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Guide to the Use of Mariner Images

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16. Abstract

Planetary imaging from unmanned spacecraft is almost exclusively done by digital systems. The Mars Mariner 9 television camera is representative of such systems. The image consists of 700 lines, each containing 832 picture elements, or pixels. Each pixel contains nine binary bits of information capable of displaying 512 discrete brightness levels. The photo interpreter using these images must be aware of several problems inherent in television systems. These include non-uniform target response, residual images, noise, and blemishes. These defects can be removed to some extent by decalibration of the image. The final product is geometrically corrected for camera distortion and photometrically corrected. Several versions of the decalibrated images are available. The most generally useful are the geometrically corrected images with enhanced contrast. A summary of Mariner 10 imaging of Mercury is also included.

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PREFACE

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ABSTRACT

Planetary imaging from unmanned spacecraft is almost exclusively done by digital systems. The Mars Mariner 9 television camera is representative of such systems. The image consists of 700 lines, each containing 832 picture elements, or pixels. Each pixel contains nine binary bits of information capable of displaying 512 discrete brightness levels. The photo interpreter using these images must be aware of several problems inherent in television systems. These include non-uniform target response, residual images, noise, and blemishes. These defects can be removed to some extent by decalibration of the image. The final product is geometrically corrected for camera distortion and photometrically corrected. Several versions of the decalibrated images are available. The most generally useful are the geometrically corrected images with enhanced contrast. A summary of Mariner 10 imaging of Mercury is also included.

I. INTRODUCTION

Planetary photointerpretation is beginning to acquire the status of an established discipline. Therefore, it is necessary for the investigator to gain some familiarity with the techniques for acquiring and enhancing pictures. Since television cameras have been used almost exclusively as the imaging device on all unmanned spacecraft – Lunar Orbiter with its film system is a notable exception – our remarks have applicability extending beyond the Mars and Mercury Mariner missions. There are a number of sources of additional information, in particular, Cutts (1974) and Danielson et al. (1975). The discussion to follow applies to Mariner 9 images. A summary of the Mariner 10 (Mercury) camera and images is included at the end.

II. MARINER 9 INSTRUMENT DESCRIPTION

The Mariner 9 cameras are similar to those used in commercial television (Masursky et al., 1970). The system is entirely electronic, capitalizing on the use of an image tube, the vidicon. The camera is similar to a conventional film camera with a photoconductive target substituted for the photographic film. The scene is recorded on the target by opening and closing a shutter. An image is focused onto the target, increasing the conductivity at each point. The inside face of the target acquires an electrical charge proportional to the intensity of light. As the target is scanned with a narrow-beam focusable electron gun, electrons are supplied to the target, creating variations in the output electrical signal. The entire image is recorded on the target plate but it is read line by line by the electron gun. Output signal strengths are recorded as the electron beam scans the target. Variations of signal strength can be related to light intensity at each point on the target. Finally, the vidicon signals are converted to a digital form and telemetered back to Earth.

Each picture comprises 700 lines. Each digitized line contains 832 picture elements, or pixels. For each of these pixels, there are 512 brightness levels. In brief, then, the pictures we examine are mosaics of 582,400 points with varying brightnesses. Since a pixel contains nine binary bits, each photograph represents a total of more than five million bits of information.

Each camera system consists of optical elements, filters, and shutter in addition to the vidicon. The wide-angle A-camera has a 50-mm focal length lens and an eight-position filter wheel. Filter passbands in the orange, blue, and green parts of the visible spectrum permit acquisition of color data, especially if the same region is imaged in all three spectral bands under similar illumination conditions. Details of filter spectral transmittance may be found in Snyder (1971). Unfortunately, since the filter wheel mechanism failed early in the Mariner 9 mission, the majority of pictures were taken through a polarizing filter. The narrow-angle B-camera has a 500-mm focal length lens with a fixed haze filter designed to block out the blue end of the spectrum. The shutter in each camera is positioned near the vidicon target.

Knowing how the camera works, some of its shortcomings can be appreciated. The optics introduce very little distortion, but the vidicon tube has some frustrating liabilities. It is very difficult to construct a target that is uniform over its entire surface. During the mission the left side of the Mariner 9 camera became somewhat more sensitive relative to the right side. (This sensitization may have resulted from similar lighting geometry throughout the mission. Most of the pictures were taken near the evening terminator, causing the left side of the image to be brighter than the right.) Target response also varies as a function of temperature and time. For these several reasons precise photometric correlations are impossible. Another serious problem arises because the electron beam is unable to completely discharge the scanned surface, even after several repeated scans. The result is a residual image observable in successive pictures, something like a double exposure in conventional photography. Another problem is geometric distortion of the image, which results from deflection of the electron beam arising from various sources, including variations in target conductivity. Accordingly, the amount of deflection varies with light level in the scene. Electrical noise, both random and coherent, may be superposed on the image-related signal for any number of reasons, including faulty circuit design. Finally, blemishes on the conductive target and dust shadows on the lens must be recognized so they do not lead to faulty interpretations. The removal of all these effects is termed decalibration.

III. DESCRIPTION OF IMAGE DATA

The Mariner 9 pictures were transmitted to Earth in digital form. Usually, 31 to 33 frames were recorded on a tape recorder aboard the orbiter during a single revolution about Mars. The entire tape load was then transmitted to the Deep Space Network on Earth. Data were again recorded on tape and relayed to the JPL Space Flight Operations Facility (SFOF) over high-speed data lines. The first version of the pictures was then produced by the Mariner 9 Mission Test Computer/Mission Test Video System (MTC/MTVS) (Levinthal et al., 1973). Basically, the computer assembles the data in picture format, and the video system prepares a permanent file copy. Several versions of each frame were produced (Fig. 1). The raw picture approximately duplicates what the camera actually recorded – a very flat low-contrast scene with geometric and shading distortions. The second version includes rudimentary photometric corrections for camera shading. Two other versions were produced to enhance topographic details. These are a horizontal high-pass filter (HPF) and a vertical automatic-gain-control (VAGC) version. Early in the mission one or the other of these versions was used, but later frames were modified by both filter transformations. These versions are termed "stretched," a digital process that enhances contrast. For most users, the stretched versions are the most attractive and meaningful. A comprehensive label appears beside each MTVS picture (Fig. 2). The label data were preliminary and must always be verified. All of the MTC/MTVS versions were recorded on 70-mm film, from which positive transparencies were made for distribution to experimenters and to the National Space Science Data Center (NSSDC). The NSSDC is responsible for public distribution of the data.

