). Its faults and grabens radiate from the Alba Patera region but predate Tharsis volcanism. Wise (1979) suggested that the fractured plains are volcanic lavas that are contemporaneous with the Lunae Planum extrusives, subsequently faulted by the Tempe plains uplift. The unit is embayed and partly covered by later lava flows from the Tharsis region. Crater densities of the moderately degraded cratered and fractured plains unit (cratered near lat 60° N., long 330°) are about three times as great as those of any other unit in the region (table 1).

*The mottled cratered plains unit* (unit Alfcm) covers about about 1,400,000 km² and represents about 20 percent of the map area. It extends as far as 400 km into the Mare Acidalium quadrangle (Witbeck and Underwood, 1984), where it is mapped as burrowmoky mottled plains material. The unit is characterized by subdued crater rims and irregularly ridged patterns of ridges. It was first defined by Soderblom and others (1973b) on the basis of Mariner 9 images as a facies of their mottled cratered plains unit. It was also recognized by Squyres (1979) and Botts (1980) on Viking 2 images; the latter described it as the hulbous plains subunit of the mottled cratered plains material. Soderblom and others (1978b) suggested that the dark areas represent terrain that is relatively free of dust and sand.

The unit is interpreted to be a remobilized crust composed of volcanic material and water ice. Rossbacher and Judson (1981) have suggested that permafrost is as much as 3 km thick at the north pole. Soderblom and Wenner (1978) proposed a stratigraphic model for the Martian crust between the ±30° latitudes and suggested that layers of water ice and liquid water exist beneath a permafrost zone and that residual liquid may be stored in the upper part of this zone and in the north polar area.

High-resolution (about 50 m/pixel) Viking 2 images show evidence of past volcanic activity in the unit: clusters of dark rings 1 to 2 km in diameter (Viking image 538B04), highly irregular clusters of dark material (Viking images 541B03 and 517B11), and dark linear ridges resembling terrestrial dikes (Viking image 565B08). The material of these ridges may have been emplaced originally in troughs, either as resistant material later exhumed by erosion or as highly viscous lava flows (Pechmann, 1980).

*The plains unit, undivided* (unit Alfpu) is represented only by remnants of buried crater rims exhumed from the residual ice cap between lat 75° and 80° N. and long 80° and 360°. However, it includes those parts of the mantled and mottled cratered plains materials that underlie the massive dune field and cannot be clearly distinguished. It may also include parts of the mantled polygonal plains unit. The undivided unit covers an area of nearly 700,000 km², about 10 percent of the map area.

Because of the massive dune field cover, counts of crater rims exposed within the unit (table 1) are relatively low when compared with those of other units in the region. Crater counts, however, are the only means available to the author to determine the relative age of the undivided unit. However, the mantled and mottled cratered plains units and the mantled polygonal plains unit can be recognized from long 80° to long 300° up to the base of the residual ice cap at about lat 78° N. This distribution indicates that their equivalent (the undivided plains material) lies in the same circumpolar belt and underlies the massive dune field.

### Mantled plains materials

As indicated by their names, virtually all of the mantled plains units are covered by a debris mantle, which Soderblom and others (1973b, 1974) described as a thin, fine-grained deposit from atmospheric suspension. (The one exception is a small area at the mouth of Chasma Boreale, noted below in the description of the mantled polygonal plains unit.) Squyres (1979) interpreted the mantle as a combination of a debris mantle and layered deposits, on the basis of the proposal of Cutts and others (1976) that both of these materials were formed by deposition of dust at the same time as formation of the seasonal $CO_2$ frost cap. Botts (1980) interpreted the mantle as windblown dust that covers his hulbous plains unit. The mantle may be composed, at least in part, of palagonite dust: Toulmin and others (1977) and Soderblom and Wenner (1978) suggested that palagonite could form in a Martian environment and could produce dust.

*The mantled cratered plains unit* (unit Alfpc) was described by Soderblom and others (1973b) from Mariner 9 images. It is the oldest unit mapped in about 1,400,000 km² and includes all areas above 50 percent of the map area. It was mapped as knobby plains material in the Mare Acidalium quadrangle (Witbeck and Underwood, 1984). The diffuse, serrated boundaries (seen in Viking images 672B24 and 672B25) between the mantled and mottled plains unit indicate stripping of the latter's mantle by wind, exhuming the hummocks and knobs of the mantled terrain.

A cumulative size-frequency curve for the mantled cratered plains unit is shown in figure 2. The curve has a crater-retention slope of -2.3 for crater diameters between 3 and 20 km. A characteristic break in slope occurs on the curve for craters 3 km in diameter, where crater retention is reduced to a -0.7 slope. This slope change is consistent with Botts' study (1980), in which he described a cratering interpretation and fallout boundary function. Hartmann and others (1981) have concluded that such a decrease in the slope of the curve may indicate a constant, slow deposition of material over cratered surfaces that results in the obliteration of craters below a given diameter.

*The mantled polygonal plains unit* (unit Apc) is concentrated in a single area of about 93,000 km². Albedo is low. The major characteristic of the unit is subdued polygonal trough pattern, for which several theories have been proposed: Hallenstein and Mougnotia Mark (1980), in a study of fractured patterns on Mars, stated that many of the polygons have upturned edges and that their size increases with distance from the pole as a result of Chasma Boreale (which forms the map unit) at 10 to 20 km across in the Utopia and Acidalia regions. They concluded that enlargement of the polygonal troughs is the result of preferential desiccation occurring in a warmer southern latitude, and that it predates successive episodes of basalt to exhumation. Other proposed mechanisms for the formation of the polygons include cooling of basaltic lavas or frost wedging (Carr and Schaber, 1977), or tensional tectonics caused by large-scale warping of the surface (Pechmann, 1980).

The origin of the unit is probably volcanic. Hodges and Moore (1979) have suggested that some of its craters may be volcanic; Carr (1981) has suggested that the unit may be a volcanic flow. Rossbacher and Judson (1981) and Kargel and Strom (1992) suggested that the upturned edges of troughs that form polygons near the edge of the polar ice cap at the mouth of Chasma Boreale (Viking image 568D42) resemble terrestrial ice wedges, and that these troughs could result from thermokarst processes and may reflect the interaction of volcanism and ice. Referring to this same area, Squyres (1979) proposed that the unit was here stripped of its mantle by strong winds blowing outward from the chasma. In Viking images (70B02–12, 70B23–31, and 560B42–63), the unit is seen to overlie the mottled cratered plains unit. The age designation of the polygonal unit is based on these relations and on the scarcity of small craters. Where image resolution is low, some areas of the unit may be mapped as undivided plains material.

*The mantled smooth plains unit* (unit Aps) almost completely surrounds the polar materials, covering about 300,000 km² above lat 75° N. Over much of its extent, it is covered by barchanoid ridge and megabarchan materials. Elsewhere its surface is mantled and is relatively flat, but where the mantle is thin it is protruded by knobs, some of which have summit craters, and by pedestal craters of the underlying mantled and mottled cratered plains materials (Viking images 74B02 and 74B04). The existence of only a small number of fresh impact craters less than 4 km in diameter suggests that the mantled smooth plains material is relatively young. It appears to be gradational with the mantled polygonal plains and the mantled and mottled cratered plains materials.

### Polar materials

*The layered polar plains unit* (unit Apl) was recognized as layered deposits by Soderblom and others (1973a) in the north polar area and by Murray and Malin (1973) in the south polar area. It was described extensively by Dzurisin and Blasius (1975), Blasius and others (1982), and Howard and others (1982). Blasius and others (1982) estimated thickness is 4 to 6 km and is area is about 900,000 km².

The eccentricity of the Martian orbit and variations in Mars' obliquity, which ranges from 15° to 35° (Toon and others, 1980), affect the amount of energy the poles receive from the Sun, which in turn affects the climate. Climatic variations caused by the orbital and rotational motions of Mars may affect the rate of accumulation of each component of the layered polar plains material (Toon and others, 1980). Cutts (1980) has suggested that the condensation and stability of volatiles in the Martian atmosphere depend on obliquity, eccentricity, and precession of the orbital and rotational axes of Mars. For these reasons, the materials of the layered polar plains are thought to have been formed by the alternate deposition of frozen volatiles and windblown dust caused by climatic variations.

Several hypotheses have been proposed for the origin of the troughs and escarpments that form the distinctive spiral pattern of the north polar ice cap. Murray and Malin (1973) suggested that the spiral pattern of the escarpments may have resulted from a shift in position of the pole and consequent circular movement of layered plains. Clark and Mullin (1976) suggested that the stratification and spiral pattern of the laminated deposits, which they thought to be $CO_2$ ice, were results of polar wandering and true polar wander. Cutts and others (1976) and Howard (1978) suggested that the troughs are the result of a sublimation process: the troughs may have formed when the protective ice cover was removed as a result of a change in insolation. Howard and others (1982) suggested that alternating erosional widening and deepening and depositional infilling of the troughs created multiple unconformities within them. These authors also concluded that the troughs may migrate poleward, becoming more deeply filled as they move north. An absence of fresh impact craters indicates a very young age for at least the surface of the unit.

*The polar residual ice cap* (unit Apr), centered near the north geographic pole, is the youngest unit in the map area other than eolian materials. It is shown here in summer, near the time of its minimum extent, when it displays a peculiar kidney shape first described by Soderblom and others (1973b, fig. 1).

## PICTURE QUALITY AND MAPPING TECHNIQUES

One of the several perennial ice remnants that are detached from the main mass was observed by Mariner 9 during the Martian summer of 1972 (DAS–13506660) and by Viking in the Martian summer of 1976 (6B32). It is 53 km long and 48 km wide, at lat 80° N., long 200°. Enhanced images reveal very fine, lineated, light and dark markings, 2 to 3 km wide, which are interpreted as eolian features. Infrared observations by Kieffer and others (1976, 1977) and Farmer and others (1976) indicate lower temperatures for the remnant material (215 to 225 K) than for the surrounding, dark, dune-covered terrain (240 K). However, the temperature of the remnant is 10 K higher than that of the residual cap, which is near 205 K. This difference may be caused by the fact that the thinner and therefore more easily crystallike is overlain by windblown sand than is the residual cap. Special attention was given to patterns of dark areas within the remnant show a resemblance to small dune fields on the floor of a crater shown on Viking images 6B31 and 6B830 at lat 72° N., long 50°.

The residual ice cap is probably composed of dirty water ice (Kieffer and others, 1976); no evidence of permanent $CO_2$ has been found. During the Martian summer and spring, $CO_2$ condenses out of the north polar atmosphere, producing clearer air and increased insolation, thus creating a higher temperature on the residual ice cap (Pollack, 1979). This increased warmth results in sublimation of $CO_2$ at the north pole during the Martian summer. Thus, the polar ice cap and its remnants serve as a source of water vapor for the northern atmosphere during summer and as a reservoir for water vapor during the winter and spring (Kondratyev and Hunt, 1982, p. 331–346). The residual ice cap probably contains minor amounts of volcanic and silicic dust derived from global dust storms. Its remnants may be a major source of eolian material in the great erg or sand sea located between the cap and the mantled plains units. Like the layered polar plains unit, the ice cap exhibits no basin impact craters.

### Eolian materials

The enormous north polar erg on Mars has been described by many authors, including Cutts and others (1976), Breed and others (1979), Tsoar and others (1979), and Mainguet and Moreau (1982). Observed as a dark band surrounding the polar residual ice cap on low-resolution Mariner 9 frames (DAS–13317500 and DAS–13333320), this area was described by Soderblom and others (1973b) as composed of rippled plains material. Viking Orbiter 2 images reveal the area to be a vast belt of dunes, which Cutts and others (1976) and Tsoar and others (1979) interpreted to be longitudinal barchans and braided and other varieties of transverse dunes.

The dune field that is mapped in figure 3 is very similar to that shown by Tsoar and others (1979). Here, transverse dunes are divided into two types, linear and braided. Together they cover an area of about 200,000 km². The younger barchan dunes, which overlie about 28,000 km², are subdivided into isolated barchans and megabarchans, barchan chains, and barchanoid ridges. Most of the dune fields occur between lat 75° and 80° N. and long 10° and 300°.

The transverse dune field lies mostly between lat 77° and 80° N. and long 115° to 270°. Summer Viking images (514B56–63) show two dune types within the field. Linear dunes are formed mainly in a long belt extending the length of the field, winds in the western part are interpreted as blowing counterclockwise, whereas those in the eastern part appear to blow clockwise (Tsoar and others, 1979). Interpretation of wind directions that formed linear dunes, however, is difficult: dune slopes do indicate wind path, but not all workers would specify the wind directions listed above (M. Mainguet, oral commun., 1980).

The second type of transverse dune is the braided dune, formed between the linear dunes and the ice cap by converging winds of equal strength blowing both clockwise and counterclockwise off the ice cap.

Two areas of barchans surround the residual ice cap, both north of lat 75° N. The first area, between long 40° and 120°, is composed of isolated barchans and barchan chains, which grade into three transverse dune fields, two near 77° and 80° N., at long 90° (Viking image 72B20), and the third at lat