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Photogrammetry of the Viking Lander Imagery

The most accurate methods of mapping the two Viking lander areas were (1) to do computerized rectifications on a large computer where a pixel-by-pixel conversion could be made, or (2) to make all conversions and corrections in real time on an analytical stereoplotter.

Introduction

In 1976 the United States put two Viking landers on the Martian surface. Imagery from their facsimile cameras is essentially derived only from image elements obtained by scanning in both the azimuth and vertical directions. Therefore, the reconstituted pictures are virtually equivalent to imagery on a spherical surface rather than on a plane as in point-perspective photography. We can perform a purely computational photogrammetric solution for map compilation, but photogrammetric measurements cannot be made by conventional methods on presently available plotters. Therefore, we have developed two solutions to the problem of stereo mapping from Viking lander imagery. The first is the use of a gnomonic projection to transform this type of digital imagery to the equivalent of a plane picture by computerized rectification. The second solution is the interfacing of a high-speed digital computer to an AS-11A analytical plotter so that all computations of rectification and corrections can be performed in real-time operation of the plotter (Wu, 1976b).

Abstract: *Two fixed-base facsimile cameras are installed on each of the two Viking landers now on Mars. Imagery from the cameras is composed of image elements recorded by scanning in both azimuth and vertical directions; the resulting pictures are equivalent to images on a spherical surface. We have solved the problem of photogrammetric mapping from the Viking lander photography in two ways: (1) by converting the azimuth and elevation scanning imagery to the equivalent of a frame picture by means of computerized rectification; and (2) by interfacing a high-speed, general-purpose computer to the AS-11A analytical plotter so that all computations of corrections can be performed in real time during the process of model orientation and map compilation.*

A series of pre-mission tests, comparing accuracy of terrestrial maps compiled by the photographic rectification method with maps made from aerial photographs, has shown both the efficiency of the lander cameras and the validity of the rectification method. The cameras and the method have been further validated on the Martian surface by topographic maps of Viking lander sites 1 and 2 at a scale of 1:10 with a contour interval of 1 cm. Examples are presented of photographs and maps of Earth and Mars.

Several pre-mission tests have proved that topographic maps can be compiled from the imagery of the facsimile cameras. We have compiled such maps of the areas surrounding the Viking landers at a scale of 1:10 with a contour interval of 1 cm.

Photogrammetric Engineering and Remote Sensing,
Vol. 48, No. 5, May 1982, pp. 803-816.

0099-1112/82/4805-0803$02.25/0

THE FACSIMILE CAMERA AND ITS IMAGERY

The imaging system installed on the Viking landers (Figure 1) consists of two identical facsimile cameras separated by a nominal base of 0.821 m. The facsimile camera (Tompkins, 1965) as shown in Figure 2 is an optical-mechanical type of scanner comprising an optical system and an array of photosensors. The light ray from the ground object is reflected by a scanning mirror to a lens that focuses images of the incoming light through an aperture onto a photosensor. The photosensor then generates electrical signals that vary according to light intensity. The signals can be either transmitted to the orbiter for storage and subsequent transmission to Earth, or directly transmitted to Earth. When camera data are received on Earth, they are recorded on magnetic tape either for display in the form of television imagery, or for reconstruction of pictures for mapping and scientific investigations of the Martian surface. The calibrated focal length of the lens is 2.1143 inches (53.703 mm) (Itek Corp., 1974).

As shown in Figure 2, the mirror is rotated in the vertical direction by a servo that provides a vertical scan rate of 4.7 scans per second. Each vertical scan line contains 512 pixels. For scanning in the azimuth direction, the entire camera rotates about the vertical axis in a stepwise fashion under servo control. The stepping movements occur between vertical line scans, while the mirror is reversing its scanning direction. Because pixel spacings of azimuth and elevation are equal, each pixel image element can be represented in a spherical coordinate system. The coordinate components of each image point are azimuth, elevation, and a gray level value.

The photosensor array (PSA) in Figure 3 consists of 12 silicon photodiodes, which include four focus-step, broadband (unfiltered) diodes (BB) with an angular resolution of 0.04° (high resolution), one survey (low resolution, wide angle field of view) diode, one diode for sun observation, and six multispectral photodiodes, three for color (red, blue, green) and three for near-infrared (IR1, IR2, IR3). The last eight photodiodes mentioned all have an angular resolution of 0.12° (low resolution). The two diferent scanning resolutions are achieved by placing either of two aperture sizes at selected distances from the lens. The light from objects in space reflected by the mirror is in sharp focus on the PSA. For black-and-white photographs, the four outer broadband diodes (Figure 4) are spaced at different distances from the lens so that objects at distances of 1.9 m, 2.7 m, 4.5 m, and 13.3 m are at best focus at locations BB1, BB2, BB3, and BB4, respectively. The apertures covering the survey diode and the rest of the photodiodes are placed at a focal plane appropriate for objects at 1.7 m to infinity. However, 3.7 m is the optimum focusing distance for these eight diodes.

The 512 pixels scanned in each vertical scan line cover 20.48° in the broadband modes and 61.44° in the survey and color modes. The depression angle of each picture, which is the depression angle of the center of the vertical scan, can be

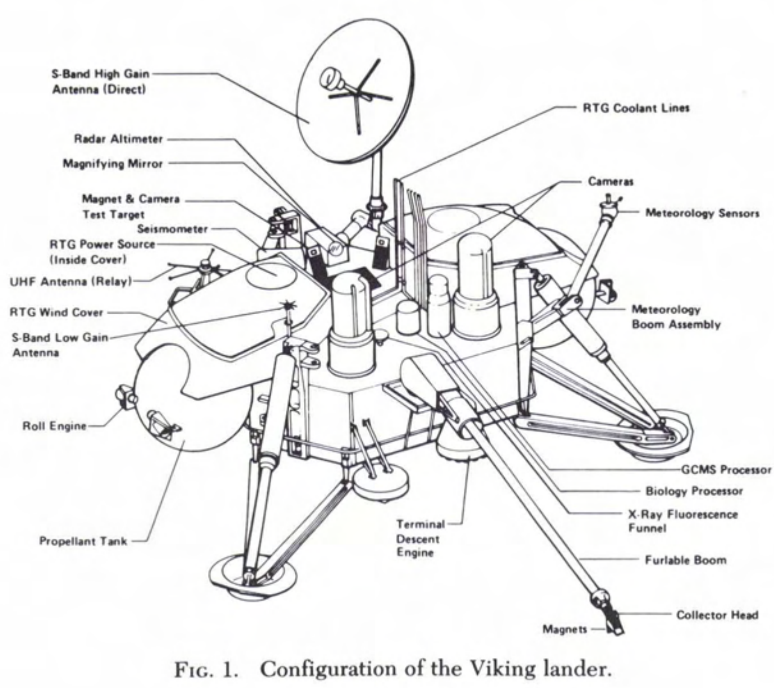


FIG. 1. Configuration of the Viking lander.

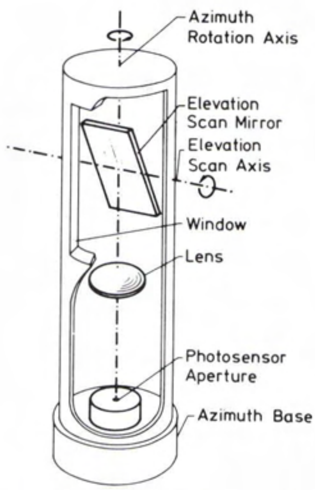


FIG. 2. Basic optical components of the facsimile camera.

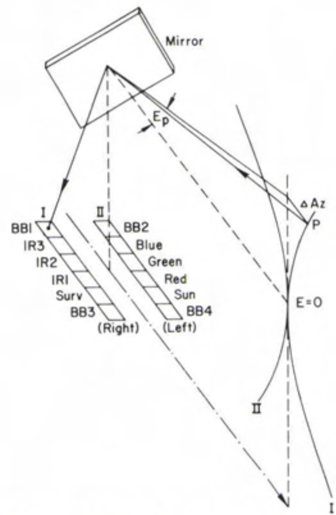


FIG. 4. Relation of coning corrections and photosensor array (PSA).

varied in 10° increments. The elevation of the entire field of view of the camera can be selected upon command to cover a field of view ranging from about 40° above to 60° below a plane perpendicular to the vertical axis of the camera. The picture width (azimuth direction) can be varied in 2.5° intervals up to 342.5°. If the azimuth of the first scan line and the depression angle of the center of the vertical scan are known, the azimuth and elevation of any pixel at either of the two resolutions can be determined.

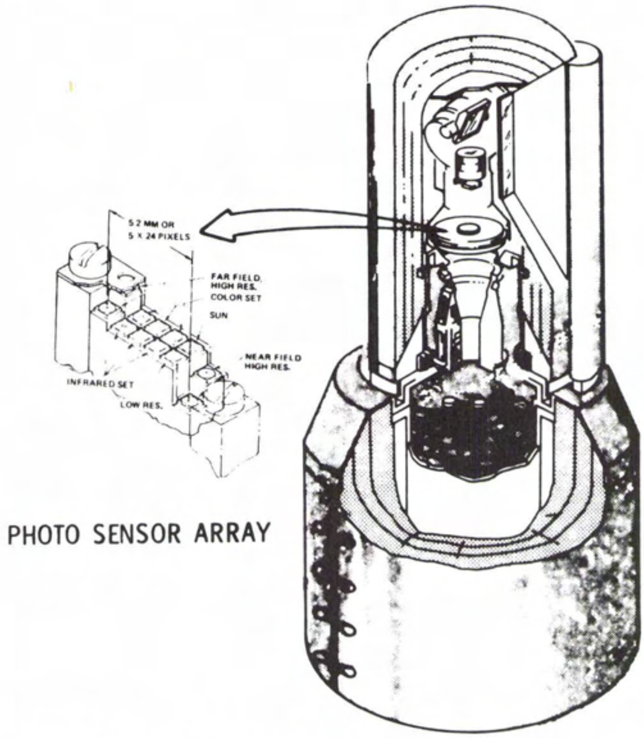


FIG. 3. Diagram of the facsimile camera and its photosensor array (PSA).

TABLE 1. MAGNITUDE OF CONING CORRECTIONS WHICH ARE A FUNCTION OF ELEVATIONS

	Elevation in degree	±0	±5	±10	±15	±20	±25	±30
Azimuth error	Angle (degree)	0.00	0.00	0.01	0.02	0.03	0.05	0.07
	Pixel no. (High-Resolution)	0.0	0.0	0.2	0.4	0.8	1.2	1.9
	Elevation in degree	±35	±40	±45	±50	±55	±60	
Azimuth error	Angle (degree)	0.11	0.15	0.20	0.27	0.37	0.58	
	Pixel no. (High-Resolution)	2.6	3.7	5.0	6.7	9.0	12.0	

The ground resolution of the facsimile camera imagery ranges from 2 mm at the footpad of the spaceraft to 8 mm at a distance of about 5.5 m (Mutch *et al.*, 1972). About half of the surface imagery obtained covers the area between 0.8 m and 2.3 m from the lander at resolutions ranging between 2 and 4 mm for the high-resolution image mode. At a camera height of 1.3 m above the Martian surface, the distance to the horizon, neglecting topographic relief, is approximately 3 km, at which distance the resolution is about 2 m per pixel (Huck *et al.*, 1975).

For the best surface contrast in black-and-white pictures, low sun elevation angles are recommended (Wu, 1976a). On the other hand, high sun elevation angles provide the best conditions for color and infrared imaging (Huck *et al.*, 1975).

Because each image element is obtained by scanning in both the azimuth and elevation directions, the photogrammetric accuracy of the facsimile camera is determined primarily by the performance of the servo mechanisms. Analyses by Huck *et al.* (1975) give maximum angular errors of ±0.15° and ±0.30° for azimuth and elevation, respectively, in the survey mode photography; and ±0.1° and ±0.2° for azimuth and elevation, respectively, in the high-resolution and multispectral photography. These figures include all errors of the servo mechanisms, position of the photosensor array, and the camera mounting deviations. The errors amount to less than two pixels in low-resolution photography, about three pixels in high-resolution photography along the azimuthal direction, and about twice these values in the elevation direction because of the mirror reflection. In the near field (between 1 and 10 m from the spacecraft), accuracy of ground points ranges from 1 to 70 mm.

However, because the photodiodes are off the optical axis by 0.48° in azimuth and the broadband diodes by 2.4° in elevation, the scan lines in the object space determined by the different mirror positions do not lie on a plane, but on a cone (Wolf, 1975). As shown in Figure 4, the lines are concave to the left for the six diodes on the right side of the axis (BB1 through BB3), and concave to the right for

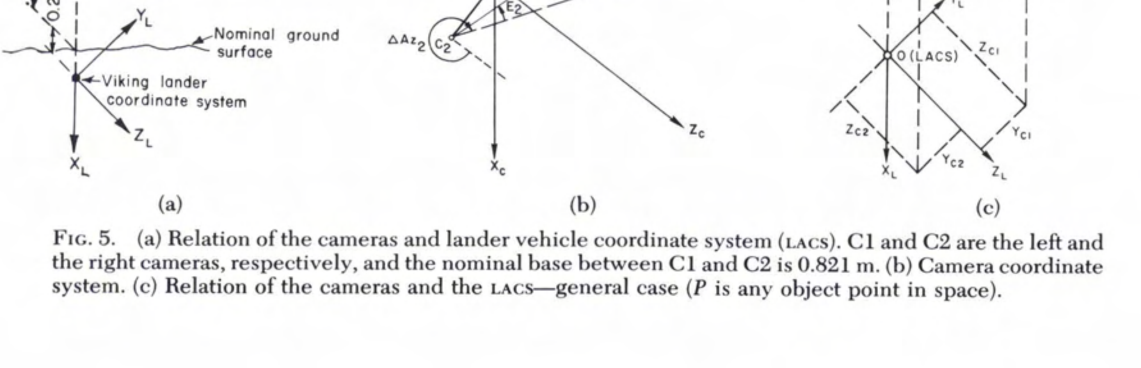


FIG. 5. (a) Relation of the cameras and lander vehicle coordinate system (LACS). C1 and C2 are the left and the right cameras, respectively, and the nominal base between C1 and C2 is 0.821 m. (b) Camera coordinate system. (c) Relation of the cameras and the LACS—general case (*P* is any object point in space).

TABLE 2. CAMERA CALIBRATION DATA FOR THE VIKING LANDERS (WOLF, M. R., JET PROPULSION LABORATORY, WRITTEN COMMUNICATION, 1976.)