IV. DECALIBRATION

As useful as the MTVS versions of the images are for displaying the surface detail of Mars, further processing is required to allow photometric or geometric measurements. Especially important is the decalibration previously discussed – removal of photometric distortions, geometric distortions, and residual images. Digital computer processing to produce a final archival version of the images was done by the JPL Image Processing

Laboratory (IPL). The final data set is called the Television Reduced Data Record (TV RDR, or simply RDR). Technically, the RDR exists as magnetic tape containing the numerical data for each frame in a form such that each picture element is represented by a data number (DN) proportional to the luminance in the corresponding point in the scene. Data on the magnetic tape has been converted to photographic prints in two enhanced versions. One is given a linear contrast stretch that portrays correct relative brightness differences throughout the frame; the other is high-pass-filtered and given a contrast stretch that emphasizes topographic detail (Fig. 3).

The RDR pixel format differs from that of the MTVS in that the pixels have been squared and scaled so that 1 mm on the vidicon tube equals 75 pixels in the RDR picture. The resultant format includes 800 lines, each with 950 samples, or pixels. The original DN range of 9 bits is retained; each pixel may have a DN value of 0 (black) through 511 (saturated white). For photometric work the actual numbers from the RDR tapes should be used in preference to the gray levels recorded on the film products.

A. RESIDUAL IMAGE

The formation of a residual image is a complex, poorly understood phenomenon. Basically, the response characteristics of the target depend partly on the response to preceding images. As a consequence, an image may contain a faint overprint of a preceding image. This is especially noticeable when the preceding image contained sharp, high-contrast boundaries, such as the bright edge of the planet adjacent to dark space. Craters are particularly troublesome when they appear as residual images. A sharp, fresh crater may have a subtle residual image that looks precisely like a highly degraded and blanketed crater.

The removal of residual images is complicated and imperfect. It is assumed that the residual contribution is only from the directly preceding image. Although a necessary simplification, this assumption is clearly invalid. Frames taken as the spacecraft approached the planet contain residual images from all preceding frames. Residual images of the limb persisted through the first frames of orbital photography. Residual images are removed by subtracting a small part of the preceding image. If the subtraction is excessive, an equally objectional "negative" residual image may be produced.

B. GEOMETRIC DISTORTION

The raw frames contain large amounts of distortion which can be removed by reference to a grid of 111 reseau marks (the black dots in Figs. 1 and 2) placed on the vidicon target. The positions of the reseaus were accurately determined by preflight measurements. During mission operations a slight shift of the entire set was noted. This is attributed to camera operation outside the Earth's magnetic field. In addition, at higher light values, there is a slight upward shift of reseaus relative to the image. This is chiefly because the unscanned part of the target carries a charge that can deflect the electron beam by as much as 3 pixels.

C. NOISE

Two kinds of noise must be removed: coherent and random. Coherent noise arises chiefly from two sources. Faint vertical bars with an amplitude of about 2 DN (not to be confused with vertical lines produced by vertical high-pass filtering) resulted from harmonic effects between the carrier frequency and the spacecraft power frequency. This gives a pervasive, but generally unobtrusive, texture to the images. A larger effect producing a horizontal pattern with an amplitude of 5 to 30 DN occurred when ultraviolet spectrometer (UVS) measurements were made. Mechanical vibrations of the UVS mirror were transmitted through the scan platform. Using appropriate digital filters, it is possible to eliminate much of the coherent noise.

Random noise produces a salt and pepper pattern on the image, known more familiarly as "snow" in the early days of home television. These errors in individual pixels are produced by preamplifier noise in the camera system and by telemetry bit errors (loss in transmission). The snow can be removed by replacing a pixel varying more than a specified DN value by the average of its neighbors. This is only a cosmetic improvement. No additional data are displayed.

Line dropouts are significant defects related to noise. These generally arise from telemetry errors in the spacecraft to ground link. However, many lines in the MTVS frames were lost in the ground link. Most of these were subsequently recovered and appear in the RDR frames.

D. BLEMISHES

A number of dark patches and small bright specks have been identified on Mariner images. The large dark patches are about 30 pixels across. They are probably produced by shadows of dust particles on the faceplate. The bright spots are smaller, probably defects in the target. Table 1 lists the more significant blemishes. They have caused embarrassment for some casual investigators since, in some images, they look like faint craters or protuberances. Unattractive though they are, the dark spots do have some value. They can be used to estimate contrast variation in the pictures since their amplitude is approximately known.

A series of concentric arcs appear in the corners of some stretched pictures, superficially resembling part of a natural circular feature. In fact, the circular pattern is produced by internal focusing of the electron beam.

V. RDR LABELLING

The image processing steps applied to each picture appear on the picture label (Fig. 4). A description of the processing is given by Seidman et al. (1973). In general, the following sequence of label names on a picture identifies the RDR version:

(1) "GEOMA" is the first step in decalibration. This program transforms the image to correct geometry, removing geometric distortions produced in the camera.

(2) "RESRED71, CORRECTED FOR RESIDUAL IMAGE" appears on pictures that were processed for residual image; not all frames could be treated.

(3) "FICOR71" is the photometric correction program. The message "TO CONVERT TO FT-L, MULTIPLY DN VALUE BY..." is added to allow conversion of RDR data numbers to luminance in foot-lamberts (cd/m^2). "RESSAR" removes the reseau marks and fills in by interpolation.

(4) "FASTFIL2" is a high-pass filter program that enhances detail and suppresses low frequency in the picture.

(5) "IPL ROLL NO..." label indicates the permanent roll number by which the negative is filed in the JPL Science Data Library or at NSSDC. "P..." is the revolution or orbit number.

(6) "MASK" is the program step that creates the grey-scale, pixel grid, and label.

(7) "STRETCH xxx-xxx" indicates a linear contrast stretch. The two numbers separated by a hyphen are the original data numbers that have become black and white respectively in the enhanced picture. For example, a rather low-contrast picture has nearly all the data numbers clustered around some intermediate value. The parameters of STRETCH 246-269 would assign the value zero to 246 in the original image and the value 511 to original DN values of 269 and greater. This "stretches" a contrast range of only 23 DN to a full 512. This process brings out details in otherwise very flat-appearing images. An image with a narrow histogram of DN values has low contrast; after stretching, it has a broad histogram. The stretch parameters must be carefully chosen to include most of the original histogram. Otherwise, information is lost. If the scene has extremely low contrast, with the DN values ranging over only 5 or 6 values, the stretch produces noticeable contouring or density steps in the enhanced image.

