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DEPARTMENT OF THE INTERIOR
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INTERAGENCY REPORT: ASTROGEOLOGY 61

Mapping the planet Mars by Mariner 9

by

R. M. Batson and S. E. Dwornik

Presented at: The Seventh International Conference of the International Cartographic Association

Madrid, Spain
April 29 thru May 4, 1974

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

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ILLUSTRATIONS

PREFACE

The guiding philosophy in the formualtion of the NASA Planetary Program is the concept of balanced exploration. This concept involves a strategy of broad exploration of the entire solar system, rather than concentration on the detailed examination of one or two planets. Thus, within appropriate levels of resources and technology, the NASA program seeks a balance between the expansion of knowledge by the inclusion of new targets, and the refinement of knowledge obtained on previously investigated targets. It also favors a reasonable balance between expenditures on immediate missions and investment in the development of the technology which makes future missions possible.

In formulating its solar system exploration program, a major consideration has been the development of a progressive understanding of each target, so that proposed missions may build on the results and understanding generated by their predecessors. Generally, the sequence of proposed exploration progresses from earth-based observations being first augmented by flyby missions, then considerably improved by orbiter missions. Details of planetary atmospheres, composition, structure and dynamics are then investigated by atmospheric probes, followed by landers to study geology, and, where deemed appropriate, biology. Finally, sample return missions to allow earth-based analysis are considered. Orbiter missions allow the spacecraft to obtain photography for cartographic purposes. Flyby missions, because of their encounter profile, can only provide partial photo coverage of a planet at resolutions usually below mapping specifications.

Cartography plays an extremely important role in all phases of planetary exploration. Initial mission planning is based on maps made from available data obtained by earth-based observations of a planet. Maps are made with data taken at each successive stage of exploration to support scientific analysis of data obtained at that stage and to provide a basis for further exploration. These concepts are being developed and tested on Mars. The techniques used there will apply, in general, to the continuing exploration of the solar system.

INTRODUCTION

The Mariner 9 spacecraft was launched by the National Aeronautics and Space Administration in May 1971 and was inserted into Mars orbit in November 1971. In addition to collecting Mars surface and atmospheric data, Mariner 9 took over 7,000 television pictures of Mars. Compilation of these photographs into maps required extensive modification of conventional methods of mapping.

The purpose of this paper is to illustrate the processing of the digital Mariner 9 television pictures into base maps of Mars. In this context, a base map is defined as a pictorial representation of planetary surface morphology accurately reproduced on standard map projections. Topographic contour lines, albedo or geologic overprints may be superimposed on these base maps. The compilation of geodetic map controls, the techniques of mosaic compilation,computer processing and airbrush enhancement, and the compilation of contour lines are discussed elsewhere by the originators of these techniques. A bibliography of applicable literature is included for readers interested in more detailed discussions.

The mapping of Mars with data from spacecraft sensors alone is unique in the history of cartography. Many sensors were used for measurement of topography and the Martian geoid. Television pictures, however, revealed for the first time the surface morphology of the planet, and are the sole sources of data for planimetric delineation of that surface.

A Mariner television picture is an array of numbers representing image brightness of points within the image array. The original picture is recorded on magnetic tape and reconstituted as a photographic image with special video-to-film convertors. The picture data sets contain far more information than can be printed on film or photographic paper. New or newly modified cartographic techniques are therefore utilized for television cartography in conjunction with traditional ones. These include the use of computers to enhance and transform pictures geometrically, and the use of an airbrush to retouch mosaics or to draw shaded relief maps. These techniques were developed by many investigators, and are described here only in general terms.

A requirement for completing the Mars mapping within a very short time resulted in the production of several generations of map products. During Mariner 9 mission operations, crude, quick-look products were required for sequence analysis and for finding the coordinates of areas of special interest for taking higher resolution pictures. Prior to completion of a preliminary net of horizontal control points and a set of geometrically corrected pictures, improved map products were required for preliminary scientific analysis and reporting. Even after the control net and picture processing was completed a long delay time was inevitable in making final products, requiring yet another generation of mosaics so that geologists could begin compiling their maps. It was during this stage of mosaicking that the need for custom processing of particular pictures was identified. Final mosaics were carefully controlled geometrically, and provided the control upon which the published shaded relief maps are based.

THE MARINER 9 CARTOGRAPHIC PLAN

The object of the Mariner 9 cartographic effort is to compile an atlas of Mars, upon which photo-geologic or other scientific information may be overprinted. This atlas is to include shaded relief maps at a scale of 1:5,000,000 showing features as small as 2km in size. Overprints of light and dark surface markings and topographic form lines at approximately 1km intervals will be superimposed on the shaded relief maps. A supplementary set of maps is being made at larger scales (e.g. 1:1,000,000) of selected areas of special interest, including proposed landing sites of unmanned spacecraft.

The basic series of maps that shows the entire surface of Mars consists of 30 quadrangles arranged in the format shown in figure 1. The two maps of the polar regions are polar stereographic projections; those in north and south latitudes between 65 deg. and 30 deg. are Lambert conformal (conical orthomorphic) projections, and those in the equatorial region are Mercator projections. All of the projections have common scales at adjoining latitudes; hence, the Lambert conformal and polar stereographic projections have scales somewhat larger than 1:5,000,000.

This wide variety of scales is necessary because of the extremely eccentric orbit of Mariner 9, which required that pictures be taken with a wide range of surface resolution. Two cameras were used, with focal lengths differing by a factor of ten, further extending the range of available resolution to features as small as 100m in diameter in some areas. In general, the philosophy of the design of the television sequences was to take small scale pictures for photogrammetric computation of a planet-wide net of horizontal control and for study of time-variable markings; medium scale pictures for systematic planet-wide mapping; and large-scale pictures for special area studies and random views of the Martian surface at high resolution.

In addition to the 1:5,000,000 series, many special purpose maps are being prepared, including small maps of the entire planet, a 16-inch globe, and several maps at 1:1,000,000 and 1:250,000 scales. Maps at scales of 1:1,000,000 or larger are drawn on tranverse Mercator projections.

CARTOGRAPHIC PRODUCTS

The cartographic atlas of Mars is expected to be complete by the landings of the unmanned Viking spacecraft in 1976. This schedule, coupled with the urgent requirement for base maps

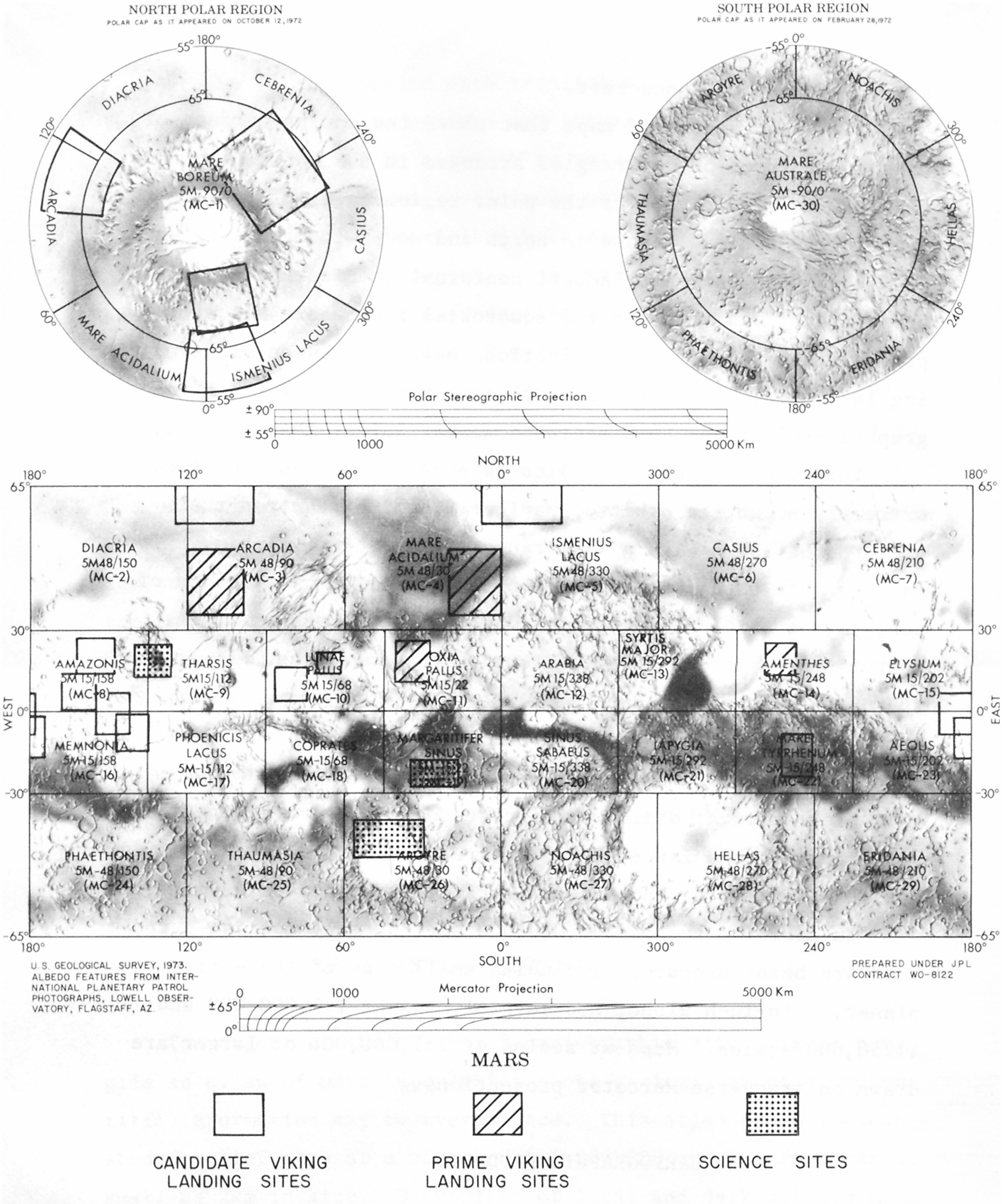

Figure 1.--Layout of quadrangles on Mars. The 1:5,000,000 quadrangles are identified by names proposed to the International Astronomical Union.

for geologic compilation, requires that mapping phases normally performed sequentially be conducted simultaneously. This schedule has also led to the production of a large number of preliminary maps and mosaics compiled for evaluation of the data-gathering sequence during mission operations, and to support the beginnings of geologic analysis that eventually will result in a geologic atlas of Mars. Many of the preliminary mosaics and maps were reproduced in numbers sufficient only for distribution to members of the MM '71 Television Team. Much of the preliminary material has been superceded by later generations of materials, and although released in the U. S. Geological Survey open files, is not recommended for further use in scientific analysis. Figures 2 and 3 are samples of these early mosaics. The following materials are likely to have continuing use:

1) Semicontrolled mosaics. These are mosaics of mapping pictures that have been transformed to the appropriate map projections by computer. The pictures were joined for best visible fit to each other and to the latest primary control net available at the time the mosaics were made. (Figure 4)

2) Controlled mosaics. The pictures used here are duplicates of the pictures used in the semicontrolled mosaics. Correct relative placement of a set of selected points in areas where pictures overlap has been computed by least squares adjustment of their photo coordinates. This secondary net is then adjusted to fit the primary control net. In areas of dense primary control, the semicontrolled mosaics have been found to be as accurate as the controlled mosaics. Controlled mosaics are therefore being made only in those areas where primary controls are sparse over the area of the mosaic. This includes all mosaics at scales larger than 1:5,000,000. (Figure 5)

3) Shaded relief maps. These are final cartographic products of the Mariner 9 mission. They will be published by the U. S. Geological Survey. A shaded relief map is a drawing made with an airbrush by a cartographer, utilizing techniques described

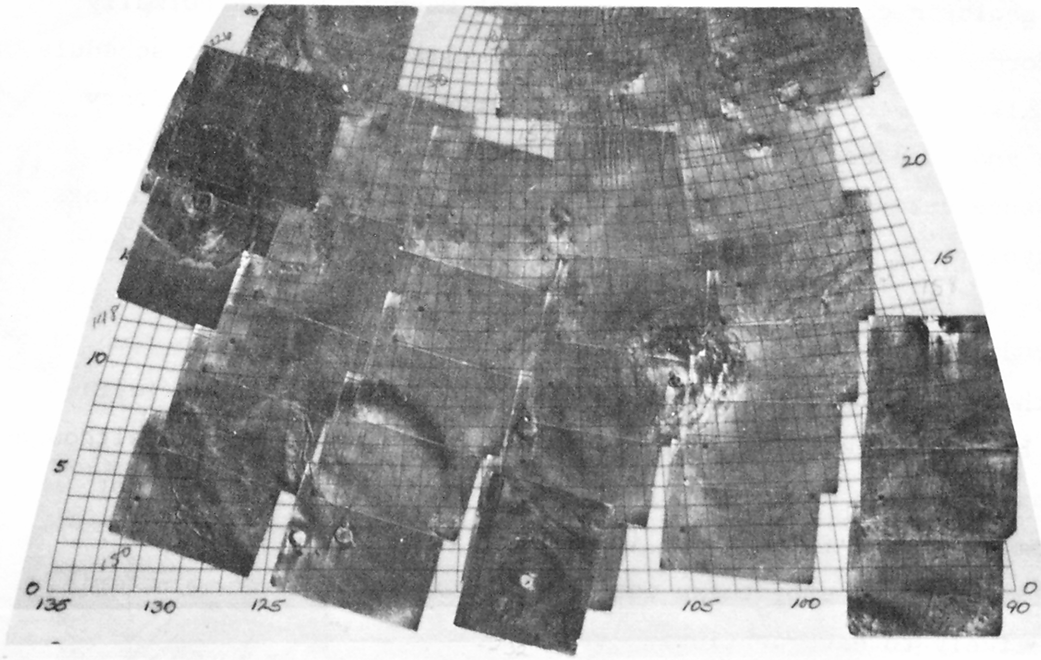

Figure 2. --"Variable-scale" mosaic of the Tharsis (MC 9) quadrangle of Mars. "Variable-scale" mosaics were made during the Mariner 9 mission with contact prints from the 70mm video film recorder at JPL. High-pass filtered and vertical AGC enhancements were used in this mosaic. Horizontal placement of pictures was made solely with reference to picture footprints predicted in sequence planning (the POGASIS program). These mosaics were the earliest cartographic products from Mariner 9, and were used to review existing photo coverage and to plan subsequent data gathering.

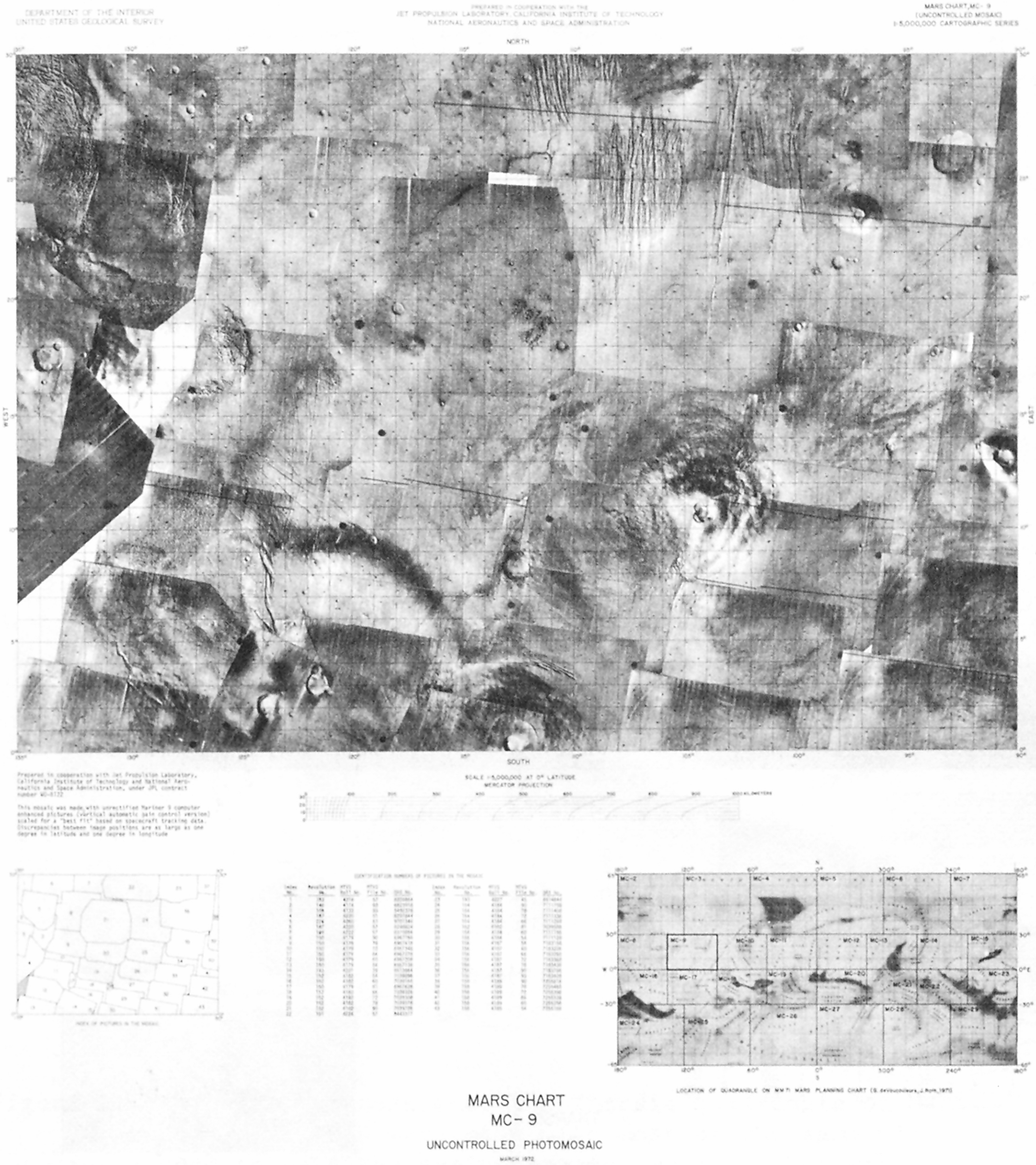

Figure 3. -- Uncontrolled mosaic of the Tharsis quadrangle of Mars. "Uncontrolled" mosaics were made with enlargements of the same pictures used for the "variable-scale" mosaics. The high-pass filtered versions were used. The pictures were enlarged to match approximately their "footprint" sizes on standard map projections, but were not geometrically transformed to fit those projections. Horizontal placement of pictures was done solely with reference to spacecraft tracking data (Supplementary Engineering Data Record, or SEDR). These mosaics were made for preliminary scientific analysis of Mariner 9 data before the pictures could be processed and transformed in more sophisticated ways.

