DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

Prepared in Cooperation with the
JET PROPULSION LABORATORY, CALIFORNIA INSTITUTE OF TECHNOLOGY
FOR THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ATLAS OF MARS
1:5,000,000 GEOLOGIC SERIES
COPRATES QUADRANGLE
M 5M –15/68 G, 1978
I-897 (MC-18)

## 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 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°. Longitude increases to the west in accordance with the 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 5-10 km.

### MAPPING TECHNIQUES

A series of mosaics of Mercator projections of Mariner 9 pictures was assembled at 1:5,000,000.

Shaded relief was copied from the mosaics and portrayed with uniform illumination with the sun to the west. Many Mariner 9 pictures besides those in the base mosaic were examined to improve the portrayal (Levinthal and others, 1973; Green and others, 1975; Inge and Bridges, 1976). The shading is not generalized and may be interpreted with nearly photographic reliability (Inge, 1972).

Shaded relief analysis and representation were made by Patricia M. Bridges.

### 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).

The contour lines on most of the Mars maps (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 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; 1977).

MC-18: Abbreviation for Mars Chart 18
M 5M –15/68 G: Abbreviation for Mars 1:5,000,000 series; center of sheet, 15° S latitude, 68° longitude; geologic map, G.

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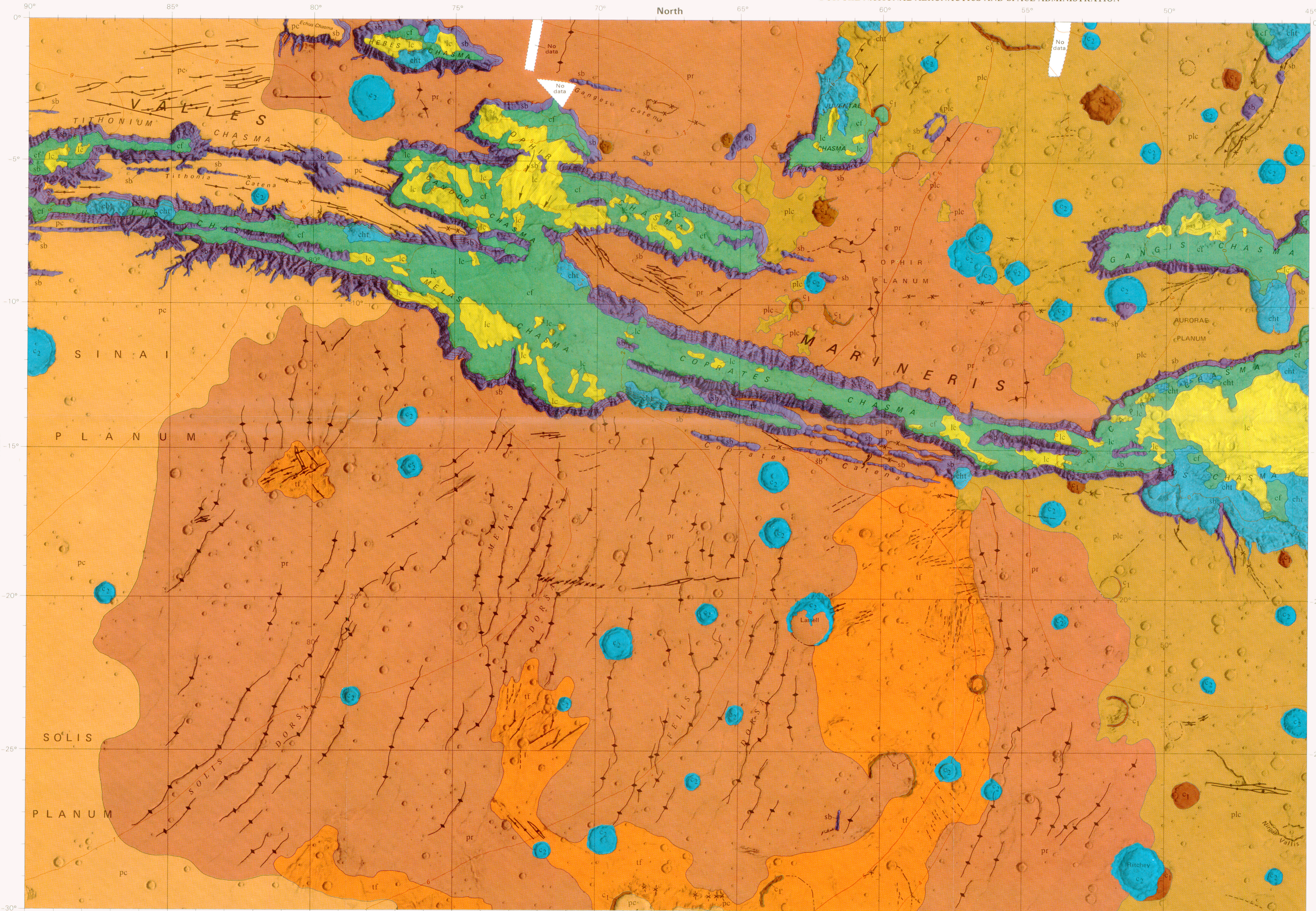
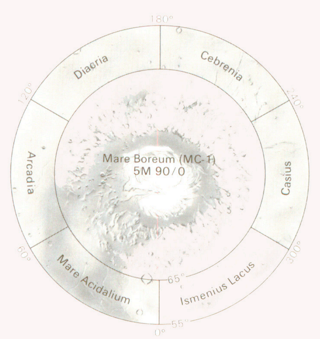