There are numerous other enhancement programs that may be indicated in the labels of specially processed images. The rectified and scaled pictures produced for the U. S. Geological Survey quadrangle mosaics occur as one of the standard projections: Mercator, orthographic, Lambert conformal, or polar stereographic (Fig. 5). These are made from RDR data. The nine-bit data is truncated to eight bits (256 grey levels), and they are projected in a program called SUPERMAP on many of the earlier labels, and, later, more prosaically, MAP2.

VI. IMAGE IDENTIFICATION

Critical information in picture labels should always be checked against another data source, ideally the SEDR.

Each Mariner 9 television image has a "unique" number, the DAS time, associated with it. This number is attached to each line of the image by the Data Automation Subsystem (DAS) as the target is scanned and digitized. The DAS time is an eight-digit integer incremented by one count every 1.2 seconds. Since it takes about 42 seconds to scan a frame, successive frames will be separated by no less than 35 DAS counts. In fact, three different DAS numbers may appear for a single frame. In the Supplementary Experiment Data Record (SEDR), the DAS time when the camera was shuttered is listed. This is 5 counts ahead of the time on the RDR version because the number listed on the picture is the time when the first line of the frame was acquired. On the MTVS picture the DAS time is that of the first line received on Earth. This may be many counts higher than the RDR time if some of the first lines were lost in transmission.

VII. RESOLUTION AND SCALE

Resolution is a property that can be described in a number of ways. There is no completely satisfactory definition since factors such as the experience of the interpreter may, to a large extent, determine the effective resolution of an image. A list of the physical factors that control resolution includes target contrast, system resolving power, atmosphere, illumination, image motion, and the viewing geometry.

The resolving power of a system is simply the ability to detect two closely spaced point targets. For a lens, the diffraction-limited resolving power can be expressed by the relation:

$$a = \frac{F\lambda}{D}$$

where a is the distance two objects are separated in the image, F is the focal length of the lens, λ is the wavelength of the light, and D is the diameter of the lens.

Optical resolution is frequently stated as optical line pairs per millimeter (ℓpm), a spatial frequency. In terms of image separation,

$$k_0 = \frac{1}{a}$$

where k_0 is the limiting spatial frequency, and a is the width of a line plus a space.

Film resolution is normally expressed in terms of line pairs. The resolution of film is ultimately limited by grain size and other film properties. A very high resolution film can resolve better than 400 ℓpm depending on target contrast.

In determining the resolving power of a vidicon tube, the scanning process complicates the matter. One of the limiting factors is the diameter of the scanning spot. To reproduce an optical pair, consisting of a line and space, it takes at least 2 TV lines. However, in imaging a line target, it is possible that, with 2 TV lines per optical line, nothing will be resolved if the TV lines fall midway between optical lines. The convention usually adopted is that the spacing between pairs of optical lines is equal to $2\sqrt{2}$ TV lines. The Mariner 9 cameras scan at 70 TV lines per millimeter corresponding to optical resolution of about 25 ℓpm for very high-contrast targets. Although this is outstanding for a vidicon, it is an order of magnitude below than for film.

A common method of expressing resolution is as <u>ground resolution.</u> This is the distance on the ground corresponding to the smallest distance resolvable in the image. For the Mariner 9 camera this would be the projected size of a pixel on the ground. This is a convenient way of measuring features since they can be easily expressed in terms of pixels and then converted to meters or kilometers. Ground dimensions of pixels may be obtained approximately by the following:

$$d = S\theta$$

where d is the ground dimension in kilometers, S is the slant range in kilometers, and θ is the angular field of a pixel in radians (Table 2 and Fig. 6).

The slant ranges to 9 points in each picture are given in the Mariner SEDR. Values on the individual prints are for the center of the image.

Measurements on RDR prints are more reliable than on MTVS versions because camera distortions have been removed. The pixel scale on MTVS pictures depends on whether they are measured horizontally or vertically (Fig. 6). RDR images have been reprocessed to square pixels spaced at 75 pixels per millimeter on the vidicon sensor. On the RDR pictures, the approximate height and width of the picture is given on the label. For MTVS pictures, a good rule of thumb for determining the approximate width in kilometers is to divide the slant range by four or forty for A and B frames, respectively. For example, a typical mapping frame taken at a slant range of 1600 km is about 400 km across. For accurate measurements, it is best to determine the pixel dimensions of the object by actual measurement. It is convenient to use the pixel grid on the margins of each photograph for this purpose.

A somewhat subjective measure of resolution is called identification resolution. For example, experience with planetary images has shown that most craters can be identified as such if they are four to six pixels in diameter, a dimension which is equivalent to two optical lines. Reasonably enough, the characteristic crater pattern includes a bright sunlit wall and a dark wall facing away from the Sun, essentially the same pattern as two optical lines. Some smaller craters might be seen, depending on their contrast and the way pixels are distributed, but many other craters will be undetected since the pixels average adjacent small dark and bright regions.

A final and very significant factor in image resolution is atmospheric clarity. Particulate and molecular constituents of the atmosphere absorb and scatter light, reducing contrast. Turbulence in the atmosphere reduces resolution further by causing apparent motion of objects in the image. For these reasons, Earth-based telescopes with lenses larger than 76 cm (30 in.) in diameter are made exclusively for stellar studies where capability to detect very faint objects is required but spatial resolution is less important.

VIII. BRIGHTNESS, SHADOWS, AND TOPOGRAPHY

Many of the more spectacular lunar pictures are taken near the terminator where subtle topographic protuberances and depressions are accentuated by dark, crisp shadows. With this lunar situation in mind, it is understandable that some persons examining Mariner pictures have identified dark slopes as shadowed areas. Were this actually the case, it would be a powerful research tool. Shadows could be used in determination of local relief.

There are several lines of evidence suggesting that most of the dark slopes are not shadows. The steepest slopes in shadow should have angular gradients complementary to the lighting angle. In terrestrial situations unconsolidated material cannot maintain slopes in excess of 30°. For many Mariner pictures the lighting angle is 60° or less from vertical. Any alleged regions in shadow would have to be associated with unnaturally steep cliffs. Another demonstration of the lack of shadow is to look at the lower left blemish in an A frame. This region is darker than it should be by about 6 percent. In other words, if the region is fairly homogeneous, this spot is 6 percent darker than its surroundings. The upper spot is 3 percent darker. Frequently these are the darkest areas in the image although they are much brighter than the 10 or so DN to be expected in true geometric shadow. This can be verified by DN listings of particular regions on a picture, a tedious and expensive undertaking.

