DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

Prepared for the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ATLAS OF MARS
1:5,000,000 GEOLOGIC SERIES
CEBRENIA QUADRANGLE
M 5M 48/210 G, 1979
I-1140 (MC-7)

NOTES ON BASE

This map sheet is one of a series covering the entire surface of Mars at nominal scales of 1:25 000 000 and 1:5 000 000 (Batson, 1973, 1976). The major source of map data was the Mariner 9 television experiment (Masursky and others, 1970).

ADOPTED FIGURE

The figure of Mars used for the computation of the map projection is an oblate spheroid (flattening of 1/192) with an equatorial radius of 3393.4 km and a polar radius of 3375.7 km. This is not the height datum which is defined below under the heading "Contours".

PROJECTION

The Lambert conformal conic projection is used for this sheet with standard parallels at 35.8° and 59.2°. A scale of 1:4 336 000 at lat 30° was chosen to match the scale at lat 30° of the adjacent Mercator projections. Longitudes increase to the west in accordance with usage of the International Astronomical Union (IAU, 1971). Latitudes are areographic (de Vaucouleurs and others, 1973).

CONTROL

Planimetric control is provided by photogrammetric triangulation using Mariner 9 pictures (Davies, 1973; Davies and Arthur, 1973) and the radio-tracked position of the spacecraft. The first meridian passes through the crater Airy-O (lat 5.19° S) within the crater Airy. No simple statement is possible for the precision, but local consistency is about 10 km.

MAPPING TECHNIQUE

Selected Mariner 9 pictures were transformed to the Lambert conformal projection and assembled in a series of mosaics at 1:5 000 000.

CONTOURS

Since Mars has no seas, and hence no sea level, the datum (the 0 km contour line) for altitudes is defined by a gravity field described by spherical harmonics of fourth order and fourth degree (Jordan and Lorell, 1973) combined with a 6.1-millibar atmospheric pressure surface derived from radio-occultation data (Kliore and others, 1973; Christensen, 1975; Wu, 1975, 1978).

The contour lines (Wu, 1975, 1978) were compiled from Earth-based radar determinations (Downs and others, 1971; Pettengill and others, 1971) and measurements made by Mariner 9 instrumentation, including the ultraviolet spectrometer (Hord and others, 1974), infrared interferometer spectrometer (Conrath and others, 1973), and stereoscopic Mariner 9 television pictures (Wu and others, 1973).

CONTROL

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Formal analysis of the accuracy of topographic elevation information has not been made. The estimated vertical accuracy of each source of data indicates a probable error of 1-2 km.

NOMENCLATURE

All names on this sheet are approved by the International Astronomical Union (IAU, 1974), except Hrad Vallis, which is provisional.

MC-7: Abbreviation for Mars Chart 7.
M 5M 48/210 G: Abbreviation for Mars 1:5 000 000 series center of sheet lat 48° N., long 210°; geologic map, G.

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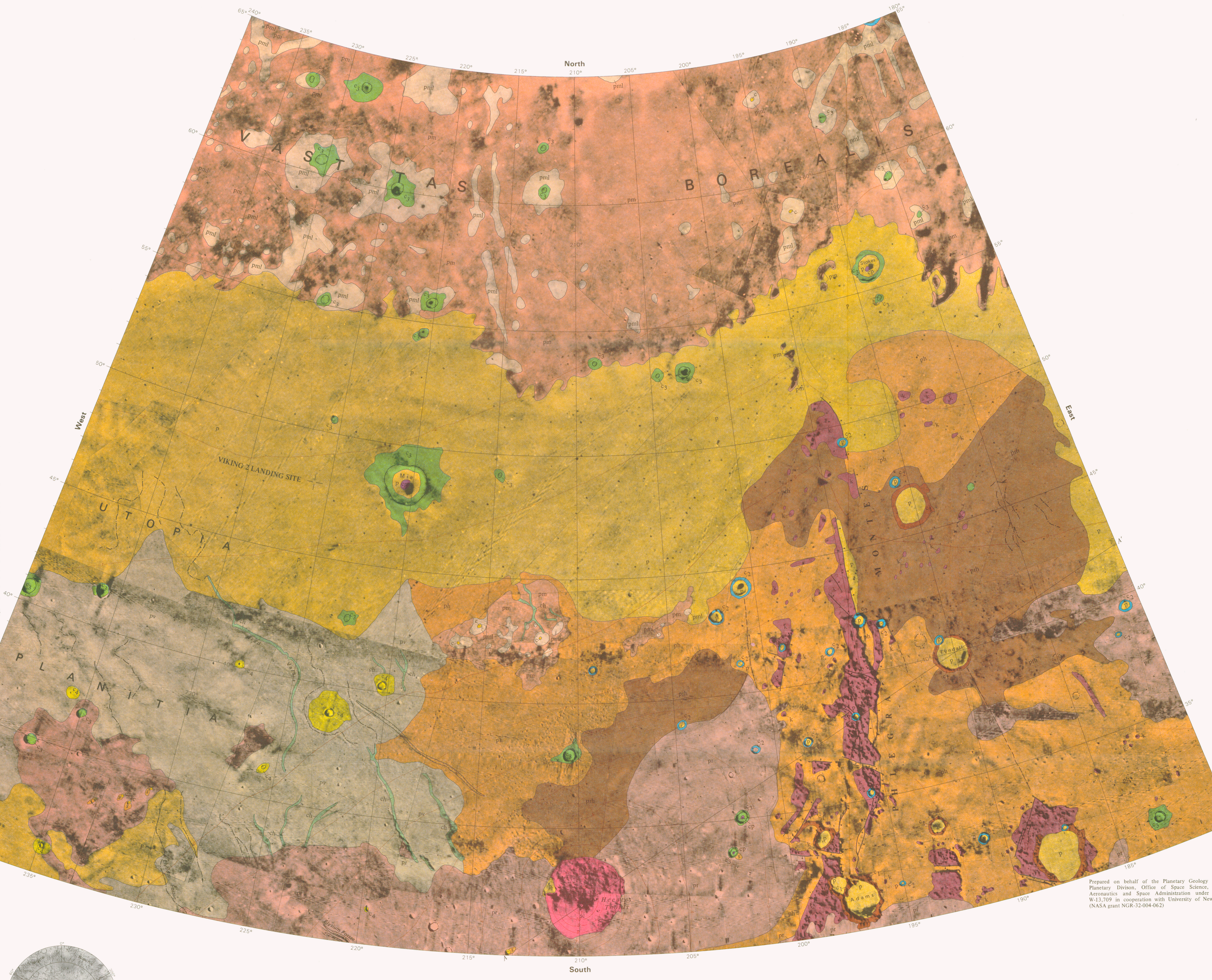
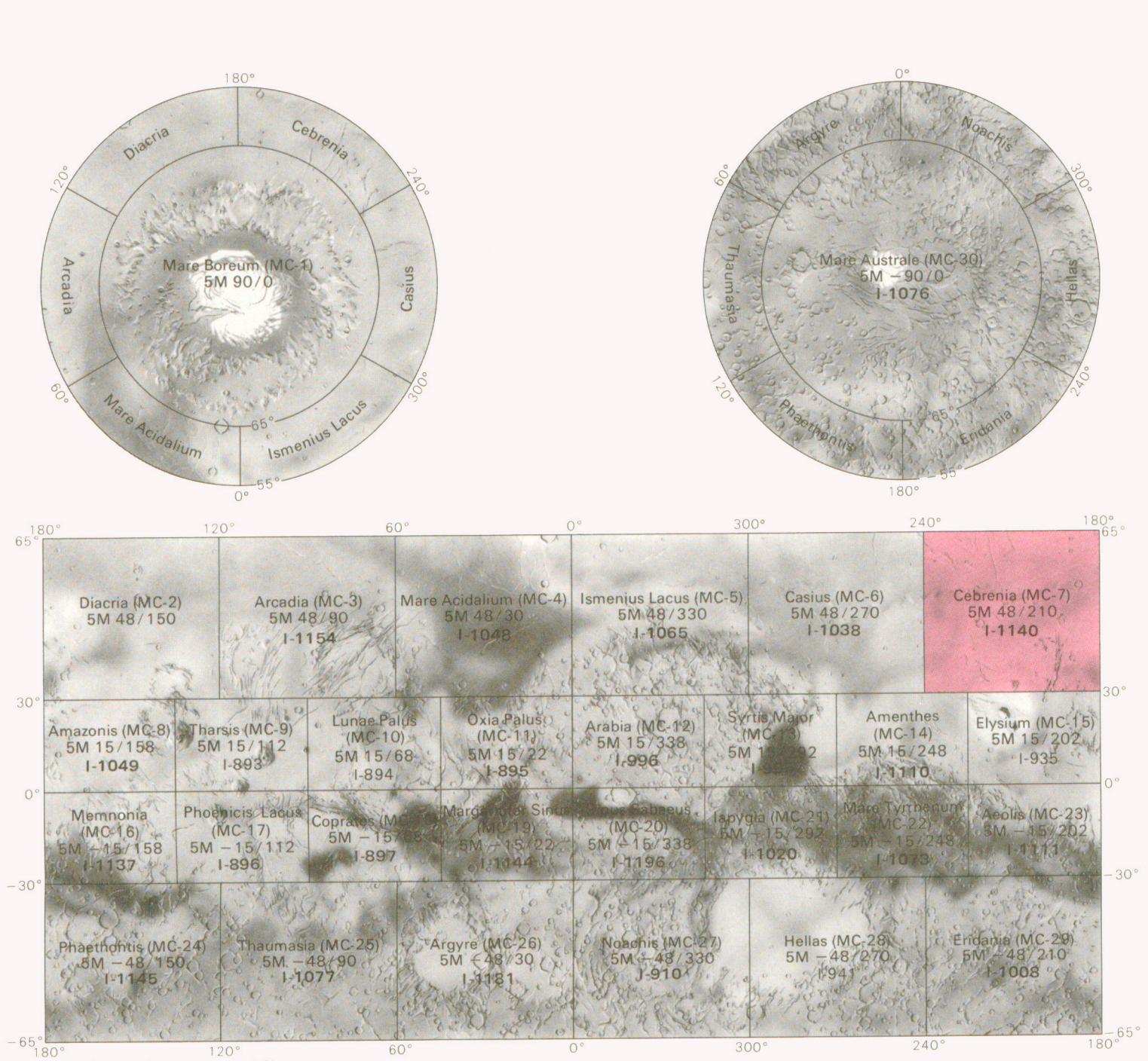
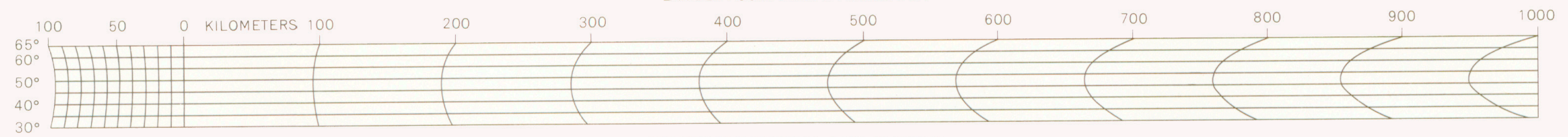


Prepared on behalf of the Planetary Geology Program, Planetary Divison, Office of Space Science, National Aeronautics and Space Administration under contract W-13,709 in cooperation with University of New Mexico (NASA grant NGR-32-004-062)

