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
ELYSIUM QUADRANGLE
M 5M 15/202 G, 1976
I-935 (MC-15)

NOTES ON BASE

This is one map in a series of preliminary mosaics covering the entire surface of Mars at a nominal scale 1:5,000,000 (Batson, 1973). 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.

PROJECTION

The Mercator projection is used for this sheet, with a scale of 1:5,000,000 at the equator and 1:4,336,000 at lat 30°. 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 radio-tracked positions of the spacecraft and telemetered camera pointing angles. The first meridian passes through the crater Airy-O (latitude 5.19° S) within the crater Airy. No simple statement is possible for the precision, but local inconsistencies may be as large as 50 km.

MAPPING TECHNIQUES

Selected Mariner 9 pictures were transformed to the Mercator 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). This datum is a triaxial ellipsoid with semi-major axes of A=3394.6 km, B=3393.3 km, and a semi-minor axis of C=3376.3 km. The semi-major axis A intersects the Martian surface at long 105°.

The contour lines (Wu, 1975) 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). Formal analysis of contour-line accuracy 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 the following name which is provisional: Cerberus Rupes.

MC-15: Abbreviation for Mars Chart 15.
M 5M 15/202 G: Abbreviation for Mars 1:5,000,000 series; center of sheet, 15° latitude, 202° longitude; geologic map, G.

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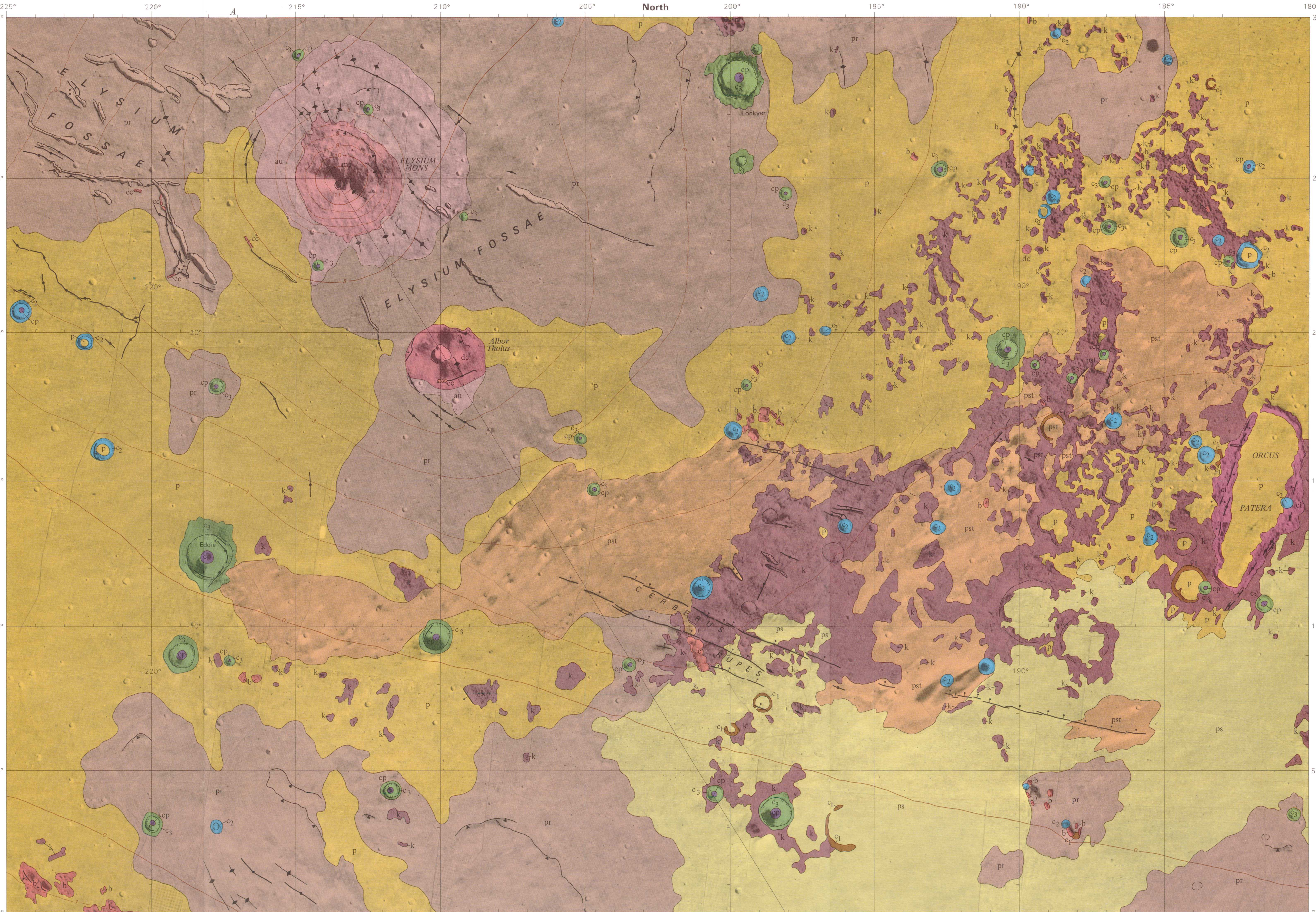

Interior—Geological Survey, Reston, Va.—1976—G75215

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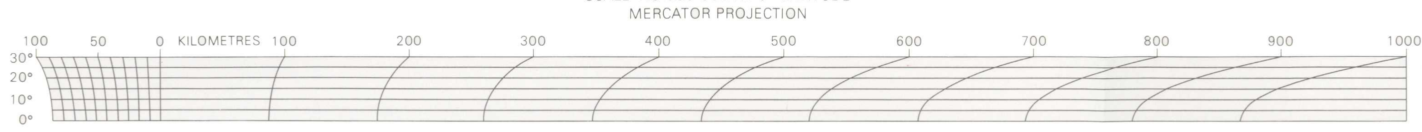
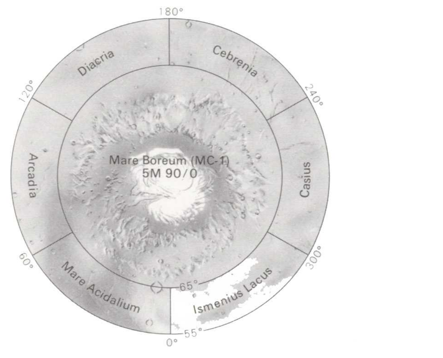
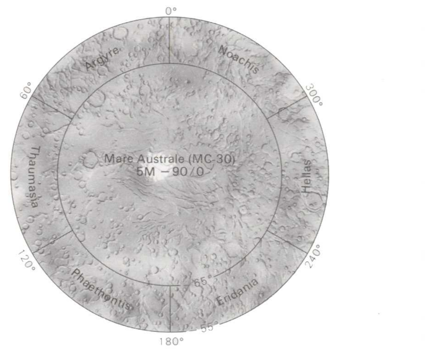
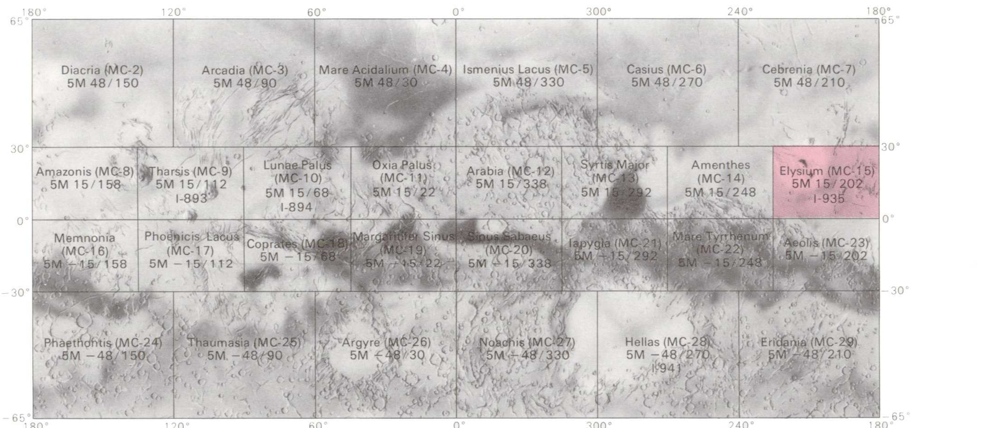
SCALE 1:5 000 000 AT 0° LATITUDE
MERCATOR PROJECTION