Although true shadows are infrequent in the Mariner 9 images, the topography is well expressed by the enhanced versions of the pictures. As with the low Sun lunar pictures, however, the stretched pictures of Mars give an impression of far more pronounced relief than the rather gentle slopes that actually occur on the surface.

IX. OBTAINING MARINER DATA

The organization responsible for public distribution of spacecraft data is the National Space Science Data Center (NSSDC) at Goddard Space Flight Center in Greenbelt, Maryland. The following summarizes the Mariner 9 data available from NSSDC. For a more complete list, the reader is referred to the current NSSDC Mariner 9 Data Announcement Bulletin.

(1) MTC/MTVS pictures in all versions

(2) RDR pictures in two enhanced versions

(3) Rectified and scaled pictures

(4) Picture indexes arranged by latitude, longitude, features, roll and file numbers, DAS time, or revolution

(5) SEDR on microfilm

(6) Special mosaics

(7) MTC/MTVS microfiche and users' guide

(8) RDR microfiche and users' guide

X. DATA RECORDS

Most of the Mariner data of interest to potential investigators are available at NSSDC. However, many of the more specialized and intermediate data sets are in archival storage in the JPL Science Data Team library (Holmlund, 1973). The TVS EDR contains the raw data for the television pictures.

The MTC/MTVS real-time pictures are kept in the science data library as 70-mm duplicate negatives, strip contact prints, and 8 x 10 prints of all versions. Also in the library are prints of all frames processed by IPL and by the Artificial Intelligence Laboratory at Stanford University (Levinthal et al., 1973). These have been specially processed according to specific experimenter requests. The MTC/MTVS images are also available on microfiche, along with a users' guide. Information on spacecraft altitude, camera pointing directions, picture corner coordinates, slant range, etc., is catalogued in the Supplementary Experiment Data Record (SEDR). Listings of the SEDR are available from the NSSDC. A comprehensive review of picture coverage and sequence design is contained in Koskela et al. (1972) and Koskela (1973).

XI. MAPS

The United States Geological Survey has prepared a series of 1:5,000,000 scale quadrangle maps of Mars using Mercator projections in the equatorial region, Lambert conformal projections at higher latitudes, and polar stereographic projections at the poles. The 1 to 5 million series will contain 30 maps. A number of larger scale maps are also being made at scales of 1:1,000,000 and 1:250,000 for Viking landing site studies and for various science studies. The 1:5,000,000 series will include controlled photomosaics, and shaded relief versions. The latter will be formally published by the Survey. A global 1:25,000,000 scale map has been compiled showing topography, albedo features, and official nomenclature.

XII. MARINER 10 TELEVISION DATA

The Mariner 10 mission to Venus and Mercury carried a pair of vidicon cameras similar to those on Mariner 9. A high-resolution camera with a focal length of 1500 mm, and a wide-angle camera with a focal length of 50 mm were used to photograph most of the illuminated hemisphere of Mercury. Seventy-five percent of the lighted surface was imaged at a resolution of better than 2 km.

The television system on Mariner 10 was improved over the Mariner 9 system, particular results being the lack of residual images and low noise levels. The imaging system and its operation are described by Danielson et al. (1975). The principal characteristics of the imaging system are summarized in Table 3.

Since Mariner 10 was a fly-by rather than an orbiting mission, the sequencing of imaging differed from that of Mariner 9. In fact, Mariner 10 was a unique fly-by mission since the spacecraft re-encountered Mercury and obtained useful imagery on three separate passes.

For several days prior to and after the first encounter, far-encounter imaging was used to verify camera operation and calibrate the television system. Between 16 and 4 hours prior to and after closest approach, a series of images were obtained through a variety of spectral filters.

Highest resolution images were obtained between 4 hours prior to and after closest approach, about 700 km for the first encounter. All images were exposed through clear filters to reduce exposure time. The high data transmission rate of 117.6 kbits/second allowed real-time transmission of over 2000 images during first encounter alone. Fifteen of the highest resolution images were recorded on the on-board tape recorder for transmission to Earth at a slower data rate (22.05 kbits/second) to reduce noise. Failure of the tape recorder made this impossible for subsequent encounters. More complete details of imaging sequences, and footprint plots of many images, are summarized by Danielson et al. (1975).

Each image was assigned a unique identifier number by an on-board Flight Data Subsystem (FDS). The FDS number was supposed to increase throughout the mission, but several times system failures reset the FDS number to zero.

Processing of all images was accomplished at JPL using the MTC/MTVS system described earlier for Mariner 9. Systematic processing produced contrast enhanced, high-pass-filtered, and vertical AGC versions. Software was adjusted because each pixel was defined by 8 bits (0 to 255 grey levels) instead of the 9 bits (0 to 511) used on Mariner 9. Details of Mariner 10 image processing are presented by Soha et al. (1975).

REFERENCES

Cutts, J. A., Mariner Mars 1971 Television Picture Catalog: Vol. I. Experimental Design and Picture Data, Technical Memorandum 33-585, Jet Propulsion Laboratory, Pasadena, Calif., June 30, 1974.

Danielson, G. E., Jr., Klassen, K. P., and Anderson, J. L., "Acquisition and Description of Mariner 10 Television Science Data at Mercury," J. Geophys. Res., Vol. 80, pp. 2357-2393, June 10, 1975.

Holmlund, G. L., Mariner Mars 1971 Science Data Team Library, Final Report, Report 610-243, 1973 (JPL internal document).

Koskela, P. E., et al., Mariner Mars 1971 Television Picture Catalog: Vol. II. Sequence Design and Picture Coverage, Technical Memorandum 33-585, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1972.

Koskela, P. E., Mariner Mars 1971 Television Picture Catalog: Vol. II, Addendum 1. Sequence Design and Picture Coverage, Technical Memorandum 33-585, Jet Propulsion Laboratory, Pasadena, Calif., July 1, 1973.

Levinthal, E. C., et al., "Mariner 9 - Imaging Processing and Products," Icarus, Vol. 18, pp. 75-101, 1973.

Masursky, H., et al., "Television Experiment for Mariner Mars 1971," Icarus, Vol. 12, pp. 10-45, 1970.

Seidman, J. B., et al., A User's Guide to the Mariner 9 Television Reduced Data Record, Technical Memorandum 33-628, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1, 1973.

