UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

INTERAGENCY REPORT: ASTROGEOLOGY 58

Television Cartography

by

R. M. Batson

September 1973

Prepared under JPL Contract WO-8122

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

Prepared by the Geological Survey for the National Aeronautics and Space Administration

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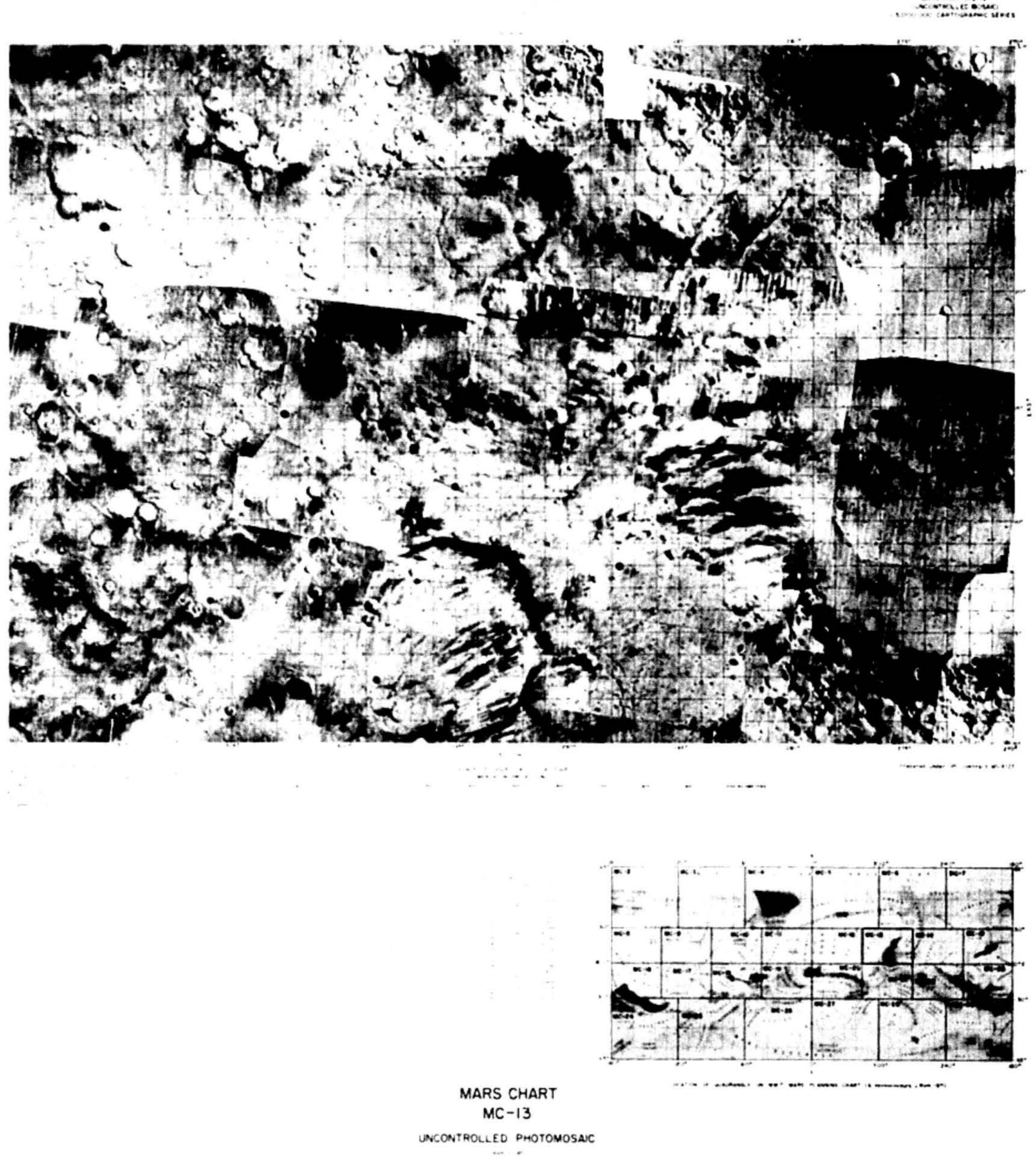

Figure 10b.--Uncontrolled mosaic of the Syrtis Major quadrangle of Mars.

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INTRODUCTION

The purpose of this paper is to illustrate the processing of digital television pictures into base maps. 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 in conjunction with traditional ones for television cartography. 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 a number of people (not including the author), 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 of 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.

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 acquisition 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 1 through 7 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 fig. 6.

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 7 is a small scale Mariner 9 picture that is uncorrected for sun angle variation. Figure 8 is the same picture with the correction made.

MOSAICS

Four generations of mosaics of Mariner 9 pictures were made to satisfy the requirements of mission operations sequence anal-

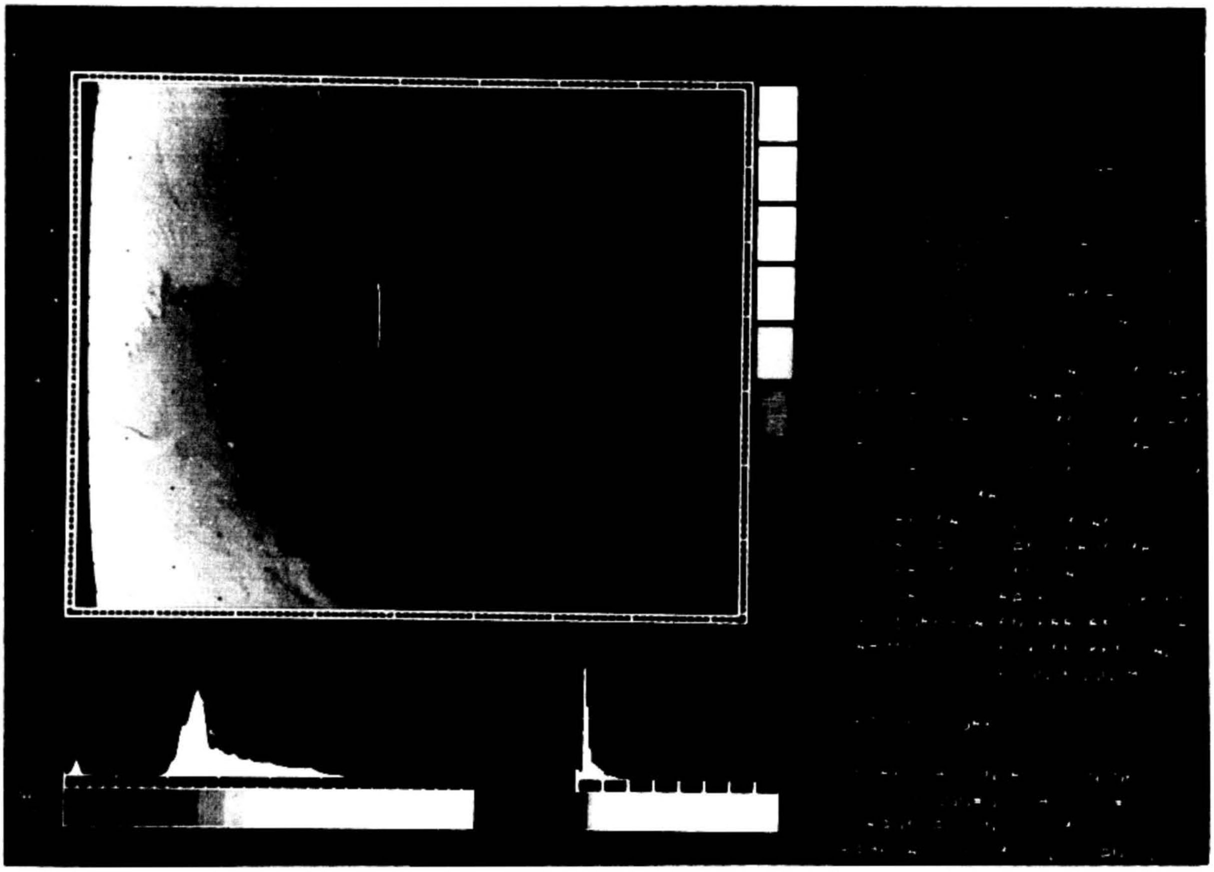

Figure 1.--A "raw" picture received from Mariner 9. The image signal from the Martian surface occupies a narrow band within the very broad dynamic range of the camera. Furthermore, tonal variations caused by variable density across the video tube are greater than those in the target. An unenhanced "raw" image with such low contrast has virtually no cartographic utility. (Picture DAS 6895738)

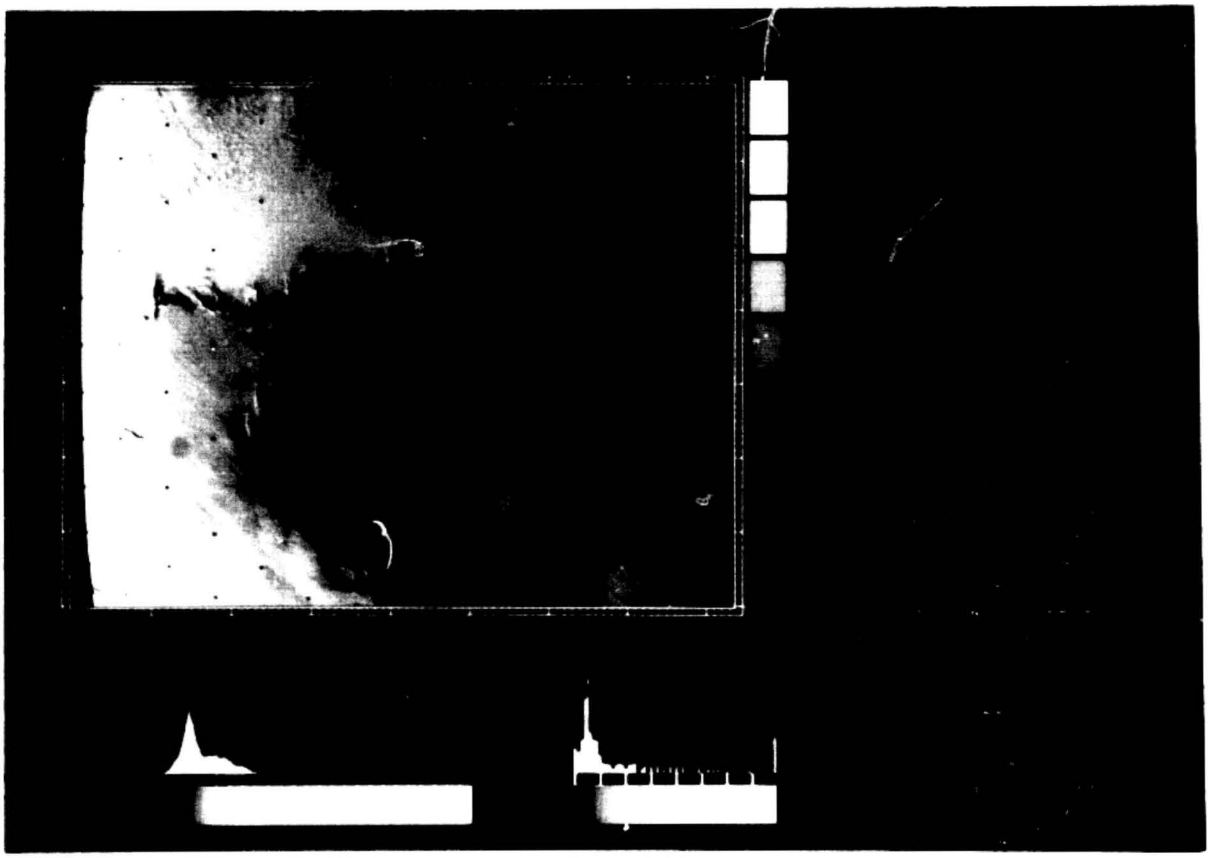

Figure 2.--"Shading corrected" picture received from Mariner 9. The known shading characteristics of the Mariner 9 camera have been subtracted from the picture. The contrast of the picture was then enhanced to utilize the full tonal range available in the photographic print. Although pictures processed 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 3.--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 subdued coherent noise patterns in the pictures, because these patterns tended to be perpendicular to the scan lines, and were enhanced by horizontal high-pass filtration. (DAS 6895738)

Figure 4.--"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)

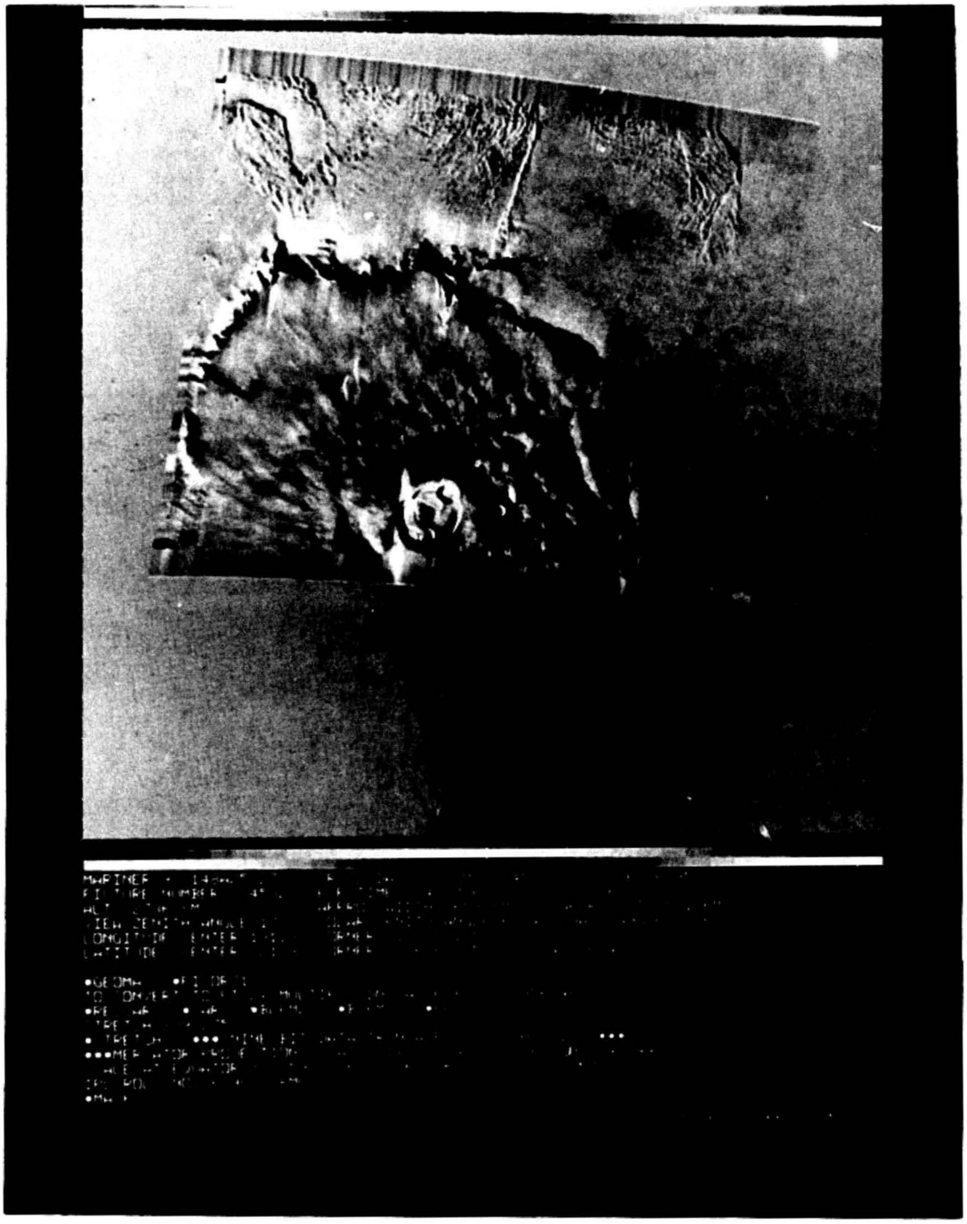

Figure 5.--Map projection processing. The RDR pictures were high-pass filtered and geometrically transformed to a Mercator, Lambert conformal, or Polar stereographic projection, as appropriate. The transformed pictures were intended primarily for making mosaics. The fine detail is degraded as a result of the geometric processing because individual elements are averaged in generating the transformed output. (DAS 6895738)

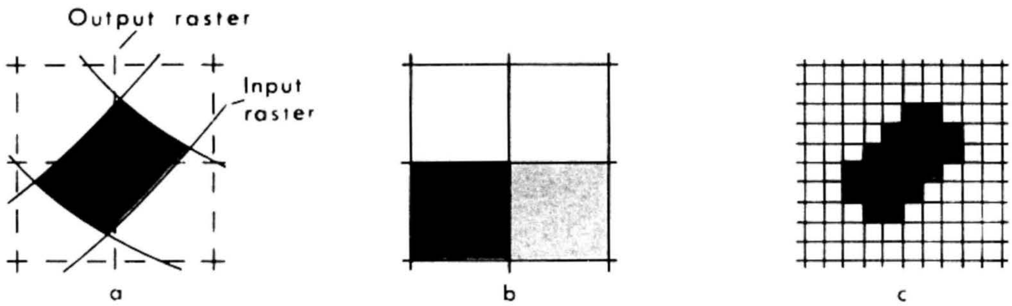

Figure 6a.--The dark area represents the actual shape that should be assumed by a single picture element in a hypothetical transformation.

6b.--The picture element of 6a is represented by four picture elements in the transformation array. The shape and density of the original picture element is lost.

6c.--The picture element of 6a is represented by many picture elements in the transformation array. Its shape and density is diffused, but not lost.

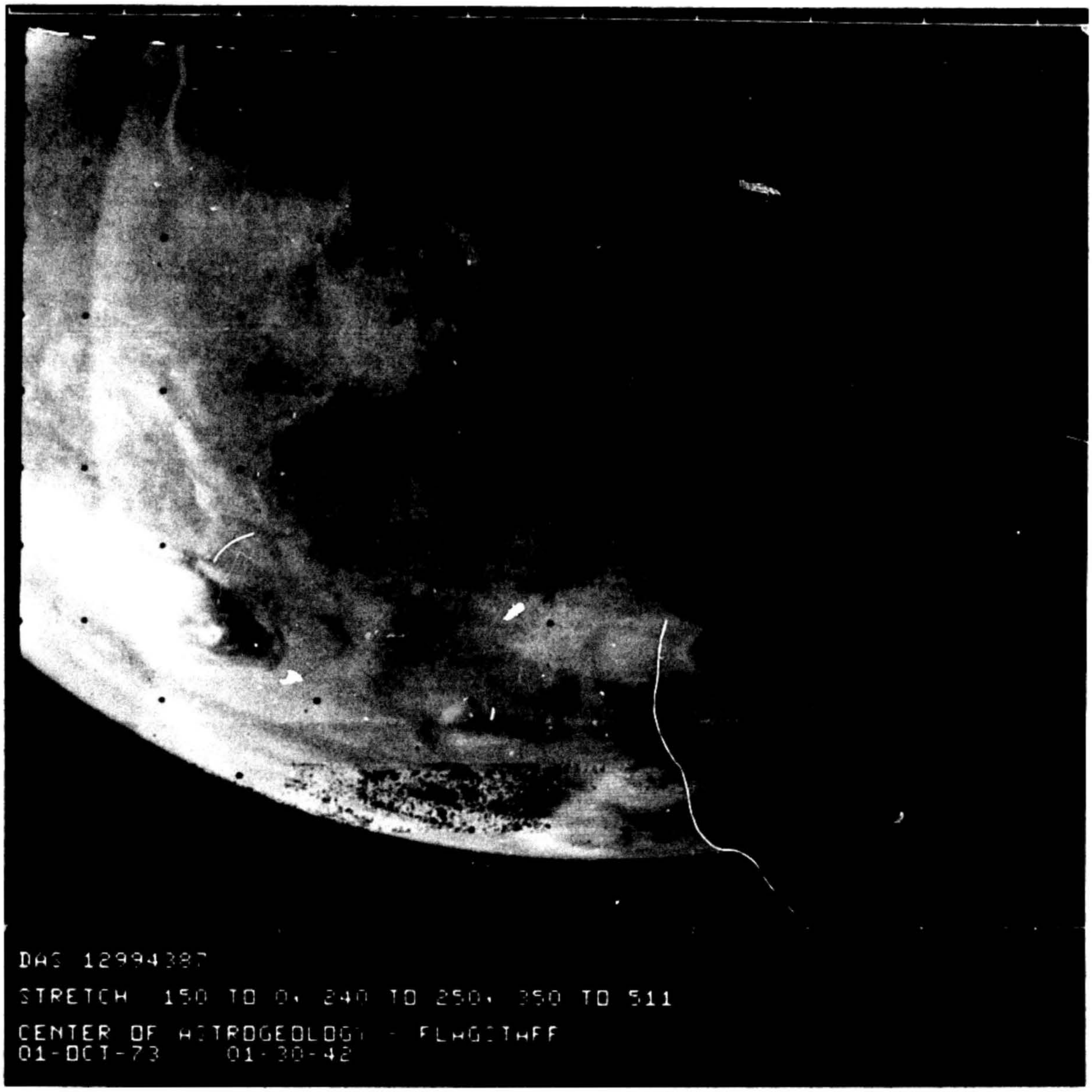

Figure 7.--"Shading-corrected" version of a Mariner 9 picture. The wide variation in illumination between the sunlit limb of Mars and the terminator obscures the surface mottling. (DAS 12994387)

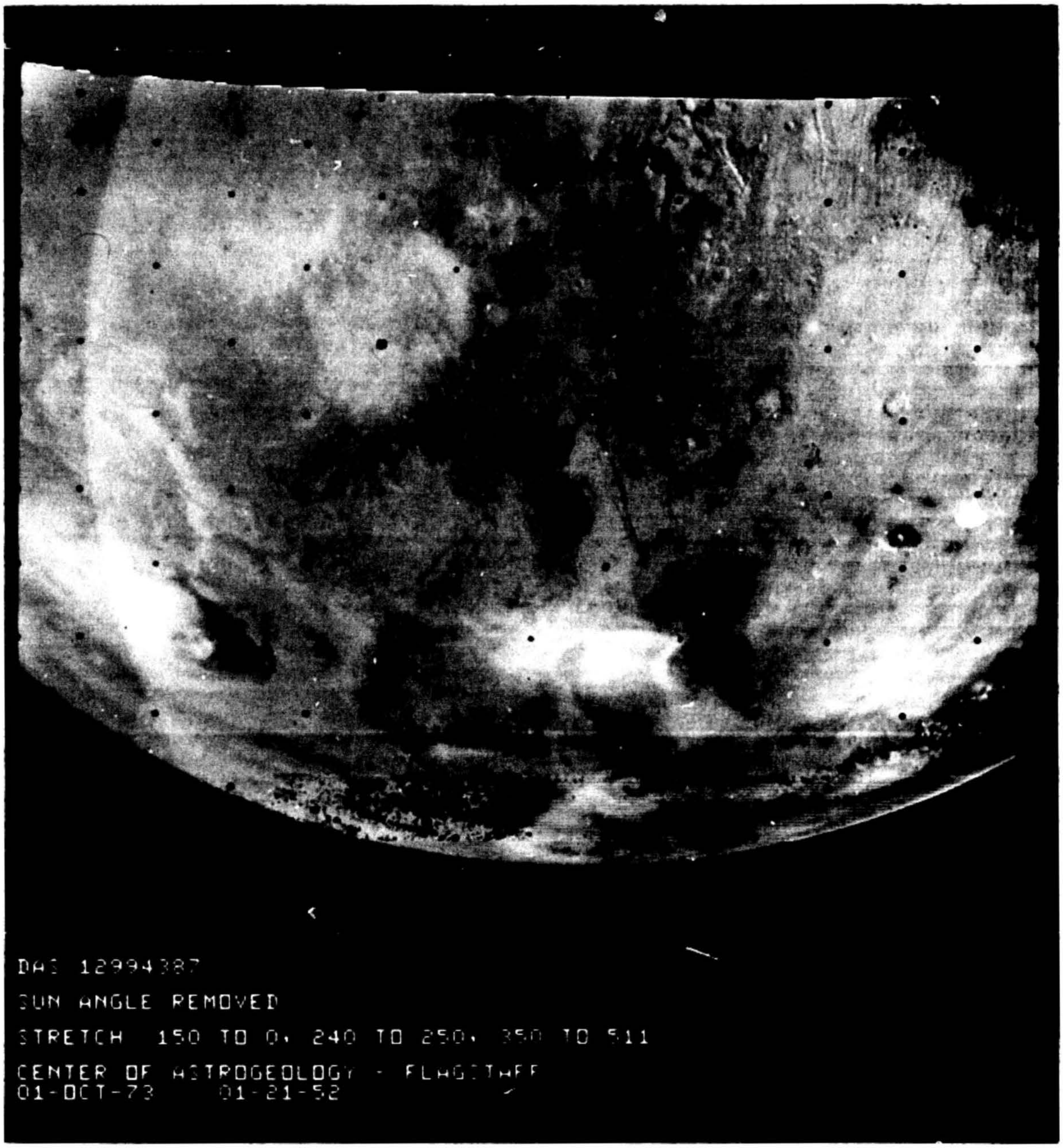

Figure 8.--"Sun-angle corrected" version of the picture in fig. 7.

ysis, preliminary scientific analysis of the Martian surface, preliminary geologic mapping, and to provide a geometrically accurate base for final topographic and geologic mapping. Figures 9 through 12 are examples of these mosaics.

AIRBRUSH ENHANCEMENT

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 picture edge effects 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 13 through 16 illustrate the effect of the airbrush enhancement technique.

Enhancing mosaics is a means of providing useful 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 17 through 19 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 20 and 21 show the difference between a mosic and an airbrush drawing.

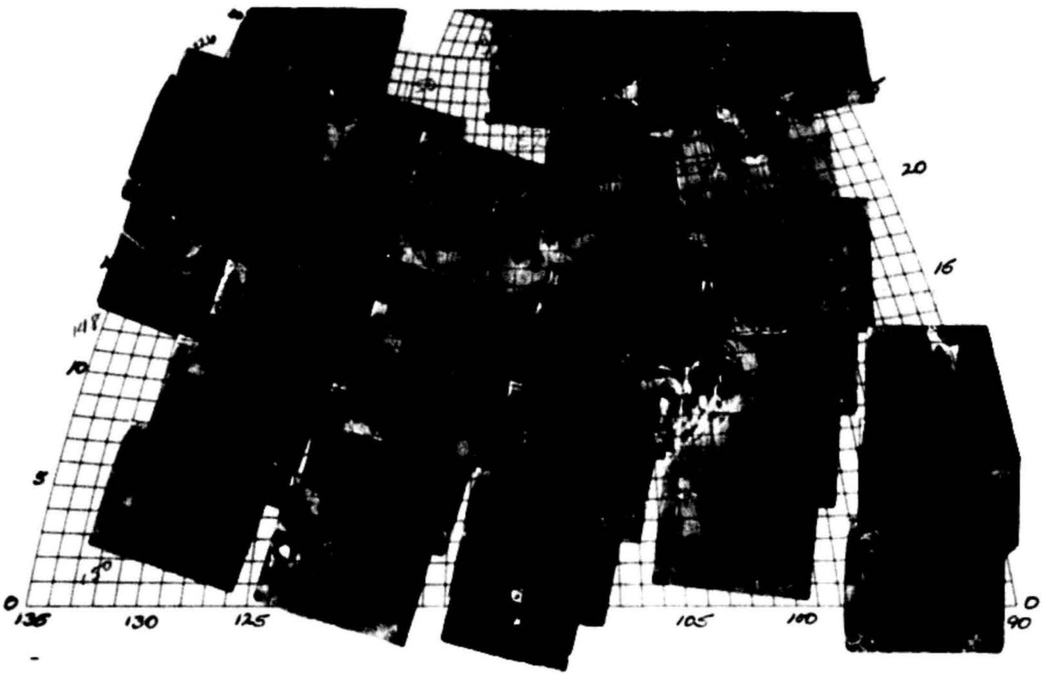

Figure 9a.--"Variable-scale" mosaic of the Tharsis (MC 9) quadrangle of Mars. "Variable-scale" mosaics were made during the Mariner 9 mission with contact prints from the 70mm video film recorder at JPL. High-pass filtered and vertical AGC enhancements were used in this mosaic. Horizontal placement of 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.

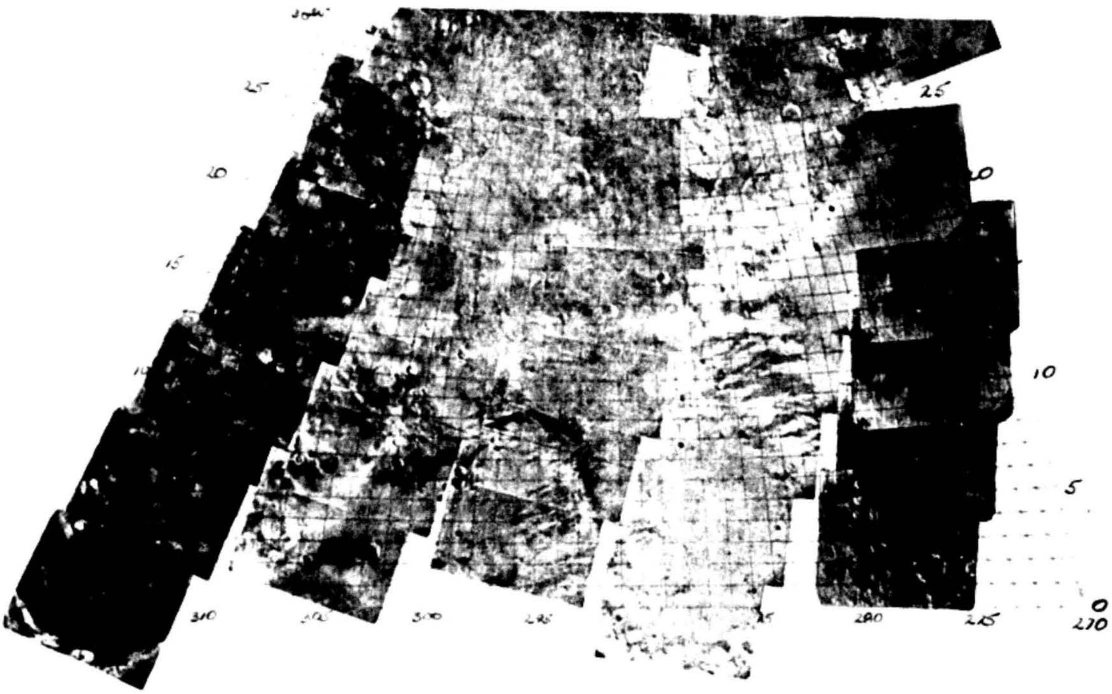

Figure 9b.--"Variable-scale" mosaic of the Syrtis Major (MC 13) quadrangle of Mars.

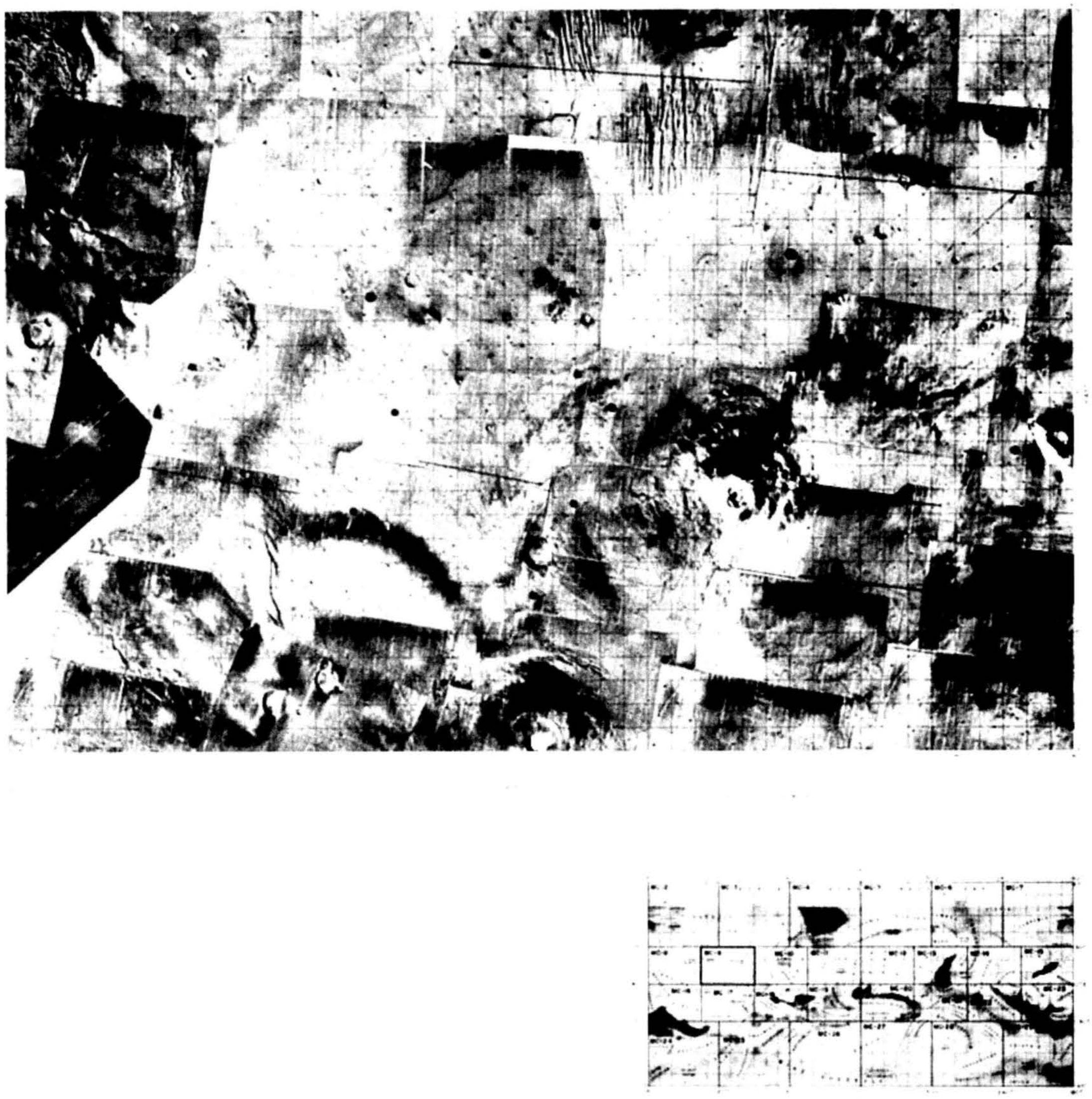

Figure 10a.--Uncontrolled mosaic of the Tharsis quadrangle of Mars. "Uncontrolled" mosaics were made with enlargements of the same pictures used for the "variable-scale" mosaics. The high-pass filtered versions were used. The pictures were enlarged to match approximately their "footprint" sizes on standard 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 10c.--The computed footprint shape of a Mariner 9 picture (DAS 6895738) to which the high-pass filtered version of that picture was fitted for making uncontrolled mosaics.

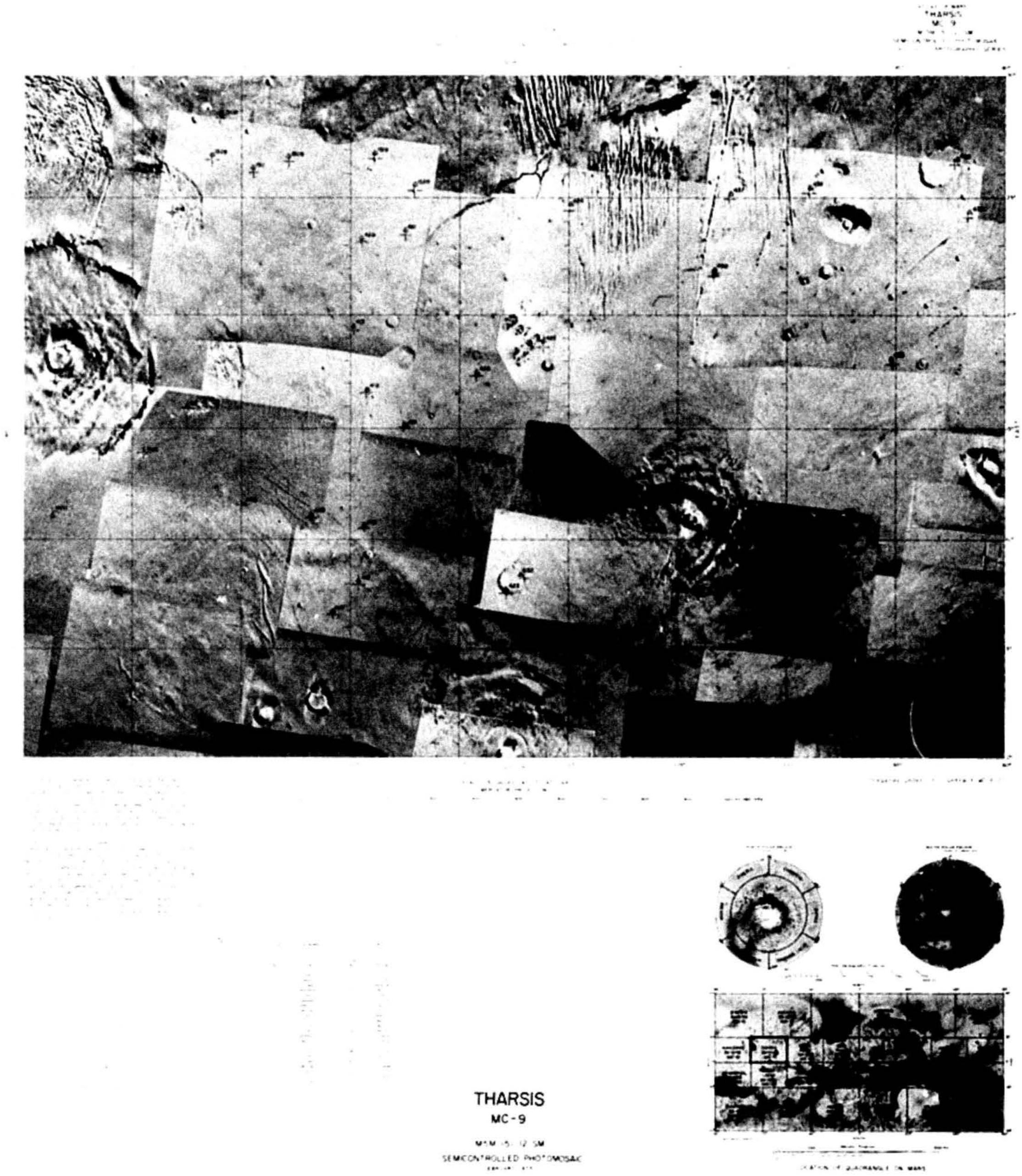

Figure 11a.--Semicontrolled mosaic of the Tharsis quadrangle of Mars. "Semicontrolled" mosaics were made with enhanced pictures geometrically transformed to the appropriate map projections. Horizontal placement was controlled by available preliminary primary control points. Where these points were not 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.

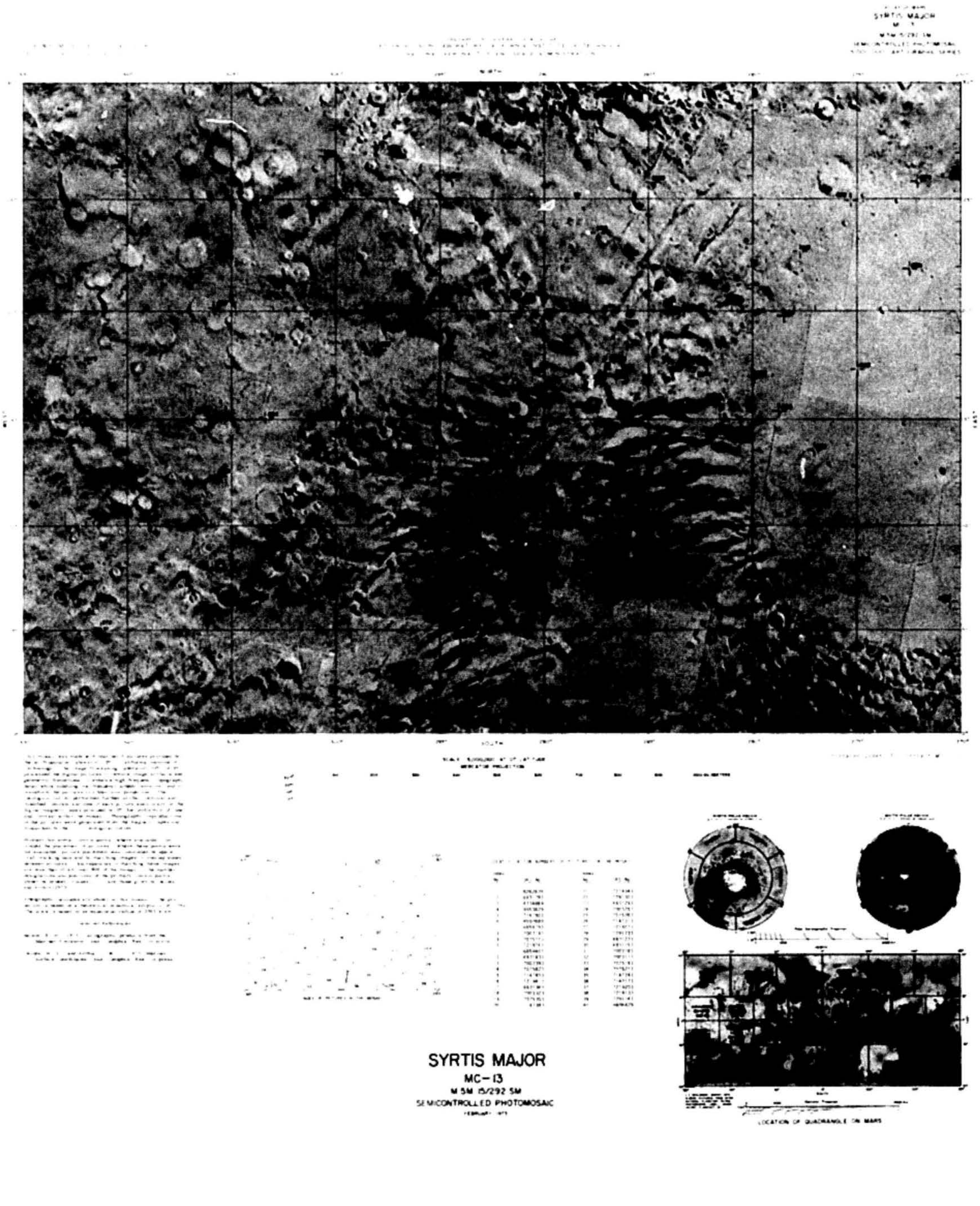

Figure 11b.--Semicontrolled mosaic of the Syrtis Major quadrangle of Mars.