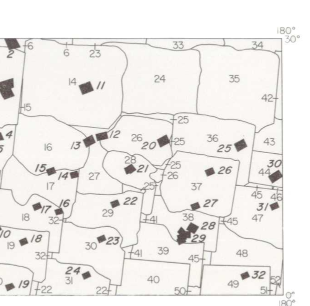
CONTOUR INTERVAL 1 KILOMETRE







QUADRANGLE LOCATION
Number preceded by I refers to published geologic map



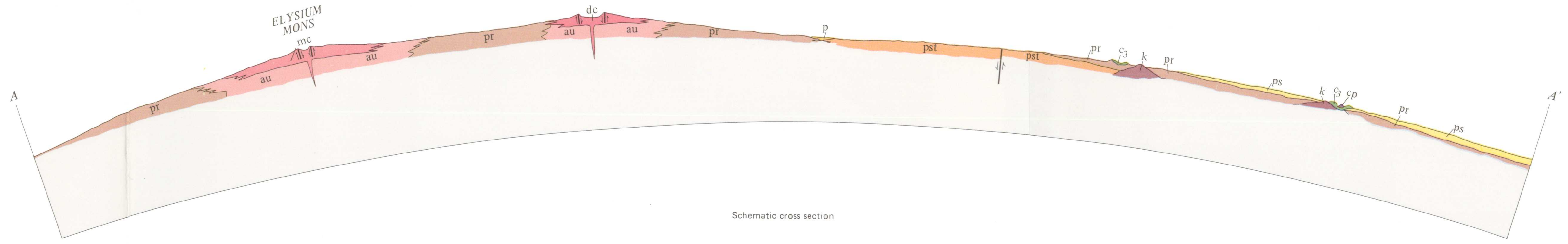
A-camera pictures

Index No.	DAS No.	Index No.	DAS No.	Index No.	DAS No.
1	7435853	21	7651313	41	7795093
2	7579563	22	5704753	42	7939013
3	7579213	23	9126429	43	7938663
4	7579143	24	7795233	44	7938593
5	8982649	25	7795163	45	7866983
6	9054539	26	7794883	46	7938943
7	7651453	27	7723273	47	7938523
8	7651103	28	7794813	48	7938453
9	7651033	29	7794743	49	7938383
10	7650963	30	7794673	50	12326306
11	7650893	31	7794603	51	5848813
12	7650823	32	7723203	52	6607333
13	7579493	33	9198319		
14	7723343	34	9270209		
15	7651593	35	7867123		
16	7722993	36	7866773		
17	7722923	37	7866703		
18	7722853	38	7866633		
19	7722783	39	7866563		
20	7722713	40	7866493		

High-resolution B-camera pictures

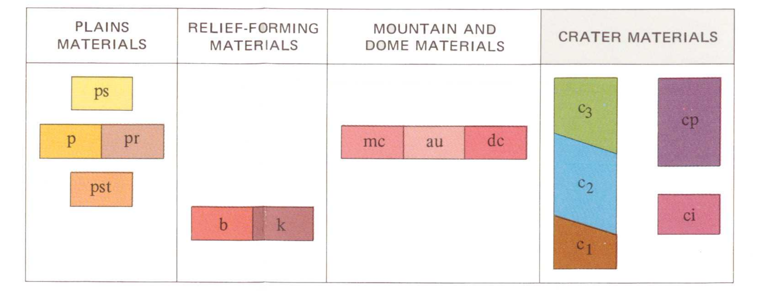
Index No.	DAS No.	Index No.	DAS No.
1	*7579528*	*17*	*7722888*
2	*6391388*	*18*	*7722818*
3	*13496083*	*19*	*7722748*
	6391768	*20*	*7795198*
	13496013	*21*	*12985878*
4	*6391698*		*7794848*
5	*7651418*	*22*	*7794778*
6	*7651068*	*23*	*7794708*
7	*7650998*	*24*	*7794638*
8	*7650928*	*25*	*7867088*
9	*7650858*	*26*	*7866738*
10	*12150817*	*27*	*7866668*
	12150747	*28*	*12326686*
	12150957	*29*	*9269124*
11	*7651628*		*12326546*
12	*6248058*		*12326476*
13	*7723308*		*7866598*
14	*6319808*	*30*	*9413674*
15	*7722958*	*31*	*7938558*
16	*6319808*	*32*	*7938418*