Snyder, L. M., Mariner 9 TV Subsystem Calibration Report, Report 610-702, 1971 (JPL internal document).

Soha, J. M., et al., "IPL Processing of the Mariner 10 Images of Mercury," J. Geophys. Res., Vol. 80, pp. 2394-2414, June 10, 1975.

Thorpe, T., Mariner 9 Television Imaging Performance Evaluation, Report 610-237, Vol. 2, 1972 (JPL internal document).

Table 1

Blemishes on Mariner 9 Vidicon (Modified from Thorpe, 1972)

RDR locations are in parentheses.

In addition to those listed, there are about a half dozen blemishes, several pixels across, on the A frames. Under certain conditions these might be mistaken for small craters. The best check on small features is to look at the same location in several frames to verify that the feature is on Mars and not on the vidicon. The B frame vidicon defects are listed in the table because they are large and occur as black and white spots identical to small, sharp craters.

A CAMERA - MTVS IMAGES

Dust Shadows

Line	Sample	Size, pixels	Amplitude
120 (155)	165 (195)	30	2%
204 (285)	760 (865)	30	3%
485 (550)	130 (155)	30	6%

B CAMERA

Dust Shadows

Line	Sample	Size, pixels	Amplitude
425 (475)	645 (750)	40	< 1/2%
535 (590)	275 (320)	40	1%
690 (755)	330 (395)	50	1 1/2%

Black and White spots

Line	Sample	Size, pixels	Amplitude
50 (70)	320 (355)	15	+60 DN, -30 DN
187	195	10	+20 DN, -20 DN
240	148	10	+30 DN, -20 DN
118	725	10	+20 DN, -20 DN
322	770	10	+10 DN, -15 DN
522	758	10	+20 DN, -15 DN

Table 2

Specifications for Mariner 9 Cameras

	Camera A	Camera B
Focal length, mm	52.267±0.006	500.636±0.036
Sensor dimensions, mm (within outer reseaus)	12.343x9.561	12.342x9.545
Angular field, deg	13.56 x 10.50	1.413 x 1.092
MTVS pixel dimensions, μ radians	284 x 261	29.6 x 27.2
RDR pixel dimensions, μ radians	255 x 255	26.6 x 26.6
MTVS picture elements per frame	832 x 700	832 x 700
RDR picture elements per frame	950 x 800	950 x 800

Table 3

Mariner 10 High-Resolution Camera Characteristics
(From Danielson et al. (1975))

Characteristics	Value
Focal length	1500 mm
f/number	f/8.4
Field of view	$0.36 \times 0.48^{\circ}$
Scanned area	9.6×12.35 mm
Format	700×832 pixels
Encoding level	8 bits
Frame time	42 seconds
Resolution per TV line	9.5×10^{-6} rad

Fig. 1. Real-time MTC/MTVS versions of a Mariner 9 image of an area transitional between plains and cratered terrain south of the Elysium region. The raw picture (a) shows no detail. The shading corrected version (b) has some of the photometric distortion removed and shows the scene enhanced, but with the relative brightness preserved across the scene. The extreme change of luminance from left to right occurs because the picture is taken in the afternoon when the Sun is in the western sky; curvature of the planet leads to variable lighting conditions across the image--brightest in the west, darkest in the east. The elongate dark marking at the top is the eclipse shadow (penumbra) of the natural satellite, Deimos. In the filtered version (c), the effects of Sun angle are removed by subtracting from the shading corrected version a smoothed version of the image and then stretching. This procedure introduces some artifacts seen as vertical lines. The other round dark spots, about 30 pixels in diameter, are the shadows of dust spots on the faceplate of the vidicon. [DAS 07507 [illegible], MTVS ROLL/FILE 4196-70, 71, 72]

Fig. 1 (contd)