Viking Lander	X_c (m)		Y_c (m)		Z_c (m)	
	Camera 1	Camera 2	Camera 1	Camera 2	Camera 1	Camera 2
1	−1.5835	−1.5831	0.4125	−0.4062	0.4691	0.4710
2	−1.5827	−1.5835	0.4081	−0.4091	0.4690	0.4685

the six diodes on the left side of the axis (BB2 through BB4). This configuration causes a systematic error in azimuth angles as a function of the elevation angle. The magnitude of the error is symmetric about the zero-elevation axis, as shown in both Table 1 and Figure 4.

The corrected azimuth, Az_p, is obtained by applying Equations (1a) and (1b) as follows (Itek Corp., 1974):

$$Az_p = Az_c + \Delta Az \qquad (1a)$$

$$\Delta Az = \text{Arc tan}\left(\frac{\tan \alpha}{\cos E}\right) - \alpha \qquad (1b)$$

In these, $\alpha = \pm 0.48°$; E is the elevation angle of the point in question; and α is positive for photodiodes BB2, blue, green, red, and BB4 at the left side, and negative for BB1, IR3, IR2, IR1, survey, and BB3 at the right side of the camera axis. Azimuth corrections, which are called coning corrections, are made during photograph rectification.

PHOTOGRAPH RECTIFICATION

We have tested two methods of photograph rectification. The first method performs an off-line computer rectification to convert the facsimile camera imagery to the equivalent of point-perspective frame pictures, thus enabling map compilation and other photogrammetric measurements in presently available stereoplotters. The second method—the ideal one—programs the necessary equations into a high-speed digital computer interfaced to one of the existing analytical plotters; thus, rectification computations and other corrections can be performed in real time, without linear interpolation, during the process of model orientation and map compilation.

TABLE 3. CALIBRATED BOLT-DOWN ERRORS AND CALIBRATED AXIS AZIMUTHS OF THE LANDER CAMERAS. CORRECTIONS ARE ADDED TO THE AZIMUTH AND ELEVATION OF EACH IMAGE ELEMENT. (DATA SUPPLIED BY M. R. WOLF, JET PROPULSION LABORATORY, WRITTEN COMMUNICATION, 1976.)

LANDER 1				
	Azimuth of Z-axis		Elevation Correction	
Camera	Bolt-down Error	Corrected Azimuth	High Resolution	Low Resolution
1	+0.79°	261.29°	−0.123°	−0.185°
2	+0.20°	84.70°	−0.025°	−0.083°

LANDER 2				
	Azimuth of Z-axis		Elevation Correction	
Camera	Bolt-down Error	Corrected Azimuth	High Resolution	Low Resolution
1	+0.87°	261.37°	0	0
2	+0.10°	84.60°	0	0

To project the imagery from a spherical surface to a plane, a gnomonic projection is employed. 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 photograph. The principal point of the rectified photograph can be somewhat arbitrarily located but must correspond to the point of tangency between the sphere and the projection plane. In fact, because the presently available analytical plotters such as the AP/C (Ottico Meccanica Italiana, 1966), have tilt-angle limitations of 25°, the reduction of the tilt angle of the photograph is best accomplished during the rectification process by simply determining where the projection plane is made tangent to the sphere.

The camera axis of the equivalent frame picture can be set at any azimuth but is usually selected in such a manner that the axes of the two cameras are parallel and normal to their base. If Az_p and Az_o are, respectively, the azimuth of any image point P referring to the zero-azimuth of the Lander system and of the selected camera axis, and E_p and E_o are, respectively, the elevations of point P and of the selected camera axis, then the converted photo coordinates x and y along the azimuth and elevation directions are (Richardus and Adler, 1972)

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

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

where $\Delta\lambda = Az_p - Az_o$

The rectification can be performed pixel-by-pixel using a general-purpose computer with magnetic tape output to a raster printer, such as an

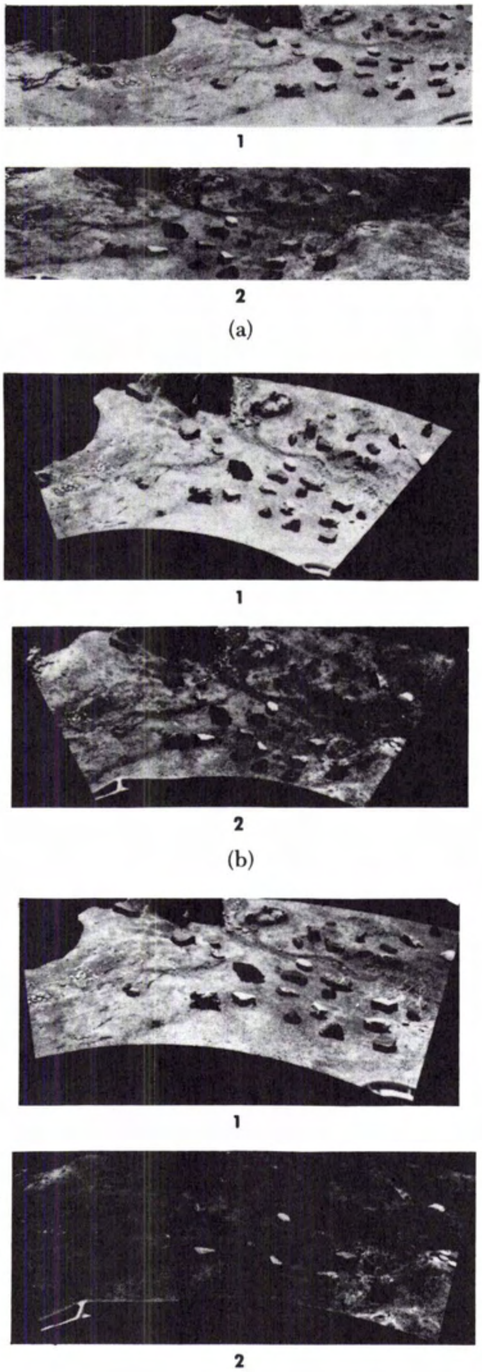


FIG. 6. (a)Unrectified photographs of the Red Rock Science Test Site (depression angle = 30°). (b) Rectified photographs of the Red Rock Science Test Site (depression angle = 65°; i.e., tilt angle = 25°). (c) Rectified photographs of the Red Rock Science Test Site (depression angle = 20°; i.e., tilt angle = 70°).

TABLE 4. PRECISION AT VARIOUS RANGES ALONG THE Z-AXIS OF LACS

Ground Distance (m)	1	2	3	4	5	6	7	8	9	10
Standard error (mm)	2	7	16	27	43	61	84	109	138	170

Optronics Photowrite. The Optronics writes the image on photosensitive film wrapped around a uniformly rotating drum.

This experiment was performed on a PDP 11/45 minicomputer using a program which performs linear interpolations between the points of a 40 by 20 control grid. In other words, using Equations 2a and 2b, the conversion was not made pixel-by-pixel: only the 800 points of the control grid were converted. This number is small in comparison with the 800,000 pixels of a 60° by 20.5° picture. In this case, the linear interpolation produced errors as large as 15 mm on the ground; the degree of error is dependent on the magnitude of the original depression angle of the facsimile photograph, which determines the tilt angle of the rectified photograph.

The coning correction, as previously discussed and expressed in Equations 1a and 1b, is applied to Az_c (the azimuth of the image point) before rectification is made.

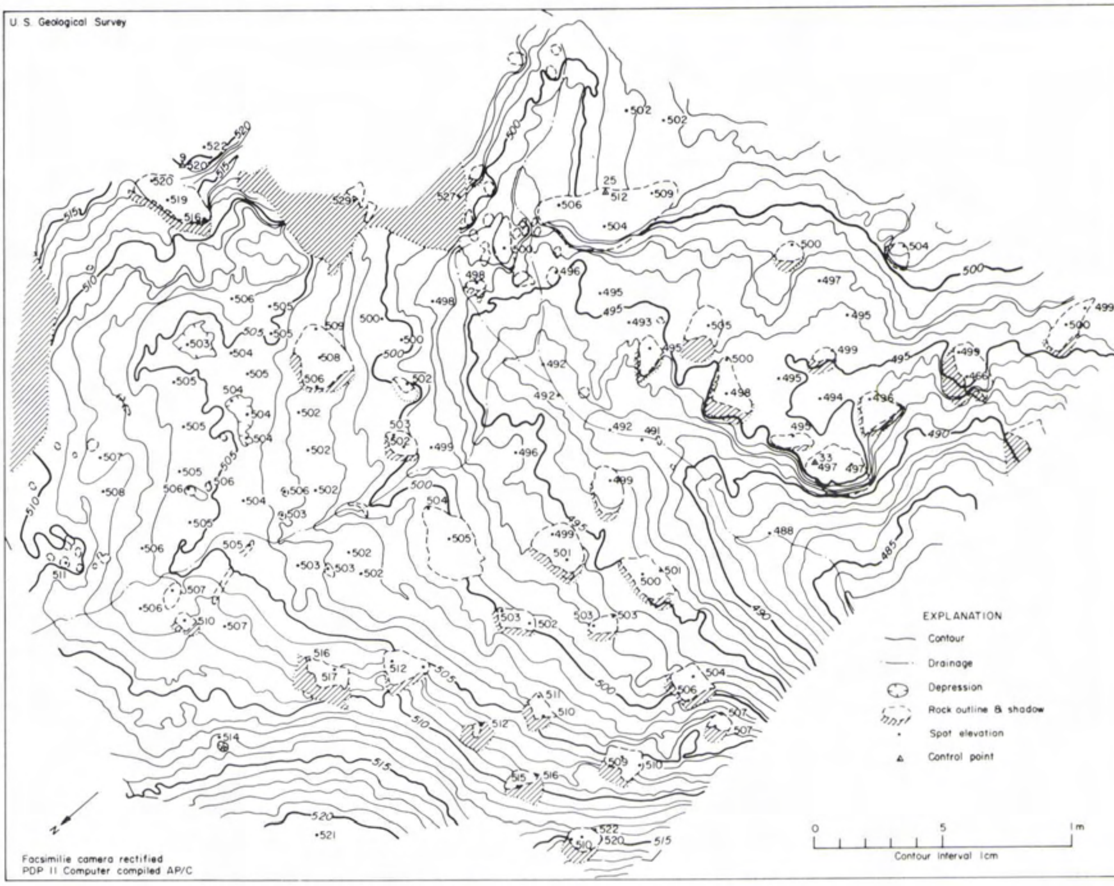
Examples of photo-rectifications are discussed in later sections.

To accomplish the ideal solution to the stereo mapping problem of the Viking lander imagery, a Modcomp minicomputer with 64,000 words of core memory was interfaced with one of the AS-11A analytical plotters at the Branch of Astrogeologic Studies, U.S. Geological Survey, Flagstaff, Arizona. This plotter computer is now able to use unrectified raw pictures taken by facsimile cameras for map compilation on the plotter.

DETERMINATION OF CONTROL POINTS

Each pixel, or image element, of the Viking lander imagery has an azimuth and elevation angle associated with it. Using this information along with the predetermined depression angle of each picture and the fixed camera base for a stereo pair of unrectified photographs, the coordinates of control points for the map compilation can be obtained from a pure analytical solution. The computed coordinates are referred to the lander vehicle coordinate system (LACS) (von Struve, 1975), as one purpose of the mapping was to provide spatial information for guiding the soil sampler.

The camera coordinate system (Figure 5a) is set up so that the Y-axis coincides with the line connecting the two cameras, with the positive direction toward camera 1 (the left camera). The X-axis is a line normal to the Y-axis through the midpoint (origin) between the cameras, with the positive direction toward the foreground. The X-axis is per-



VIKING LANDER - RED ROCK TEST SITE

FIG. 7. Contour map of the Red Rock Science Test Site compiled on the AP/C analytical plotter from rectified photographs shown in Figure 6b.

pendicular to the Y- and Z-axes and positive in the downward direction toward the ground to form a right-hand system. In this system, as shown in Figure 5b, the X_c, Y_c, and Z_c coordinates of a ground object in the camera system are

$$Z_c = \frac{b}{\tan \Delta Az_1 - \tan \Delta Az_2} \tag{3a}$$

$$Y_c = -Z_c \tan \Delta Az_1 + \tfrac{1}{2}b \tag{3b}$$

or

$$= -Z_c \tan \Delta Az_2 - \tfrac{1}{2}b \tag{3b$'$}$$

Adding Equations 3b and 3b′,

$$Y_c = -\tfrac{1}{2}Z_c\,(\tan \Delta Az_1 + \tan \Delta Az_2) \tag{3c}$$

$$X_c = -Z_c \frac{\tan E_1}{\cos \Delta Az_1} \tag{3d}$$

or

$$= -Z_c \frac{\tan E_2}{\cos \Delta Az_2} \tag{3d$'$}$$

Adding Equations 3d and 3d′,

$$X_c = -\tfrac{1}{2}Z_c\left(\frac{\tan E_1}{\cos \Delta Az_1} + \frac{\tan E_2}{\cos \Delta Az_2}\right) \tag{3e}$$

where ΔAz_1 and ΔAz_2 and E_1 and E_2 are the azimuth and elevation elements of the point in question in photo 1 and photo 2, respectively; and b is the camera base.

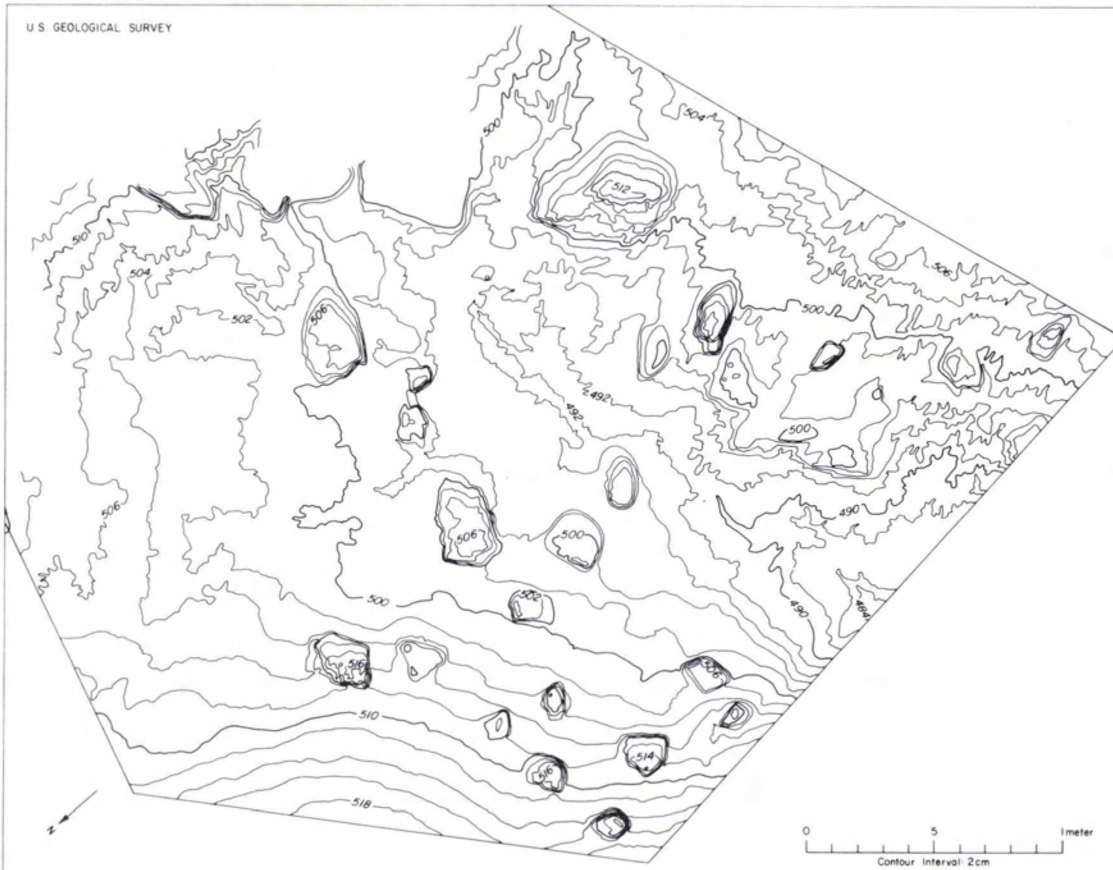
Then, as shown in Figure 5a, the LACS is simply the result of linear translations along the X and Z axes of the camera coordinate system. That is,

$$Z_L = Z_c + 0.4699 \text{ m} \tag{4a}$$

$$Y_L = Y_c \tag{4b}$$

$$X_L = X_c - 1.584861 \text{ m} \tag{4c}$$

Equations 3 and 4 as well as the relation of the cameras and the LACS as shown in Figure 5a are



VIKING LANDER RED ROCK TEST SITE

FIG. 8. Contour map of the Red Rock Science Test Site compiled on the Wild Autograph A-5 from rectified photographs shown in Figure 6c.

the ideal case. The actual camera installation is not always perfect: The Z_L axis does not usually pass exactly through the middle point of the two cameras, and the camera base is not usually exactly parallel to the Y-axis of the LACS, as shown in Figure 5c and Table 2. The actual camera condition may be expressed with the following inequalities:

$$X_{c1} \neq X_{c2}, |Y_{c1}| \neq |Y_{c2}|, Z_{c1} \neq Z_{c2}$$

Table 2 lists the values obtained from the camera calibration.

Equations 3 and 4, used for computing control points, are then modified to Equations 5 and 6.

$$\Delta Z_L = \frac{b_L}{\tan(\Delta Az_1 - \epsilon_H) - \tan \Delta Az_2} \qquad (5a)$$

where

$$b_L = \Delta Y_{12} = Y_{c1} - Y_{c2}$$

$$\Delta Az_1 = Az_{p1} - Az_{c1}$$

$$\Delta Az_2 = Az_{p2} - Az_{c2}$$

$$\epsilon_H = \frac{\Delta Z_{12}}{Z_c} \sin \Delta Az_1 \cos \Delta Az_1$$

Az_{c1} and Az_{c2} are calibrated azimuths of camera axes 1 and 2, respectively; they are listed in Table 3. Z_c can be approximated by using Equation 3a, where

$$b = \sqrt{\Delta X^2_{12} + \Delta Y^2_{12} + \Delta Z^2_{12}} \text{ and } \Delta X_{12} = X_{c1} - X_{c1}; \text{ etc.}$$

This modification is made to fix the position of camera 2 and to shift the position of camera 1 (C_1) to C_{1L}, so that the camera base is parallel to the Y-axis of the LACS. The small angle ϵ_H is the azimuth change of a point in question due to the shift of camera 1.

$$\Delta Y_{L1} = \Delta Z_L \tan(\Delta Az_1 - \epsilon_H) \qquad (5b)$$

$$\Delta Y_{L2} = \Delta Z_L \tan \Delta Az_2 \qquad (5c)$$

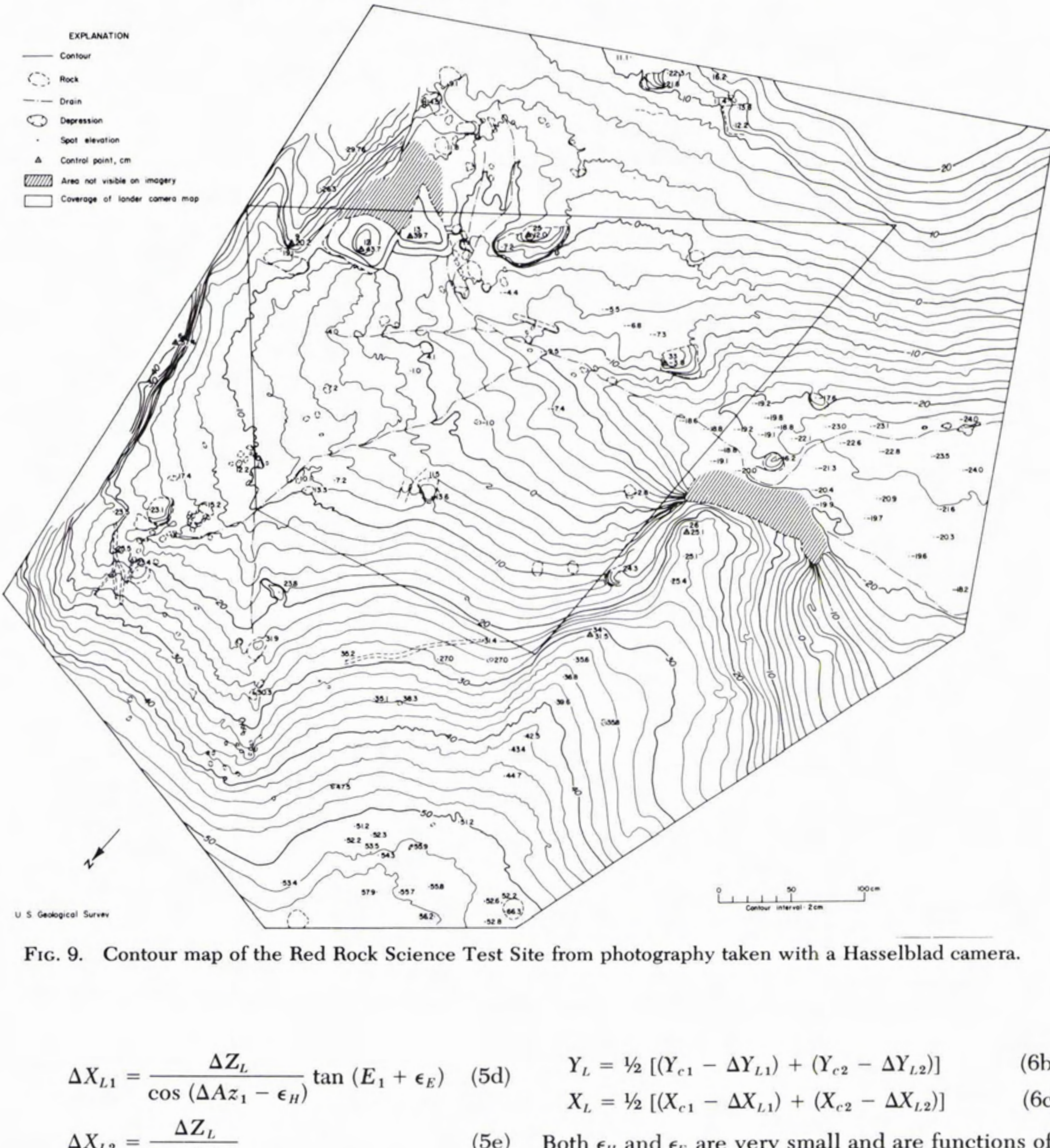


FIG. 9. Contour map of the Red Rock Science Test Site from photography taken with a Hasselblad camera.

$$\Delta X_{L1} = \frac{\Delta Z_L}{\cos(\Delta Az_1 - \epsilon_H)} \tan(E_1 + \epsilon_E) \quad (5d)$$

$$\Delta X_{L2} = \frac{\Delta Z_L}{\cos \Delta Az_2} \quad (5e)$$

where ϵ_E (not shown in Figure 5c) is the small change in the elevation angle at camera station 1 due to the position shift of camera 1.

$$\epsilon_E = \frac{\cos E_1 \cos \Delta Az_1}{Z_c}(\Delta X_{12} \cos E_1 - \Delta Z_{12} \sin E_1) \quad (5f)$$

The coordinates of control points in the LACS are then obtained by:

$$Z_L = Z_{c2} + \Delta Z_L \quad (6a)$$

$$Y_L = ½\,[(Y_{c1} - \Delta Y_{L1}) + (Y_{c2} - \Delta Y_{L2})] \quad (6b)$$

$$X_L = ½\,[(X_{c1} - \Delta X_{L1}) + (X_{c2} - \Delta X_{L2})] \quad (6c)$$

Both ϵ_H and ϵ_E are very small and are functions of ΔZ_{12} and the range of the point in question. When ΔZ_{12} and ΔX_{12} become zero, meaning that the camera base coincides with the Y-axis of the LACS, then Equations 5a to 5e become Equations 3a to 3e.

After all geometric corrections are made to the lander imagery, the precision of the range computations along the Z-axis, based on Equation 3a and a resolution of one pixel, is given in Table 4.

PRE-MISSION TESTS

A series of pre-mission tests was conducted to evaluate the performance of the Viking lander cameras, the digital photographic rectification

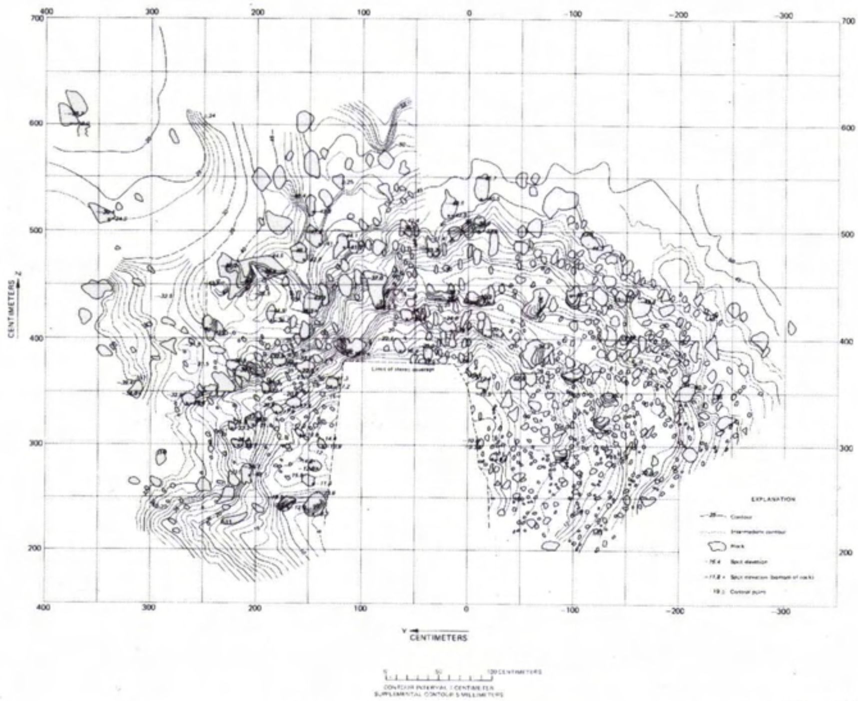


FIG. 10. Topographic map of Viking 1 landing site. Elevations are referred to X-axis of the Lander Coordinates system.

method, and techniques of map compilation. The tests took place at the Red Rock Science Test Site of the Martin Marietta facility, Denver, Colorado. Figures 6a(1) and 6a(2) are unrectified photographs of the site, taken with a facsimile camera of the simulated Viking lander spacecraft. The broadband high-resolution diodes were used; both pictures were taken at a 30° depression angle. Figures 6b(1) and 6b(2) are computer rectified portions of Figures 6a(1) and 6a(2), respectively. These converted pictures are not only equivalent to a pair of point-perspective pictures, but each picture also has a depression angle of 65°. In other words, the pictures have a 25° tilt angle with respect to the local vertical, which is equivalent to the tilt angle of 25° of an aerial photograph. This procedure allows the photography to be within the 25°-tilt-angle limitation of the AP/C analytical plotter so that map compilation can be accomplished on that plotter. The contour map compiled from this model on the AP/C analytical plotter is shown in Figure 7.

Figures 6c(1) and 6c(2) are computer-rectified photographs of the same portions of Figures 6b(1) and 6b(2), respectively, but with a depression angle of 20°, thus permitting map compilation in the Wild Autograph A-5 in the terrestrial mode. The contour map compiled from this model on the A-5 is shown in Figure 8. This map and that shown in Figure 7 were compiled at a scale of 1:10 with a contour interval of 1 cm on the AP/C and 2 cm on the A-5. A comparison of these two maps with that shown in Figure 9, which was compiled from a model of conventional aerial photography taken with a Hasselblad camera, shows elevation differences of ± 3 cm. (Control points of all three maps were obtained by field survey.) The magnitudes of the differences are symmetric about a zero difference axis. They might be caused by the fact that coning corrections to the azimuth angles were not available and not applied at the time of the test. By applying the coning corrections in a subsequent series of tests, elevation differences between maps compiled from lander camera imagery and maps compiled from conventional camera imagery were reduced to about ± 1 cm, and approximately 60 percent of the points compared have no error. Horizontal displacements on the maps are no larger than 2 mm, which represent 2 cm on the ground.