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



Schematic cross section

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

PLAINS MATERIALS

ps — SMOOTH PLAINS MATERIAL—Occurs in Southeastern part of quadrangle; flat, light, featureless surface at high and low resolution. Frequency distribution of craters >3 km in diameter less than $100/10^6 km^2$. Partly buries fault scarp having sharp topographic appearance in older units. *Interpretation:* Relatively thick eolian deposits. Extreme youth indicated by low crater population and blanketing of young-looking scarp

p — PLAINS MATERIAL—Resembles smooth plains (unit ps) but has greater crater population ranging from about $100\text{-}200/10^6 km^2$. In places, subjacent topography, including hills and fractures, is visible on high-resolution photographs. *Interpretation:* Eolian deposits, older and (or) thinner than unit ps

pr — ROLLING PLAINS MATERIAL—Occurs mostly around large volcanic constructs, Elysium Mons and Albor Tholus; smooth, uneven, moderately cratered, mottled appearance. Lobate overlapping scarps shown on high resolution picture southeast of Albor Tholus (DAS 7722958). Crater density similar to unit p. *Interpretation:* Mostly lava flows thinly covered by eolian deposits; some flows originated from Elysium Mons and Albor Tholus

pst — STREAKED PLAINS MATERIAL—Forms smooth, flat to undulating, moderately to highly cratered surface; many light and some dark northeast-trending streaks on the southwest sides of craters and hills. Darkest unit in map area. High-resolution pictures show lobate escarpments and abundant dark groovelike lineaments striking east-west (DAS 12150817) to northeast-southwest (DAS 7722888); lineaments become subdued toward plains unit p. Crater density higher than other plains units. *Interpretation:* Mostly lava flows. Light streaks, deposits of relatively fine material in wind shadows of topographic obstructions such as craters and hills; dark streaks, exposures of bedrock denuded by wind. Wind direction from Northeast to southwest. Dark grooves are fracture systems coincidentally alined in places with wind vectors; become progressively buried toward plains material (unit p)

RELIEF-FORMING MATERIALS

b — BLOCKY MATERIAL—Forms mesas, cuestas, and sharp ridges rising above plains units; mostly rectilinear outlines. Small occurrences intergradational with knobby material (unit k). *Interpretation:* Remnants of an older higher surface, dislocated and tilted in places by block faulting and embayed by plains units; erosion has nearly reduced some blocks to knobby material

k — KNOBBY MATERIAL—Consists of rounded to subangular, commonly equidimensional hills forming rugged upland terrain. Highest crater density of any unit in quadrangle, ranges from about $200\text{-}300/10^6 km^2$. Forms part of rims and walls of craters older than c_2 in age; proportion increases with increasing crater age. High-resolution photographs show triangular-faceted faces and elongate shapes resembling yardangs as well as conical forms. Summit craters rare. *Interpretation:* Remnants of ancient cratered terrain; dissected by faults and fractures and embayed by all plains units

MOUNTAIN AND DOME MATERIALS

mc — CRATERED MOUNTAIN MATERIAL—Forms Elysium Mons, an elongate cone-shaped mountain 200 km across the base with a circular, shallow, flat-floored summit crater 15 km in diameter. Greatest relief occurs along the flanks of a northwest-trending ridgelike prominence that forms the main structure. Partly surrounded by conspicuous concentric and radial troughs and depressions as far as 500 km from the center of the structure. Shadow geometry suggests flank slopes are relatively steep, possibly as much as 27° within 10 km of the rim crest. A-frames show hummocky flanks with ridges, scarps, and troughs roughly concentric to summit crater. B-frames show braided and lineated radial textures extending outward from summit and numerous overlapping chain craters intergradational in places with deep troughs. Density of craters not associated with chains similar to that of rolling plains (unit pr). *Interpretation:* Volcano with summit caldera. Interlayered lava flows and pyroclastic material forms relatively steep-sided structure near summit; source of widespread, probably basaltic, flows at base (units pr and au)

au — AUREOLE MATERIAL—Occurs around base of Elysium Mons and around south side of Albor Tholus as a gently outward-sloping apron; radial ridges common; lobate scarps present. Grades into rolling plains unit (pr). *Interpretation:* Lava flows probably originating from radial dikes around volcanoes; may be equivalent (an inner facies) in part to rolling plains (unit pr)

dc — CRATERED DOME MATERIAL—Forms Albor Tholus, a smooth to slightly hummocky, convex-upward dome with large summit depression (35 km in diameter). Base of dome has sharp steep contact with adjacent plains (unit pr) except on south, where it merges with aureole material (unit au). Crater density about same as rolling plains. Also includes small domical hill with summit crater near 23°N, 190°. *Interpretation:* Albor Tholus, volcano; possibly formed by extrusions of more viscous silica-rich flows than those of Elysium Mons. Small dome may be either a volcano or hill with impact crater on summit

CRATER MATERIALS

Craters are classified according to relative age on the basis of their morphological characteristics. Craters less than 20 km in diameter not mapped. *Interpretation:* Most craters in the following first three categories are believed to be of impact origin

c_3 — MATERIAL OF SHARP-RIMMED CRATERS—Rims complete, raised, and rough-looking where diameter >30 km. Floors lower than adjacent terrain; rough in crater >30 km, otherwise bowl shaped. Central peaks present and conspicuous. Secondary craters visible on B-frames near primary craters Eddie and Lockyer

c_2 — MATERIAL OF SUBDUED CRATERS—Rims similar to c_3 craters but partly consist of knobby material (unit k). Floors smooth, flat, lower than adjacent terrain. Central peaks small to absent

c_1 — MATERIAL OF HIGHLY DEGRADED CRATERS—Rims incomplete, consist in large part of unit k. Floors like those of c_2 craters but about same elevation as adjacent terrain. Central peaks absent

cp — CENTRAL PEAK MATERIAL—Prominent hill near centers of all c_3 age craters and some c_2 age craters. *Interpretation:* Brecciated crater floor uplifted by rebound during shock decompression following compressive stage of impact

ci — IRREGULARLY SHAPED CRATER MATERIAL—Forms rims and walls of Orcus Patera (15°N, 180°), the largest (380 km x 140 km) known crater of this type on Mars or the Moon. Rimcrest made up in places of arcuate segments having different radii of curvature; elsewhere rims and walls show linear adjustments to north-northeast-trending normal fault systems. Craters of c_2 age superposed; one c_1 crater shown on B-frame (DAS 7938558) is partly buried by rim material of Orcus Patera. *Interpretation:* Believed to be formed by coalescing, overlapping impact craters; subsequently modified by faulting

Contact

Narrow depression or graben

Fault scarp—Bar and ball on low side

Scarp—Line at base. Barb points downdip. *Interpretation:* Flow front or fault scarp

Ridge

Crater rimcrest—Not shown around smaller crater or where indistinct

Remnant or buried crater rimcrest

Depression or caldera rim

cc — Crater chain or cluster—*Interpretation:* Probably overlapping impact craters, possible maar-type volcanoes or tuff rings

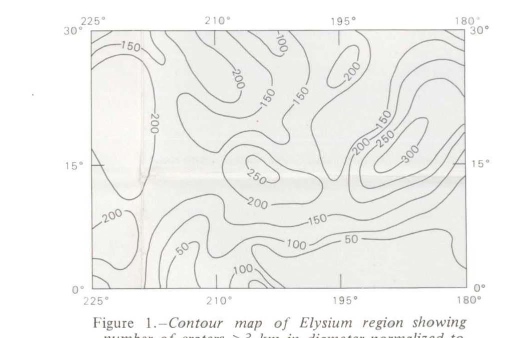


Figure 1.—Contour map of Elysium region showing number of craters >3 km in diameter normalized to $10^6 km^2$.

INTRODUCTION

The Elysium quadrangle includes part of the vast, relatively low and featureless plains that encircle the subpolar region of Mars immediately north of the more elevated and cratered equatorial belt. The plains are interrupted in the northwest by two large volcanoes, second only in size and youthful appearance to some of the large constructs that form the planet's most prominent volcanic center in the Tharsis region several thousand kilometres to the east (Carr, 1975). The large irregularly shaped crater Orcus Patera, at the east boundary of the map, closely resembles the lunar crater Schiller but is more than twice as long. A band of knobby, relatively old terrain extends in a broad arc northeastward through the center of the quadrangle. Thus, plains, volcanoes, and knobby terrain constitute the major physiographic and geologic subdivisions within the map area. In places, the plains and the knobby terrain are similar in appearance to the mare and terra regions of the Moon although they lack comparable contrasts in albedo.

GEOLOGIC SUMMARY

Geologic units are given names that describe their dominant physical characteristics. Genetic names are avoided so as not to introduce bias as to possible origin. For example, the large cone-shaped mountain Elysium Mons is described as cratered mountain material and designated unit mc although it is almost certainly a volcano with a summit caldera and is so interpreted. An objective classification is needed because the origin of many units is not known, and characteristics diagnostic of a landform's origin are degraded and lost through time. Relative ages of units are shown on the correlation chart and are based on crater frequency distributions (fig. 1), superposition and crosscutting relations, and morphology. Figure 1 shows that a gross relation between geologic units of different ages and crater density exists. Possible ranges in the absolute ages of the units may be estimated from densities of intermediate-size craters and comparative impact flux histories of the Moon and Mars (Soderblom and others, 1974).

To a large extent, definition and interpretation of rock units made from remote imagery are based on topography. Although fine details of rock texture and structure generally are not resolvable, certain clues as to rock types and origins of landforms may still be provided by the photographs. Thus, the striking resemblance between the large cratered mountain mentioned above and certain types of terrestrial volcanoes provides an obvious interpretation as to its origin; similarly, some plains units with lobate scarps and (or) marelike ridges are also probably correctly interpreted to be volcanic because of their similarity to known lunar lava flows. Windblown material appears as light (and possibly dark) plume-shaped streaks extending away from many craters and prominent hills. Other mapped units such as knobby and blocky materials may be more representative of erosion and tectonic processes than lithologic variations between units.

Materials that make up the geologic units have been subdivided into four general categories according to the landforms they most nearly represent. Two of these subdivisions, crater materials and mountain and dome materials, reflect intrinsic properties of the units that relate to both their origin and composition. The plains and relief-forming categories, however, include materials that appear to differ from place to place, and similar morphologies do not necessarily indicate common origins or compositions.

STRATIGRAPHY

Relief-forming materials

Highly cratered rough terrain (mostly knobby material unit) extends in a broad arc from the south-central part to the northeast part of the map area. Frequency distributions (fig. 1) of all craters visible at A-frame resolution (minimum diameter about 3 km) are similar to those of the lunar highlands. Such regions are considered to be old and probably record an initial period of high impact flux during the final accretional stages of the planet. Most original crater morphologies have been highly degraded, and for many, only circular outlines remain. The impact breccias and highly shocked rocks that formed the rims, walls, floors, and ejecta blankets of these ancient craters have been reshaped by tectonic and erosional processes into knoblike hills resembling inselbergs in arid terrestrial regions. Craters as young or younger than the c_2 classification are mostly unaffected by this alteration process but have otherwise been subdued to varying degrees depending on their age. Knobby terrain is not everywhere associated with old crater forms but also occurs in irregular patches having positive relief and as isolated peaks projecting above plains. In this area, it seems to be representative of an intermediate to advanced stage in the planation of a landscape. Faulting, fracturing, slumping, and wind erosion are probably chiefly responsible for shaping the knobs, which in places are faceted or have angular sides suggestive of a transition from more blocklike forms, such as unit b. This blocky material occurs as mesas and plateaus with rectilinear outlines; some are inclined and resemble cuestas. They probably are residual landforms of an older and higher surface that has been embayed by the plains materials; possibly they are remnants of a surface that is being eroded to form the plains.