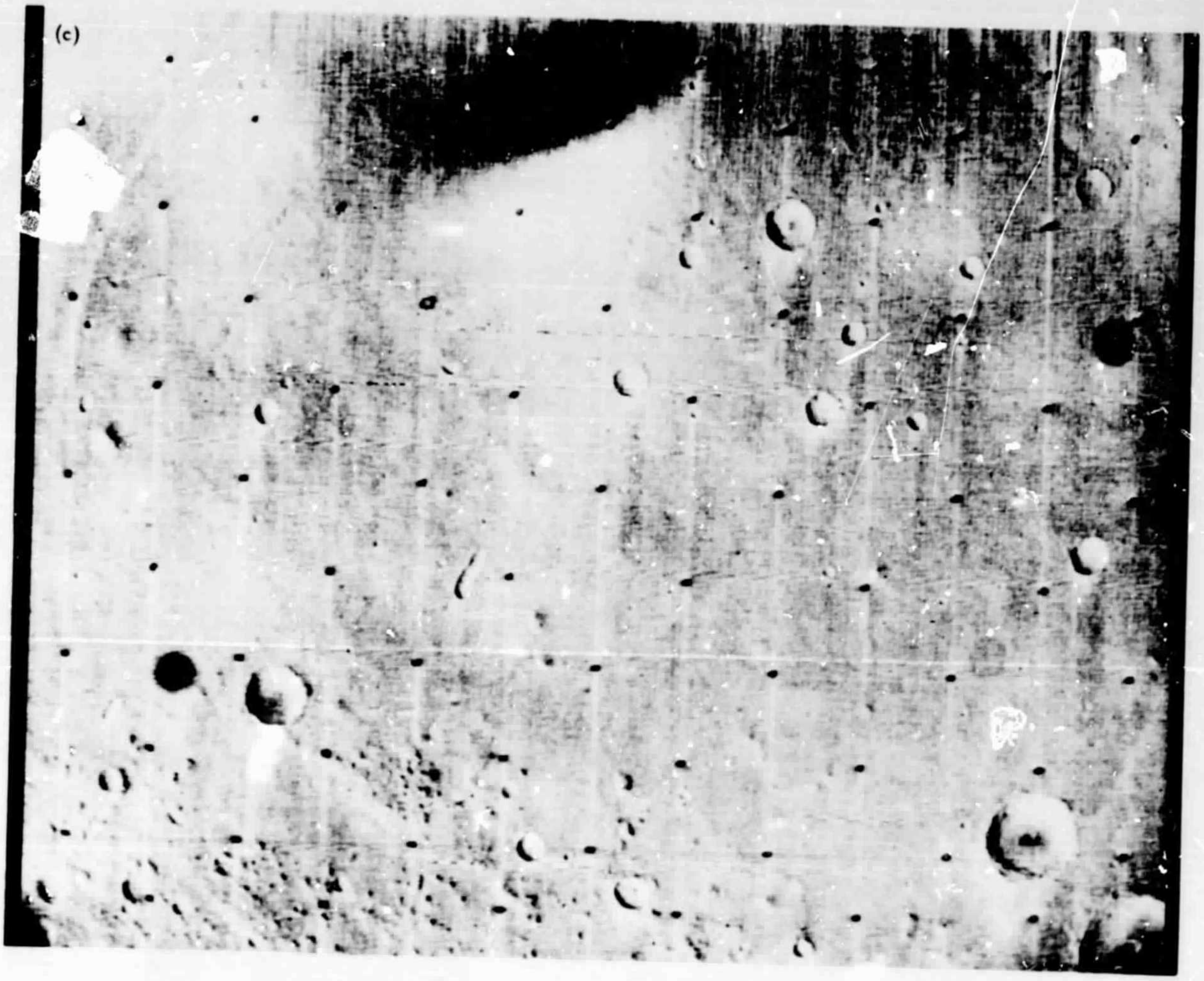

Fig. 1 (contd)

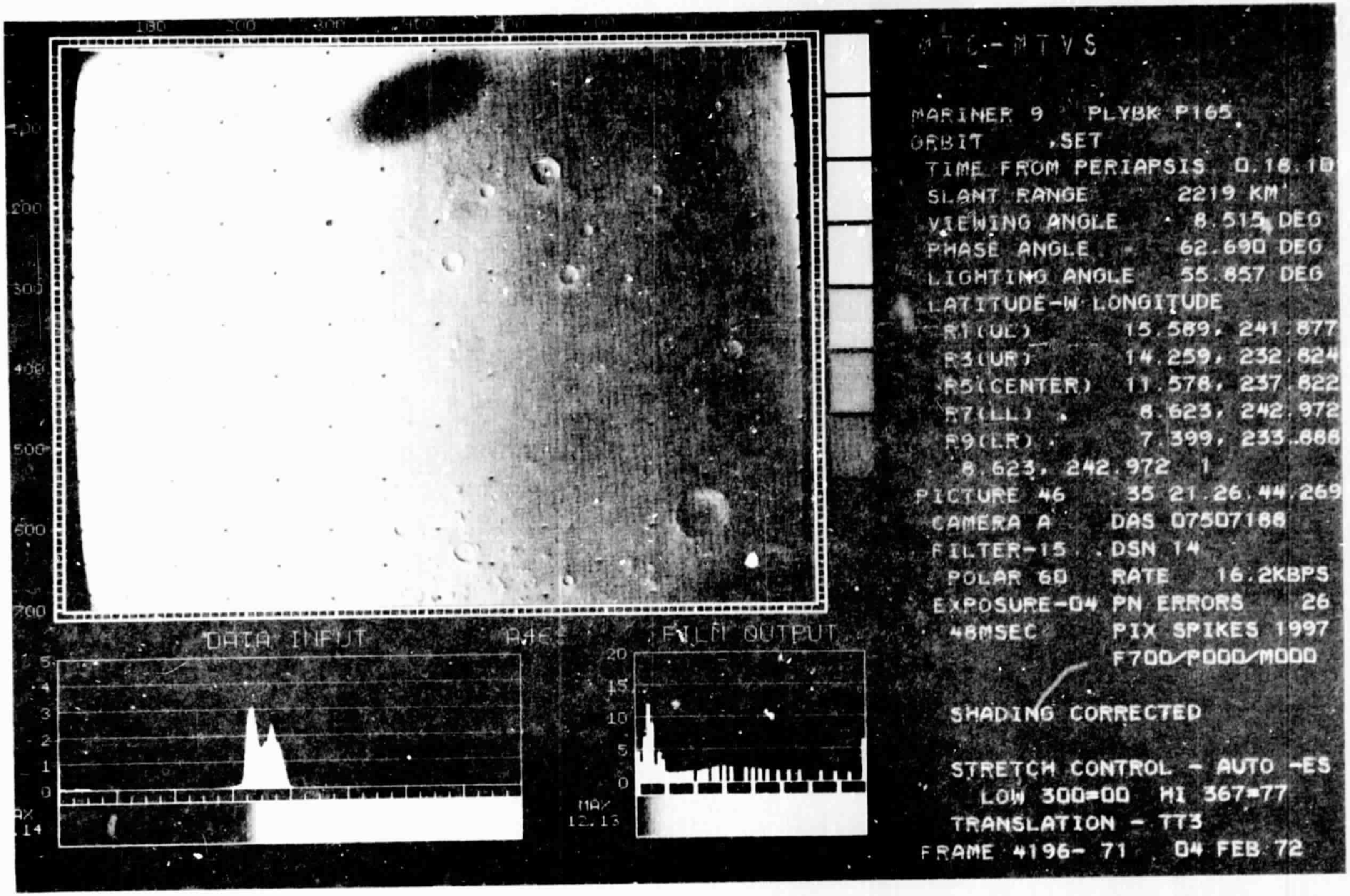

Fig. 2. Standard format for MTVS picture, data block, and histograms of input and output data numbers. The data block is reprinted with explanatory notes.

MTC-MTVS

	MARINER 9 PLYBK P165	orbit number
	ORBIT ,SET	not used
	TIME FROM PERIAPSIS 0.18.10	
	SLANT RANGE 2219 KM	
	VIEWING ANGLE 8.515 DEG	angle at center of picture from vertical to spacecraft
	PHASE ANGLE 62.690 DEG	angle at center of picture between Sun and spacecraft
	LIGHTING ANGLE 55.857 DEG	Sun elevation measured from vertical
	LATITUDE-W LONGITUDE	
reseau no.	R1 (UL) 15.589,241.877	
	R3 (UR) 14.259,232.824	
	R5 (CENTER) 11.578,237.822	
	R7 (LL) 8.623,242.972	
	R9 (LR) 7.399,233.888	
	8,623,242,972 1	not used
DAS picture count (not used)	PICTURE 46 35 21.26.44.269	Earth received time (day-hr-min-sec)
	CAMERA A DAS 07507188	DAS number of first line
filter position no.	FILTER-15 DSN 14	tracking station
filter (polarizing a 60°)	POLAR 60 RATE 16.2KBPS	telemetry bit rate
shutter speed code	EXPOSURE-04 PN ERRORS 26	pseudo-noise errors (loss of code indicating the end of a line)
shutter speed	48MSEC PIX SPIKES 1997	noise spikes
	F700/P000/M000	full lines/part lines/missing lines
image processing parameters	SHADING CORRECTED STRETCH CONTROL - AUTO - ES LOW 300=00 HI 367=77 TRANSLATION - 773	
	FRAME 4196 - 71 04 FEB 72	processing date

Fig. 2 (contd)

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Fig. 3. RDR versions of the same Mariner 9 pictures shown in figures 1 and 2. The albedo version (a) has been given a linear stretch to preserve relative scene brightness across the image. The filtered version (b) has been processed to emphasize topographic detail. (IPL Roll Nos. 7350 and 1631.)

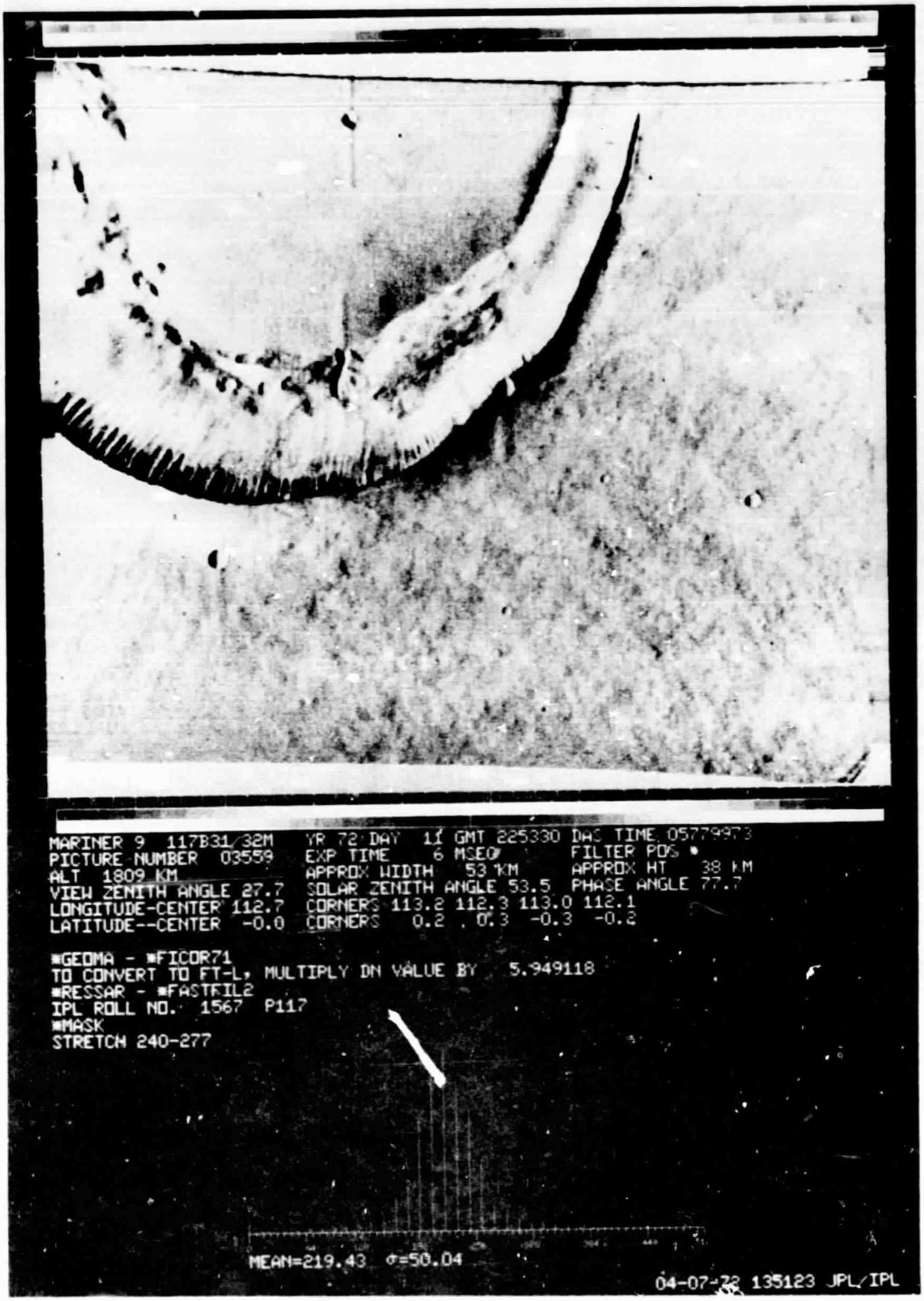

Fig. 4. A typical picture label for an RDR picture. This version is intended to show topography to best advantage. The caldera of Pavonis Mons is shown in the picture.

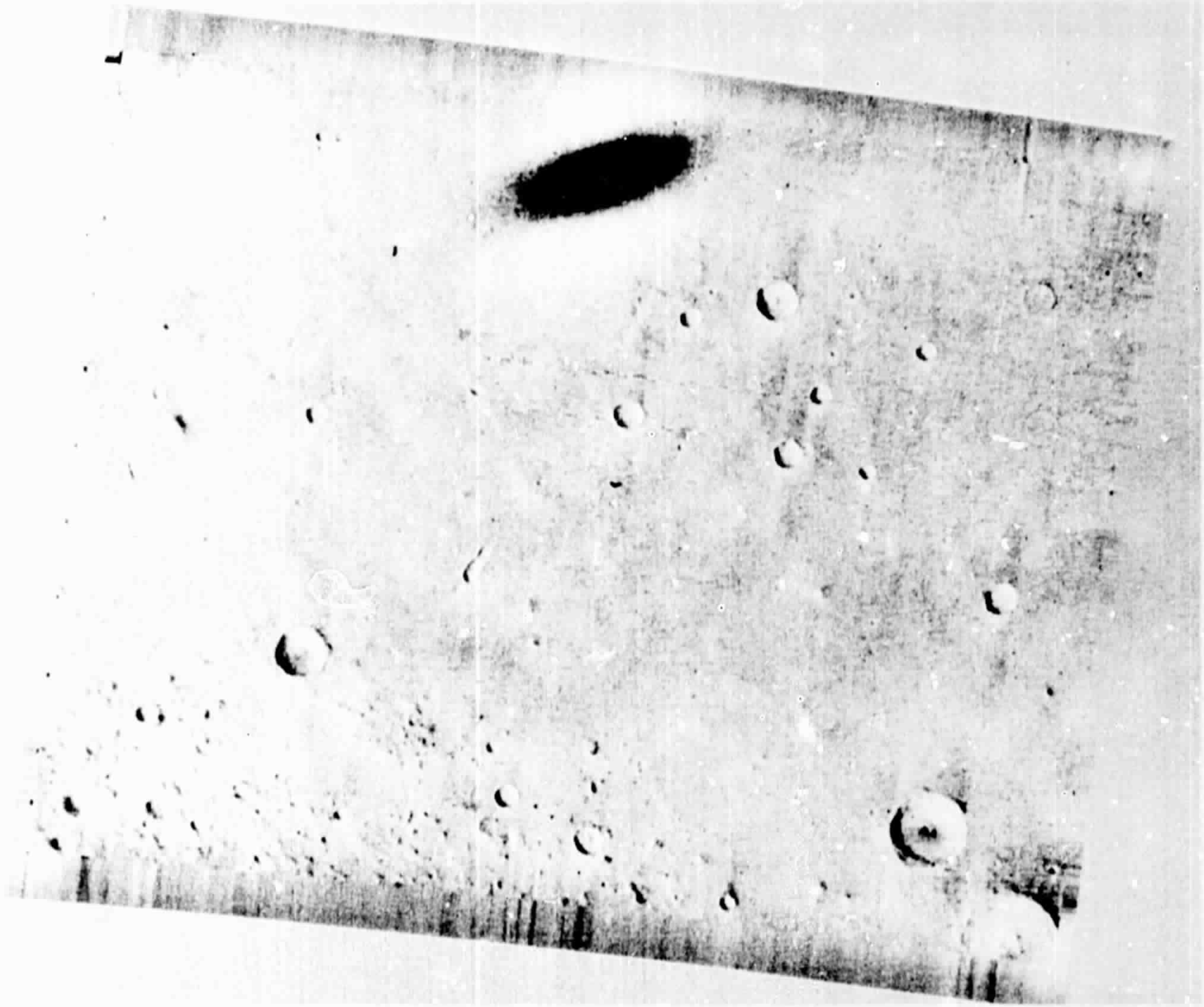

Fig. 5. Mercator version of picture in figures 1, 2, and 3. North is to the top. The scale of the image can be determined precisely from equations for the Mercator projection.

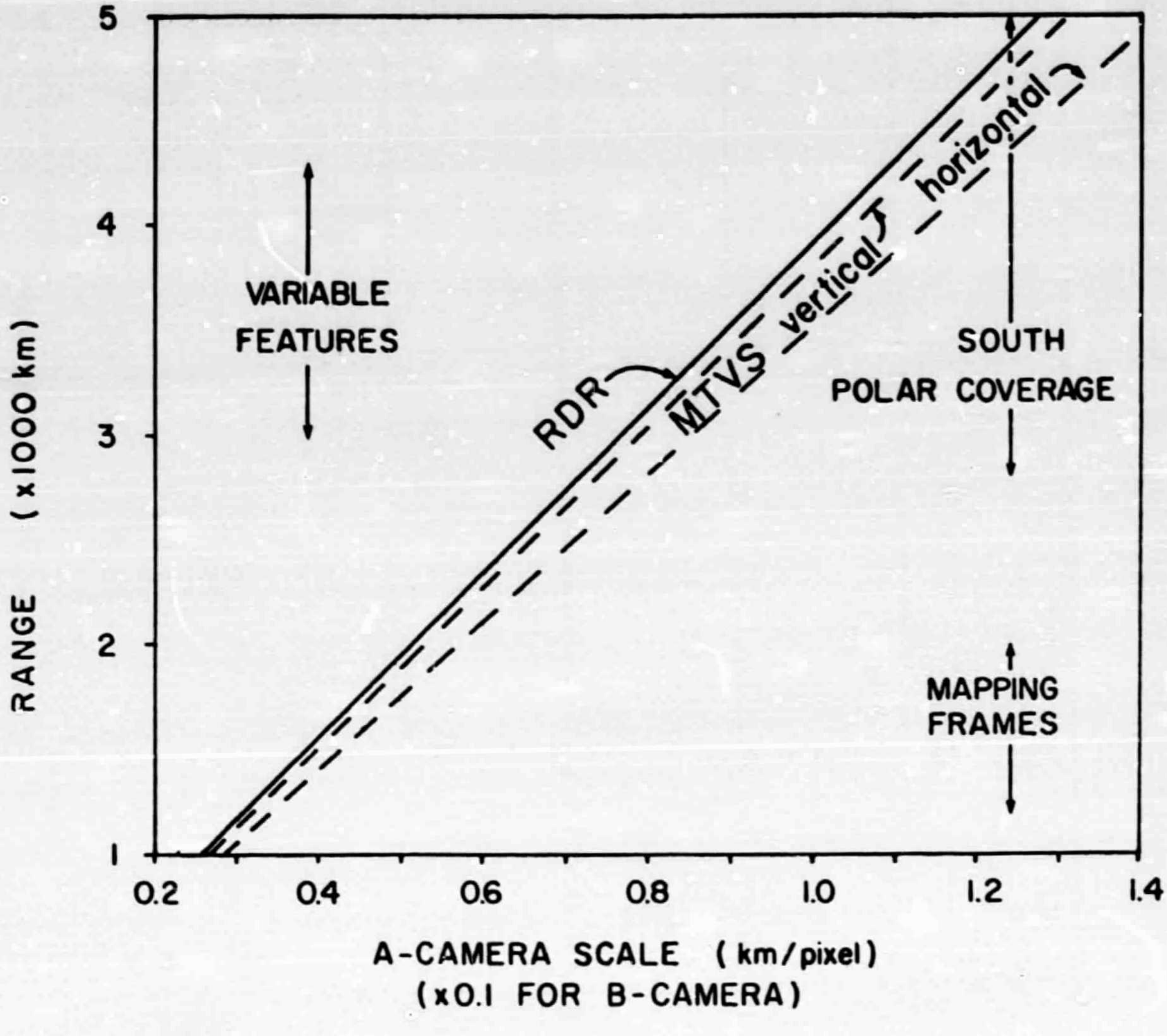

Fig. 6. Resolution of Mariner 9 pictures and approximate variation of slant range for different types of picture coverage. The two lines for MTVS pictures represent the rectangular horizontal and vertical dimensions of the pixels. Although the lines diverge at greater slant range, the ratio between the two dimensions remains constant.

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