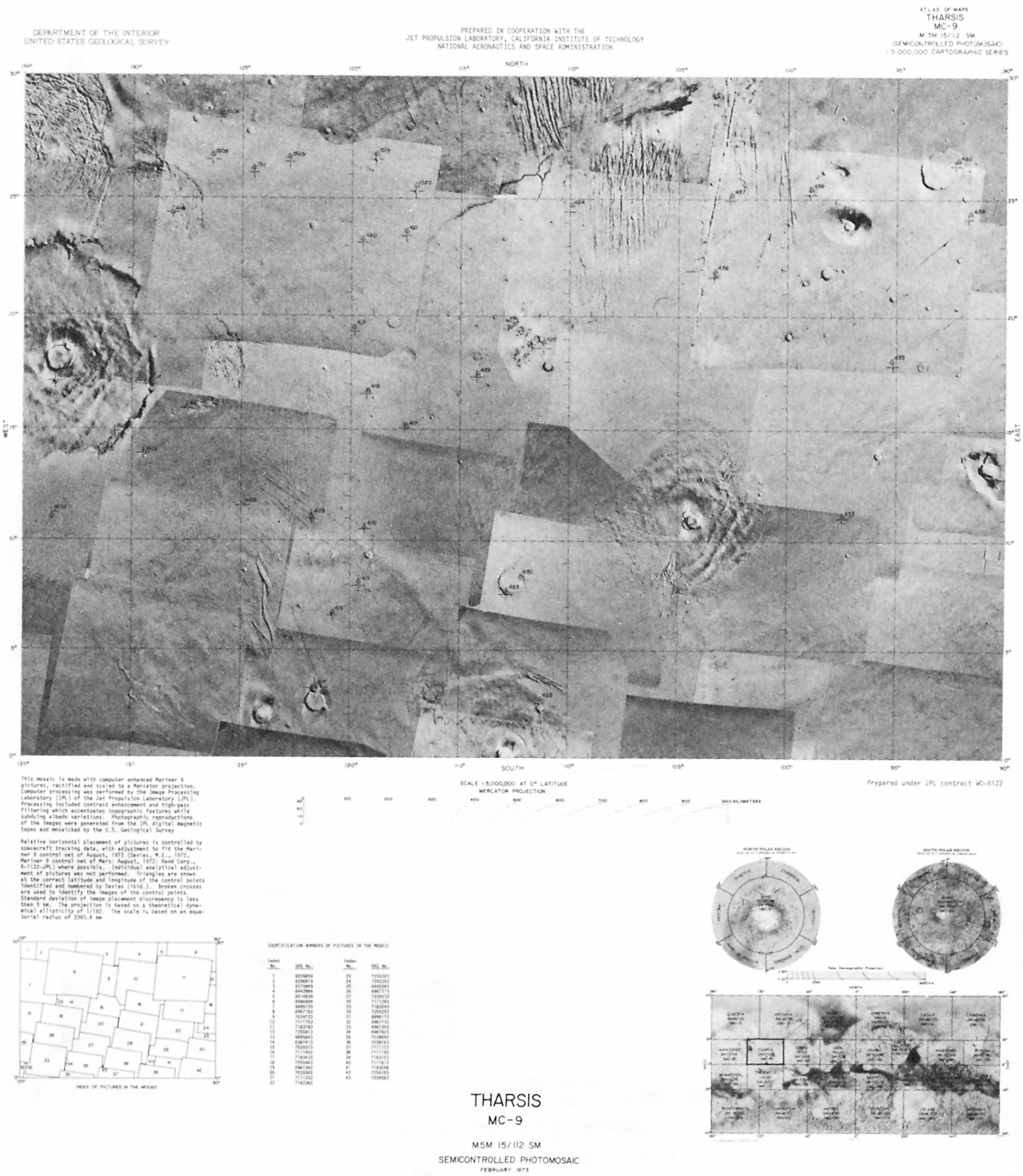

Figure 4. -- Semicontrolled mosaic of the Tharsis quadrangle of Mars. "Semicontrolled" mosaics were made with enhanced pictures geometrically transformed to the appropriate map projections. Horizontal placement was controlled by available preliminary primary control points. Where these points were not available, images on adjacent pictures were matched and adjusted to fit spacecraft tracking data (SEDR). These mosaics were made for detailed scientific analysis as an intermediate stage prior to completion of final maps.

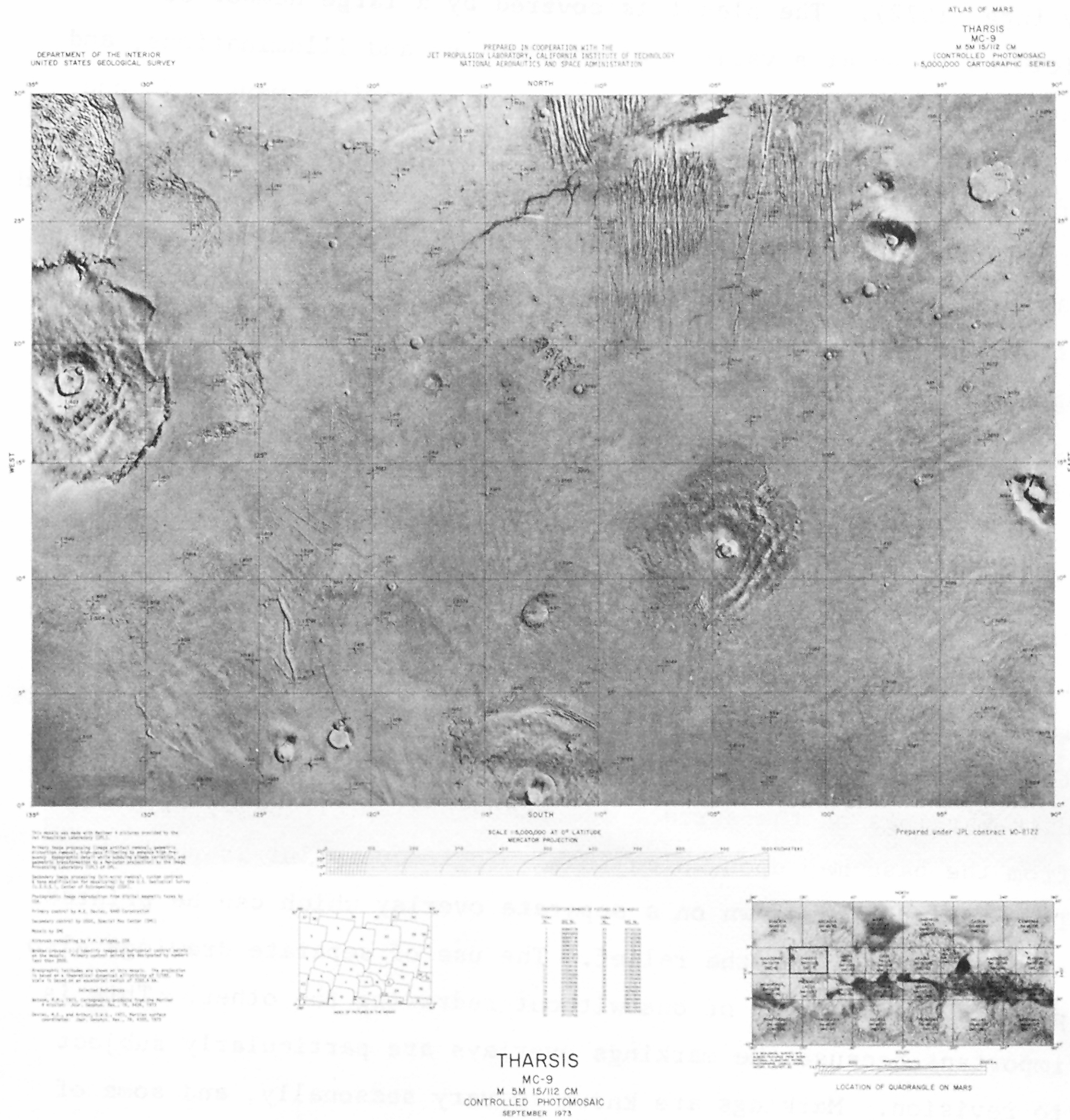

Figure 5. -- Controlled mosaic of the Tharsis quadrangle of Mars. "Controlled" mosaics were made with most of the same pictures used to make the semicontrolled mosaics, but with some custom processing of problem frames. Horizontal placement of the pictures is controlled by computed positions of selected image points that lie in areas of overlap between mapping frames. This net is tied to the primary control net. These mosaics are made when the semicontrolled mosaics are not accurate enough to serve as final base mosaics. This condition occurs in areas of sparse primary control, and in areas where 1:1,000,000 and 1:250,000 maps are to be made.

by Inge (1972). The planet is covered by a large number of pictures taken at a variety of resolutions and illuminations, and each picture has been computer enhanced in various ways. No one picture or mosaic shows all available information about the surface of the planet. Given a suitable geometric base such as a controlled or semicontrolled mosaic, however, highly skilled cartographers can add these details through examination of all available image data. Subjective interpretation is carefully avoided by the cartographer, and his work is carefully reviewed by geologic mappers and other persons familiar with the area. The resulting map shows all features visible on any of the pictures, with exaggerated contrast but with correct relative emphasis. (Figure 6)

4) Overlays of surface markings. Since a primary function of the maps is to serve as bases for colored geologic overprints, it is important that base map tones not distort overprint colors. The television pictures contain much tone variation not related to topography, whereas the airbrush drawing does not. Light and dark markings on the surface are therefore specifically excluded from the base map upon which the geologic overprint is published. The markings are drawn on a separate overlay which can be printed as a composite with the relief. The use of separate drawings also permits the revision of one without redrawing the other. This is important because the markings overlays are particularly subject to revision. Markings are known to vary seasonally, and some of those observed by Mariner 9 are difficult to correlate precisely with those observed telescopically from Earth. (Figure 7) The drawings of relief and markings can be superimposed to form the composite of figure 8.

5) Contour overlays. The topography of the Martian surface is measured in a variety of ways (See Bibliography), most of them highly unorthodox by terrestrial standards. Each method has its own datum and its own level of precision and reliability. They include Earth-based radar, ultraviolet and infrared spectroscopy (pressure mapping), spacecraft occultation, and stereoscopy

Figure 6. -- Shaded relief map of the Tharsis quadrangle of Mars. This version, from which all non-topographic image information has been excluded, is a suitable base for colored geologic overprints. The illustrator has examined all available computer processed versions of all Mariner 9 pictures of the area, and added many details not visible in the mosaic. Contrast is exaggerated, but relative contrast values have been carefully preserved.

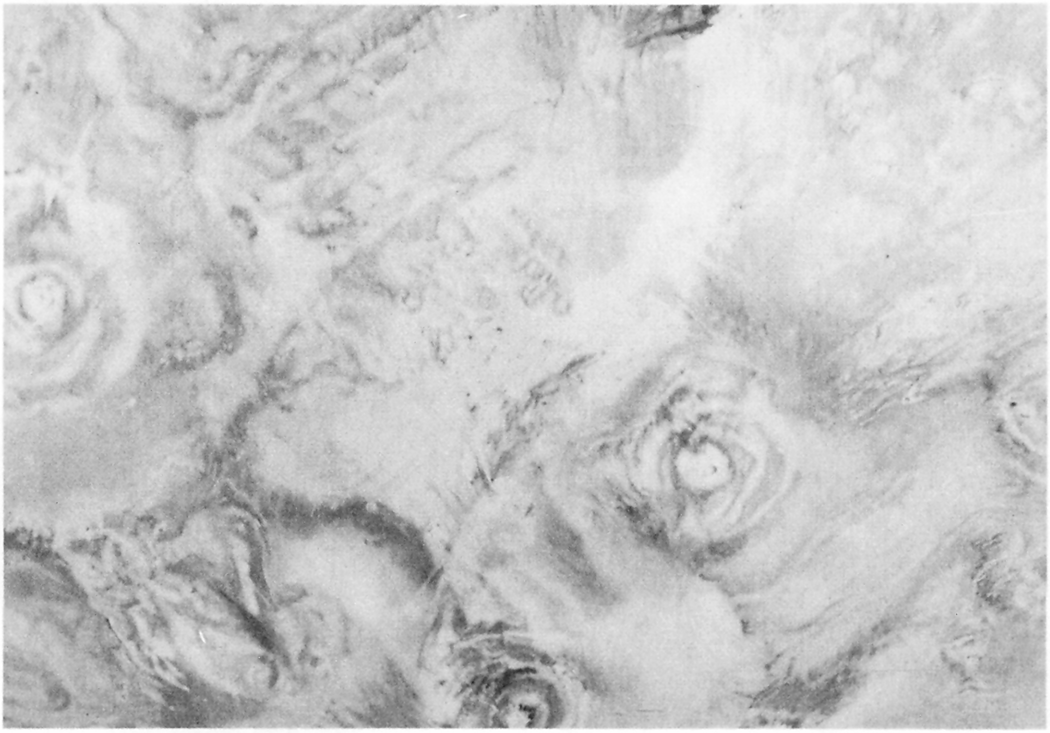

Figure 7. -- Light and dark markings on the Tharsis quadrangle. These markings are taken solely from Mariner 9 pictures, and differ somewhat from earth-based observation of the area. This difference is caused by wind generated patterns altered by the great dust storm of 1971, and by the vast increase in resolution over the Earth-based observations. Separating drawings of markings from drawings of topography permits independent revision of one without modification of the other.

Figure 8. -- Composite print of topography and markings on the Tharsis quadrangle.

with convergent B-camera pictures. Discrepancies between these data sources must be computed with respect to a reference geoid (which must in turn be derived from the particular data set involved and from the celestial mechanics experiment), and then be reconciled by the appropriate principal investigators. The points are then plotted on the quadrangles at their correct latitude and longitude, and annotated with their adjusted elevation values. Final contour lines are compiled with reference to vertical control points and to ground shapes evident in the pictures. Contour intervals are large (on the order of 1km) and the contour lines serve primarily to show major high and low areas on the planet. Unlike most terrestrial contour maps, they cannot show detailed surface morphology. Only the shaded relief can do that. Stereoscopic photogrammetry is possible with a few Mariner 9 pictures. The photogrammetric measurements are added to the vertical control data set for the planet, and, when practical, are used to make contour maps of areas of special interest. In a few very small areas contour intervals as small as 100m are feasible.

MAP DESIGNATIONS

Each map that is either placed on open file or published formally is designated by the name of a conspicuous feature lying wholly or largely within its boundaries. Alphanumeric designators are also used for simplicity in filing and cataloging. The alphanumeric designation permits one to determine at a glance the scale of a map, its location on the planet, and the series. For example, the Tharsis quadrangle is designated M 5M 15/112. This code has the following meaning:

M	Mars
5M	Scale is 1:5,000,000 (250k is used for a scale of 1:250,000)

15/112 Latitude of center point is (+) 15 deg. and longitude is 112 deg.

This notation is followed by a letter code designating the type of product. For example, M 5M 15/112 SM refers to the semicontrolled mosaic of Tharsis, whereas M 5M 15/112 R refers to the shaded relief version of the same map. M 5M 15/112 RMC is the shaded relief map with markings and contour lines.

The 1:5,000,000 maps are also designated by arbitrary numbers from 1 to 30, prefixed by the letters MC (for "Mars Chart"). All three nomenclature systems are shown in figure 1.

FEATURE NOMENCLATURE

The only currently accepted names for Martian features are those applied to telescopically observed light and dark markings. Few of these markings relate in any definite way to the markings recorded by Mariner 9 cameras. The naming features on the new maps of Mars is the province of the International Astronomical Union (IAU), and is likely to involve much controversy. Many years will certainly pass before a final set of names will be agreed upon. In the meantime, many provisional feature names will be used on the maps.

IMAGE PROCESSING

Picture data from Mariner television cameras lend themselves to computer processing of various kinds. As received from the spacecraft, and prior to reconstitution as photographic images, the pictures are arrays of numbers specifying image point brightness. In the Mariner 9 mission, these arrays were modified mathematically for a variety of special purposes. Many versions of each picture were made routinely because:

1) Incoming data was processed as quickly as possible for preliminary analysis. Sophisticated processing could not be performed without falling behind the data acquistion rate. Preliminary enhancements were therefore done with minimum processing for mission operations use.
2) There is more information in the digital picture data than can be reproduced in a single photographic image. Even the more sophisticated processes applied to the pictures after mission operations may therefore require more than one kind of enhancement.

Figures 9 through 15 are examples of the various kinds of computer enhanced pictures that were routinely produced and used in Mars cartography with Mariner 9 pictures.

Custom processing of selected frames is often required for special purpose mapping because production processing of digital pictures results in some loss of image details. This loss was usually considered acceptable for 1:5,000,000 Mars mapping, but 1:1,000,000 maps must show all available image information to be useful. Much of the resolution loss resulting from geometric transformation can be avoided if the picture is transformed to a larger array of image points than the untransformed image array. This condition is illustrated in figure 14.

Occasionally, standard processing results in tone and contrast mismatch between overlapping pictures in a mosaic. This can be corrected by modifying the parameters used to enhance contrast in one or both of the pictures, and reprocessing the pictures.

A correction for variation of picture density caused by variation in solar illumination is required if surface albedo markings are to be portrayed accurately on maps. The ways in which Martian surface materials reflect light are not fully understood, but reasonable empirical models can be used for removing the gross effects of sun angle variation from a picture. Figure 15 is a small scale Mariner 9 picture that is uncorrected for sun angle variation. Figure 16 is the same picture with the

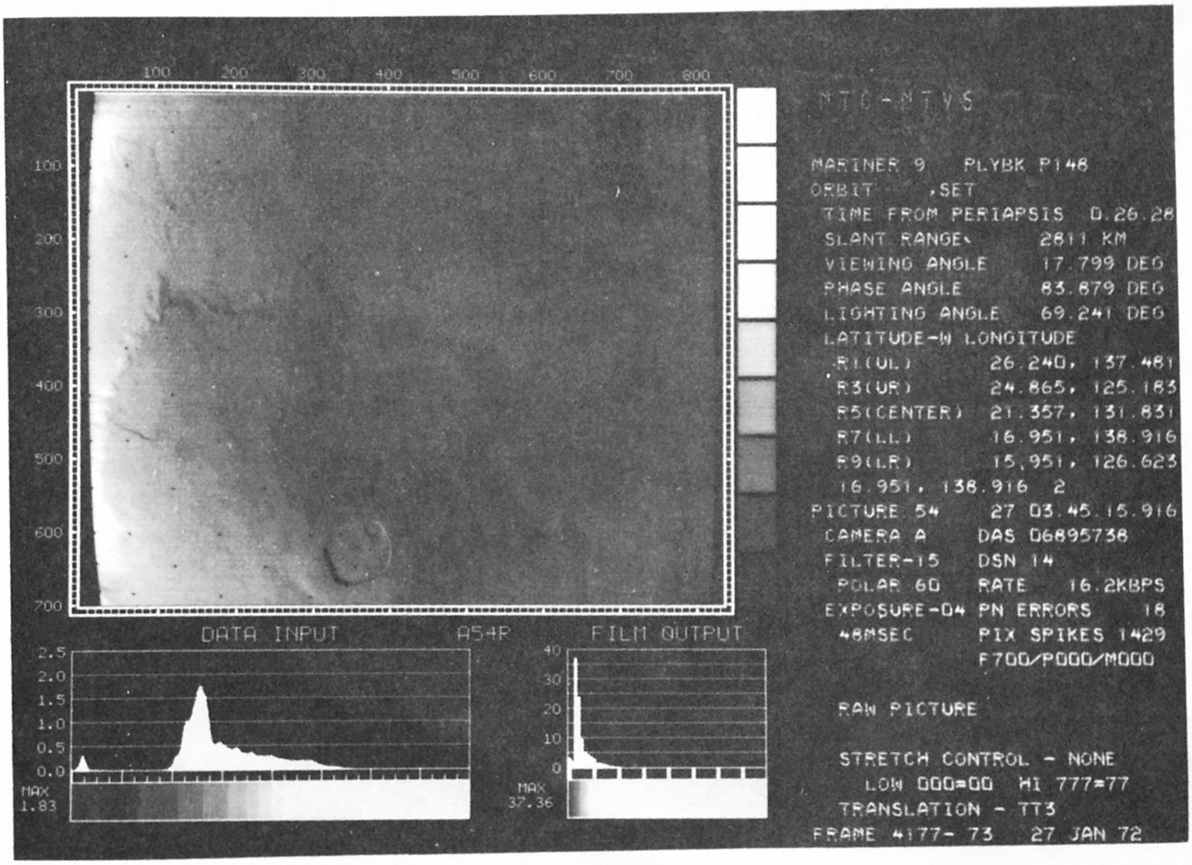

Figure 9. -- A "raw" picture received from Mariner 9. The image signal from the Martian surface occupies a narrow band within the very broad dynamic range of the camera. Furthermore, tonal variations caused by variable density across the video tube are greater than those in the target. An unenhanced "raw" image with such low contrast has virtually no cartographic utility. (DAS 6895738)

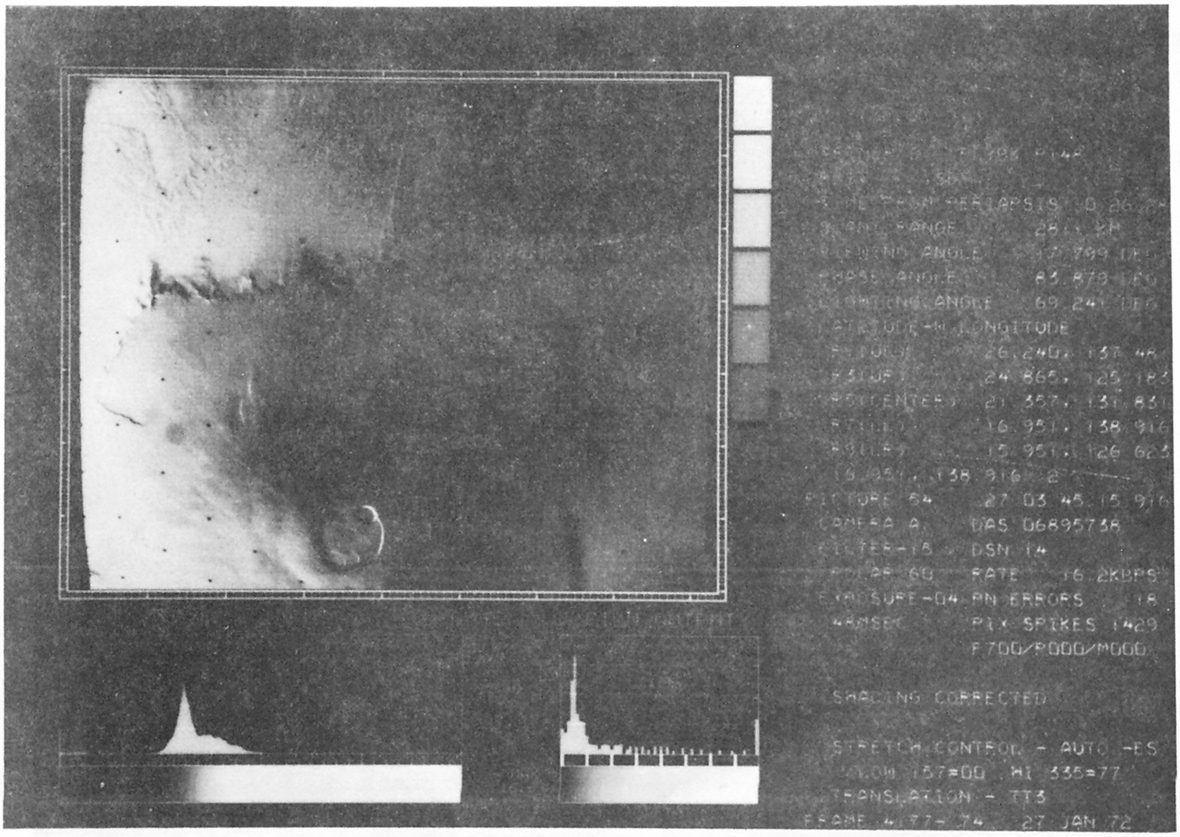

Figure 10. -- "Shading corrected" picture received from Mariner 9. The known shading characteristics of the Mariner 9 camera have been subtracted from the picture. The contrast of the picture was then enhanced to utilize the full tonal range available in the photographic print. Although pictures processed in this way show surface albedo markings undistorted by camera shading, variation in solar incidence angle across the scene usually causes shading that is much greater than these albedo variations. (DAS 6895738)

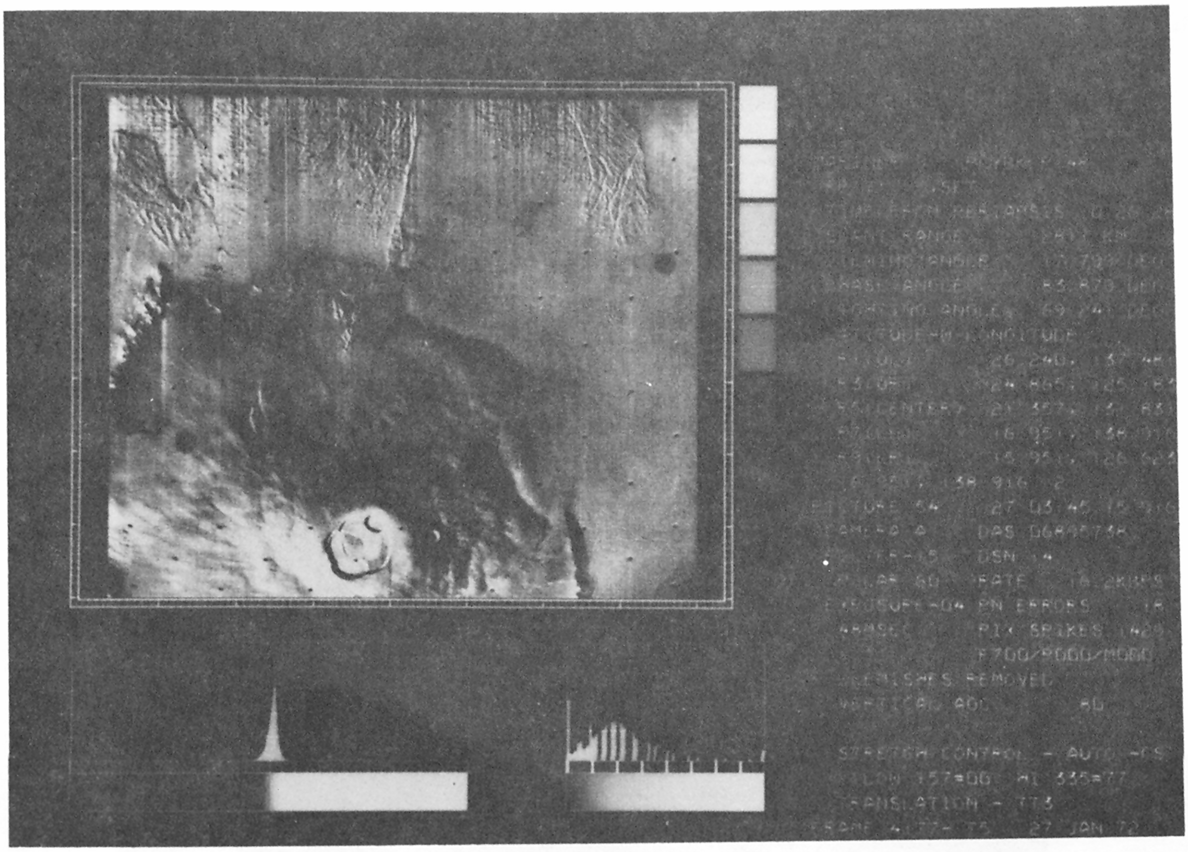

Figure 11. -- High-pass filtered picture. This kind of enhancement is generated by subtracting from the original picture a smoothed or averaged version of that picture. The smoothed version contains all low frequencies (shading effect, large albedo features, lighting variation). The resulting picture is the difference between the original and the smoothed versions and shows only small details. The direction along which the running average is taken may be either parallel or perpendicular to the television scan lines. In the jargon of the Mariner 9 mission, filtration parallel to the scan lines is termed "High-pass filtered", whereas filtration perpendicular to the lines is termed "Vertical AGC" (for Vertical Automatic Gain Control). High-pass filtration enhances small topographic features, while subduing or obliterating broad albedo markings. Vertical high-pass filtration subdues coherent noise patterns in the pictures, because these patterns tend to be perpendicular to the scan lines, and are enhanced by horizontal high-pass filtration. (DAS 6895738)

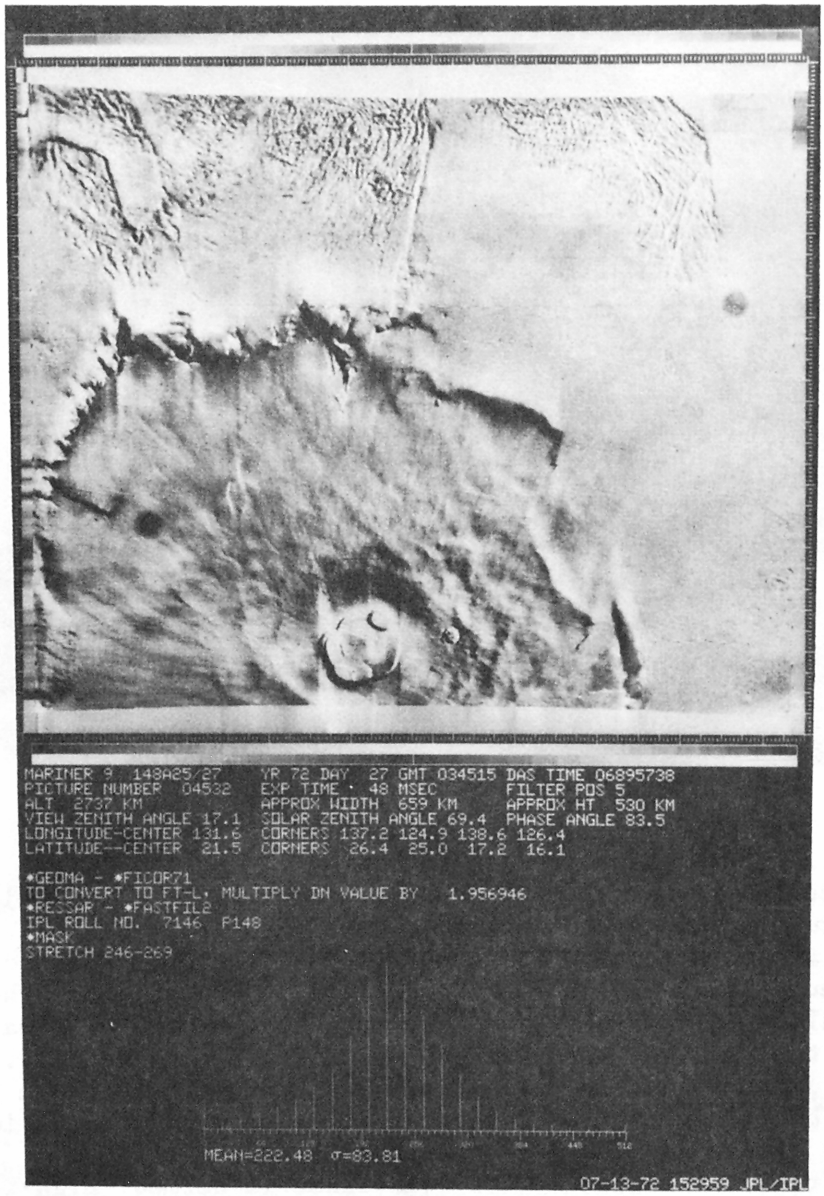

Figure 12. -- "Reduced Data Record" (RDR) picture. Reseau marks, geometric distortions and camera shading have been removed from these pictures and the contrast enhanced. The RDR processing was intended to produce optimum enhancement of pictures for general purpose interpretation. (DAS 6895738)

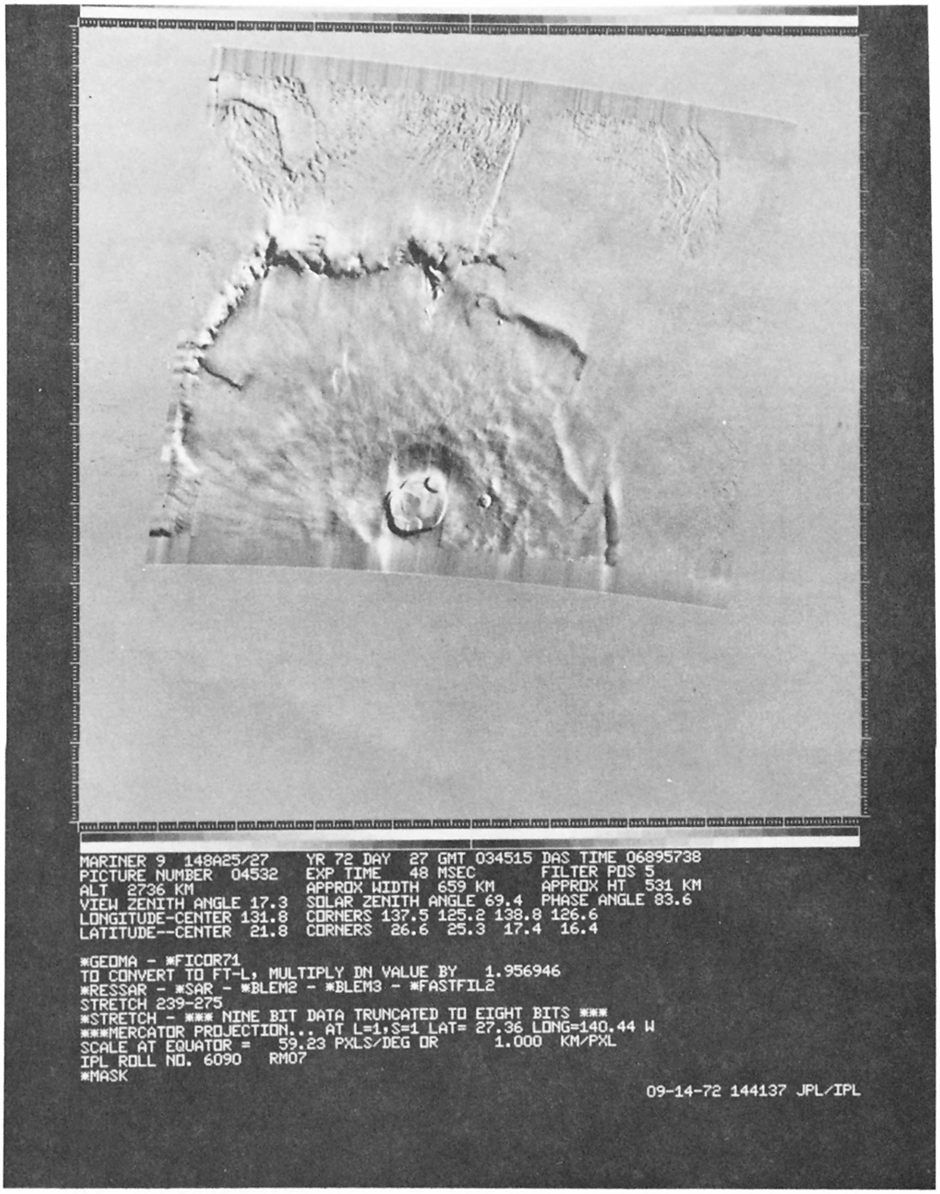

Figure 13. -- Map projection processing. The RDR pictures were high-pass filtered and geometrically transformed to a Mercator, Lambert conformal, or Polar stereographic projection, as appropriate. The transformed pictures were intended primarily for making mosaics. The final detail is degraded as a result of the geometric processing because individual elements are averaged in generating the transformed output. (DAS 6895738)

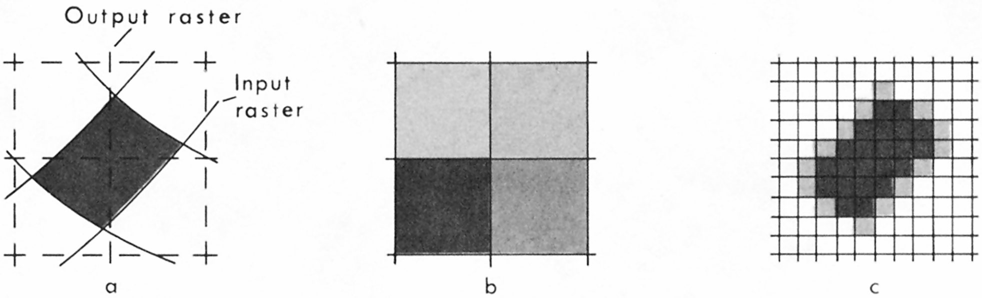

Figure 14a. -- The dark area represents the actual shape that should be assumed by a single picture element in a hypothetical transformation.

14b. -- The picture element of 14 is represented by four picture elements in the transformation array. The shape and density of the original picture element is lost.

14c. -- The picture element of 14 is represented by many picture elements in the transformation array. Its shape and density are diffused, but not lost.

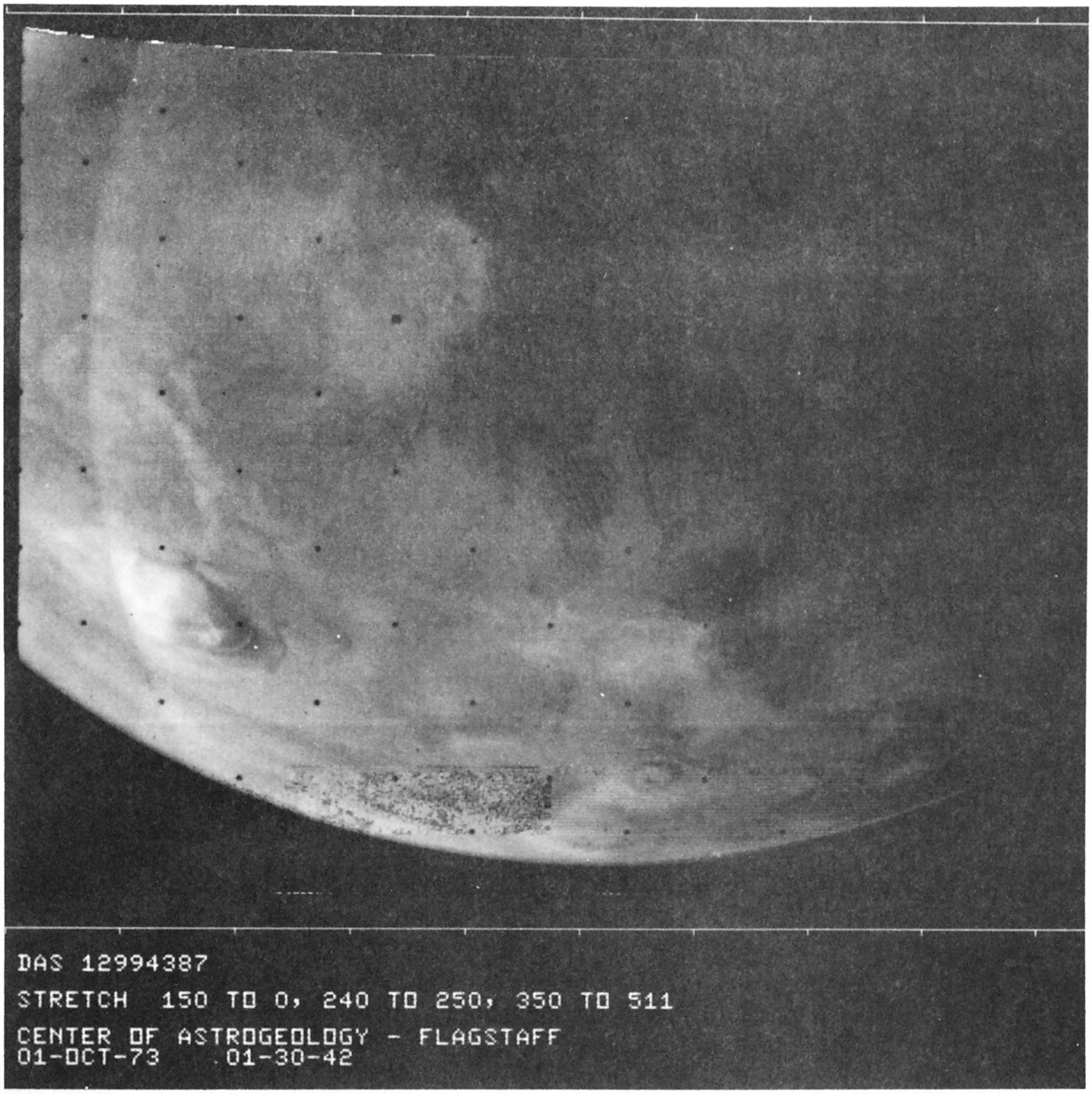

Figure 15. -- "Shading-corrected" version of a Mariner 9 picture. The wide variation in illumination between the sunlit limb of Mars and the terminator obscures the surface mottling. (DAS 12994387)

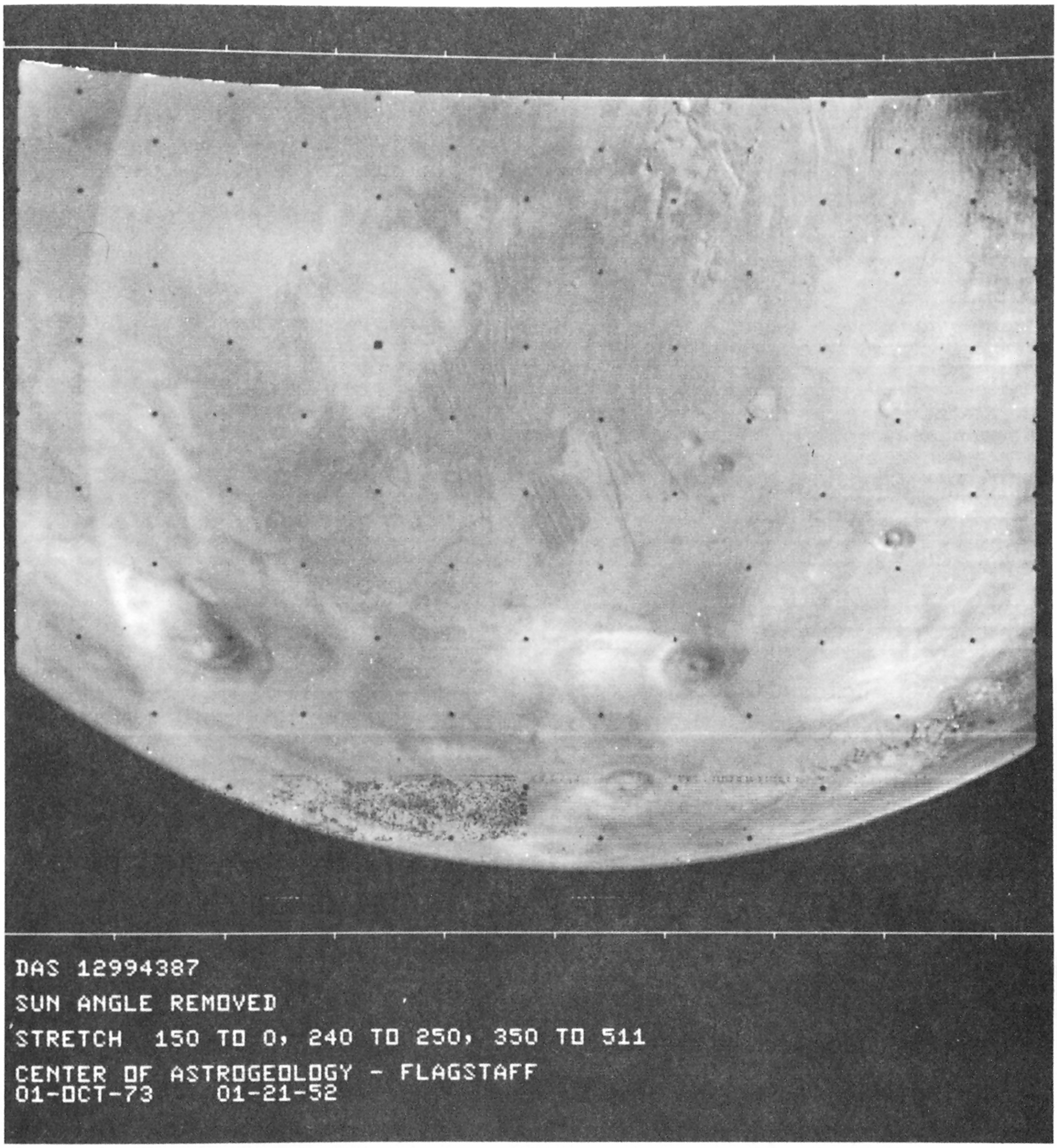

Figure 16. -- "Sun-angle corrected" version of the picture in fig. 7.

correction made.

AIRBRUSH ENCHANCEMENT

An essential stage in television cartography is performed with a tiny spraygun called an airbrush. This stage is required because it is not economically feasible to perform certain important processing functions in a computer. These functions include:

1) eliminating distracting artifacts (edge effects, etc.) in mosaics
2) compositing all available image data into a single pictorial representation of the planetary surface
3) separating relief from light and dark markings, so that colored geologic overprints may be superimposed without color distortion caused by tonal variation in the base map

Simple airbrush enhancement of mosaics is a useful and inexpensive technique for cosmetic improvement of mosaics. Mosaic artifacts can be reduced, and image enhancement can be performed, although image enhancement if carried out in detail, quickly becomes as expensive as totally redrawing the map with the airbrush. Figures 17 through 20 illustrate the effect of the airbrush enhancement technique.

Enhancing mosaics is a means of providing interim cartographic products quickly, before the final maps are complete. The final maps are shaded relief drawings in which all the processing functions listed above are performed. Figures 6 through 8, and figure 22 are examples of airbrush drawings.

An airbrush drawing is a marked improvement over a mosaic because it incorporates all information visible on all enhancements of all pictures of a given area. Figures 21 and 22 show the difference between a mosaic and an airbrush drawing.

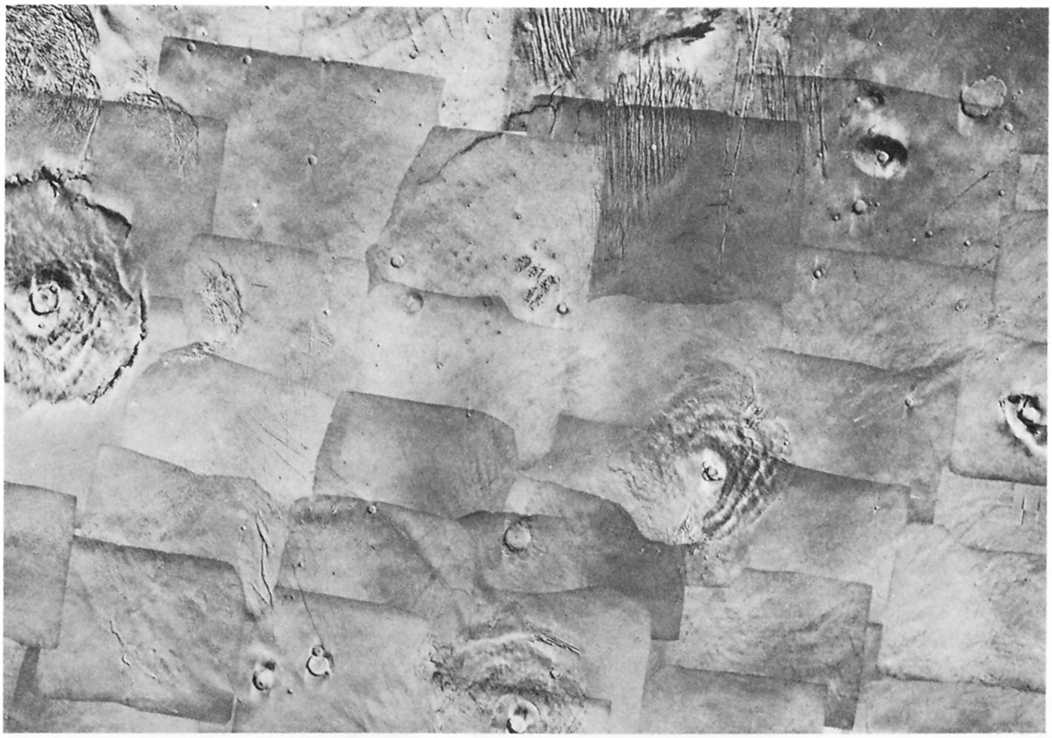

Figure 17. -- Unretouched photomosaic of the Tharsis Quadrangle of Mars.

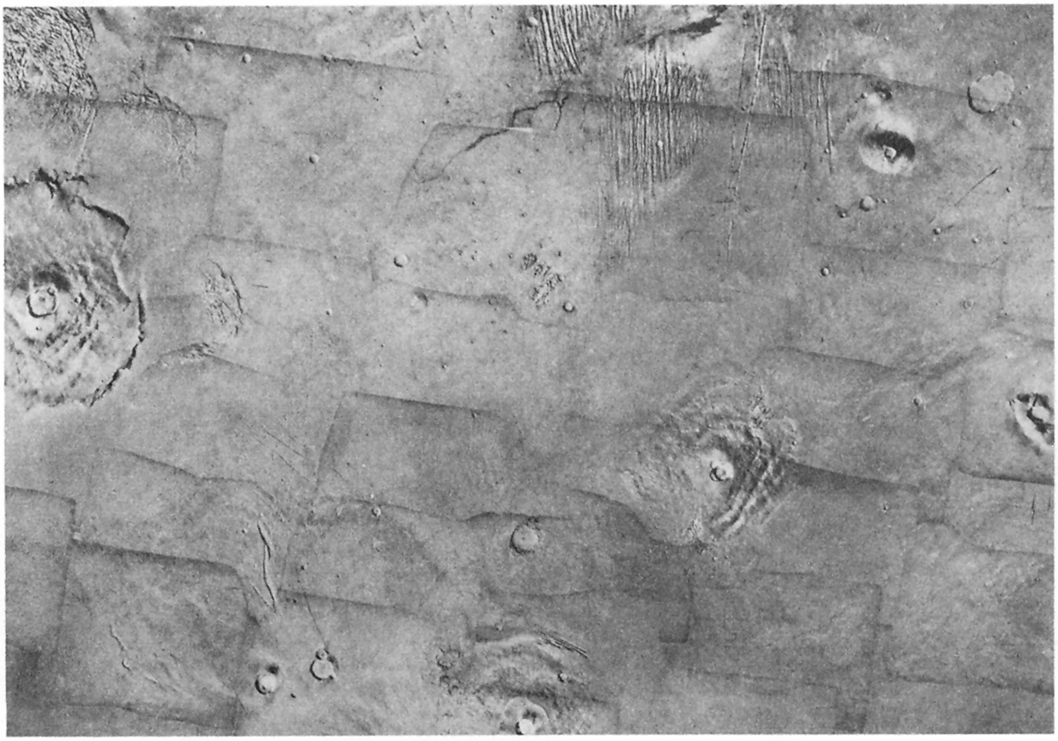

Figure 18. -- First stage of retouching. Light toned areas on the mosaic have been darkened with the airbrush.

Figure 19. -- Negative copy of the first stage of retouching. Light toned areas on the negative are darkened with the airbrush.

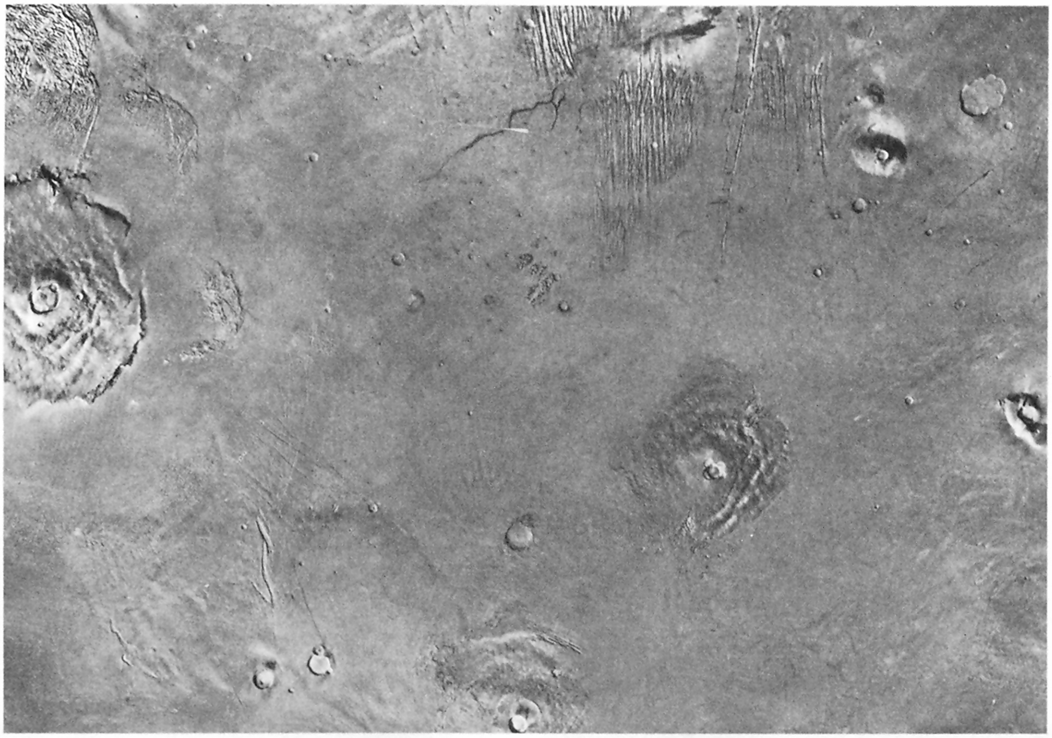

Figure 20. -- Final retouched copy of the mosaic with uniform tone throughout.