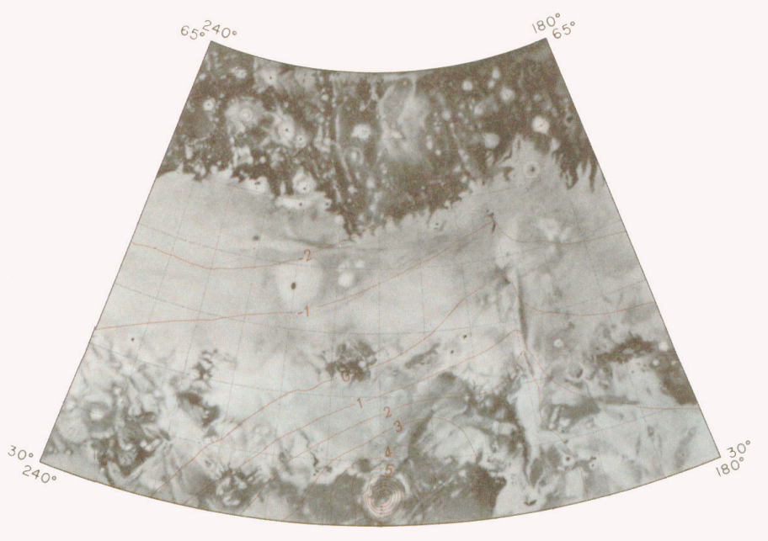


QUADRANGLE LOCATION
Number preceded by I refers to published geologic map

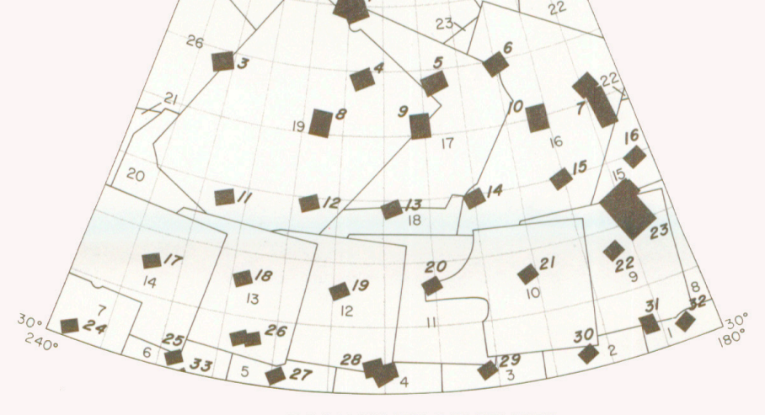
SCALE 1:4 336 000 AT 30° LATITUDE
LAMBERT CONFORMAL PROJECTION



CONTOUR INTERVAL 1 KILOMETER



ALBEDO MARKINGS AND CONTOURS
Contour interval 1 kilometer. Surface markings derived from selected Mariner 9 photographs.



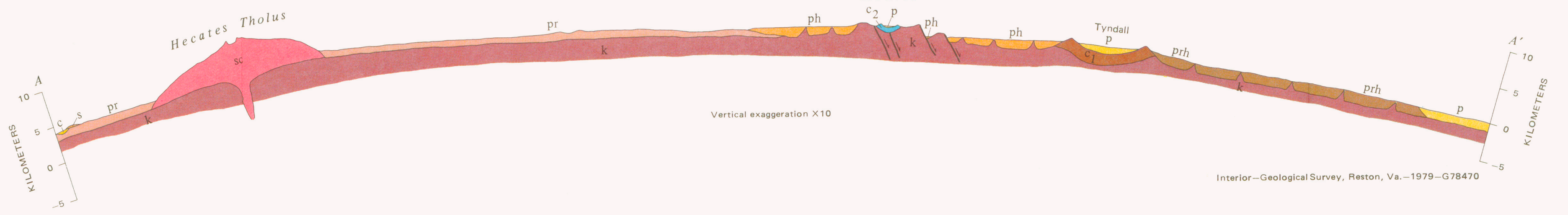
INDEX TO MARINER 9 PICTURES
The mosaic used to control the positioning of features on this map was made with the Mariner 9 A-camera pictures outlined above, identified by vertical numbers. Also shown (by solid black rectangles) are the high-resolution B-camera pictures, identified by italic numbers. The DAS numbers may differ slightly (usually by 5) among various versions of the same pictures.

A-camera pictures

Index No.	DAS NO.	Index No.	DAS No.
1	9270214	14	8838944
2	9198324	15	9198604
3	9126434	16	12152607
4	9054544	17	12152467
5	8982658	18	8982934
6	8910694	19	11976729
7	8838804	20	8839084
8	9270354	21	8767126
9	9198464	22	9198464
10	9126574	23	12152887
11	9054684	24	11973009
12	8982794	25	11800151
13	8910834	26	11976589

High-resolution B-camera pictures

Index No.	DAS No.	Index No.	DAS No.
1	*11977039*	*19*	*8982824*
	8983244	*20*	*9054714*
2	*12152917*	*21*	*9126604*
3	*8839324*	*22*	*9198494*
4	*8983174*	*23*	*7867298*
5	*9055964*		*9198844*
6	*9126954*		*13352510*
7	*9198914*	*24*	*8838834*
	6535618	*25*	*8910724*
8	*11976759*	*26*	*7507778*
9	*12152497*		*7579738*
10	*12152637*	*27*	*8982684*
11	*8839114*	*28*	*13496363*
12	*8911004*		*13496293*
13	*8982964*		*9054574*
14	*9054854*	*29*	*9126464*
15	*9126744*	*30*	*9198354*
16	*9198634*	*31*	*6535478*
17	*8838974*	*32*	*9270244*
18	*8910864*	*33*	*10313874*



Vertical exaggeration X10

Interior—Geological Survey, Reston, Va.—1979—G78470

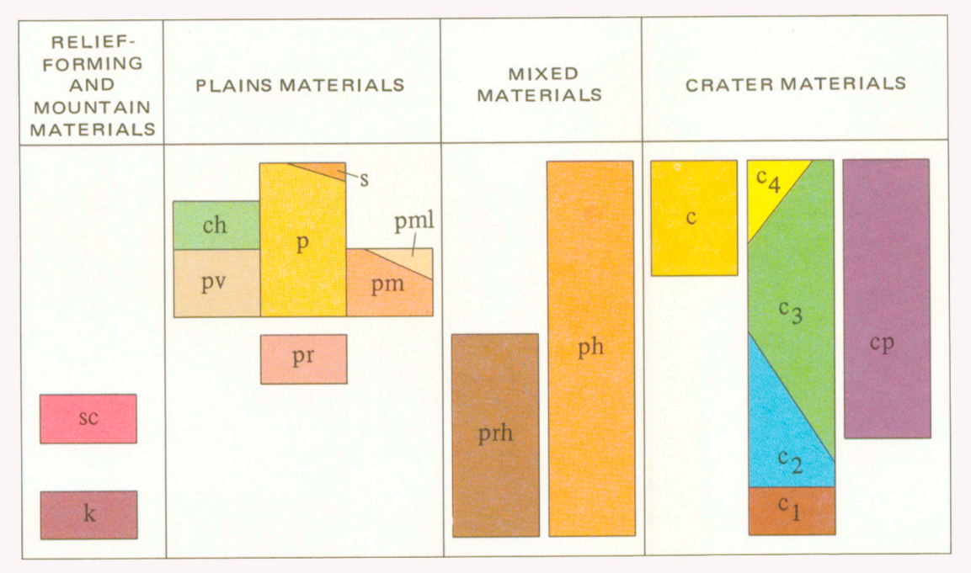
GEOLOGIC MAP OF THE CEBRENIA QUADRANGLE OF MARS

By

Wolfgang E. Elston

1979

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

RELIEF-FORMING AND MOUNTAIN MATERIALS

sc CRATERED SHIELD MATERIAL—Forms Hecates Tholus. On the lower convex slopes, material forms narrow chains of elongated hummocks; on the upper concave slopes, fan-shaped deposits radiate from scalloped summit crater. Surface is pitted by rimmed and rimless craters, chains of rimless craters, and clefts. *Interpretation:* Relatively viscous lava flows on lower dome; less viscous flows and (or) mixed flows and pyroclastic materials on upper cone; mixed population of impact and volcanic pit craters

k KNOBBY MATERIAL—Forms Phlegra Montes and surrounding hilly terrain. Knobs, as much as 8 km in diameter, are steep sided and rounded but tend to have conical aprons around their bases. Knobs are tightly grouped together. Crater density of knobby terrain is highest for the Cebrenia quadrangle. Knobs grade into the degraded walls of class 1 craters. *Interpretation:* Remnants of ancient cratered material that was uplifted and partly eroded to a new pediment level; knobs remain as inselbergs; conical surfaces at the base of the knobs are bajadas

PLAINS MATERIALS

s STREAKY PLAINS MATERIAL—Local light or dark plumes on one side of craters. *Interpretation:* Eolian deposits and scour marks

p SMOOTH PLAINS MATERIAL—Mainly in north-central part of quadrangle (Utopia Planitia). Surface nearly featureless on A-frames, except for sparse craters and vague dark streaks; B-frames resolve gently rolling terrain and partly buried craters. *Interpretation:* Mainly eolian deposits and regolith, some fluvial material transported through channels, and impact ejecta. Lava flows may exist beneath surficial materials

ch CHANNEL MATERIAL—Deposits on flat floors of sinuous channels, most of which dissect variegated plains material. *Interpretation:* Fluvial sediment with local veneer of eolian sediment

pv VARIEGATED PLAINS MATERIAL—Occurs in southwestern part of Cebrenia quadrangle. B-frames show mesas with moderately cratered capping; intermesa areas are hummocky and dissected by channels. Superimposed craters tend to be surrounded by large and continuous blankets of rim materials. A-frames show channels and irregular dark patches. *Interpretation:* Sedimentary material sufficiently cohesive to support cliffs but also capable of slumping to form hummocky terrain. Broad ejecta blankets suggest low cohesion when subjected to shock. Material may resemble terrestrial loess. Irregular dark patches may be local exposures of underlying lava flows

pm MOTTLED CRATERED PLAINS MATERIAL—Forms the circumpolar plains of Mars. Material has highly variable albedo and surface of low relief; craters are sparse but have conspicuous rim deposits. *Interpretation:* Sedimentary material that loses cohesion on impact to an unusual extent; possible eolian deposits cemented by permafrost

pml MOTTLED CRATERED PLAINS MATERIAL, LIGHT-COLORED—Forms high-albedo patches and streaks on mottled cratered plains. Patches form haloes around craters. *Interpretation:* Thin but extended blanket of impact ejecta around craters. See interpretation of class 3 craters. Streaks may be chains of small patches around craters below limits of resolution

pr ROLLING PLAINS MATERIAL—Occurs in southern part of quadrangle. B-frames show lobate bodies of low-albedo material terminated by low scarps; clefts and low ridges transect the surface. A-frames show moderately cratered, otherwise featureless, surface with low but variable albedo. *Interpretation:* Lava flows resembling terrestrial flood basalt, or lunar mare basalt, in topographic expression

MIXED MATERIALS

prh ROLLING AND HUMMOCKY PLAINS MATERIAL—Occurs east and west of Phlegra Montes between rolling plains and hummocky plains material. West of Phlegra Montes, surface resembles that of rolling plains except for hummocks that rise above the plain. East of Phlegra Montes, the plains material appears to be layered and has a gently rolling surface. *Interpretation:* Lava flows, as on rolling plains, have partly inundated ancient knobby terrain

ph HUMMOCKY PLAINS MATERIAL—Occurs east and west of Phlegra Montes. Material resembles knobby material, but knobs are spaced farther apart and become smaller west of Phlegra Montes. Material between hummocks resembles smooth plains material. *Interpretation:* Knobby material partly buried by smooth plains material

CRATER MATERIALS

Craters with diameters greater than 20 km have been divided into four classes on the basis of morphology. A few smaller craters were mapped but not classified. All craters interpreted as volcanic (for example, summit caldera of Hecates Tholus and numerous rimless pits on its flanks) are less than 20 km in diameter. All other craters have either been identified as impact craters or are so degraded that their origin cannot be determined.

c_4 MATERIAL OF WIDE-RIMMED CLASS 4 CRATERS—Occurs mainly in variegated plains material, in bowl-shaped craters with sharp and continuous rim crests; all known examples are less than 30 km in diameter. Rim deposits either are hummocky on B-frames or are more than 1.5 crater diameters wide on A-frames. *Interpretation:* Relatively young craters formed by impact into material that formed a large and symmetrical ejecta blanket, not necessarily younger than class 3 craters

c_3 MATERIAL OF SHARP-RIMMED CLASS 3 CRATERS—Ubiquitous. Craters smaller than 30 km are bowl shaped, with sharp and continuous rim crests. Craters greater than 30 km have slightly subdued rim crests, rim deposits less than 1.5 crater diameters wide, and central peaks. *Interpretation:* Formed by impact into material more competent than variegated plains material, except on mottled cratered plains. There, class 3 craters have an inner blanket of rim material, generally less than 1.5 crater diameters wide. However, a veneer, probably of thin ejecta, generally continues for 5 or 6 crater diameters and was mapped as mottled cratered plains material, light-colored

c_2 MATERIAL OF NARROW-RIMMED CLASS 2 CRATERS—Superimposed on knobby material, hummocky plains material, and, possibly, rolling and hummocky plains material. Craters are rings with subdued but continuous rim crests, no blanket of outer rim deposits, no central peaks; floors are at the same level as surrounding plains. *Interpretation:* Moderately degraded craters, partly buried by plains material

c_1 MATERIAL OF DEGRADED CLASS 1 CRATERS—Occurs only in areas mapped as knobby material, hummocky plains material, and rolling and hummocky plains material. Crater rims discontinuous and degraded to knobs, floor buried by plains material, no central peak. *Interpretation:* Relicts from an early episode of intense impact cratering

c CRATERS, UNCLASSIFIED—A few craters smaller than 20 km have been mapped because they are associated with larger features

cp CENTRAL PEAK MATERIAL—Occurs in class 3 craters greater than 30 km. *Interpretation:* Brecciated crater-floor material in central uplift

Contact

Fault scarp—Bar and ball on low side

Lineament, interpreted as buried or degraded fault scarp

Crater rim crest

Remnant or buried crater

Narrow channel

Caldera, Hecates Tholus

Fissure

Viking 2 landing site

INTRODUCTION

Most of the Cebrenia quadrangle (lat 30° to 65° N., long 180° to 240° W.) is in the circumpolar plains of Mars. Craters from an early episode of intense bombardment have been largely obliterated by later volcanism, tectonism, erosion and sedimentation by wind and water, and by circumpolar glacial and periglacial processes. South of 47° N. the plains are dissected by numerous channels, most of which drained off a broad volcanic upland near the southern border of the quadrangle. The impressive Elysium volcanoes cap the crest of this upland; their northernmost member, Hecates Tholus, lies within the Cebrenia quadrangle.

The southeastern part of the Cebrenia quadrangle is dominated by the Phlegra Montes, which may be the only purely tectonic mountain range on Mars. It seems to have been formed by block faulting; there is no evidence that impact or volcanic processes played a role. An ancient pediment appears to have been uplifted by normal faults to form a north- to north-northeast-trending mountain range 1,400 km long, as much as 250 km wide, and more than 1 km high. Its foothills were partly covered by later volcanic and eolian deposits.

This map is based solely on Mariner 9 imagery. More detailed images are now available from the Viking mission, especially near the Viking 2 landing site (lat 47.968° N., long 225.9° W.). Relative ages of geologic map units are based on superposition, transection, and the number of impact craters > 3 km per 10^6 km^2. All of these are inherently uncertain on photogeologic maps. Crater densities are particularly uncertain because of differences in resolution between images, difficulty in distinguishing impact and volcanic craters, and differences in the rates of degradation and burial in different parts of Mars. The primary shape of impact craters depends in part on the nature of the target materials. Crater counts reported here are minima. Because of small samples, counts are accurate only to about ±25 percent. Except for the youngest wind-blown deposits, absolute ages of map units are likely to be in the hundreds of millions and billions of years. More precise determinations of absolute ages will be possible only after there is better agreement on flux rates of impacting bodies (Hartmann, 1973; Neukum and Wise, 1976).

PHYSIOGRAPHY

Photogeologic map units are largely distinguished by the influence of rock materials on landforms. For this reason, physiographic provinces of the Cebrenia quadrangle correlate broadly with the rock-stratigraphic units shown on the geologic map. The following physiographic provinces can be recognized:

(1) **Circumpolar mottled cratered plains** (Soderblom and others, 1973) were mapped as mottled cratered plains material and mottled cratered plains material, light-colored. The circumpolar mottled cratered plains are characterized by relatively high crater density, high-albedo haloes around the visible ejecta blankets of impact craters, and irregular dark patches of unknown origin. The plains extend from beyond the northern boundary of the quadrangle south to lat 52.5° N. Isolated areas that resemble mottled cratered plains occur farther south, between long 203° and 217.5° W. and lat 40.5° and 44.5° N. Cratering, wind action, and permafrost all seem to have played a role in forming the mottled cratered plains.

(2) **Smooth plains**, mapped as plains material, form Utopia Planitia, a broad belt south of the circumpolar mottled cratered plains. The smooth plains are characterized by a lower density of resolvable craters than the circumpolar mottled cratered plains and by terrain that is nearly featureless on A-frames, except for vague low-albedo streaks interpreted as a result of wind action. Low rolling hills appear on some B-frames (DAS 11976624). It is uncertain whether the low crater density indicates a relatively young age for the smooth plains or denotes relatively rapid obliteration of craters by burial and wind erosion.

(3) **Variegated plains**, mapped as variegated plains material and channel material, make up much of the southwestern part of the Cebrenia quadrangle and continue westward into the Casius quadrangle. B-frames show a landscape of mesas, valleys with hummocky topography, and channels. Mesa scarps seem to have retreated by slumping; mesa tops preserve remnants of a cratered plain (B-frames DAS 8910864 and 8910724). Impact craters have unusually broad and continuous rims.

(4) **Volcanic upland** was mapped as rolling plains material, rolling and hummocky plains material, and cratered shield material. The volcanic upland is a broad arch, about 4 km high and 1700 km long, that extends from the Elysium quadrangle northeastward into the south-central part of the Cebrenia quadrangle. It is capped by the great volcanic shields of Elysium Mons and Hecates Tholus.

Hecates Tholus rises 5 km above the main arch of the volcanic upland (U.S. Geological Survey, 1976). The volcanic edifice seems to have formed in two stages. It consists of an upward-concave cone, about 50 km in diameter, superimposed on a convex dome 150 km in diameter. A scalloped-rim crater on the summit of Hecates Tholus, about 12 km in diameter, is interpreted as a caldera of the Kilauea type (Williams, 1941). Two partial terraces above the present crater floor appear to be remnants of former surfaces of a lava lake.

Chains of craters, < 0.5 to 2 km in diameter, radiate from the summit caldera across the flanks of the upper cone. Where adjacent craters merge, the chains become clefts. Flows that fan out from the summit of the upper cone are as much as 7 km wide at their termini and have relatively smooth surfaces. The lower dome is covered with chains of hummocks 1 - 2 km across and elongated radially to the volcano. Adjacent hummocks tend to merge, so that the surface of the dome takes on a striated appearance. Clefts and crater chains are less distinct on the lower dome than on the upper cone.

It appears that material of the upper cone was either less viscous, or had a larger pyroclastic component, than material of the lower dome. The lower slopes of Hecates Tholus are cut by gullies, and an erosional escarpment has formed locally on its western foot. The state of erosion and density of impact craters greater than 3 km of about $530/10^6\text{km}^2$ suggest a volcano that has been inactive for a long time.

Hecates Tholus is overlapped by material of rolling plains, interpreted as lava flows. The rolling plains are characterized by low albedo on A-frames. Light patches, especially on one side of many craters, are interpreted as dunes. B-frames show lobate tongues of material terminated by low escarpments, and ridges resembling mare ridges of the moon. Northwest-trending clefts are part of the Elysium Fossae.

(5) **Phlegra Montes**, mapped as knobby material, are located in the southeastern part of the Cebrenia quadrangle. On A-frames the Phlegra Montes appear as a range of mountains bounded by escarpments on the east and falling off more gently toward the west. On the only B-frame (DAS 9126604), part of the range resolves into a group of rounded knobs, as much as 8 km in diameter. Some of the knobs are partly buried by conical slopes resembling terrestrial bajadas. One rounded hill has a small (less than 0.5 km) summit pit. Arcuate chains of knobs are interpreted as relict walls of ancient and strongly degraded craters.

The Phlegra Montes give the impression of a block-fault mountain range. Their trend is arcuate, convex toward the east; the strike gradually changes from northeast, at lat 32° N., to north at lat 40° N. An ancient cratered terrain, beveled to a plain, seems to have been uplifted by east-facing normal faults and tilted to the west. Subsequent erosion dissected the range into knobby hills, partly buried by their own debris, in the manner of inselbergs. On the gentle western slope of the Phlegra Montes the knobby hills were partly buried by plains-forming material, and the mountain range merges with the hummocky plains.

(6) **Hummocky plains** were mapped as hummocky plains material and rolling and hummocky plains material. Much of the southwestern part of the Cebrenia quadrangle consists of a broad plain broken by numerous rounded hills or hummocks. It is interpreted as a region of rocks similar to those of the Phlegra Montes, beveled to a pediment with residual inselbergs. Northeast of Hecates Tholus and, possibly, west of the Phlegra Montes, this landscape was partly buried by lavas of the rolling plains to form the rolling hummocky plains. Elsewhere it was partly buried by material of the smooth plains.

A few hummocks resemble flat-topped buttes (B-frame DAS 8982824). Their caps may be remnants of an erosion surface older than the present pediment. West of the Phlegra Montes, the tendency of the hummocks to become progressively lower with distance from the mountains suggests that this ancient erosion surface has been tilted.

STRATIGRAPHY

RELIEF-FORMING AND MOUNTAIN MATERIALS

Knobby Material

Knobby material is the oldest stratigraphic unit recognized in the Cebrenia quadrangle. The type locality is in the Phlegra Montes, on A-frame DAS 9126574 and B-frame DAS 9126609 (lat 38° N., long 196° W.). It also makes up isolated hills east and west of the Phlegra Montes and the hummocks of the hummocky plains and rolling plains. In some places, it grades into the material of class 1 craters, such as Adams. It is interpreted as material of an ancient surface, intensely cratered in the early history of Mars and subsequently degraded. It is mapped as knobby material wherever the outlines of class 1 craters are no longer recognizable. On the basis of a small sample, the density of craters younger than class 1 and greater than 3 km is about $1{,}000/10^6\text{km}^2$.

Knobby material of the Cebrenia quadrangle correlates with knobby material of the Casius quadrangle to the west (Greeley and Guest, 1978) and the Elysium quadrangle to the south (Scott and Allingham, 1976).

Cratered Shield Material

Cratered shield material makes up Hecates Tholus and is interpreted as the product of a large central volcano. Cratered shield material is not in contact with knobby material but seems to be younger. This relative age is suggested by a lower crater density (about 530 craters greater than $3\text{ km}/10^6\text{km}^2$), the absence of class 1 craters, and the preservation of primary volcanic features. The type locality for cratered shield material is on Hecates Tholus, lat 31.5° N., long 210° W., A-frame DAS 9054544, B-frame DAS 9054579. Cratered shield material correlates with cratered mountain material of the Elysium quadrangle and cratered shield material of the Tharsis quadrangle (Carr, 1975).

PLAINS MATERIALS

Rolling Plains Material

Rolling plains material crops out over most of Elysium Planitia, part of the volcanic upland along the southern boundary of the Cebrenia quadrangle, west of the Phlegra Montes. The type locality is between Hecates Tholus and the Phlegra Montes (A-frame DAS 9054684 and B-frame DAS 9126469). The material is interpreted as lava flows locally covered by eolian deposits. The density of impact craters greater than 3 km is about $210/10^6\text{km}^2$. Rolling plains material appears to be younger than the cratered shield material of Hecates Tholus. The steep lower slopes of Hecates Tholus are cut off abruptly by flat-lying rolling plains material; no flows from Hecates Tholus can be seen on the rolling plains. The rolling plains material continues south into the Elysium quadrangle, where it was given the same designation by Scott and Allingham (1976).

Variegated Plains Material

Variegated plains material crops out in the southwestern corner of the Cebrenia quadrangle. The type locality is on A-frame DAS 8839084 and B-frame DAS 8910869, about lat 38° N., long 224° W. This unit is interpreted as a plains-forming material that is capable of slumping where dissected by channels; it may be wind-deposited sedimentary rock with some of the characteristics of loess. The density of impact craters greater than 3 km is about $150/10^6\text{km}^2$.

The stratigraphic position of variegated plains material is uncertain. The boundary between variegated plains material and rolling plains material gives the impression that variegated plains material is younger. A transition zone (mapped as part of rolling plains material) is dissected by channels and embayed by typical variegated plains material along channels. The interpretation of younger age for variegated plains material is supported by the lower apparent crater density.