Plains materials

Crater populations (fig. 1) range from less than 50 (>3 km)/$10^6 km^2$ on the smooth plains in the southeast to 250 (>3 km)/$10^6 km^2$ on the streaked plains in the central part of the map. The higher figure is more nearly comparable to crater densities on the lunar maria (Shoemaker and others, 1962). Aside from crater populations, visible differences in surface textures are not readily detectable on A-frames between plains units—especially plains (unit p) and smooth plains (unit ps). High-resolution pictures, however, show that each of the plains have different characteristics and also that variations may occur from place to place within the same unit. On a fine scale (500-m resolution), some of the plains are exceptionally smooth (unit ps), and where small fresh craters occur, their rims appear to be partly buried—probably by eolian deposits generated by a succession of dust storms in the recent past. Wind-plume streaks are not common on the plains and smooth plains, and their rarity seems to correlate with relatively thick accumulations of fine materials. In other areas, where the plains are slightly rolling to hilly (unit pr) or streaked (unit pst), lobate scarps are visible at both A- and B-camera resolution. Parallel sets of dark lineaments on the streaked plains resemble fractures and suggest that a hard or consolidated surface is only thinly covered by windblown material that is concentrated on the lee side of obstacles. Thus, the plains that generally appear to be smooth on A-camera photographs evidently consist of young eolian deposits, relatively young lava flows, older flows, and surfaces of unknown but consolidated materials.

Mountain and dome materials

Preliminary contours (Wu, 1975) show that Elysium Mons has gently sloping flanks (5°-10°) and thus may be a shield volcano like Olympus Mons (Carr, 1975). However, estimations from shadow geometry of the upper parts of the mountain indicate steep slopes, possibly as much as 27°, suggesting a strato-volcano type of structure. This observation is also more in accord with the overall appearance of Elysium Mons, which seems to be much sharper than other shields of the Tharsis region. Albor Tholus, on the other hand, closely resembles some large domical volcanoes in the Tharsis quadrangle, and it also is similar in appearance to terrestrial cumulo domes whose rounded convex forms are composed of silicic lavas. Some very small domes of volcanic origin may be scattered among the knobby material (unit k) where they are not recognizable as distinct units; one has been mapped near 23°N., 190°.

Crater materials

Martian craters, like those on the Moon, become degraded with time, and small craters are more readily subdued by erosional processes than are larger ones. After an early period of high impact flux on both planets, where meteoroid bombardment was the primary agent for the destruction as well as the formation of craters, the erosional histories of Mars and the Moon diverged. On Mars, the wind, and perhaps locally water (Milton, 1973), became the major agents for the alteration of landforms by both removal and deposition of material. Moreover, the effect of the wind does not appear to be constant even within the Elysium quadrangle, where wind plumes vary not only in direction and length but also in their frequency (see section on wind patterns). For this reason, the apparent relative age of craters cannot be readily or accurately ascertained from morphologic criteria alone. As on the Moon, superposition and crosscutting relations are very useful in places; however, the absence on Mars of widespread ejecta blankets as stratigraphic markers precludes all but a gross threefold subdivision of craters by relative age—at least within the Elysium quadrangle.

The huge, irregularly shaped crater Orcus Patera (unit ci) is the largest known crater of this type on Mars or the Moon. Its origin is not known; perhaps the elongate shape represents the coalescence of clusters of large, overlapping impact craters whose rims and walls have been structurally modified by faulting. Although terrestrial volcanic craters and calderas are commonly elongated in the direction of fissure zones following structural trends, there is little evidence of volcanic flow textures around Orcus Patera.

Within the quadrangle there are many nearly circular outlines that presumably are remnants of ancient craters. Most of them consist of groups of sharp hills and are mapped as knobby material (unit k), but their rim crests are shown by a special symbol.