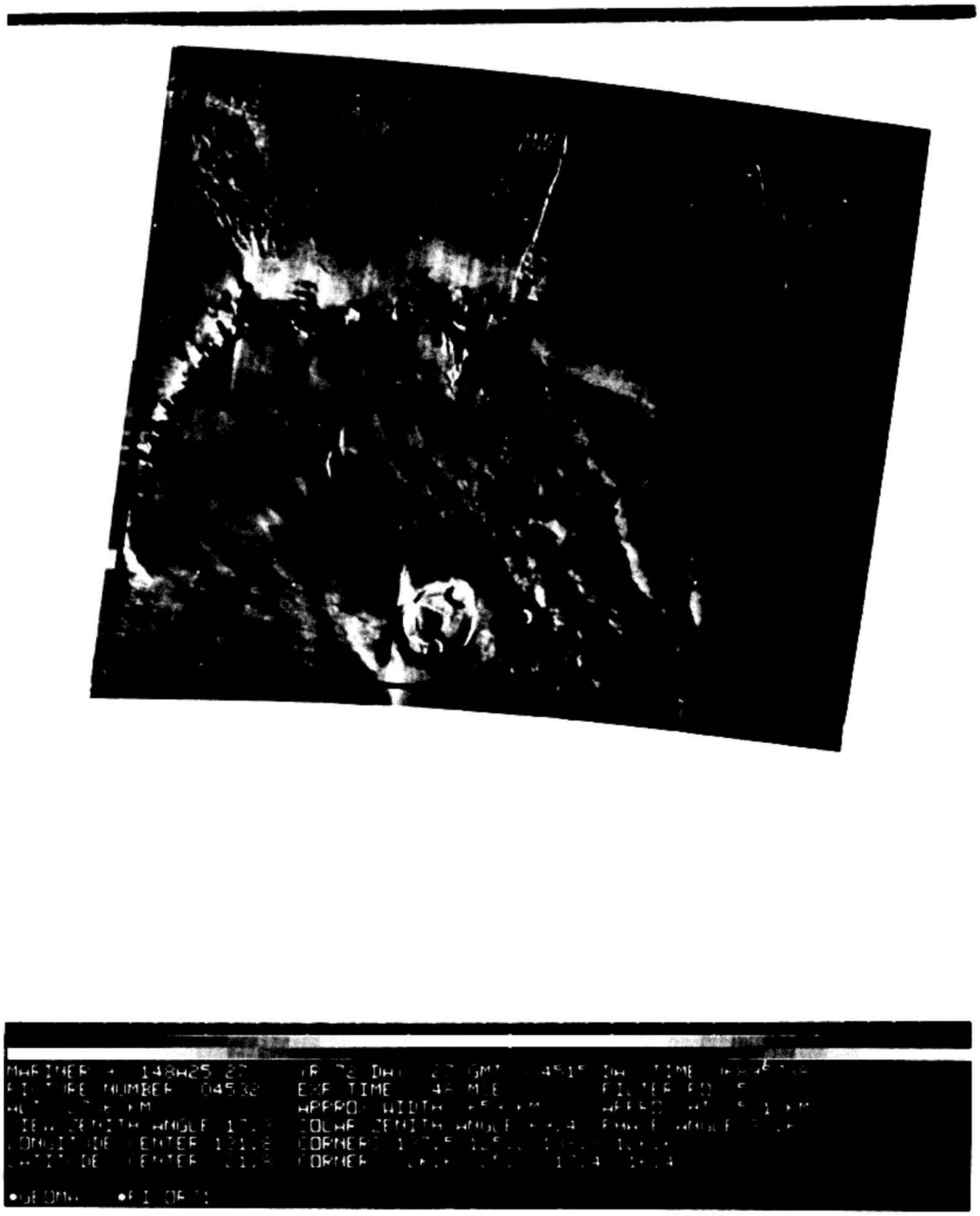

Figure 11c.--The computed shape of the footprint of Mariner 9 picture 6895738, superimposed on the scaled and transformed version of that picture. The footprints were drawn by connecting their computed corner points with straight lines and therefore do not match the picture edges. The corner points of the pictures are defined as the corner reseau points, which are not precisely in the corners of the picture images.

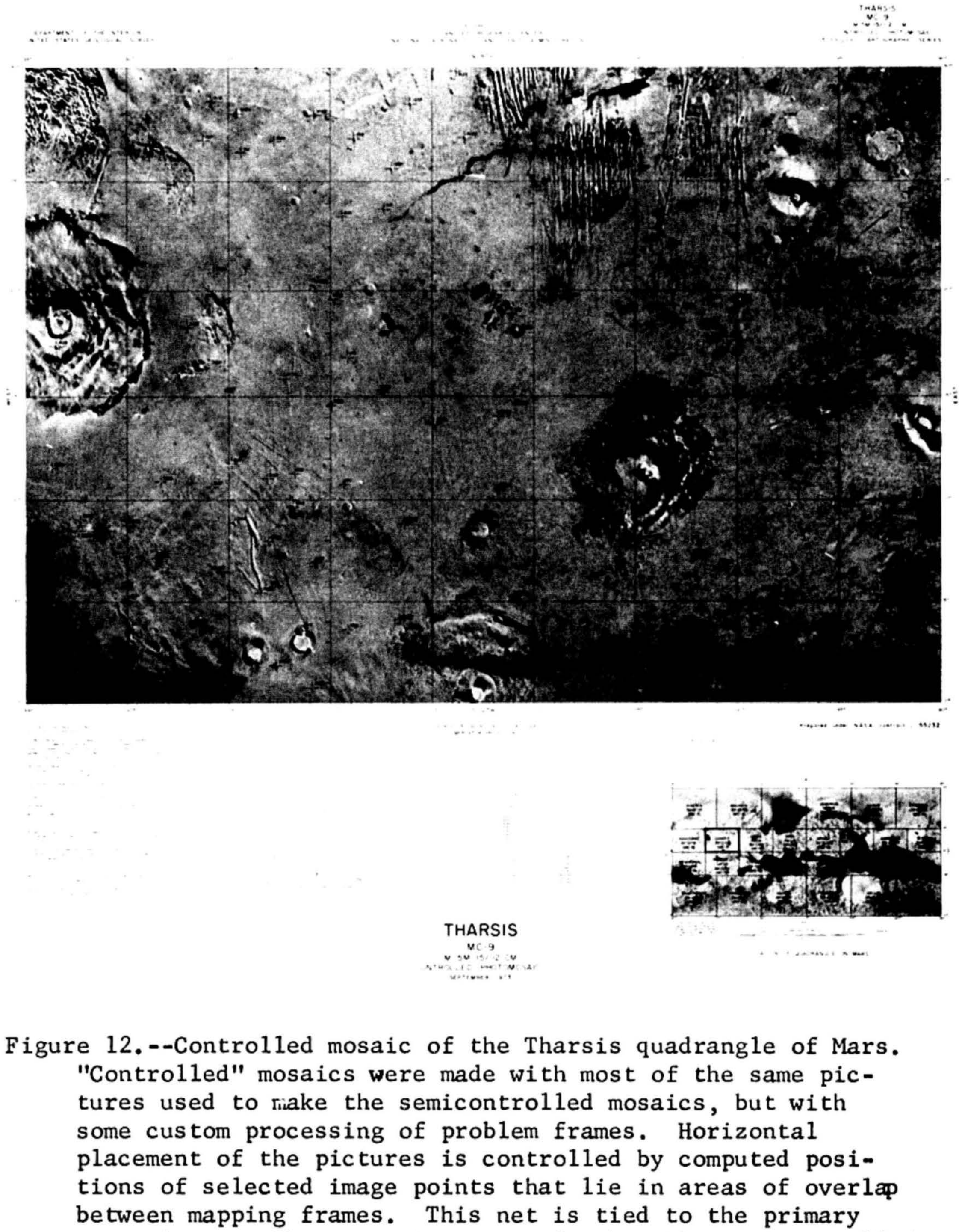

Figure 12.--Controlled mosaic of the Tharsis quadrangle of Mars. "Controlled" mosaics were made with most of the same pictures used to make the semicontrolled mosaics, but with some custom processing of problem frames. Horizontal placement of the pictures is controlled by computed positions of selected 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.

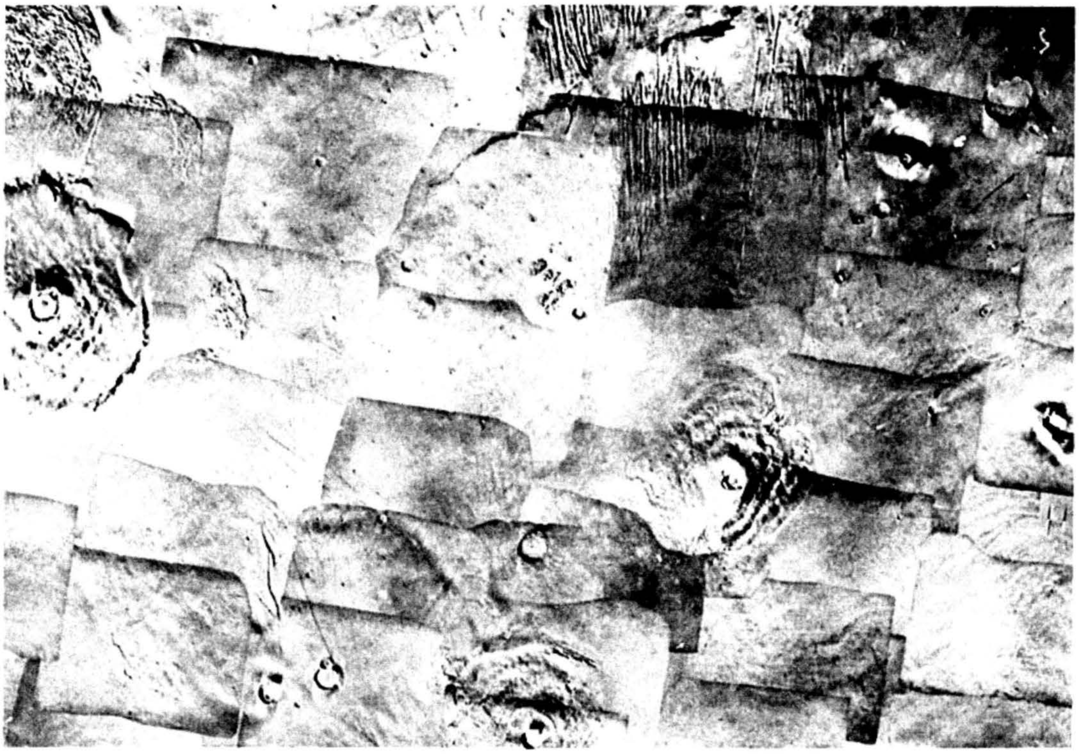

Figure 13.--Unretouched photomosaic of the Tharsis Quadrangle of Mars.

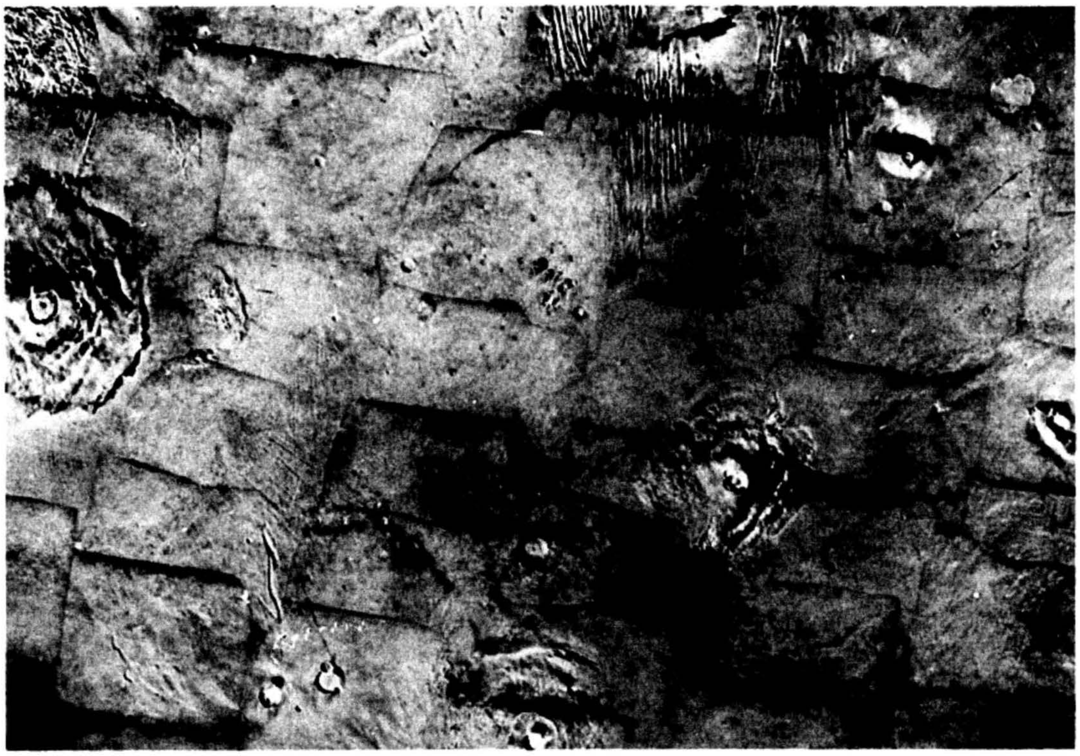

Figure 14.--First stage of retouching. Light toned areas on the mosaic have been darkened with the airbrush.

Figure 15.--Negative copy of the first stage of retouching. Light toned areas on the negative are darkened with the airbrush.

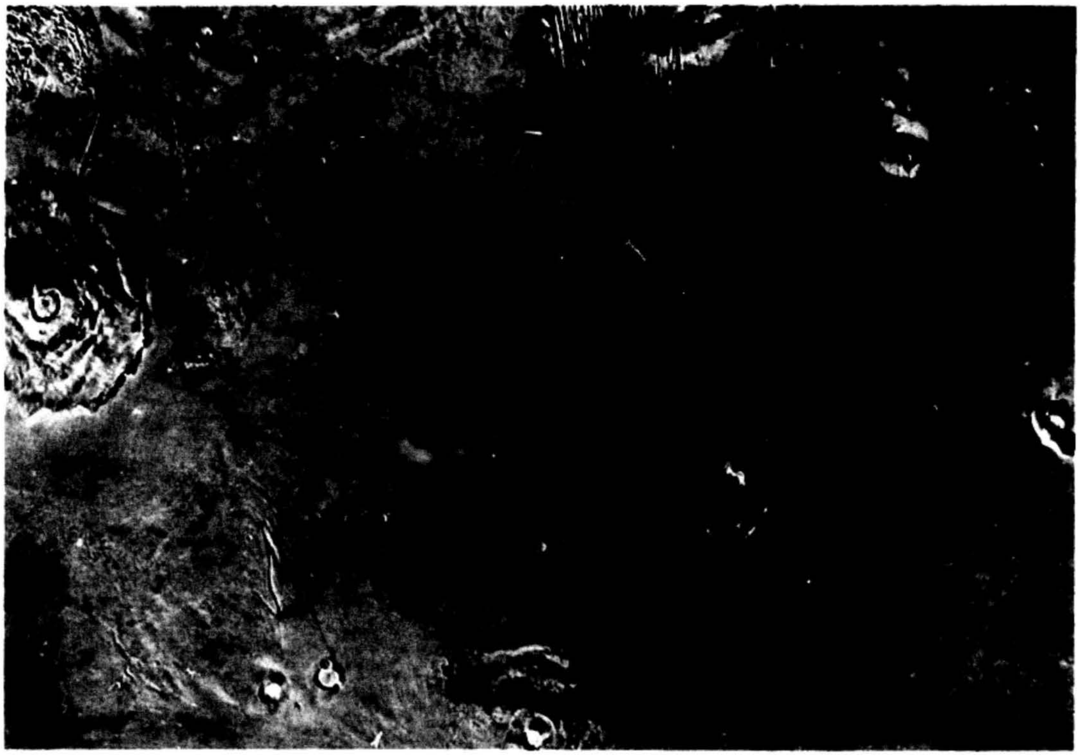

Figure 16.--Final retouched copy of the mosaic with uniform tone throughout.

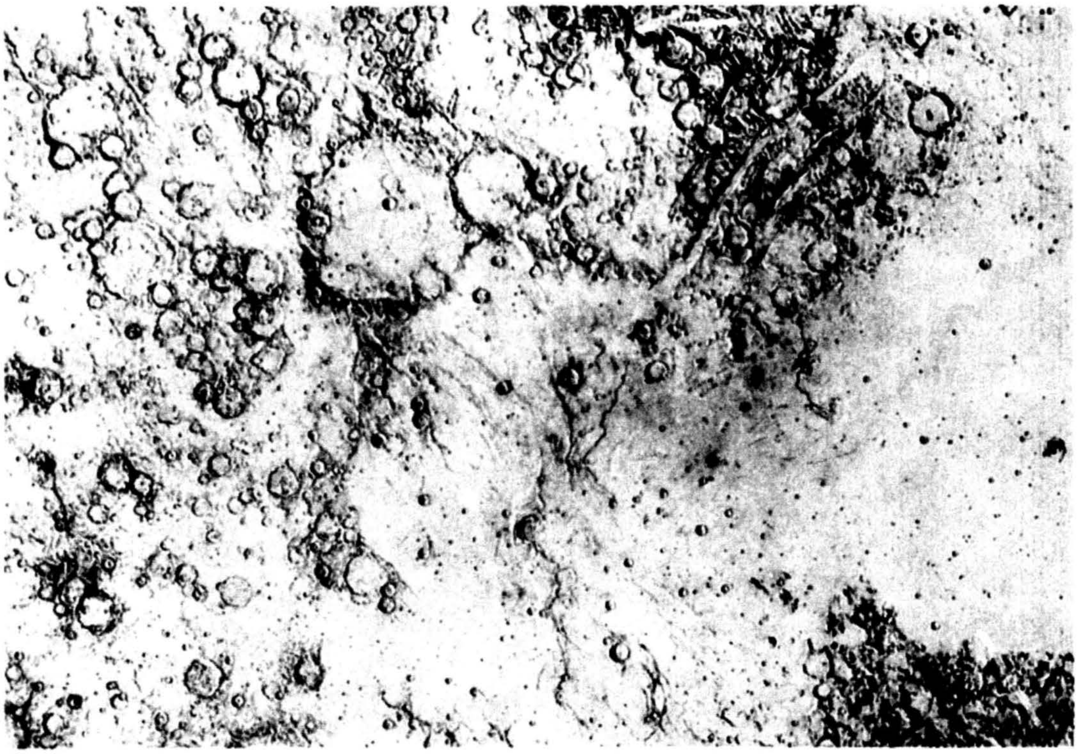

Figure 17.--Shaded relief map of the Syrtis Major quadrangle of Mars. This version, from which all non-topographic image information has been excluded, is a suitable base for colored geologic overprints. The illustrator has examined all available computer processed versions of all Mariner 9 pictures of the area, and added many details not visible in the mosaic. Contrast is exaggerated, but relative contrast values have been carefully preserved.