Variegated plains material derived its name from irregular dark patches on A-frames. The origin of the patches is uncertain. Possibly, erosion has locally exposed lava flows from underlying rolling plains material. Variegated plains material continues westward into the Casius quadrangle, where it was given the same designation by Greeley and Guest (1978).

Mottled Cratered Plains Material

Mottled cratered plains material forms a belt along the northern boundary of the Cebrenia quadrangle. All B-frames within the Cebrenia quadrangle have poor resolution (DAS 12152922 is the best), and no type locality is designated; A-frame DAS 11977013, about lat 59° N., long 218° W., shows the general characteristics of the unit. B-frames from the Casius quadrangle are more satisfactory.

Because of poor B-frame resolution, crater counts on the mottled cratered plains of the Cebrenia quadrangle are unreliable. The best estimate is about 150 craters greater than 3 km per 10^6km^2. On A-frames, the mottled appearance of the plains results from irregular dark patches of unknown origin and from high-albedo patches and streaks. Some of the high-albedo areas are splashlike patches centered on craters. They appear to be part of an outer ejecta blanket that extends for 5 or 6 crater diameters, far beyond the usual distance for visible ejecta blankets on Mars. Concentric inner "splashes" spread for 1 to 2 crater diameters, which is typical for ejecta from martian class 3 craters. Craters cannot always be resolved within high-albedo patches; for this reason the larger patches were mapped as a separate facies (mottled cratered plains material, light-colored). Streaks may mark lines of secondary craters, similar to rays of fresh lunar craters.

Mottled cratered plains material is tentatively interpreted as sediment in which pore spaces are filled by permafrost. Polygonal patterns, similar to those of terrestrial permafrost regions, show up on B-frames from the Casius quadrangle. Perhaps the unusual extent of outer ejecta blankets is caused by liquefaction of previously frozen ground by impact events. The inner ejecta blankets tend to resist erosion and to form pedestals.

The age of the mottled cratered plains material relative to other units is uncertain. It is in contact only with smooth plains material, and the two units embay each other about equally. The density of impact craters is higher on the mottled cratered plains than on smooth plains, but it is uncertain whether this higher density results from longer exposure to impacts or from better preservation and conspicuous contrasts in albedo.

The mottled cratered plains material continues into adjoining quadrangles to the east, west, and north.

Channel Material

Channel material is most conspicuous on the floors of channels that dissect the variegated plains in the southwestern part of the Cebrenia quadrangle. A few channels occur around lat 45° N., long 185° W. and in outliers of mottled cratered plains near lat 44° N., long 212.5° W. In the variegated plains, most A-frames, and almost every B-frame, show channels. The type locality is near lat 38° N., long 224.5° W. (A-frame DAS 8910834; B-frame DAS 11977013).

Channel material forms flat and featureless floors of channels as much as 20 km wide. Within the channels, streamlined "islands," as much as 15 km long, resemble schools of tadpoles with heads that point up-channel (B-frame DAS 8910729).

Channel material is younger than the variegated plains material and mottled cratered plains material that it transects. Where the channels end, at about 47° N., streams presumably debouched their load of sediment, which then became part of the smooth plains material.

Smooth Plains Material

Smooth plains material occurs in a broad belt that virtually encircles Mars, south of the mottled cratered plains (Carr and others, 1973). The type locality for the Cebrenia quadrangle is near lat 50° N., long 206° W. (A-frame DAS 21252467; B-frame DAS 12152502). The density of craters greater than 3 km is about $80/10^6\text{km}^2$. Even relatively young craters with sharp rims are largely filled with smooth plains material, presumably wind-blown sediment. Many small craters must have been obliterated. The ejecta blanket from the large crater Mie, classified as class 3, seems to cover smooth plains material, but later smooth plains material partly buried the floor of Mie.

The smooth plains seem to be underlain by a variety of materials, differing greatly in age. The prevalence of impact craters shows that this surface has been a target for hundreds of millions of years or longer. Mariner 9 images acquired prior to the end of February 1972 show mainly clouds and ground obscuration (A-frame DAS 8983144), which suggests that eolian erosion and deposition occurred during the mission. Viking Lander 2 has confirmed that the surface layer of the smooth plains is a mixture of regolith, dune deposits, and lag deposits of blocks, possibly ejecta from Mie (Mutch and others, 1977). Smooth plains material of the Cebrenia quadrangle is contiguous with similar material to the east and west.

Streaky Plains Material

Plumes of light or dark materials occur on one side of a few craters. They are interpreted as modern eolian deposits or scour marks. In the southwestern corner of the Cebrenia quadrangle they suggest prevailing winds from the northeast (A-frame DAS 8910694).

MIXED MATERIALS

Hummocky Plains Material

Hummocky plains material occurs east and west of the Phlegra Montes. It merges with the knobby material of the mountains and with smooth plains material of Utopia Planitia. The type locality is about lat 38° N., long 215° W. (A-frame DAS 8982794; B-frame DAS 9054719). On the A-frame, albedo is intermediate between that of rolling plains material and hummocky plains material. The B-frame shows a plain with ridges resembling lunar mare ridges and numerous hummocks above the plain. The hummocks are interpreted as relicts of ancient knobby material, partly buried by rolling plains material interpreted as lava flows. Superficial sedimentary material may also be present.

A large area east of the Phlegra Montes was tentatively mapped as rolling and hummocky plains material but is difficult to interpret. Its albedo is lower than that of adjoining hummocky plains material. B-frame DAS 7867303 shows a rolling plain made up of material that appears to be layered and dissected by narrow branching channels. Hills, partly buried by bajadas, rise above the plain and are interpreted as protruding remnants of ancient knobby material. The veneer of plains material is thin; class 1 craters and patches of knobby material rise through it. The nature of the rolling and dissected plains material is uncertain. It does not slump or form mesas, as does the material of the variegated plains. It could be lava or relatively consolidated sediment. Its boundary with hummocky plains material is rather indefinite. B-frame DAS 9198499, on the boundary, seems to show at least two kinds of plains material. One resembles that of smooth plains and covers the floors of class 2 craters; the other, darker and more rolling, could be lava.