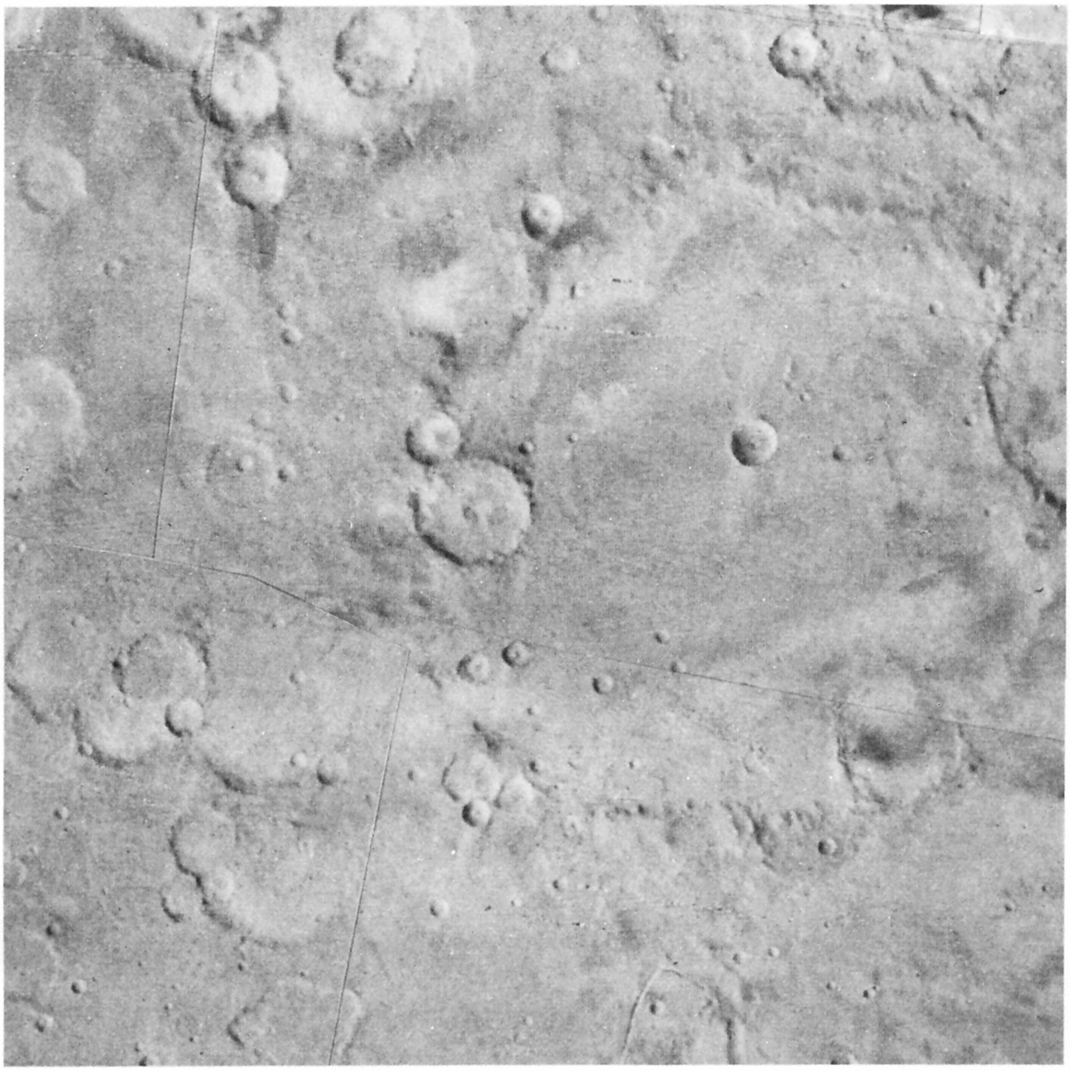

Figure 21. -- A section of the mosaic of the Syrtis Major quadrangle of Mars. The best available pictures were used, but even they show only part of the surface information available on other pictures. For example, computer processing that enhanced topography in the pictures subdued, but did not eliminate, surface markings and non-topographic tonal variation. The mosaic is not a suitable base for colored geologic overprints because the colors are distorted by variation on the base tone.

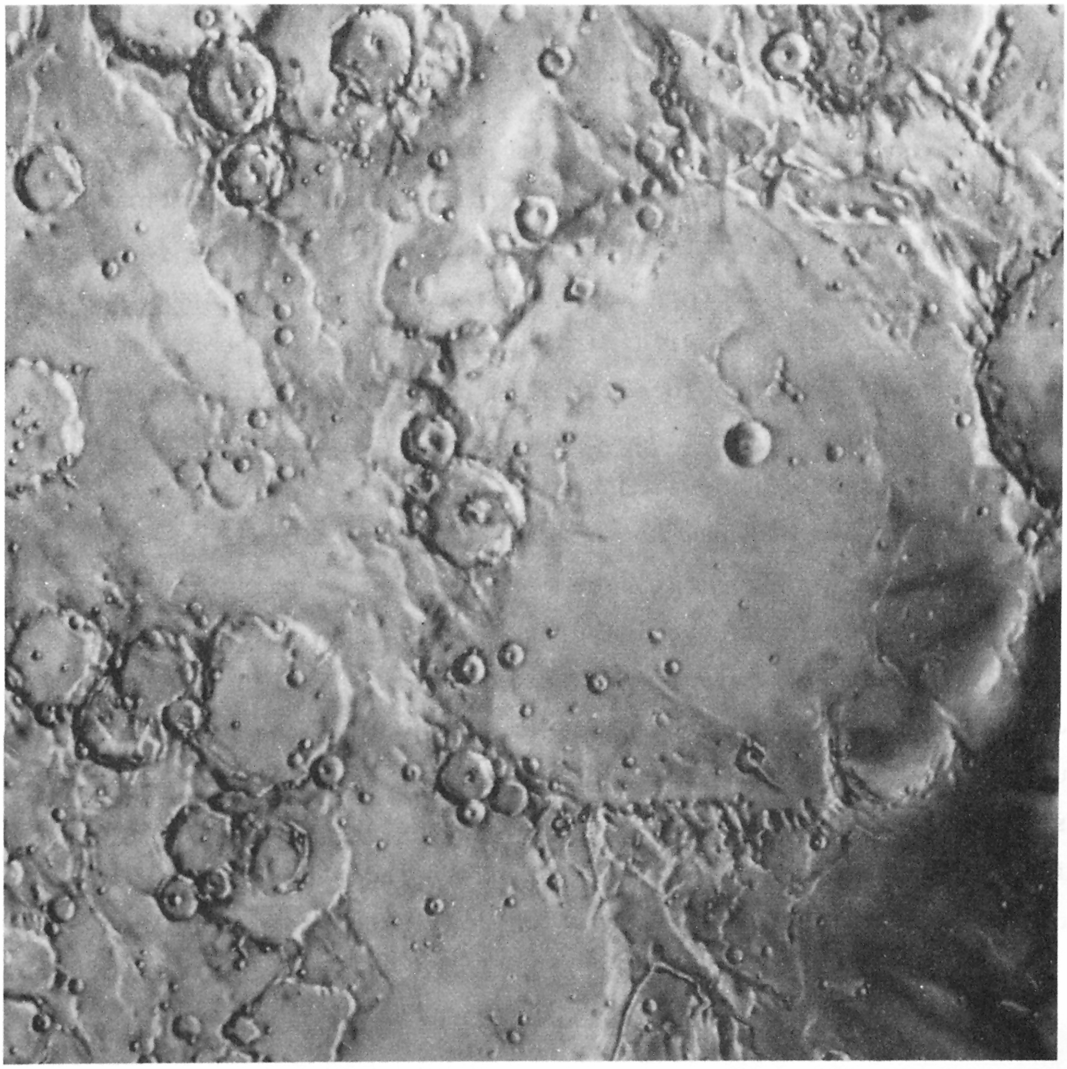

Figure 22. -- A section of an airbrush drawing of the area of the Syrtis Major quadrangle shown in fig. 21. Many details not visible in the mosaic have been added through examination of all available pictures of the area.

CONCLUSIONS

The combination of traditional mapping and mosaicking methods with computer processing of digital images and airbrush enhancement is a new cartographic technique and one that is applicable to all planetary mapping with Mariner type spacecraft. The cartography of Mars with Mariner 9 pictures has been the proving ground for the processes illustrated here, but the methods are under continuing development, particularly in the area of computer processing. Mosaics have been assembled entirely within the computer; the day may not be far off when this will be done routinely. We may expect to see more and more sophisticated picture enhancement in the computer.

All phases of television cartography require human interaction. Even in computer processing, few operations are fully automated, nor are they likely to be in the near future. What is probable is that cartographers, mosaickers and illustrators will begin spending less and less time at their drafting tables and more and more time at television display consoles of computers.

ACKNOWLEDGEMENTS

Initial processing of Mariner 9 pictures was done by personnel of the Jet Propulsion Laboratory (JPL) with the Mission Test Computer (MTC), Mission Test and Video System (MTVS). This organization produced figures 9 through 11, figure 15, and the pictures in figures 2 and 3.

The RDR, map projection processing, and much of the custom processing of Mariner 9 pictures was done by the Image Processing Laboratory (IPL) of JPL. This organization produced figures 12 and 13, the pictures in figures 4 and 5, and the pictures in figure 21.

Further custom processing and substantial contributions to

the techniques of image processing for television cartography were made by L. A. Soderblom and the image processing unit at the U. S. Geological Survey, Center of Astrogeology. This group produced the picture in figure 16.

The Illustrations Unit at the Center of Astrogeology is responsible for the final formatting and reproduction for limited distribution of map products. The key personnel in this effort were R. D. Carroll and W. E. Miller.

The Cartographic Unit at the Center of Astrogeology, under the direction of the author, is responsible for compilation of the map products illustrated here, with the exception of the controlled mosaic of figure 5. Projection computation and plotting were done by K. B. Larson. Mosaics were made by V.S. Reed, R. L. Tyner, and V. C. Cheeseman. The airbrush touchup and drawings were done by P. M. Bridges.

Personnel of the U. S. Geological Survey's Special Map Center at Reston, Va. compiled the controlled mosaic of figures 5, and 17 through 20.

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