STRUCTURE

Major structural trends are expressed as a series of normal faults, grabens, and troughs trending about N. 65° W. through the central and southeastern parts of the map area. These faults appear topographically distinct in the knobby and streaked plains units but are subdued and partly buried in the plains and smooth plains materials. Thus, the time of faulting is only very loosely defined because of the wide disparity in ages (probably a billion years or more) between these pairs of units. In the northwest corner of the quadrangle, long troughs mapped as grabens partly encircle Elysium Mons on the northeast and southwest about 200 km from the summit caldera. Other large flat-floored depressions are subradial or somewhat concentric to this volcano, whereas only a few are present around Albor Tholus. All these structures are characteristic of crustal extension and are attributed to updoming of the surface around a major volcanic center. They are younger than the volcanic flows that form the surrounding rolling plains and may also be younger than the major fault systems, which do not appear to transect these plains. In places, however, the depressions subradial to Elysium Mons show a preferred orientation along these preexisting structural trends. In the northwest part of the quadrangle some depressions are sinuous and branching and resemble channels elsewhere on Mars believed to be fluvial in origin (Milton, 1973). On a smaller scale, numerous northeast-trending lineaments in the east-central part of the map area appear to have normal separation where they have formed terraces in the rims and walls of Orcus Patera. Also, high-resolution pictures (DAS 12150747, 12150817, 12150957) of the streaked plains show a nearly east-west orientation of sets of dark lineaments in the southwestern part of the map area that are interpreted to be fractures, possibly predating younger units. There is some physiographic evidence shown by the pattern of both knobby and streaked plains materials for a series of ancient basin rims extending from the central to the northeastern part of the quadrangle. However, structural and stratigraphic characteristics associated with most large lunar basins have not been identified.

WIND PATTERNS

Wind-direction indicators are abundant in the streaked plains, where light tapering plumes, and some outstanding dark ones, occur in the lee of craters and other prominences. They indicate that the prevailing winds are directed toward the southwest over most of the map area. On the north and northwest flanks of Elysium Mons, however, wind directions are reversed, and there is a suggestion that wind plumes curve around this part of the volcano; this appears to be a local effect probably caused by topography.

On some high-resolution photographs (for example, DAS 07794848 and DAS 12985878) triangular-faceted hummocks several kilometres across generally have one prominent face directed toward the prevailing wind. Also, streamlined erosional remnants resembling yardangs are elongated in the wind direction.

GEOLOGIC HISTORY

The final stage of high meteoroidal impact flux in the formation of Mars is recorded within the Elysium quadrangle by a relatively small area of knobby terrain. In this area, numerous overlapping highly degraded crater outlines are still visible; elsewhere they have been obliterated by volcanism and erosional processes. Volcanic eruptions and the formation of sheetlike lava flows seem to have occurred, as on the Moon, during the period of waning impact flux. These flows were probably low-viscosity basalts that formed the streaked plains and whose flow fronts are visible on high-resolution photographs. The stress field may have been different at this time as shown by dark subparallel sets of lineaments resembling fractures that trend nearly east-west, whereas the younger more prominent faults strike about N. 65° W. After extrusion of the flood basalts, a change in the style or type of volcanism occurred, and large edifices like Elysium Mons and Albor Tholus were formed by extrusions of basalt and tephra, and possibly by more silicic, viscous lavas. The large troughs concentric and radial to these volcanoes were formed during this episode by updoming and dilation of the crust. The time of onset of an active wind regime is not known; possibly the first tenuous atmosphere began to develop after, and as a consequence of, a general planetwide period of major volcanism (also, see Carr, 1975). At least one of the older plains surfaces (unit p) appears to consist of eolian material and has crater densities similar to the younger volcanic plains around Elysium Mons and Albor Tholus. At the present time, the wind is actively eroding and transporting material in some places and depositing thick blankets of sand and dust in others. In the southeast corner of the quadrangle no vestiges of even small craters remain and deposition is the dominant process.

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GEOLOGIC MAP OF THE ELYSIUM QUADRANGLE OF MARS

By
David H. Scott and John W. Allingham
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