CRATER MATERIALS

Craters have been classified from class 1 to class 4 by degree of preservation and probable stratigraphic position. Ordinarily, only material associated with craters greater than 20 km was mapped. A few smaller occurrences were mapped if they helped to explain larger features, such as a deposit of streaky plains material. Craters were classified as follows:

(1) Material of class 1 craters grades into knobby material, and class 1 craters are among the oldest features in the Cebrenia quadrangle. Some rims of class 1 craters are discontinuous. Floors are mapped as smooth plains material. No central peaks or rim deposits have been identified. The crater Adams (A-frame DAS 9126434) is a good example.

(2) Class 2 craters have continuous rim crests, no visible outer rim deposits, and floors covered by smooth plains material. They are superimposed on knobby material and hummocky plains material. Four good examples can be seen on A-frame DAS 9054824. Only a few craters tentatively assigned to class 2 occur on rolling and hummocky plains, and it is uncertain whether they project from beneath the plains or are superimposed on them. Class 2 craters have not been identified on mottled, variegated, or smooth plains.

(3) Class 3 craters are bowl shaped (floors lower than surrounding terrain) and have sharp rim crests if less than 30 km in diameter. Larger craters have more subdued rims, central peaks (mapped as central peak material), and floors that are partly covered by smooth plains material. Rim material of class 3 craters of all sizes tends to be irregularly distributed. It does not extend for more than 1.5 crater diameters, except on the mottled cratered plains. Mie, the most conspicuous crater of the Cebrenia quadrangle, is a typical class 3 crater (A-frame DAS 8910974). It appears to be contemporaneous with the surrounding smooth plains material.

(4) Class 4 craters are few, and small. They have the same characteristics as bowl-shaped class 3 craters but have larger and more symmetrically disposed deposits of rim materials. The best example, on B-frame DAS 8982689, is unusual in that it is elliptical in plan; its major axis is about 18 km and its minor axis about 11 km. Hummocky rim material was preferentially ejected normal to the major axis.

All crater material mapped as class 4 on the basis of A-frame resolution is superimposed on variegated plains material. Class 4 craters appear not to differ from class 3 craters in age but in the nature of the target. Variegated plains material, which slumps chaotically along channels, also seems to splash out over wide areas on impact. The ejecta blanket protects underlying material from erosion. In mottled cratered plains, this effect is even more pronounced. There, extended outer haloes were mapped as a mottled cratered plains material, light-colored, and inner haloes as class 3 crater materials.

GEOLOGIC STRUCTURE

SUMMARY

Tectonic deformation of the Cebrenia quadrangle occurred in at least two stages: (1) uplift of the Phlegra Montes, which occurred after formation of class 1 craters and knobby material but before formation of class 2 craters, and (2) formation of northwest-trending tensional fissures, the Elysium Fossae, possibly associated with rise of the volcanic upland but subsequent to formation of rolling plains material.

PHLEGRA MONTES

Master faults that bound the Phlegra Montes are downthrown on the east and trend north to north-northwest. Subsidiary faults trend north-northwest or northwest. The entire range forms an arc; its steep and convex side faces east-southeast. The range does not seem to be a remnant of the rim of a circular basin, such as Hellas Planitia or Argyre Planitia. The mountains that surround these basins are steep on their concave sides, facing the basins. Neither is there convincing evidence that the Phlegra Montes are volcanic in origin. On B-frame DAS 9126609 a segment of the Phlegra Montes resolves into an arcuate group of hummocks. Some of them have vague surface depressions and one has a summit pit, but it is more reasonable to interpret the hummocks as remnants of a class 1 crater than as volcanic domes. Phlegra Montes is thus interpreted as a fault-block mountain range, tilted to the west by a tectonic event early in the history of Mars.

Fault traces in the Phlegra Montes and surrounding areas cut class 1 craters but are covered by class 2 craters. Well-developed fault scarps appear on knobby material. A few vague lineaments can be seen in hummocky plains material; they could be ghosts of buried fault scarps. Faulting seems to have occurred subsequent to formation of knobby material and class 1 craters and prior to formation of plains material and class 2 craters.

ELYSIUM FOSSAE

The Elysium Fossae are a group of northwest-trending fissures or grabens, each as much as 370 km long and 35 km wide. Most of the fissures occur in the Elysium quadrangle, but a few extend into the Cebrenia quadrangle. Their trend is normal to the axis of the volcanic upland, and their origin may be related to extension during or after volcanism. The fissures cut material of the rolling plains. One long fissure has been identified in hummocky and variegated plains material of the Cebrenia quadrangle, but it is somewhat subdued and may have been partially filled by plains material.

VOLCANOLOGY

Volcanic products of the Cebrenia quadrangle seem to have progressed from viscous flows in the lower dome of Hecates Tholus, to less viscous flows and (or) more abundant pyroclastic materials in the upper cone of Hecates Tholus, to relatively fluid lava floods on Elysium Planitia. This sequence could result from local fractional melting in the interior of Mars, beginning with viscous flows relatively high in silica and culminating in fluid and higher temperature flows of lower silica content.

GEOLOGIC HISTORY

The following steps can be recognized in the geologic development of the Cebrenia quadrangle:

(1) Formation of basement materials (knobby material and class 1 craters) during early stages of planetary accretion, differentiation, and intense bombardment.

(2) Beveling of basement material and burial by plains-forming material.

(3) Faulting, leading to uplift and tilting of the Phlegra Montes.

(4) Prolonged beveling and formation of a pediment. Summits of inselbergs locally preserve remnants of the erosion surface formed in stage 2. Continued bombardment to form class 2 craters.

(5) Volcanic eruptions of Hecates Tholus, followed by flood eruptions of Elysium Planitia. Rise of the volcanic upland and formation of Elysium Fossae.

(6) Deposition of material of the variegated plains. The mottled cratered plains and older materials of the smooth plains may have formed at the same time.

(7) Dissection of variegated plains by channels that drained the volcanic upland. Minor channels formed elsewhere.

(8) Continued deposition of eolian plains-forming materials to form smooth plains and the smooth-plains component of hummocky plains. Continued impacts to form class 3 and class 4 craters, depending on target materials.

A major time break at the end of stage 3 seems to separate an early stage of intense bombardment, beveling, and tectonism from a later volcanic stage. A break at the end of stage 5 separates the volcanic stage from a plains-forming stage that continues to the present day.

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