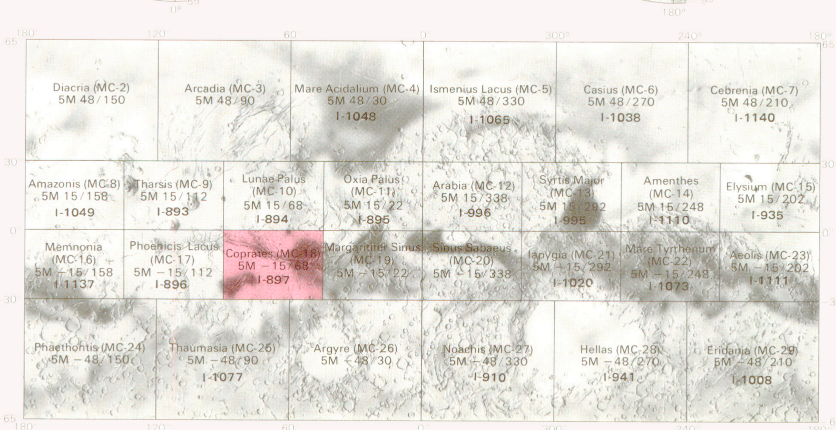

Interior–Geological Survey, Reston, Va.–1978–G77167
Prepared on behalf of the Jet Propulsion Laboratory, California Institute of Technology under contract WO-8122.

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

100 50 0 KILOMETERS 100 200 300 400 500 600 700 800 900 1000

CONTOUR INTERVAL 1 KILOMETER

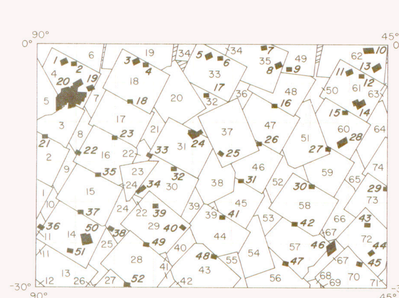





Albedo features from International Planetary Patrol photographs, Lowell Observatory, Flagstaff, Ariz.

QUADRANGLE LOCATION
Number preceded by I refers to published geologic map

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




A-camera pictures

| Index No. | DAS No. | Index No. | DAS No. | Index No. | DAS No. |
|---|---|---|---|---|---|
| 1 | 7326583 | 26 | 8873169 | 51 | 9017229 |
| 2 | 7326653 | 27 | 6067213 | 52 | 9017159 |
| 3 | 7326723 | 28 | 6067283 | 53 | 9017089 |
| 4 | 7326793 | 29 | 6067353 | 54 | 9017019 |
| 5 | 8729599 | 30 | 7470503 | 55 | 9016949 |
| 6 | 7327143 | 31 | 7470573 | 56 | 6211063 |
| 7 | 8801559 | 32 | 7470643 | 57 | 6211133 |
| 8 | 8801489 | 33 | 7470713 | 58 | 7614283 |
| 9 | 8801419 | 34 | 7471063 | 59 | 7614353 |
| 10 | 8801349 | 35 | 6139733 | 60 | 7614423 |
| 11 | 5923438 | 36 | 8945409 | 61 | 7614493 |
| 12 | 5995253 | 37 | 8945339 | 62 | 7619733 |
| 13 | 5995323 | 38 | 8945269 | 63 | 9089189 |
| 14 | 7398473 | 39 | 8945199 | 64 | 9089119 |
| 15 | 7398543 | 40 | 8945129 | 65 | 9089049 |
| 16 | 7398613 | 41 | 8945059 | 66 | 9088979 |
| 17 | 7398683 | 42 | 6139103 | 67 | 9088909 |
| 18 | 7398753 | 43 | 6139173 | 68 | 9088839 |
| 19 | 7399103 | 44 | 6139243 | 69 | 6211623 |
| 20 | 8873519 | 45 | 7542393 | 70 | 6282953 |
| 21 | 8873449 | 46 | 7542463 | 71 | 9160729 |
| 22 | 8873379 | 47 | 7542533 | 72 | 6283023 |
| 23 | 12010324 | 48 | 7542603 | 73 | 7686173 |
| 24 | 8873309 | 49 | 7542953 | 74 | 7686243 |
| 25 | 8873239 | 50 | 9017299 | | |

High-resolution B-camera pictures

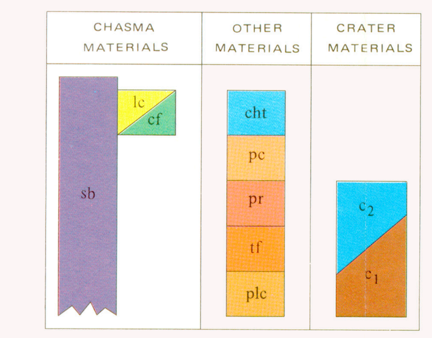
| Index No. | DAS No. | Index No. | DAS No. | Index No. | DAS No. |
|---|---|---|---|---|---|
| *1* | *7327108* | *20* | *10276494* | *34* | *12010219* |
| *2* | *7326828* | | *10204604* | | *12010289* |
| *3* | *7399068* | | *12003974* | *35* | *7398578* |
| *4* | *7398788* | | *10204884* | *36* | *8801314* |
| *5* | *7471028* | | *10132994* | *37* | *7398508* |
| *6* | *7470748* | | *10132924* | *38* | *8873274* |
| *7* | *6139768* | | *7326758* | *39* | *7470468* |
| *8* | *7542918* | | *10204114* | *40* | *8945164* |
| *9* | *7542638* | | *10204044* | *41* | *7542358* |
| *10* | *6355438* | | *10133064* | *42* | *7614248* |
| *11* | *7614808* | *21* | *7326688* | *43* | *7686138* |
| *12* | *7614528* | *22* | *8801454* | *44* | *12185957* |
| *13* | *10492654* | *23* | *7398648* | *45* | *6282988* |
| *14* | *9017614* | *24* | *7470608* | *46* | *6211658* |
| | *10492584* | | *5995918* | *47* | *6211098* |
| *15* | *7614458* | | *12865573* | *48* | *6139208* |
| *16* | *7542568* | *25* | *8945304* | *49* | *6067318* |
| *17* | *7470678* | *26* | *7542498* | *50* | *8944744* |
| *18* | *7398718* | *27* | *7614388* | | *8947814* |
| *19* | *5851998* | *28* | *10492514* | *51* | *5995358* |
| *20* | *10204954* | *29* | *7686208* | *52* | *6067248* |
| | *10204674* | *30* | *7614318* | | |
| | *10204534* | *31* | *7542428* | | |
| | *10276634* | *32* | *7470538* | | |
| | *10276564* | *33* | *8873414* | | |

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. Useful coverage is not available in some cross-hatched areas. Pictures other than those shown in the mosaic were used for portrayal in the other cross-hatched areas. Also shown (by solid black rectangles) are the high-resolution B-camera pictures, identified by italic numbers.

# GEOLOGIC MAP OF THE COPRATES QUADRANGLE OF MARS

By
J.F. McCauley
1978

## CORRELATION OF MAP UNITS




## DESCRIPTION OF MAP UNITS

### CHASMA MATERIALS

sb — SLOPE AND BEDROCK MATERIAL–Composite unit that occurs on relatively steep slopes along walls of chasmas, chain craters, and collapse features. Layering in form of dark band about halfway up chasma wall seen on south side of Coprates. Slopes average 20° to 32° over most of the chasma walls. Walls of Valles Marineris show variety of erosional patterns that include steep headwalls, downward bifurcating ridges and gullies, and large alcoves below which lie great masses of jumbled debris. Gashlike grooves controlled by regional structure pattern present along with large incised bifurcating sidewall gullies. Upper slopes commonly marked by vertical ribs and grooves. Large flow lobes common at base of scarps. Representative locality near long 61°, lat -12.5° (DAS 7542498). *Interpretation:* Exposed bedrock and talus localized along steep walls. Formed and (or) exposed mostly by mass wasting or gravitational collapse of oversteepened slopes. Large bifurcating gullies produced by rapid flowage of water-saturated sediments after breeching of isolated lake basins within Valles Marineris. Lack of benching in chasma sidewalls suggests homogeneity in vertical section exposed

lc — LAYERED CHASMA MATERIAL–Occurs on floor of Valles Marineris as subdued-appearing stratified mesas. Representative locality in northern part of Gangis Chasma near long 49°, lat-7° (DAS 9017614, 10492584), where ten or more alternating light and dark layers are recognized; lighter layers near base of section extensively fluted. No B frames of other patches available, but they have same general characteristics at A-frame resolution. Largest patch occurs at mouth of Valles Marineris in Capri and Eos Chasmas, where Mariner 9 elevation data suggest a thickness of about 2 km. Patch in both Ophir and Candor Chasmas transects gullied slope and bedrock material. This occurrence not obviously stratified; has lobate form on south suggesting different mode of emplacement. *Interpretation:* Water-laid sediments deposited in large isolated lakes successively breached by wall erosion during enlargement of Valles Marineris chasma system. Drainage of lakes produced catastrophic floods that carried away most of original lake sediments. Remnants modified by later fluvial pulses and eolian activity. Ophir-Candor patch may consist of unconsolidated sediments that flowed southward after breeching of Ophir or relict mud slide from chasma walls. Fluting at base of representative locality result of wind erosion or sapping of water-saturated layers

cf — CHASMA FLOOR MATERIAL–Flat-lying, generally smooth-surfaced materials; occupy lowest parts of Valles Marineris and Hebes and Gangis Chasmas; characteristically streaked and mottled, particularly at western end of Candor Chasma. Sinuous ridges and grooves wrap around chasma walls and isolated highs on floors (DAS 1286557). Numerous small light-appearing streamlined forms present–best examples at east end of Gangis Chasma. Includes numerous flow lobes that originate in chasma walls. Crater frequency extremely low at Mariner 9 resolutions. Representative locality near long 70.4°, lat -11.2° (DAS 7470608). *Interpretation:* Mixture of mass-wasting debris, avalanche, and mudflow deposits from chasma walls, and fluvial sediments covering jumbled downdropped bedrock of units expressed along chasma rims. Ridges, grooves, and streamlined islands on the chasma floors are scablands produced by episodic floods that traversed Valles Marineris after breaching of individual chasma lakes. Present surface probably modified by eolian erosion from wind-funneling effects within Valles Marineris

### OTHER MATERIALS

cht — CHAOTIC MATERIAL–Occurs in patches of large, broken, sharp, rectilinear blocks mostly at east end of Valles Marineris, particularly in Eos Chasma region. Blocks generally 2-4 km in size lie at base of scarps or within isolated circular to irregular depressions. Main occurrences of unit are farther east in Margaritifer Sinus quadrangle–only isolated patches are present in Coprates quadrangle. Representative locality at long 45°, lat -18.5° (DAS 7686208). *Interpretation:* Believed to be product of collapse with little horizontal motion resulting from loss of volume and support in subsurface. Alternatively, chaotic material may result from subsurface flowage of water-saturated materials into rapidly drained chasma basins, thereby causing foundering of dryer, inherently more competent surface layers. Both processes probably operative. The first explains chaos in closed depressions in Margaritifer Sinus quadrangle, the second chaos of Gangis re-entrant (long 46°, lat -10°) and Juventae and Eos Chasmas

pc — CRATERED PLAINS MATERIAL–In Sinai Planum and Solis Planum along eastern edge of map; smooth to rolling at Mariner 9 resolutions but with numerous 2- to 10-km-size sharp superposed bowl-shaped craters; representative locality near long 89.4°, lat -23.2° (DAS 880134). Sharp-appearing graben, parallel to chasma walls, common in region north of Tithonium Chasma. Large bifurcating tributaries along south wall of Ius Chasma coincident with extent of unit. Some surficial streaking and mottling along with faint irregular pits and grooves. Appears to overlap ridged plains (unit pr) along east side of mapped area. *Interpretation:* Loess or ash blanket covering older volcanic terrain consisting of numerous superposed flow units. Blanket thins to west in Tharsis-Noctis Labyrinthus region, where subjacent volcanic flow features are more apparent. Somewhat deflated by wind action since emplacement based on presence of pits and grooves

pr — RIDGED PLAINS MATERIAL–Characterized by numerous elongate and sinuous ridges identical in form to those of lunar maria. Representative locality near long 84.5°, lat -24.5° (DAS 8944744, 8944814). Some have single coalescing crests; others are broader, plateaulike features with parallel ridges enclosing smooth central high. Intervening regions generally smooth but some vague lobate scarps present; unit shows faint grooving and pitting. In places small 2- to 4-km bowl-shaped craters and high concentrations of small, irregular secondary craters. Area to north of Valles Marineris and contiguous with Lunae Planum shows a few faint ridges; ridges generally trend north-northeast; range in length from 100 to 400 km. Locally, ridges bifurcate particularly in the Melas Dorsa region, where they trend north-south. *Interpretation:* Flood basalts like those of lunar maria. Ridges may be compressional in origin or viscous fissure flows. Unit embays and deeply buries more cratered trough-and-furrow and cratered plateau materials (tf and plc). Thickness is generally sufficient to conceal all traces of the numerous 50- to 100-km-diameter craters common to the east in more heavily cratered hemisphere of Mars

tf — TROUGH-AND-FURROW MATERIAL–Consists of moderately undulating terrain characterized by numerous subdued troughs and furrows; high density of 20- to 40-km-diameter craters. Predominant structural trends are east-northeast and west-northwest. Lies at higher elevation than ridged plains; contact in southern part of map marked by subdued scarp. Prominent patch of dark splotches and crater tails occurs in vicinity of long 65°, lat -25°; unit most mottled of map units in quadrangle. Occurrence near long 80°, lat -15°, has appearance of broad symmetrical dome with diapirlike fracture pattern. Representative locality near long 57°, lat -21° (no B frames available). Atypical plateau material near long 67.5°, lat -29.5° included in this unit for sake of map simplicity. *Interpretation:* Tectonically modified and upwarped equivalent of cratered plateau material (plc)

plc — CRATERED PLATEAU MATERIAL–Moderate density of 50- to 100-km diameter degraded craters separated by smooth to rolling terrain that appears to embay and fill most of larger craters. Mare ridges absent; numerous small sinuous furrows or channels. Moderate density of small 2- to 10-km cup-shaped craters. Numerous collapse features and extensive patches of chaotic terrain appear to have formed at expense of this unit; subdued graben occur locally. Representative locality near long 48°, lat -4° (DAS 7014528). *Interpretation:* Older cratered terrain modified by fluvial and eolian activity; intercrater plains may be volcanic or reworked erosional debris. Numerous small channels and collapse features in unit suggest that it has undergone extensive subsurface devolatilization

### CRATER MATERIALS

$c_2$ — SUBDUED CRATER MATERIAL–Craters greater than 50 km in diameter with generally flat floors filled with materials of unknown origin. Some floors rough; central peaks occur in a few craters. Wall terraces moderately well developed but occupy only narrow annulus around floor. Rims stand above surrounding terrain but extent of recognizable ejecta limited to about one-fifth of crater diameter. In smaller size ranges (<50 km), numerous fresher appearing craters present but have not been mapped. *Interpretation:* Impact craters modified chiefly by variety of martian surficial processes

$c_1$ — DEGRADED CRATER MATERIAL–Highly modified, incomplete, partly buried craters greater than 50 km in diameter. Rims nearly level with surrounding terrain. Interior walls smooth and without terraces; generally filled or embayed. *Interpretation:* Impact craters that have been modified by volcanic and tectonic processes. Later fluvial and eolian activity as well as collapse has contributed to present state of degradation

Contact

Crestline of wrinkle ridge–Analogous to those of lunar maria

Narrow linear trough–Probable graben

Topographic scarp-Barb points downslope

Small chain craters–Tectonically controlled collapse structures

Small sinuous channel

Lineament–Linear feature too small for classification

Buried crater rim crest

Direction of flowage of sediments

## GEOLOGIC SETTING

The Coprates quadrangle lies to the east of the Tharsis volcanic complex and the Noctis Labyrinthus tectonic complex. To the north are the plains of Lunae Planum, to the east the vast patches of chaotic terrain and the large sinuous channels that trend northward into Chryse Planitia. On the southwest is the Thaumasia Fossae region of tectonically deformed cratered terrain, to the southeast, the Argyre Basin, the best preserved of the ancient martian impact basins.

The geology of the Coprates quadrangle is dominated by the Valles Marineris chasma system, which stretches in an east-southeast direction for about 2,500 km across the quadrangle. Its maximum width is about 600 km from the north rim of Ophir Chasma to the south rim of Melas Chasma. The terminus of Valles Marineris at the eastern edge of the map is about 500 km wide in the north-south direction. Individual segments of the chasma system are 100 to 150 km wide and 2 to 4 km deep.

Much of the geology described here is common to other regions of Mars and has been discussed previously not only in summary papers but by other quadrangle mappers. Preliminary attempts at the regional geology of Mars have been made by McCauley and others (1972) and Carr and others (1973). Those units and features common to other parts of Mars are discussed first. The focus of this discussion is on Valles Marineris and those features that are unique to this quadrangle.

## GENERAL STRATIGRAPHY

Moderately cratered plateau material occurs along the eastern edge of the mapped area and marks the beginning of the cratered hemisphere of Mars. This unit bears some resemblance to the lunar terrae but is not saturated with large craters, and the intercrater areas are smoother and more extensive. Coincident with the appearance of this terrain, the Valles Marineris chasma system widens markedly, the chasma walls become lower in height, and chaotic terrain is abundant. Sinuous channels are numerous, and the floors of many of the large craters such as that south of Ganges Chasma (10° S, 51° W) appear to have collapsed. Subsurface sapping and fluvial activity are more widespread in this unit than elsewhere in the quadrangle. Sharp (1973) and Sharp and Malin (1975) along with Milton (1974a) have suggested mechanisms by which such processes operate on Mars.

The central part of the quadrangle is mostly occupied by ridged plains that are continuous with, and similar to, the materials of Lunae Planum described by Milton (1974b). These plains do not extend much beyond the southern boundary of the map area but patches may be present in the Thaumasia (McGill, 1978) and Argyre quadrangles. In surface morphology and crater frequency, these plains here and elsewhere on Mars are similar to the lunar maria (Soderblom and others, 1974; Meyer and Grolier, 1977). The ridged plains of the Coprates quadrangle and of Lunae Planum to the north are not clearly related to large multiring basins or to craters, as are most of the lunar maria. The ridged plains embay and overlie older cratered terrains as on the moon. Along the walls of Valles Marineris and in Lunae Planum, they are, unlike the Moon, eroded into complex scarps by fluvial, eolian, and mass-wasting processes.

Several large prongs of trough-and-furrow material embayed by the ridged plains extend northward into the central part of the quadrangle. They appear to be extensions of the tectonically deformed terrain of the Thaumasia quadrangle described by McGill (1978). Although characterized by intense fracturing within Coprates, this unit appears more subdued than that identified as troughed and furrowed hills material in the Thaumasia quadrangle. It appears to occupy zones of gently upwarped terrain with the deformation imprinted on earlier materials that have escaped burial by the marelike ridged plains.

The western part of the quadrangle is underlain by cratered plains material that is almost featureless except for scattered large and small craters. This unit is, however, the most heavily cratered of a sequence of plains of varying crater density and subtle volcanic morphology that surround the Tharsis region and extend westward and northward into Amazonis (Carr, 1975; Masursky and others, 1978). The contact between the cratered plains and the ridged plains is diffuse and highly generalized on the map. The lack of any diagnostic landforms within the unit suggests that it is either an eolian loess blanket or volcanic ash of sufficient thickness to obscure most subjacent topography except for a few 100-km-size craters. The materials below the surface of the cratered plains unit may be volcanic flows that lap onto the ridged plains and are related to the martian volcanic centers to the west.

The frequency of degraded craters decreases from east to west across the quadrangle, whereas the frequency of fresh-appearing craters is almost uniform except for the almost cratterless floors and walls of Valles Marineris. This relation indicates progressively deeper westward burial of the cratered plateau unit; relatively early in martian history. Within the vast expanse of Valles Marineris are younger slope and floor units that post-date the chasmas and the plains materials that bury older cratered terrain.

## VALLES MARINERIS

Valles Marineris has no known terrestrial or planetary counterpart. This structure in its entirety resembles neither a major rift system nor a valley produced by fluvial downcutting. It is characterized by several long linear segments such as Ius Chasma and Coprates Chasma separated by the broad arcuate expanse of Melas Chasma. Candor Chasma and Ophir Chasma to the north are more boxlike and are connected with the main part of Valles Marineris by gaps in the chasma walls. Hebes, Juventae, and Gangis Chasmas are separate large depressions that are not integrated into the main system. Schafer (1974), in comparing Ius Chasma with the Rhine graben, noted similarities of form and tectonic pattern. Masson (1977) showed that the general tectonic pattern but not the present appearance of the East African Rift is similar to that observed in and around Valles Marineris. Their work suggests that lateral crustal extension may have played a role in the early development of parts of the Valles Marineris system, but this type of tectonism and the formation of linear graben cannot explain its present overall form.

The walls of the chasmas that make up the system have been extensively modified by erosion (Sharp, 1973) that has produced extensive lateral and longitudinal enlargement of Valles Marineris since the system began development. Six types of erosional features are generally recognized (McCauley, 1972; Sharp, 1973; and Lucchitta, 1978): (1) Ridge and gully topography consisting of downward bifurcating ridges with intervening talus-covered gullies that mutually interrupt one another. This terrain resembles that produced on steep slopes by mass movements of nonstratified materials. It dominates most of Coprates Chasma and the southfacing walls of other large depressions such as Candor, Ophir, and Hebes. (2) Large semicircular alcoves to 50 km across that appear to have formed by gravitational collapse along oversteepened segments of the chasma walls. The jumbled debris produced is still evident at the base of many. Campbell (1973) suggested that alcoves of this general form on Earth are initiated by ground water seepage along zones of structural weakness in massive but porous rock units. (3) Bifurcating steep-walled tributary channels to 120 km long on the south wall of Ius Chasma. Nonbranching gashlike erosional troughs are common on the north walls of Ius Chasma and Tithonium Chasma and occur locally throughout Valles Marineris. Both the bifurcating and gashlike channels are controlled by orthogonal structures in the chasma walls. The overall form of these features, though many orders of magnitude larger, is more similar to seepage gullies than to channels produced by running water. (4) Large lobate flow features that resemble large terrestrial debris avalanches or mudflow deposits emanate from the chasma walls at numerous places. The presence of debris slides or flows suggests intermittent catastrophic failure of the chasma walls, partly induced by the presence of lubricating fluids. (5) Chaotic terrain representing yet another form of chasma wall failure is generally thought to take place by removal of material from below. Within the Coprates quadrangle, such terrain consists mostly of jumbled blocks that lie at the base of scarps. Large slabs that exhibit little breakup and horizontal motion are downdropped at places as in the re-entrant on the south side of Gangis Chasma at long 46° and lat -10°. (6) Rimless chain craters that extend outward from the ends of Ophir and Candor Chasmas and also parallel Coprates Chasma. These chain craters parallel the many graben that flank Valles Marineris and are clearly controlled by major structural trends. Although they bear a superficial resemblance to volcanic vents, they are considered by most workers to be collapse features. Many have small-scale ridge-and-gully topography along their walls that in miniature mimic the erosion forms on the walls of the larger chasmas.

These six erosion features collectively contribute to an outward wall recession pattern in each of the chasmas of the Valles Marineris system, best seen at the west end of Hebes Chasma and on the south side of Gangis Chasma, where only narrow flat-topped divides now separate the individual depressions. Continued outward growth by any combination of the processes described will eventually result in chasma capture. This process of lateral erosional enlargement of individual chasmas can explain the present interconnections between Ophir, Candor, and Melas Chasmas that are otherwise difficult to account for by rifting or fluvial activity. This wall recession model is consistent with the scenario given by Sharp (1973) for the genesis of the major martian troughs. It implies that the lowermost chasmas have captured the higher ones to form most of the large but poorly integrated valley system now observed. Planetwide elevation data (U.S. Geol. Survey, I-961 and I-976, 1976) indicate that the mouth of Vallis Marineris in the Capri-Eos Chasma regions is at least 7 km lower than the upper reaches of the system at the east end of Noctis Labyrinthus. The floor of Melas Chasma is about 2 km lower than the floor of Ophir. The lateral gradient across the widest part of Valles Marineris, then, is about 1.5 times greater than its present longitudinal gradient.

In order for outward wall erosion to proceed to the point of chasma capture, the floors of each chasma have to be lowered with time to maintain wall slopes of sufficient steepness to allow gravity erosion to produce the ridge and gully topography, the most common type of erosional form in Valles Marineris. Evidence for subsidence is seen in Hebes and the east end of Candor Chasmas, where there are at least two distinct floor levels. Additional evidence of floor subsidence is seen along the north wall of Coprates Chasma and on the flanks of an island at its west end (B-frame 1286557), where small steep scarps truncate the faces of the ridges of the ridge and gully terrain. The small trough to the west of Juventae Chasma shows evidence of successive collapse and indeed may be a small protochasma. The mechanism by which subsurface collapse takes place on such a grand scale is poorly understood and has no recognized terrestrial analog. Sharp (1973) has speculated that such a process might occur by subsurface decay of ground ice.

The presence of large patches of rhythmically layered light and dark horizontal beds in the floors of Valles Marineris may be the key to its origin and evolution. The best example in Gangis Chasma has been described by various workers including Masursky (1973), Sharp and Malin (1975), and Lucchitta (1978). Similar-appearing patches for which no B-camera frames are available occur throughout Valles Marineris except in Ius Chasma. The multiple layering in these deposits does not match that seen in any part of the chasma walls. A few dark layers of regional extent occur on the south side of Coprates Chasma and what appears to be a resistant layer caps most of the headwalls of Valles Marineris. The layered chasma material is similar in appearance to eroded terrestrial water-laid sediments deposited in a low-energy environment. No other geologic process can readily explain their horizontality, the lateral continuity of individual beds, and the subtle differences in reflectance and competence of the various beds in the vertical sequence. Air-fall and ash-flow tuffs do not generally show the type of layering observed. There are no obvious volcanic sources on the chasma floors. And no similar-appearing erosional remnants are found elsewhere in the quadrangle, as might be expected if the sources were distant.

If these are indeed water-laid sediments, large, long lasting, standing bodies of water must have existed within the Valles Marineris system. The chasma capture model proposed earlier to explain the growth of Valles Marineris is compatible with the presence of lakes within most of the individual large depressions. It is possible that thermokarst processes operated at scales much greater than on Earth within the zone now occupied by Valles Marineris (Gatto and Anderson, 1975). Subsidence following the melting of ground ice may have allowed collection of water in the depressions created. Drainage of ground water from porous layers in the walls of the depressions could have occurred and each chasma may have drained an area much larger than its present extent if subsurface melting was sufficiently pervasive. Temperatures and pressures above the triple point of water must have prevailed for at least short periods during each martian year to allow extensive sedimentation in these lakes. For the lakes to persist over many seasons, atmospheric pressures would have to be high enough to retard rapid evaporation during the summer period. The Mars atmosphere at the time of formation of the chasma lakes had to be more tolerant of standing water than now implying climate change.

The existence of successively breached large lakes accounts not only for the presence of well-stratified chasma floor deposits but also for many of the other perplexing features of Valles Marineris. Most of the chasma wall erosion can be attributed to dry mass-wasting or gravity erosion aided by ground ice. The more catastrophic type of wall failure, including the mudflows or debris avalanches that produced bifurcating gullies and gashlike troughs along with some of the chaotic terrain may have another explanation. Such failure may have occurred during or shortly after drainage of each basin. The rapid lowering of base level and the resulting loss of lateral support caused the water-saturated wall materials within each lake to fail in different ways dependent on their lithologies. The apparent fluvial scouring seen on the floors of Valles Marineris and many of the immense outflow channels of the Margaritifer Sinus and Oxia Palus quadrangles can be explained by episodic floods that originated within Valles Marineris. This chasma lake hypothesis also alleviates the problem of the volumes of water necessary to produce the great outflow channels. The analogy to the channeled scablands of Washington state produced by the failure of the natural dam retaining Lake Missoula, then, may be more valid for Mars than previously recognized (Baker and Milton, 1974).

## OTHER FEATURES

Structural trends in the Coprates quadrangle were studied by Masson (1977), who prepared structure diagrams for each 5° square. The features analyzed consist of ridges, furrows, graben, and the trend lines of chasma and crater-wall segments. Three different types of patterns can be recognized: (1) along Valles Marineris the predominant structural trend is west-northwest/east-southeast; (2) in the ridged plains of the Solis Dorsa and Melas Dorsa regions, the trends are mostly north-northeast/south-southwest; (3) the trough-and-furrow material east of the crater Lassel shows trends that are mostly east-northeast/west-southwest and north-northwest/south-southeast. Thus there appears to have been a change with time of the regional stress conditions, the west-northwest/east-southeast direction that controls Valles Marineris being the youngest, the orthogonal pattern of the ridge and furrow materials the oldest.

Surficial light and dark streaks are not as prominent as in other parts of Mars. As seen in figure 1, however, the Sinai Planum-Solis Planum area has numerous bright streaks that curve in a southeast direction away from Valles Marineris. The cratered plateau unit in the southeast part of the quadrangle has bright streaks that trend south-southeast. In the same unit in the northeast part of the map area, they trend south-southwest toward the lower ends of Valles Marineris. The dark blotches of the Felis Dorsa region have a general trend that is west-southwest. Many of these markings appear to follow topography in the downslope direction, suggesting that slope winds may be a factor in their development.

## GEOLOGIC HISTORY

The earliest recognizable geologic events in the Coprates quadrangle are associated with the formation and modification of the cratered plateau material on the east side of the map area. This region is part of the more heavily cratered southern hemisphere of Mars consisting of scattered large impact craters separated by large tracts of smooth to rolling plains or hilly terrain. The origin of these plains is not understood, although considered by some workers to be volcanic. Whatever their origin, it is clear that they are the result of modification of a primitive impact-dominated surface like the lunar terrae. Formation of the trough-and-furrow material followed. This originated from intense fracturing and gentle upwarping of terrain that may be correlative with the cratered plateau material. Later flood basalts similar to those of the lunar maria erupted. These occur in the central part of the quadrangle and northward into Lunae Planum. Their thickness must be of the order of several kilometers to obliterate almost all traces of the subjacent cratered plateau and trough-and-furrow materials. The cratered plains are next in the sequence and are inferred to consist of a complex succession of superposed flows probably related to the onset of volcanism in the Tharsis region to the west and covered by eolian materials.

Some time after these major regional units were formed, thermokarst activity began in the Valles Marineris area. A series of closed depressions formed along zones of parallel graben like those still seen north of Tithonium Chasma. Individual larger graben may have been present in the Ius and Coprates Chasmas. The floors of these depressions were gradually downdropped as subsurface melting progressed and they filled with water. Copious sedimentation took place in these basins to build up stratified sequences a kilometer or more thick. The sediments probably consist mostly of volcanic ash from the Tharsis region and windborne detritus that settled out of planetwide dust storms along with the erosion products of the chasma walls. Headward erosion, mostly by mass wasting along oversteepened slopes gradually enlarged each of the chasma lakes with consequent capture of one by another. The earliest and largest of these was in the Capri-Eos Chasma region near the present mouth of Valles Marineris. Capture proceeded in the upslope direction toward the west but also northward in the Melas-Candor-Ophir Chasma regions, where the floor gradient is steeper than the down-chasma gradient. Chasma capture resulted in the breakout of enormous volumes of water that swept down the already integrated parts of Valles Marineris. These breakouts caused massive failure of the saturated walls of the lake basins that contributed to further enlargement and filling. Hebes Chasma remained isolated and was never integrated into the Valles Marineris system. Other isolated chasmas such as Gangis and Juventae were breached, giving rise to separate outflow channels to the east and north of the Coprates quadrangle.

Climatic change accompanied by thinning and drying out of the atmosphere then took place. Eolian processes became the dominant agent of land sculpture. All of the surficial units described have been deflated to some degree, depending on their competence. Loess or possibly wind-blown ash deposits blanket the western part of the quadrangle. Impact cratering occurred throughout the period of time described here but at rates substantially reduced from the initial rain of debris that produced the cratered terrain of the hemisphere to the east. No attempt is made to establish an absolute chronology for these events. The weight of present evidence suggests that the channels and associated chasmas system on Mars are more than a billion years old (Sharp and Malin, 1975). The ridged plains may be equivalent in age to the lunar maria. It will be for the Viking mission to establish a more detailed chronology and better information on the absolute time scales involved in these events.

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