TERRAIN MAPPING OF THE LANDER SITES

The landing coordinates of Lander 1 are 22.46° N and 48.01° W, and those of Lander 2 are 47.89° N and 225.86° W on Mars. Lander 1 landed facing southeast with a tilt angle of 2.99° from the horizon and a tilt azimuth of 285.174°; the azimuth of the

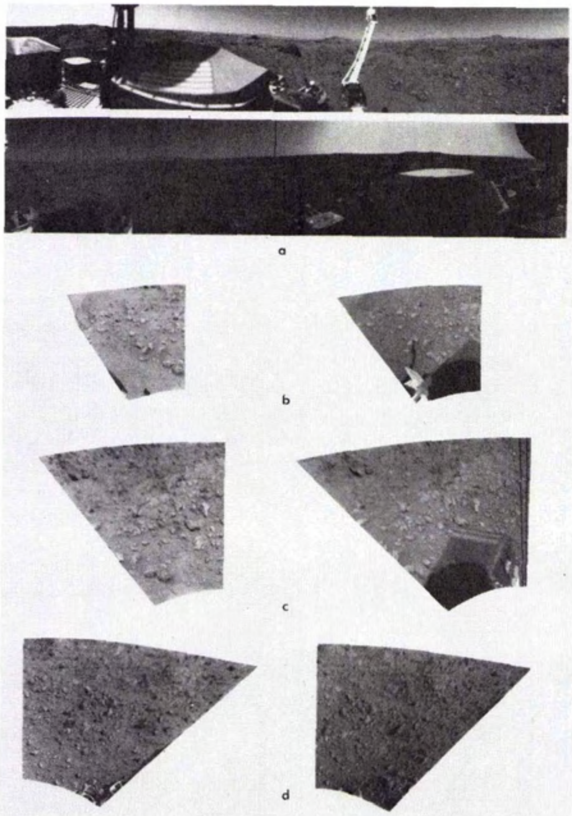


FIG. 11. Low-resolution photographs of the Viking 1 landing site taken with survey-mode diodes and used in compiling the topographic map of the landing site shown in Figure 10. (a) Unrectified pictures from the two cameras; left is from camera 1 and right is from camera 2. (b) Rectified far left portions 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 130.0°. (Angles are referred to azimuths of each camera axis, that is to say, 261.29° and 84.70°, respectively, for cameras 1 and 2.)

rear leg of the spacecraft is 321.905° which is the angle measured clockwise from North to the line connecting the rear leg and the origin of the LACS (Figure 5a). Lander 2 landed facing northwest with a tilt angle of 8.207° from the horizon and a tilt azimuth of 277.696°; the azimuth of the rear leg is 209.103°

Using combinations of pictures taken with the broadbands, survey modes, and the color diodes, topographic contour maps of the area surrounding the two landers were compiled at a scale of 1:10 with a contour interval of 1 cm. By using Equations 6, control points were also established for controlling the compilation of each landing area. However, because the purpose of these maps was to support mission operations and other spacecraft-related scientific investigations, control points were determined in the Lander Coordinate System (LACS).

Due to the bolt-down error of each camera on each lander, corrections had to be made to both azimuth and elevation of each image element. These corrections used the calibration data of Table 3, and were made before any other corrections such as the coning correction.

TOPOGRAPHIC MAPPING OF THE LANDER 1 SITE

To guide sampling during the Viking mission, several topographic maps of the area surrounding Viking Lander 1 were compiled on the AP/C analytical plotter. One map (Figure 10) covers the area surrounding the spacecraft where stereo photographic coverage is sufficient. The pictures used are from the low-resolution diodes of the survey mode of the two cameras on Lander 1. Figure 11(a) shows the unrectified pictures; Figures 11(b) through (d) are rectified portions of the same pair shown in Figure 11(a). As the survey-mode pictures are low resolution (each pixel = 0.12°) and cover azimuths ranging from 10° to 310°, the rectifications were made in three separate parts from each picture of the two cameras. The entire map was compiled by setting up four models comprised of combinations of the rectified parts. The photographic data as well as the parameters for the rectified picture portions are listed in Tables 5-a and 5-b. Twenty-six control points were computed for controlling the stereo models from which the map was compiled. The measurements were made from the same pair of survey-mode pictures that is shown in Figure 11. The photogrammetric procedure is to mark pass points on a wild PUG III and then to measure them on a Mann comparator.

TABLE 5-a. PARAMETERS FOR THE UNRECTIFIED PICTURES USED IN COMPILING THE TOPOGRAPHIC MAP SHOWN IN FIGURE 10

Camera	PSA Diodes	Depression Angle	Azimuth		Sun Elev.	Picture ID and Date (Sol)
			Start Az.	End Az.		
Left (1)	Survey	−10.185°	10.0°	310.0°	60.6°	11A018/003
Right (2)	Survey	−10.083°	10.0°	310.0°	37.0°	12A002/000

TABLE 5-b. PARAMETERS FOR THE RECTIFIED PORTIONS OF THE PICTURES USED IN COMPILING THE TOPOGRAPHIC MAP SHOWN IN FIGURE 10

Camera	Portion	Azimuth of Camera Axis	Azimuth Range Rectified	Tilt Angle After Rectification	Picture ID and Date (Sol)
Left (1)	Far left	236.00°	200.0°–236.0°	25°	11A018/003
	Left	261.35°	220.0°–261.29°	20°	
	Right	261.35°	261.29°–310.0°	20°	
Right (2)	Far left	60.00°	20.0°–60.0°	25°	12A002/000
	Left	84.67°	36.0°–84.67°	20°	
	Right	84.67°	84.67°–130.0°	20°	

Equations 6 and 1 were used to correct and to compute the coordinates of the points.

TOPOGRAPHIC MAPPING OF THE LANDER 2 SITE

Due to the fact that the sun azimuths were in opposite directions when the two survey-mode pictures were taken by the two cameras of Lander 2, they cannot be used as a stereo pair for mapping. Therefore, the topographic map of the Viking 2 landing site, as shown in figure 12, was compiled from the combination of the color pictures (red diode) and the survey-mode pictures by setting four models on the AP/C analytical plotter. The

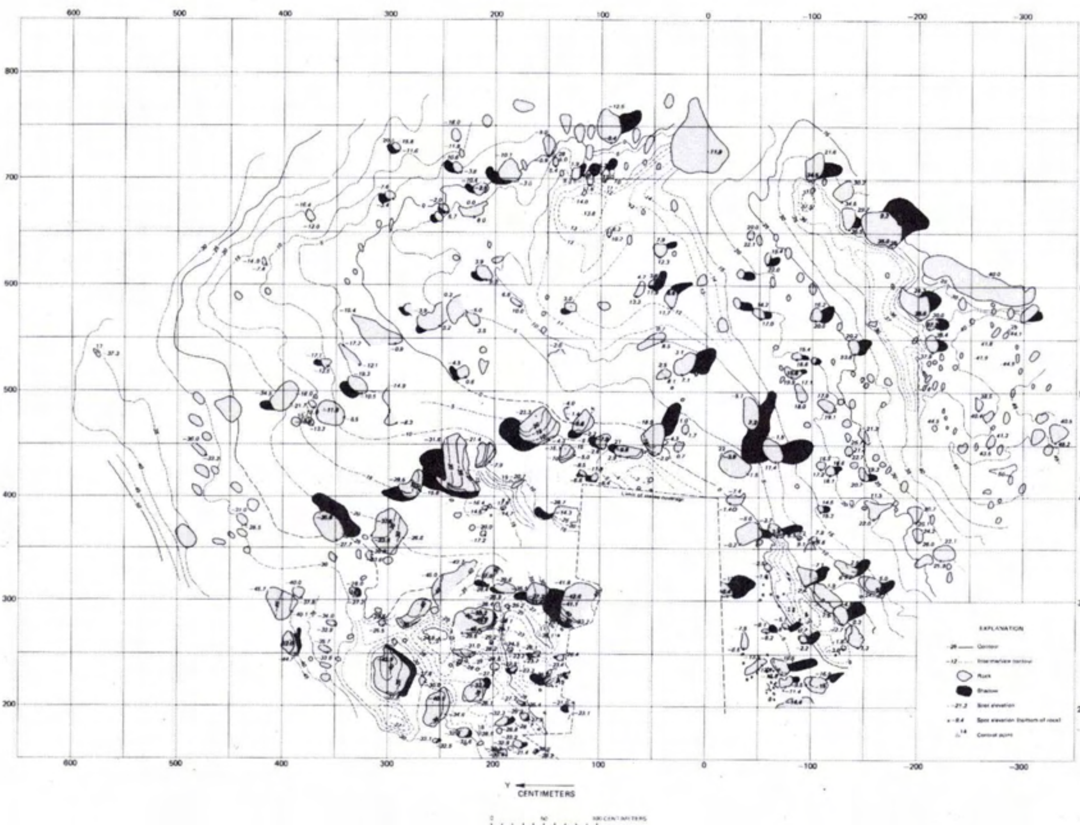


FIG. 12. Topographic map of Viking 2 landing site. Elevations are referred to X-axis of the Lander Coordinates System. (Shadows are shown in different directions because the pictures used for map compilation were taken with sun azimuths in different directions.)

TABLE 6-a. PARAMETERS OF THE UNRECTIFIED PICTURES USED IN COMPILING THE TOPOGRAPHIC MAP SHOWN IN FIGURE 12

Camera	PSA Diodes	Depression Angle	Azimuth		Sun Elev.	Picture ID and Date (Sol)	Shown in fig. 13 as:
			Start Az.	End Az.			
Left (1)	Survey	−10.0°	165.0°	302.5°	21.4°	21A025/003	a1
	Red	−10.0°	197.5°	335.0°	46.7°	21A028/004	a2
Right (2)	Red	0.0°	15.0°	80.0°	50.7°	22A016/002	a3
	Survey	−10.0°	10.0°	325.0°	51.6°	22A002/000	a4
	Red	−20.0°	80.0°	155.0°	49.4°	22A003/000	a5

pictures used are listed in Tables 6-a (unrectified pictures) and 6-b (rectified portions). Due to the reduction of the depression angle from −10° to −65° (for a tilt angle of 25°), rectification is limited to an azimuth range of less than 60°. Also, the portion of the picture above the horizon is omitted in each of the rectifications.

By using the same methods and procedures as were used for the Viking Lander 1, 18 control points were computed with measurements made on the two survey-mode pictures 21A025 and 22A002.

Unlike the maps produced from the Ranger system, in which contour lines were superimposed on the lander pictures in their unrectified ground-reconstruction format (Liebes and Schwartz, 1977), these two maps (Figures 10 and 12) are in orthographic projection with the Viking lander coordinate system (Itek Corp., 1972; von Struve, 1975).

CONCLUSION

The series of pre-mission tests proved that the facsimile cameras on Viking Landers 1 and 2 could provide stereo imagery on which accurate topographic data can be based. After the spacecraft landed on the Martian surface, the imagery sent back showed their cameras to be especially efficient for the collection of photographic data. The solution to the photogrammetric mapping problem of the Viking lander imagery has proven to be proper and accurate. The most accurate methods of mapping the two Viking lander areas are (1) to do the computerized rectifications on a large computer where a pixel-by-pixel conversion can be made, or (2) to make all conversions and corrections in real time on the AS-11A plotter. This latter method avoids the error in linear interpolation of the GEOM stretch method. In either method, maps of the lander sites should also be transferred to the local vertical system (Wu, 1975) by using the tilt-angle information of each lander. With the present state of digital image processing technology, photo-computerized rectification and photo enhancement could be more broadly applied in the photogrammetry community.

ACKNOWLEDGMENTS

The solution of the photogrammetric mapping problem of Viking lander imagery involved many people, all of whom, including those who made critical comments, contributed significantly to its success. Credit goes to the members of the Photogrammetry Section of the Branch of Astrogeologic Studies, especially to James J. Stapleton and Loretta Barcus for their programming of the photo

TABLE 6-b. PARAMETERS OF THE RECTIFIED PORTIONS OF THE PICTURES USED IN COMPILING THE TOPOGRAPHIC MAP SHOWN IN FIGURE 12

Camera	Portion	Azimuth of Camera Axis	Azimuth Range Rectified	Tilt Angle After Rectification	Picture ID and Date (Sol)	Shown in fig. 13 as:
Left (1)	Far left	236.42°	170.92°~236.42°	25°	21A025/003	
	Left	261.42°	211.42°~261.42°	25°	21A028/004	b1
	Center	261.42°	241.42°~287.50°	25°	21A025/003	
	Right	261.42°	261.42°~304.04°	25°	21A025/003	c1
Right (2)	Far left	59.72°	15.22°~59.72°	25°	22A016/002	
	Left	84.72°	34.72°~84.72°	25°	22A002/000	b2
	Center	84.72°	80.22°~100.00°	25°	22A003/000	
	Right	84.72°	84.72°~127.00°	25°	22A003/000	c2

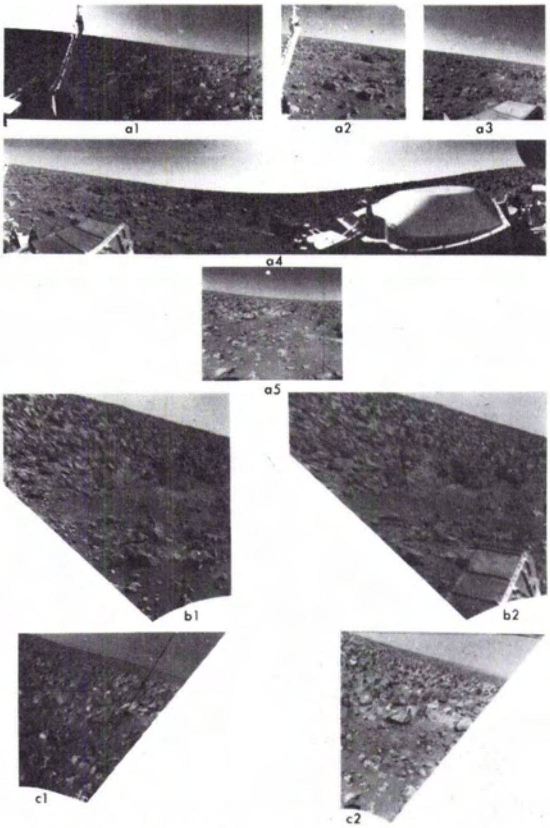


FIG. 13. Low resolution survey-mode and color-mode photographs used in compiling the topographic map of the Viking 2 landing site shown in Figure 12. Unrectified pictures 21A025, 21A028, 22A016, 22A002, and 22A003 are shown by a1 through a5, respectively. Examples of rectified portions used for compilation of the map are shown by b1, b2, c1, and c2.

rectification, and to Raymond Jordan for his dedicated efforts in the test work on the A-5 plotter. Special thanks go to members of the Image Processing Section of the U.S. Geological Survey for allowing the use of their GEOM program for photorectification.

Particular acknowledgement is expressed to Dr. Elliot Morris, the project chief of the Viking lander project. Without his support, this problem would not have been solved.

This study was performed under NASA contracts W-14,585 and L-9718.

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(Received 12 February 1981; revised and accepted 27 December 1981)