Digital Maps of Mars

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Abstract

A cartographic digital model (DM) of Mars containing controlled image mosaics and topographic measurements has been prepared for distribution on CD-ROM optical disks. This database is the product of an exhaustive Mars cartography project based on data from the Viking Orbiter missions. It includes a radiometrically and geometrically controlled, photometrically modeled global image mosaic at a resolution of 1/256°/pixel (231 m), a digital topographic model of the entire planet at a resolution of 1/64° (about 1 km), a series of multispectral image mosaics, and selected high-resolution (≥7 m/pixel) image mosaics. This collection of 21 disks is expected to provide support not only for primary scientific investigations of Mars but also for the scientific and engineering operations of future expeditions to that planet.

Introduction

Sketch maps of Mars began appearing as early as 1659, when Christian Huygens prepared a crude drawing of features he could see through a primitive telescope. In 1878, G.V. Schiaparelli made a map that forms the basis of feature nomenclature in use today. In this century, planetary cartography did not become professionally respectable until the advent of space flight, when mission planners and analysts discovered that they needed accurate maps for preflight guidance and planning and for arranging and categorizing data returned to Earth. Cartography from pictures taken by spacecraft-mounted cameras became a developing technology.

Although conventional paper maps will always be needed, the deluge of a wide variety of spatial data for the planets has made compilation of maps on digital media as essential for planetary cartography as it is for terrestrial cartography. The initial design and compilation of a digital planetary cartographic database was discussed by Batson (1987). The first set of CD-ROM optical disks containing cartographic data for Mars was compiled by the U.S. Geological Survey (USGS, 1991a through 1991f) and released through NASA's Planetary Data System (PDS). A description of the Mars collection is the subject of this paper. These disks, or volumes, contain controlled digital image mosaics made by geometric projection of radiometrically corrected and photometrically modeled Viking Orbiter images. We refer to this type of dataset as a "digital image model," or DIM. Most of the images in a 1:2,000,000-scale controlled photomosaic map series published by the USGS were reprocessed for use in the medium-resolution DIM. Volume 7 of the set contains a digital topographic model (DTM) of Mars in a format compatible with that of the DIM (USGS, 1992a). Subsequent volumes contain multispectral DIMs (USGS, 1992b through 1992g) and high-resolution (≥7 m/pixel) DIMs (USGS, work in progress). This paper presents details of the design and formats of these first volumes. Details of the multispectral processing are still in progress and are not included here.

The CD-ROM collection serves two purposes. First, the DIM serves as a database for interactively examining the character and structure of the surface of Mars. Second, the CD-ROMs provide a compact delivery medium for integrating databases into geographic information systems (GIS) and for making custom map products.

Data are presented in a set of volumes, directories, and files. In addition to the DIMs, files contain index maps consisting of digitized shaded relief maps and compressed-resolution DIMs (provided as navigation aids). Text files include the gazetteer of currently approved feature names and their coordinates on Mars, and newly derived camera orientation matrices for each of the frames. The matrices are by-products of the photogrammetric processing required to compile the DIM and the DTM. Also included in the files is software that allows access, viewing, and enhancement of the images on standard desktop computers and workstations (Martin *et al.*, 1989). More complex and comprehensive software exists (e.g., the USGS Planetary Image Cartography System, or PICS, and the JPL Video Information Communication and Retrieval, or VICAR, system), but is available at only a few universities and government agencies because of its specialized nature and lack of portability.

The medium-resolution DIM has a resolution of 1/256°/pixel (231 m/pixel on Mars). If presented as a single file, volumes 1 through 6 would constitute an eight-bit image of 92,106 samples by 46,080 lines in cylindrical geometry, far too cumbersome for most users. They have therefore been formatted in 1964 sub-areas, or "tiles," in the Sinusoidal Equal-Area projection (Figure 1) with nominal dimensions of 5° latitude by 5° longitude in the equatorial region of the planet. Higher- and lower-resolution DIMs and DTMs are tiled according to similar schemes.

NASA/PDS have also produced many CD-ROMs containing individual images returned by spacecraft (e.g., NASA/PDS, 1990). These are the uncorrected images from which maps can be made, but they are not cartographic products *per se*. Although they are not included in the present discussion, it is worth noting that the DIMs that are discussed here have been projected to a common format, a resampling process that inevitably causes some degradation of resolution. The individual images, on the other hand, have not been modified geometrically and they provide the highest resolution possible for photointerpretation.

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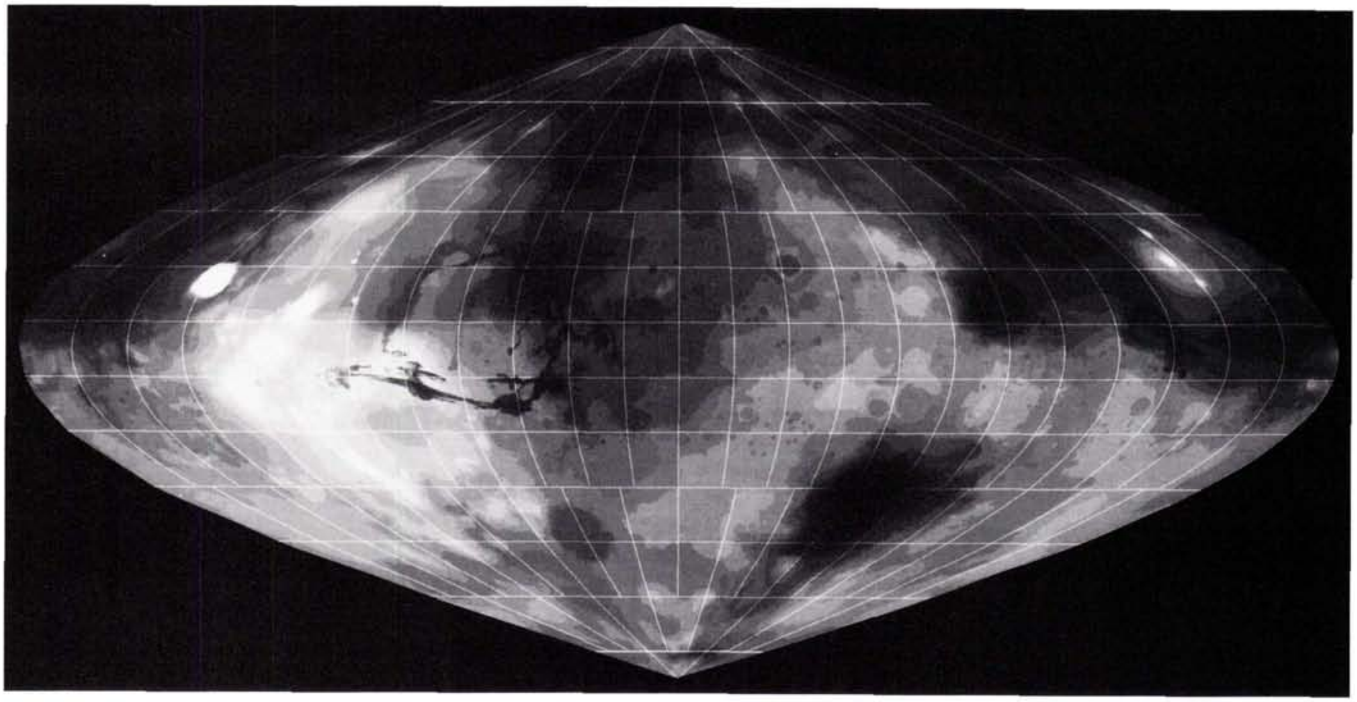


Figure 1. The tiling layout for Mars DTMs. Vertical dimension of tiles is 15° of latitude; horizontal dimensions are modified to maintain approximately equal areas in the tiles in intermediate and polar latitudes. The scheme for DIMs is similar but has nominal dimensions of 5° by 5° near the equator.

The Viking Mission

Two identical vehicles, carrying the experiments of 13 science teams, were launched from Earth to Mars in 1975 (Snyder, 1977, 1979). Each vehicle contained an orbiter and a lander. After insertion into Mars orbit, the landers separated from the orbiters and descended to the surface of the planet. Because the major scientific objective of the mission was to search for life on Mars, several experiments on the landers were designed to address this objective.

For the orbiters, however, the first objective was to gather data that would characterize and qualify potential landing sites. Additional objectives were to study the photometric and colorimetric properties of the surface, to better understand the geological history of Mars by studying various geologic features discovered by Mariner 9, to study the dynamics of the atmosphere, and to monitor the surface for changes. Systematic mapping of Mars was not part of the original plan.

The two orbiter spacecraft operated at Mars from 1976 until 1980. Their mission was divided into several phases with specific objectives for each. The "primary mission" began with orbit insertion in June and September of 1976 and lasted until November 1976. Its main objective was to collect data in support of landing-site selection and to relay communications between the Viking landers and Earth. When the orbiters were not required for these purposes, their cameras were used to collect black-and-white, color, and stereoscopic images of selected terrains on Mars and on the martian moons, Phobos and Deimos.

The "extended mission" took place between November 1976 and May 1978, and the "continuation mission" lasted from May 1978 through February 1979. During these phases, the orbiters were used independently from the landers. The imaging operations included systematic medium- and high-resolution global surveys, stereo and color surveys of the equatorial regions, observations of the polar regions and dust storm activity, and further observations of Phobos and Deimos. A special picture-taking sequence was used during the continuation mission to collect "medium-resolution" (150 to 350 m/pixel) images with similar illumination geometry (i.e., with the sun 20° to 45° above the horizon). These images were used to make the medium-resolution global DIM.

The final phase of the Viking Orbiter mission was the "survey mission" from July 1979 until July 1980. Viking Orbiter 2 had ceased to return data by the end of the continuation mission, and it did not participate in the survey mission. This mission was designed to obtain high-resolution (10 to 100 m/pixel) coverage of areas of special scientific interest as an aid in selecting landing sites for future missions. These images were used to make high-resolution (1/8192° to 1/512°/pixel, or 7 to 115 m/pixel) DIMs. Also conducted at that time were several global color surveys, which provide the source materials for a collection of color DIMs of low-resolution (1/64° to 1/128°/per pixel, or 462 to 924 m/pixel).

The Viking Orbiter Visual Imaging Subsystem (VIS)

The VIS on each Viking Orbiter consisted of two identical vidicon cameras (Benesh and Thorpe, 1976; Wellman *et al.*, 1976; Klaasen *et al.*, 1977). Each camera consisted of a telescope, a slow-scan vidicon image tube on which a pattern of reseau marks was etched, a filter wheel, and associated electronics. The angular field of view of the camera as defined by the margins of the reseau patterns was 1.51° by 1.69°. The ground area covered by an image was determined by spacecraft altitude and emission angle.

Each VIS camera contained a filter wheel with five color filters (blue, minus blue, violet, green, and red) and a clear (i.e., no filter) position. The approximate bandwidths of these filters are shown in Table 1. Collections of overlapping images were taken through two or more of these filters to form color image surveys, most of which have resolutions of 500 to 1000 m/pixel.

Table 1. Total Bandpasses of the VIS Color Filters.

Nominal color	Bandwidth (micrometres)
blue	0.35 – 0.53
minus blue	0.48 – 0.47
broad band	0.35 – 0.70
red	0.55 – 0.70

Cartography

The global cartography of Mars from Orbiter images was accomplished according to plans and methods described by Batson (1987, 1990a, 1990b, 1990c) and Edwards (1987). Because uniform topographic portrayal was the goal of the medium-resolution DIM, the photometric processing used does not lend itself to quantitative photometric and radiometric analysis of the data. Subsequent volumes contain multispectral DIMs prepared by methods devised by McEwen and Soderblom (work in progress, 1993) and high-resolution DIMs.

Control Procedures

A topographic contour map of Mars was made by methods of stereoscopic photogrammetry at a scale of 1:2,000,000 (Wu *et al.*, 1982; Wu and Doyle, 1990). The contour lines were manually adjusted to fit the DIM. The DTM was compiled by manually digitizing the adjusted contour lines. The resulting vector files were then gridded and interpolated to form the DTM raster.

The contour map was tied to a refined topographic control net for Mars (Wu and Schafer, 1984) that was based on a control net derived by Davies and Katayama (1983). This net has a standard error of about 5 km horizontally and 1000 to 1500 m vertically. The error can be attributed to a lack of precise knowledge of camera locations at the time each image was taken and to topographic parallax in oblique images of rugged terrain. Photogrammetric computation of camera locations was precluded, because the narrow fields of view of Viking Orbiter frames cannot provide triangulations with useful precision. Camera positions can therefore be derived only by tracking the spacecraft continuously during its active lifetime. Given assumed camera positions, camera orientations were derived by minimization of the discrepancies between images in overlapping frames and the control net.

Images used in the refined topographic control net were also used to make a low-resolution (1/64°/pixel) DIM to provide a control base for the medium-resolution DIM. This was necessary because control-point images from the refined control net do not have adequate density and distribution, and many are not identifiable on higher resolution images. Any image point visible on both the low-resolution base and an image to be placed in the medium-resolution DIM was, therefore, considered a valid horizontal control point. There are, however, significant positional discrepancies between frames in the low-resolution mosaic that reflect the standard error of the control net. These discrepancies commonly translate to 20 pixels at 1/256°/pixel digital scale. In order to avoid such large discontinuities in the medium-resolution DIM, a network of "nodes" was defined on the base mosaic. The nodes were distributed at intervals of 15° to 25° of latitude and longitude over the base mosaic. The medium-resolution mosaic images were forced to coincide with the base mosaic at the nodes, with adjustment allowed between them. Thus, the discrepancies in the DIM are far less than 20 pixels over most, but not all, of the planet. In general, the error was smoothly distributed so that it was not obtrusive in the mosaics.

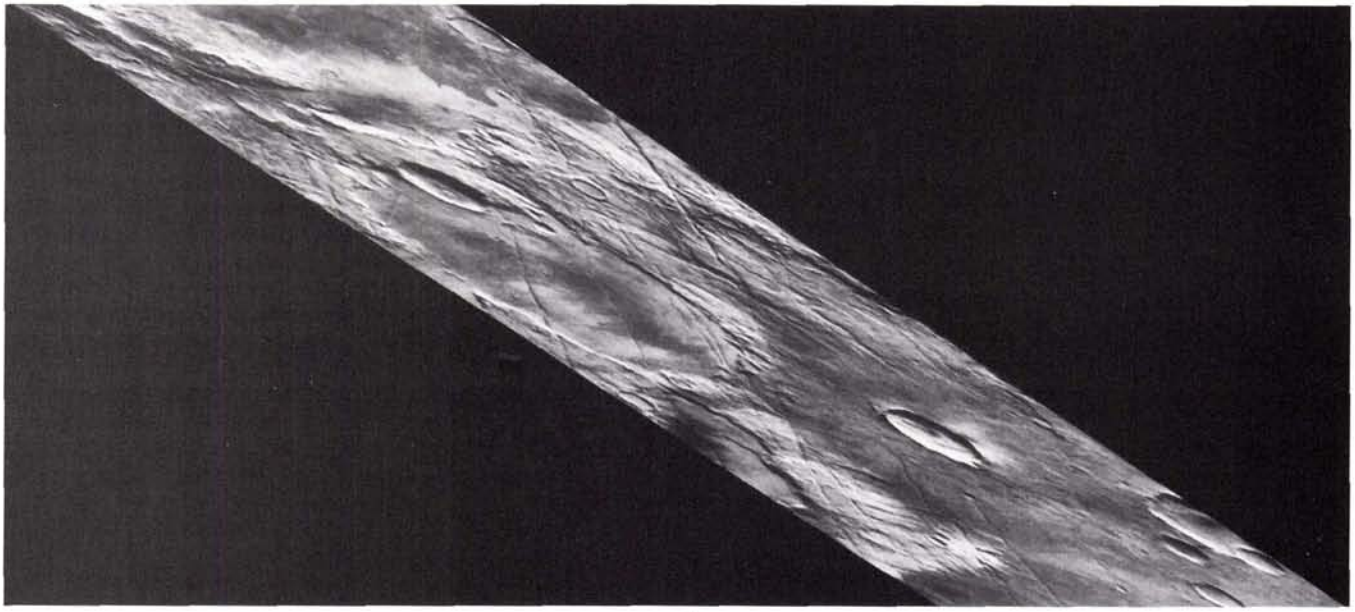
Geometric Considerations

Whereas properties of conformality or equal area are important in the selection of projection geometry for printed maps, rapid computer access to specific areas is the primary consideration in formatting digital maps. The simplest form of a digital model (DM) is one in which each image element's value is stored in a "bin" (pixel) labeled in terms of latitude and longitude. An array in which each image line, or row of bins, is a parallel of latitude and each column of samples, or bins, is a meridian has an appealing simplicity, even though the higher latitudes are oversampled. For example, the pole of a planet, in reality a point, is represented in this "Simple Cylindrical" format by an image line with as many samples as was required for the equator. Thus, a single VIS image frame containing the pole is unmanageable during DIM compilation. The Sinusoidal Equal-Area projection (Snyder, 1982), in which each parallel of latitude is shortened by the cosine of its latitude, was therefore selected. The conversions between completed Simple Cylindrical and Sinusoidal Equal-Area arrays are computationally trivial, and the two are virtually interchangeable.

The Sinusoidal projection has the simplicity of the Simple Cylindrical projection insofar as indexing is concerned (rows and columns are parallels and meridians), but compilation is much more efficient in the Sinusoidal Equal-Area because the projection does not have a singularity at the poles. However, viewing distortion becomes severe with distance from the central meridian in the sinusoidal presentation. Although this can make visual examination of the DIM difficult, it is not relevant to the integrity of the database. The central meridian can be shifted easily by simply sliding image lines parallel to one another, allowing an undistorted view of a selected region without geometric resampling (Figures 2a and 2b). Segments of the DIM are, therefore, commonly displayed with a local central meridian except for the poles, which are more easily viewed in a polar projection (Figures 3a and 3b).

Pixel Sizes

The resolution of digital images is often specified in terms of pixel dimensions in metres or kilometres on the surface of a target. DMs, however, are encoded so that the number of lines (i.e., parallels of latitude) in a global DM is an integer. It is, therefore, more convenient to specify DM resolution in terms of planetocentric degrees rather than in linear units. The size of pixels in a DM is thus specified as some negative power of 2° (1/4°, 1/8°, 1/16°, ..., 1/256°, etc.) per pixel. Resolutions intermediate between these values are not used. Thus, DMs can be registered in scale simply by successively doubling or halving the pixel sizes by subsampling or averaging, but without resampling. Selected segments of DIMs may be written as photographic prints or published as paper maps.



(a)

(b)

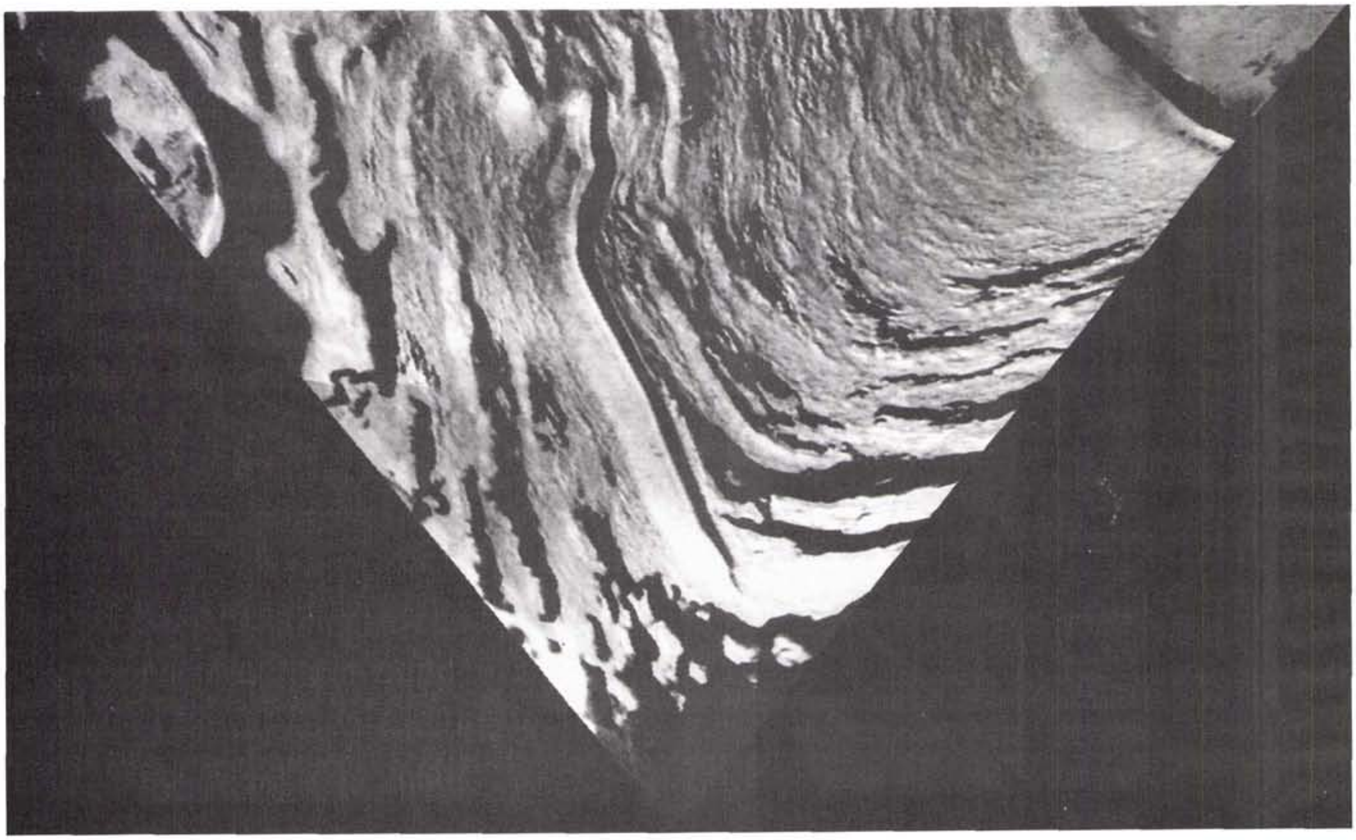
Figure 2. (a) DIM image centered on longitude 122°W; the central meridian of the Sinusoidal Equal-Area projection is 0° long, resulting in a "skew" distortion of the image. (b) The image of (a), in which the center longitude of the image coincides with the central meridian of the projection. The same pixels are used in each image without resampling, so that resolution is not degraded. The vertical dimension of the image is about 300 km (Volume 6, MG45S122.IMG).

DM Tiling Scheme

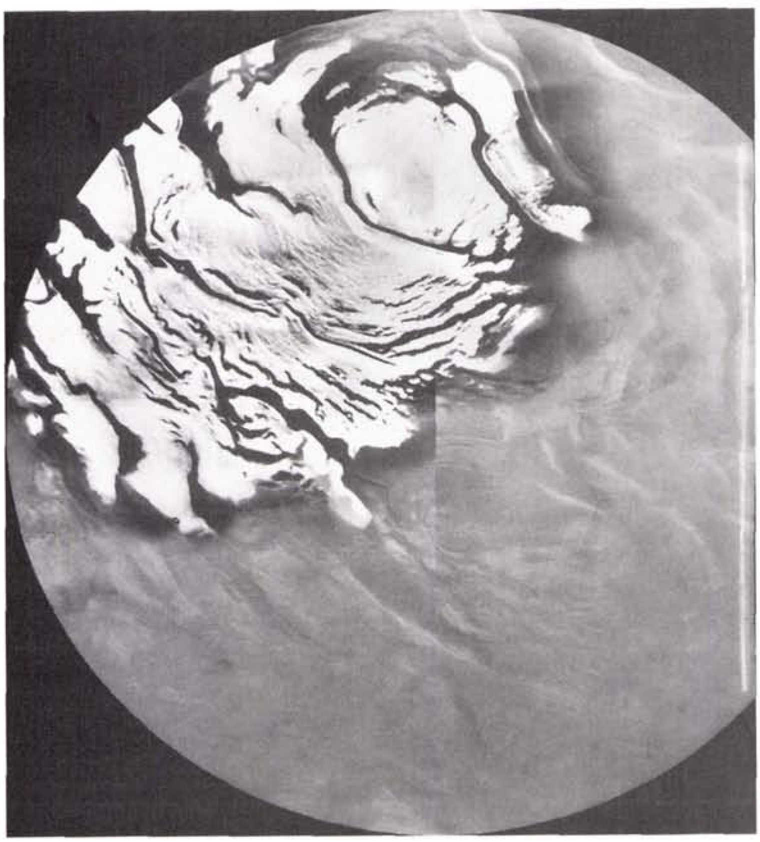
Most DMs are far too large to be managed conveniently as single files, and they must be segmented to produce tiles of manageable size for convenient access on CD-ROM disks. The scheme used for the 1/256°/pixel DIM results in unnecessarily small tiles for the 1/64°/pixel DTM. A revised scheme utilizing 15° by 15° tiles in the equatorial regions and modified for convergence of meridians in the higher and lower latitudes was therefore implemented (Figure 1).

Just as published planetary maps are indexed by the latitude/longitude of their center points (truncated to the nearest integer degree to simplify the indexing), the labels of files in any DM refer to the latitude/longitude of the center of the tile. For example, the DIM file labeled MI15S007.IMG contains the DIM tile centered on 15°S latitude, 007°W longitude (all longitudes are west on Mars). The "MI" and the extension ".IMG" identify the type of DM in the file; these codes are explained in the documentation on each CD-ROM and will not be repeated here. The central meridian of the sinusoidal projection of each tile coincides with the central meridian of the tile so that the tile can be conveniently displayed without geometric modification. Thus, craters remain round rather than skewed.

The central meridian of a Sinusoidal Equal-Area projection can be changed by sliding image lines parallel to one another. For a computer to convert a DM tile to a new central meridian, a simple algorithm can be used to calculate a starting offset (the placement of the first sample of the input line) and to simply move the pixels from the input buffer to the output buffer starting at the calculated offset. For example, if a feature of interest exists on a boundary between two tiles, a



(a)



(b)

Figure 3. (a) DIM image of part of the south polar region of Mars, in Sinusoidal Equal-Area projection (Volume 6, MI88S045.IMG). (b) DIM image including area of (a) in Polar Stereographic projection. The image is about 600 km in diameter (Volume 6, MI90S000.IMG).

simple program can be written that reads the two tiles into memory, creates an output memory array with a new central meridian equal to the boundary longitude between the two tiles, and then copies the input tile lines to output tile lines with calculated offsets.

Processing

The Mars DIMs were compiled in four stages or "levels," beginning with raw images. All of the corrections made during these stages have some level of uncertainty, so the processing sequence was designed to progress from corrections with the highest probability of accuracy to those with the lowest. Intermediate stages were preserved for future analytical use.

The first level of processing (Level 1) was radiometric. It included removal of electronic shading inherent in the imaging system, artifacts such as minute dust specks on the vidicon tube, microphonic noise introduced by operation of other instruments on the spacecraft during imaging sequences, and data drop-outs and spikes (Benesh and Thorpe, 1976; Soderblom *et al.*, 1978). Reseau marks were also located; before they were removed, their precise locations were recorded for use during later geometric processing. It was not feasible to remove all possible artifacts from the images in the DIM. Those that remain are generally caused by inadequate removal of reseau marks, of random noise, and of vidicon blemishes. Although geometric image processing was not done during Level 1, the control points and image tie points were identified on the images (still in their raw geometry), and their projected locations and camera orientation matrices were computed. Image-distortion corrections were included in these computations. This information, along with reseau-mark locations, was written to a digital image label for each Level 1 frame, and can be used to project the raw frame to any map projection while simultaneously removing image distortions.

Level 2 processing included removal of camera distortions and projection from image to map coordinates in DM format according to parameters derived during Level 1 processing. Distortion corrections were based on preflight calibration of the reseau. The resolution of each frame was preserved to some extent by oversampling in the output array, that is, by selecting a resolution step that results in an image with more lines and samples than the original image.

At Level 3, photometric models of the surface and atmosphere were applied to reduce the images to a uniform representation so that images taken under different illumination (solar incidence angle, emission angle, season) and atmospheric conditions (level of dust and condensates that scatter and absorb) could be mosaicked into a useful composite. