DIGITAL IMAGE PROCESSING FOR PLANETARY TOPOGRAPHIC MAPPING

Dr. Sherman S. C. Wu, Supervisory Physical Scientist
United States Geological Survey, Flagstaff, AZ 86001
USA
Commission III

ABSTRACT

Remote-sensing data have been used in planetary topographic mapping. The application of digital image processing techniques to such data make them geometrically compatible with existing photogrammetric equipment. Digital image processing can also enhance imagery for the improvement of measuring precision and interpretability. Such digital image processing may include geometric correction and rectification, and digital transformation for the reconstruction of shaded-relief maps, orthophoto, and perspective views including stereograms. By using digital image processing, distortions can be corrected to be less than one image element of a Viking Orbiter picture consisting of 1056 x 1182 pixels. Digital rectification can make high-oblique pictures workable on stereoplotters that would otherwise not accommodate such extreme tilt angles. By using off-line digital image processing, panoramic images with line-scan geometry from facsimile cameras can be converted for the use of map compilation. By merging digital terrain data with image data, orthophoto and perspective views including three-dimensional views of various spacecraft pictures of Mars have been produced.

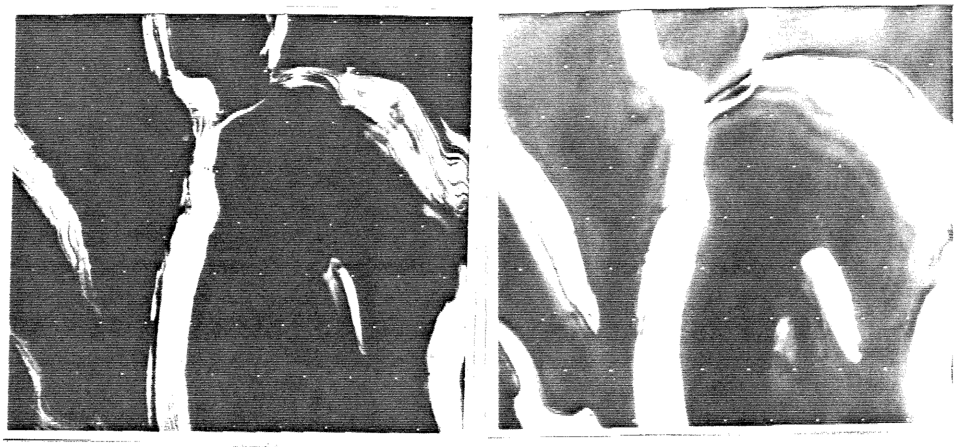
I. INTRODUCTION

The application of digital image processing techniques to spacecraft television pictures can make them geometrically compatible with existing stereo plotting equipment. It can also enhance imagery for the improvement of measuring precision and interpretability. Therefore, digital image processing may include quality enhancement, geometric transformation, rectification, correction, and geometric reconstruction of three-dimensional views as well as shaded-relief maps. A pair of high oblique Viking Orbiter images of Mars, for example, was digitally rectified in order to use available photogrammetric stereo plotters for map compilation. In order to do systematic mapping of the planet Mars using Viking Orbiter pictures, digital image-processing techniques have been extensively used for decalibration. Geometric distortions can be corrected to be less than one image element of a Viking Orbiter picture. By using off-line digital image processing, panoramic images with line-scan geometry from the pair of facsimile cameras on the Viking Landers were converted to the equivalent of frame images so that contour maps can be compiled. By merging digital terrain data with image data, perspective and three-dimensional views of distinguished features of Mars can be reconstructed from any oblique direction through digital image processing.

II. APPLICATION OF DIGITAL IMAGE PROCESSING TO VIKING ORBITAL PICTURES

Techniques of digital image processing have been extensively applied to Viking orbital pictures. Described below are some of these techniques and presentations of products.