Figure 18.--Light and dark markings on the Syrtis Major quadrangle. These markings are taken solely from Mariner 9 pictures, and differ significantly from earth-based observation of the area. This difference is caused by cloud cover, 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 19.--Composite print of topography and markings on the Syrtis Major quadrangle.

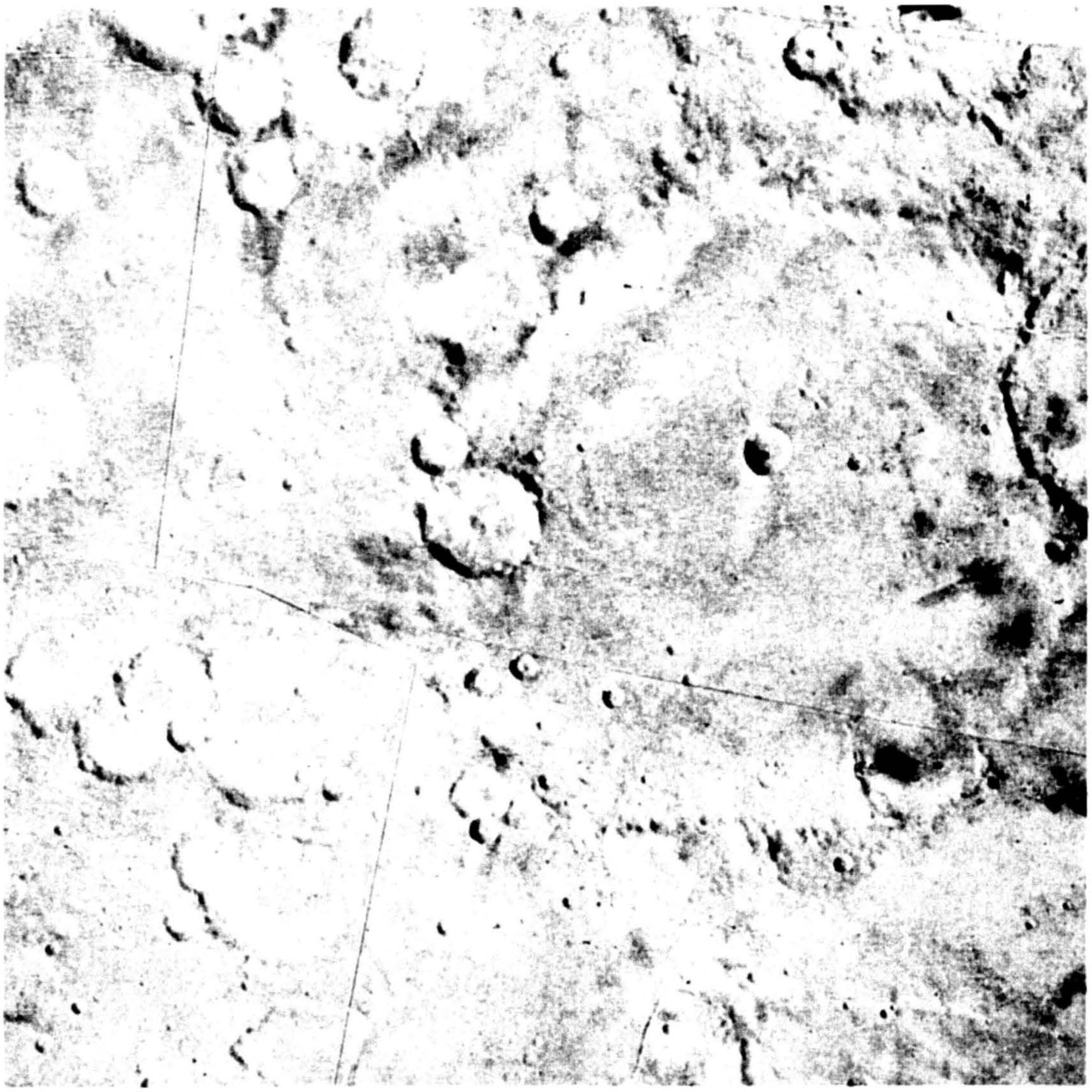

Figure 20.--A section of the mosaic of the Syrtis Major quadrangle of Mars. The best available pictures were used, but even they show only part of the surface information available on other pictures. For example, computer processing that enhanced topography in the pictures subdued, but did not eliminate, 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.

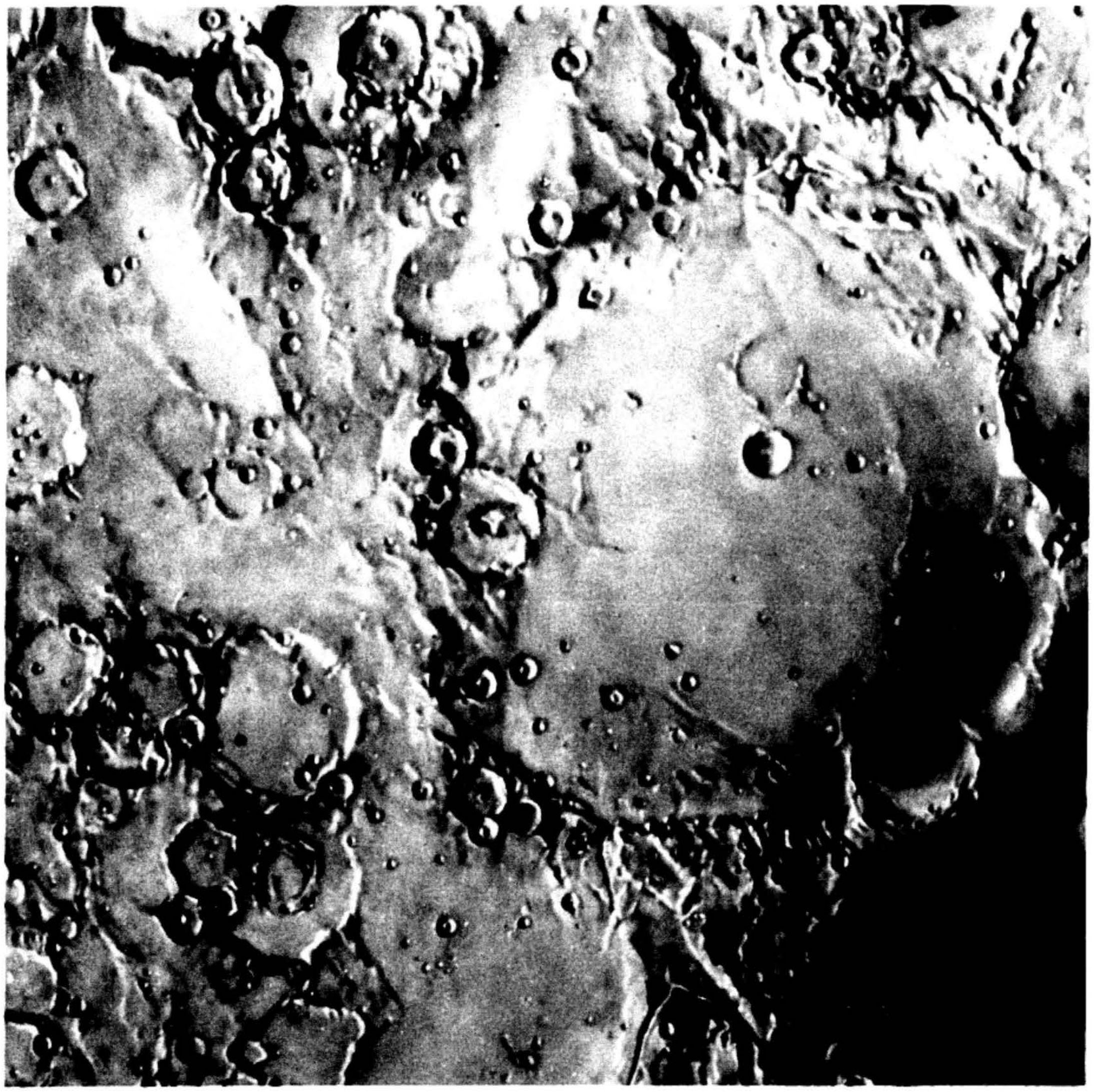

Figure 21.--A section of an airbrush drawing of the area of the Syrtis Major quadrangle shown in fig. 20. Many details not visible in the mosaic have been added through examination of all available pictures of the area.

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 1 through 3, figure 7, and the pictures in figures 9 and 10.

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 4 and 5, the pictures in figures 11 through 16, and the pictures in figure 20.

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's Center of Astrogeology. This group produced the picture in figure 8.

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 12. 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 U.S. Geological Survey's Special Map Center at Reston, Va. compiled the controlled mosaic of figures 12 through 16.

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