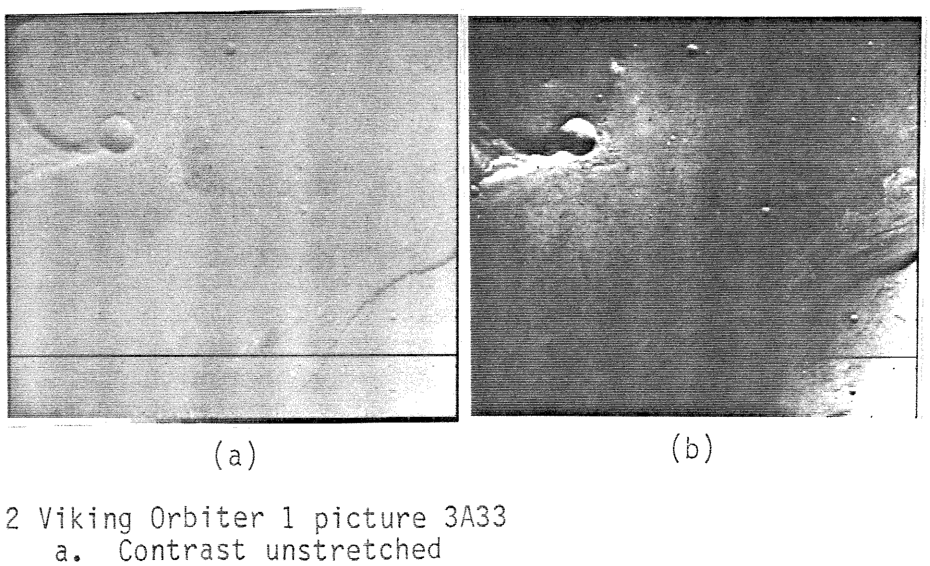
Quality Enhancement and Geometric Decalibration--The image data of some of the Viking orbital pictures require enhancement to bring out enough detail for map compilation (Fig. 1-a). Image element density-values are adjusted for contrast enhancement by using special digital image processing (Fig. 1-b). These two pictures (before and after-enhancement) cover a



(a) (b)

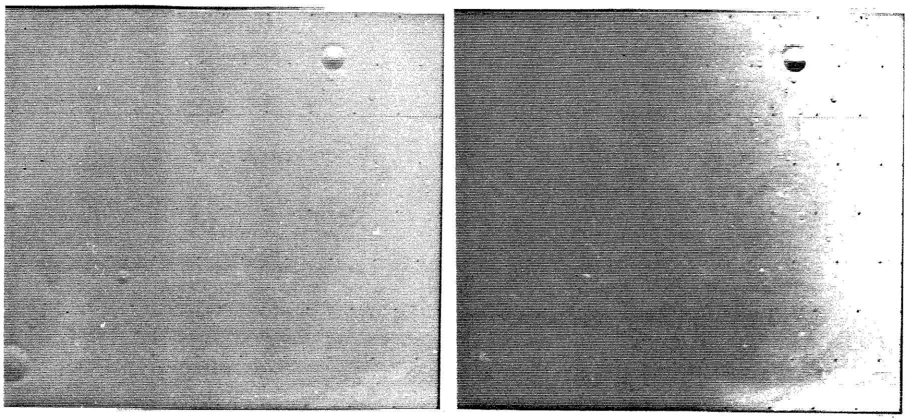
Fig. 1. Viking Orbiter 2 picture 62B30
a. Unprocessed
b. Enhanced through special digital image processing.

small portion of the layers of ice at the Mars polar cap. As shown in Figures 2-a and 3-a, without special processing, the image contrast of these two pictures is barely adequate for compilation. By using digital image-processing techniques, the image contrast of these two pictures is stretched so that they can be used for map compilation. This digital image-processing technique is applied to almost all Viking orbital pictures. Also, with 103 reseau marks incorporated in each of the 4 cameras installed in the Viking Orbiter spacecraft, the rms (root mean square) residual errors of the distortion can be reduced to less than 2 μm by digital correction of the images in the Image Processing Laboratory (IPL) at the Jet Propulsion Laboratory (JPL), California Institute of Technology, Pasadena, California (personal communication with Ruiz, 1976), and at the U. S. Geological Survey of Flagstaff, Arizona. Before decalibration, the images have rms residuals of distortion ranging from 18 μm to 46 μm. Maximum distortions in the imagery can be as large as from 71 μm to 138 μm. For example, by measuring all of the 103 reseau marks of those two Viking Orbiter pictures (3A33 in Fig. 2-a and 3A34 in Fig. 3-a)



(a) (b)

Fig. 2 Viking Orbiter 1 picture 3A33
a. Contrast unstretched
b. 1%~2% contrast stretched



(a) (b)

Fig. 3 Viking Orbiter picture 3A34
a. Contrast unstretched
b. 1%-2% contrast stretched

their rms distortion residuals are reduced to 9 μm and 8 μm after decalibration with digital image processing (Wu et al., 1982b). They are smaller than one image element (11.87 μm). Before geometric correction their rms distortion errors are 35 μm and 34 μm which are about 3 image elements. Each Viking Orbiter picture consists of 1056 scan lines with 1182 pixel elements in each line. Therefore, geometric distortions were considered to be negligible for stereo compilation with pictures produced by using decalibration software in the digital image processing (Wu et al., 1982b).

Digital Image Rectification--Fig. 4-a is a stereo pair of unrectified Viking Orbiter pictures, of which the right one has a 28.5° tilt angle. This exceeds the limit for the AP/C analytical plotter. In addition, the picture at the left has a scale of 1.5 times that of the right. Digital image rectification was performed on this stereo pair of pictures to reduce the tilt angle of the picture on the right to be zero and to reduce the photo scale of the picture on the left to be compatible with that of the right as shown in Fig. 4-b. This rectified pair, along with 22 others, was used for the compilation of a contour map of Tithonium Chasma of Mars (USGS, 1980). These pictures were taken from the Viking Orbiter 1 mission at altitudes of 3098.3 km and 4406.4 km by a camera with a focal length of 475 mm. The compiled map scale is 1:500,000 with a contour interval of 200 m (Wu, 1979).

Digital Image Transformation--Based on the concept that reflected light intensity is a function of terrain slope and illumination angle, techniques for computer-processing shaded-relief maps using digital elevation data have been developed (Levinthal et al., 1973, Batson et al., 1975). In digital image processing, gray levels are computed as a function of slopes between pairs of adjacent elevations whose values were used to compute the slopes. By merging digital image data together with digital elevation data, techniques for producing orthophoto and stereoscopic shaded-relief pictures have also been developed (Batson et al., 1975, 1976, 1979, 1981). These techniques have been widely applied to spacecraft images for the improvement of their interpretability for planetary studies.

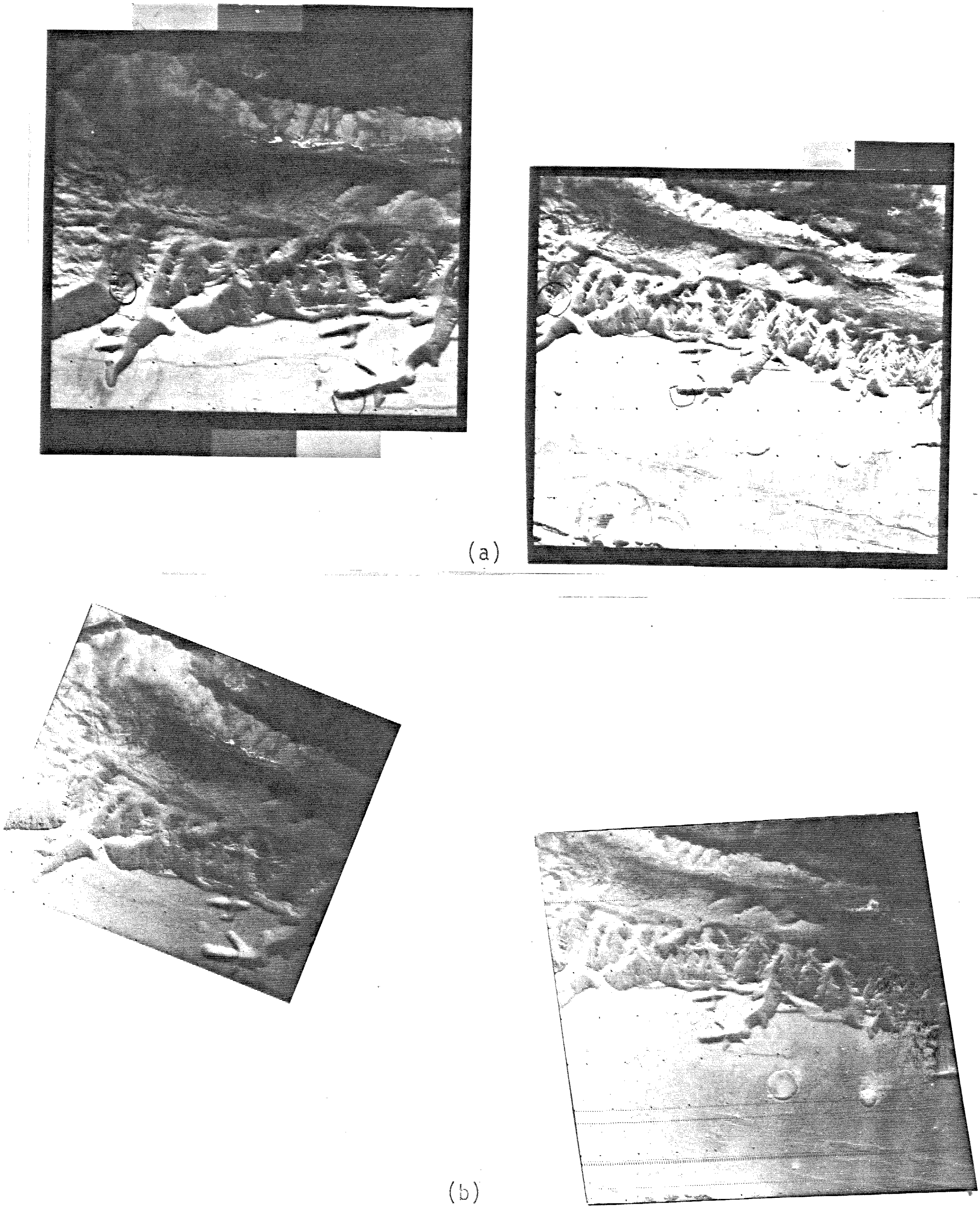
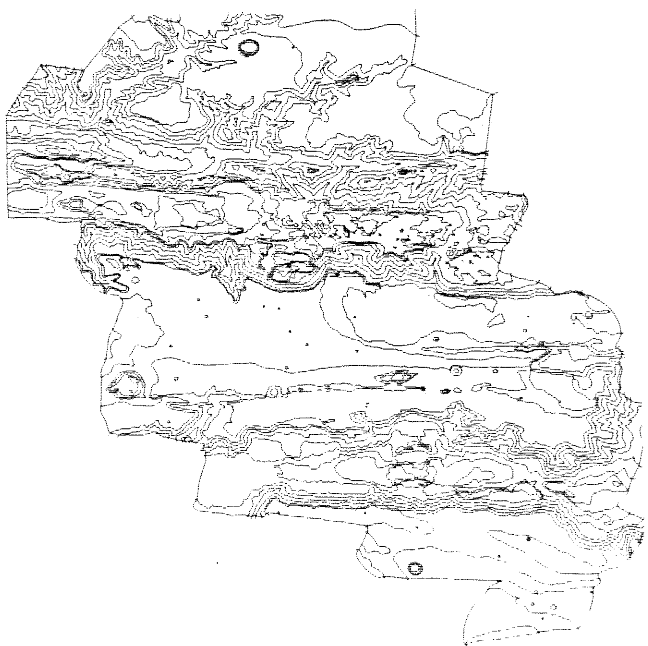


Fig. 4. (a) A stereo pair of unrectified Viking Orbiter pictures 65A12 (left) and 59A22 (right).
(b) Rectified pictures of the same pair shown in (a); tilt angle of the picture at the right is reduced to be zero and scale of the picture at the left is reduced to be compatible with that at the right.

By interpolating the digital data from a contour map (USGS, 1980) into a raster form, Fig. 5 is a computer processed shaded-relief picture of the Tithonium Chasma of Mars, a small portion of the Mars canyonland covering an area of about 2500 sq. km. It has a depth of about 9 km. This picture was processed with a 30° sun elevation angle from due west.

Figure 6 is a contour map of Olympus Mons of Mars compiled from numerous stereoscopic combinations of Viking Orbiter photographs (Wu et al., 1981-a). During stereoscopic compilation, digital elevation data were collected and stored in the computer. By merging the digital elevation data with digital image data of the Viking Orbiter picture 645A28, with a certain number of control points in the processing, image pixels are shifted as a function of their elevations and a picture which is a perspective view of Olympus Mons is produced. As shown in Fig. 7, the summit caldera and the terraced upper flanks of Olympus Mons are viewed monoscopically from the east. Since the view can be from any direction, two such perspective oblique views from different azimuths will produce stereoscopic views such as the pair shown in Fig. 8, which views the scarps of the lower flanks stereoscopically from the north. All the viewing angles are 25° from the horizon with a 5° separation in azimuth between the left and the right pictures of the stereo pair. A 5 times vertical exaggeration has been applied in the digital image transformation (Wu, et al., 1983).



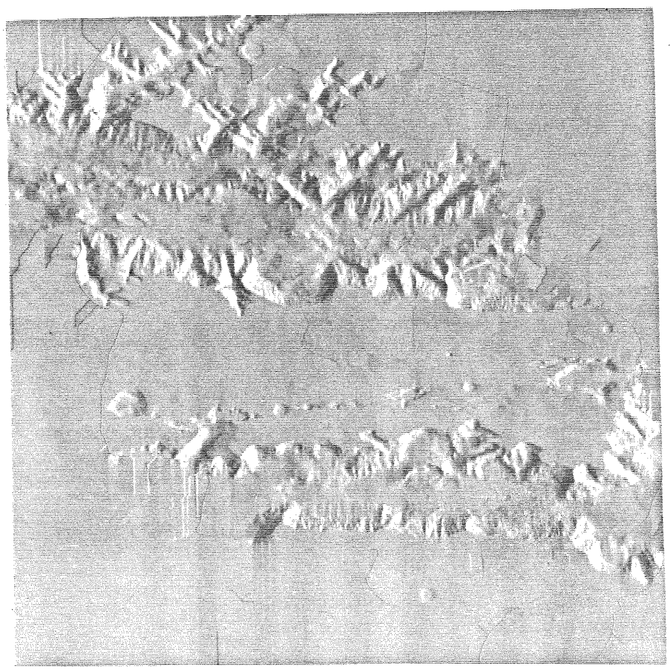


Fig. 5. Computer-processed shaded relief picture of Tithonium Chasma of Mars using only digital elevation data collected at time of map compilation.

Olympus Mons is perhaps the largest volcano in our solar system. The base spans 600 km with a height of about 27 km above the Mars topographic datum (Wu, 1981; Wu, et al. 1981b). By using digital image processing, numerous perspective stereoscopic views of Olympus Mons from various vertical features such as landslides, flows, and slope-gradient reversals greatly aid geological interpretation. In fact, using the digital terrain data, a movie of this large shield volcano has been made by the Jet Propulsion Laboratory.

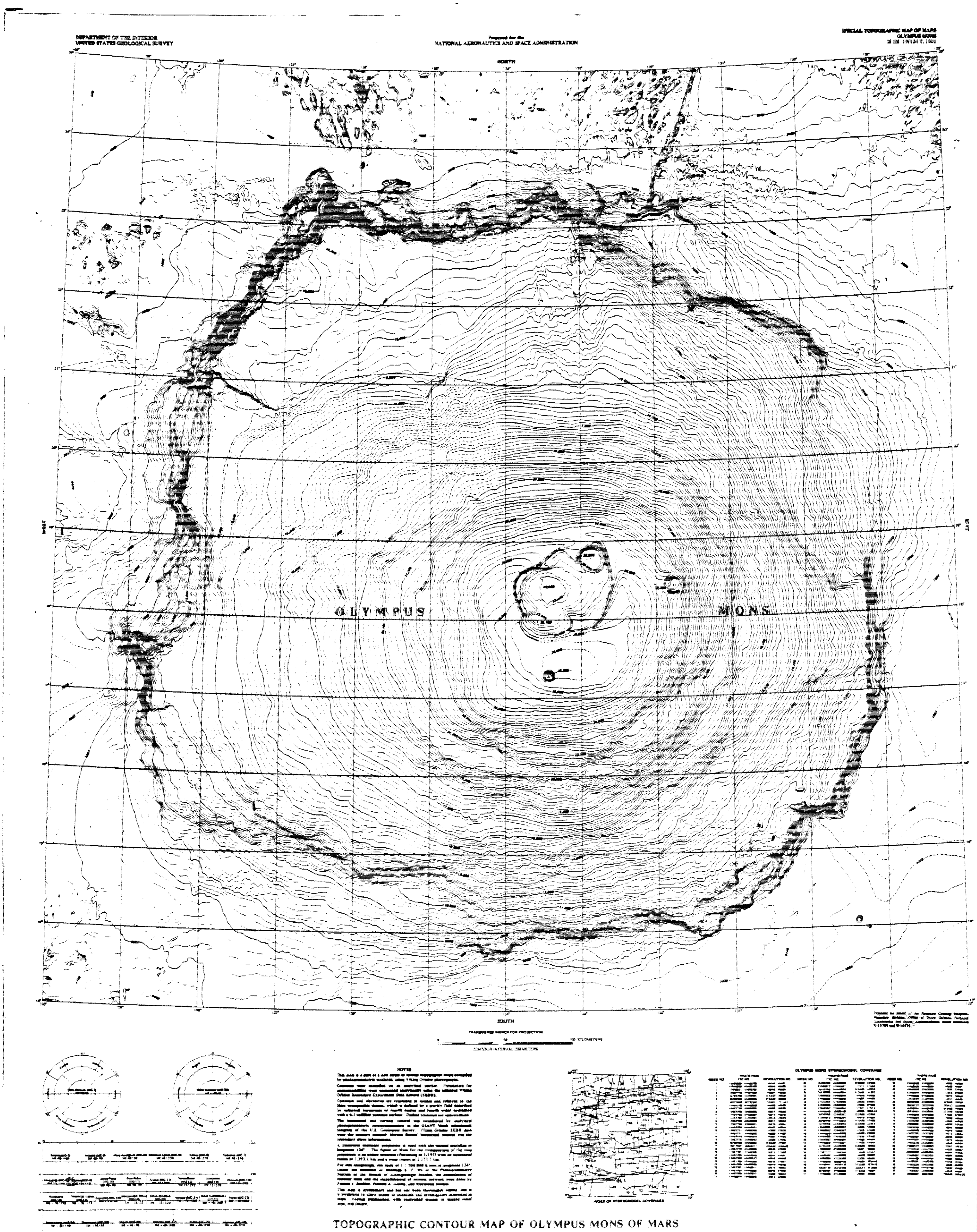


Fig. 6 Topographic map of Olympus Mons of Mars. Contour interval is 200 m. Contours and elevations are expressed in meters. Dashed contours are approximate.

IV. APPLICATION OF DIGITAL IMAGE PROCESSING TO FACSIMILE CAMERA IMAGES

To compile contour maps using images from facsimile cameras, techniques of off-line digital image conversion have been developed (Wu and Schafer, 1982). Conversion is made by projecting the facsimile imagery from a spherical surface to a plane using a gnomonic projection. Segments of rectified pictures, as shown in Fig 9-b, -c, and -d, are rectified from sections of Fig. 9-a. Segments at the left and right of Fig. 9-b, -c, and -d are rectified sections respectively, of the upper and the lower images of the stereo pair in Fig. 9-a. The view point (perspective center) of the projection being at the center of the sphere, the selected radius of the sphere will then be the principal distance of the rectified pictures. The principal point of the rectified imagery can be somewhat arbitrarily located but must correspond to the point of tangency between the sphere and the projection plane. In order to compile contour maps on the AP/C analytical plotter (Ottico Meccanica Italiana, 1966), which has a tilt-angle limitation of 25°, the reduction of the tilt angle of the picture is

Fig. 7. Perspective view of Olympus Mons of Mars viewed monoscopically from due west with a viewing angle of 25° from the horizon.

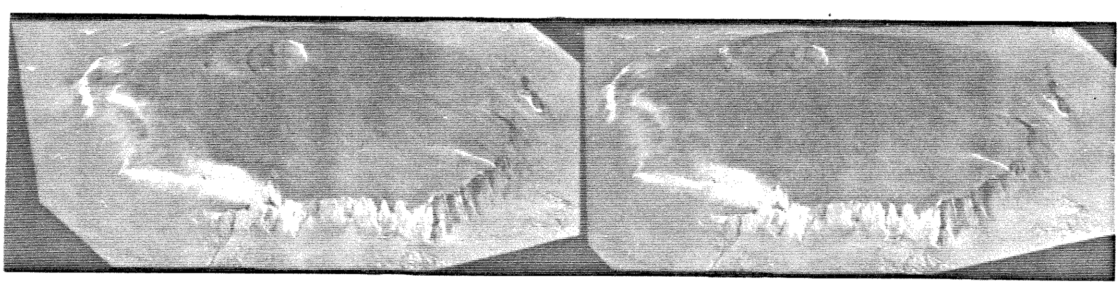


Fig. 8. Stereoscopic view of Olympus Mons of Mars viewed from due north. Stereo pair has 5° separation in azimuth between the left and the right pictures with a 5 times vertical exaggeration.

accomplished simultaneously with the rectification process. This is done by determining where the projection plane is made tangent to the sphere. Equations used for the rectification are:

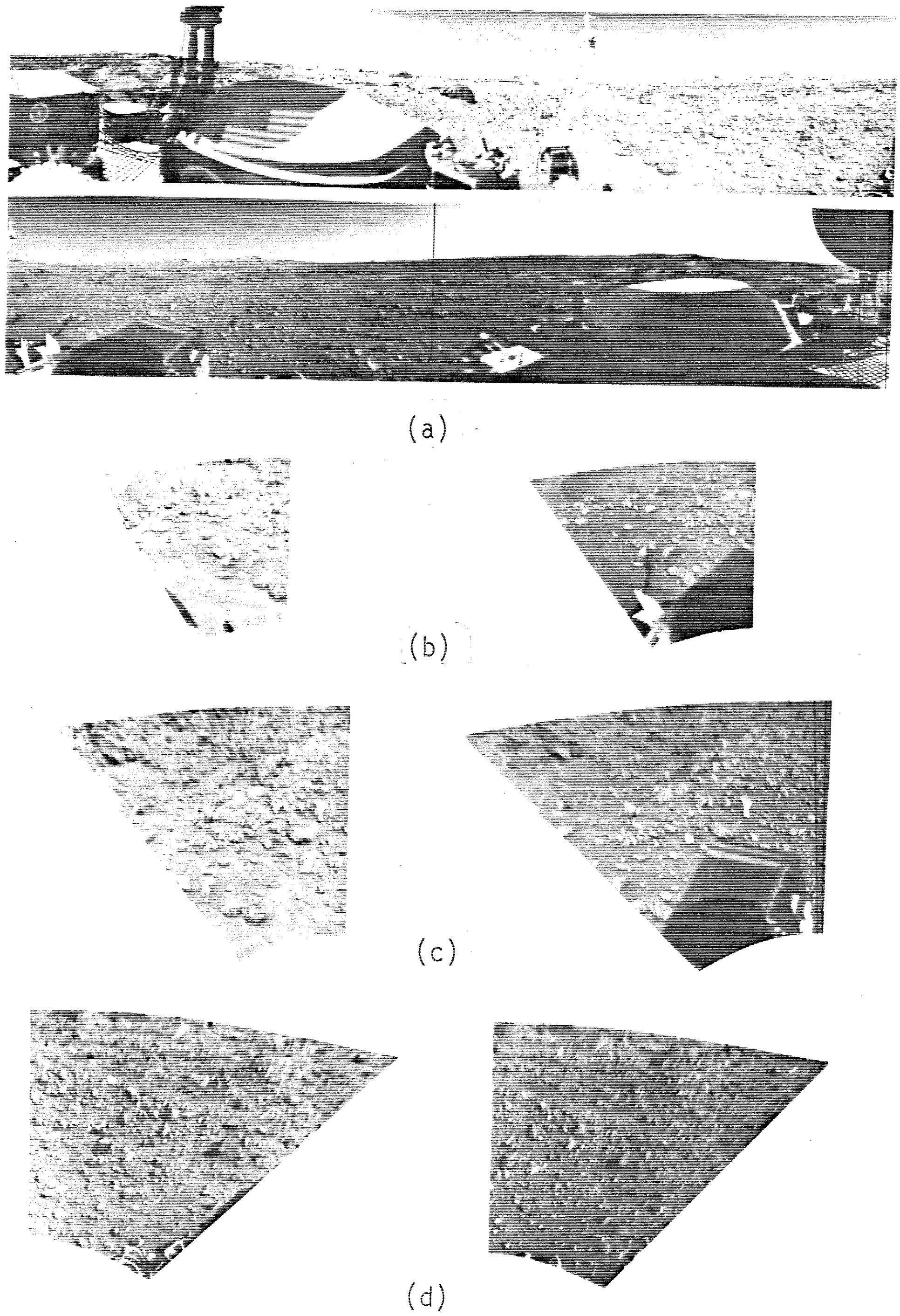


Fig. 9. Low-resolution images of the Viking 1 landing site taken with survey-mode diodes and used in compiling the topographic map of the landing site (Wu and Schafer, 1982). (a) Unrectified images from the two cameras; Rectified for left portions 200° to 236° and 20° to 60°. (c) Rectified left portions 220° to 261° and 36° to 84.7°. (d) Rectified right portions 261° to 310° and 84.7° to 130°.

$$x = f \frac{\sin \Delta\lambda}{\sin E_o \tan E_p + \cos E_o \cos \Delta\lambda} \qquad (1)$$

$$y = f \frac{\cos E_o \tan E_p - \sin E_o \cos \Delta\lambda}{\sin E_o \tan E_p + \cos E_o \cos \Delta\lambda} \qquad (2)$$

where $\Delta\lambda = Az_p - Az_o$, and Az_p and Az_o are, respectively, the azimuth of any image point P referred to the zero azimuth of the Viking Lander coordinate system (von Struve, 1975, Itek Corp. 1972, 1974) and of the selected camera axis; E_p and E_o are, respectively, the elevation angle of point P and of the selected camera axis; x and y are then, the converted photo coordinates along the azimuth and elevation directions. In other words, rectification is done to convert the original image format of the Viking Lander image with components in terms of azimuth and elevation angles into the equivalent of point-perspective frame pictures. By using these rectified stereo pairs (Fig 8-b, -c, and -d), a contour map of the surrounding area of the Viking Lander 1 (on Mars) was compiled at a scale of 1:10 with a contour interval of 1 cm (Wu and Schafer, 1982). The mapping precision varies depending on the range and side-angle of the point in the map. For example, the uncertainties of horizontal measurements are 5.5 mm and 107.0 mm, respectively for the points 1 m and 5 m of range along the camera axis (Wu et al., 1982). The fixed base between the two cameras is 0.821 m.

CONCLUSION

Digital image data have been the primary data source for planetary topographic mapping. Future photogrammetry will also likely be digital. Therefore, techniques of digital image processing will be required tools of planetary topographic mapping

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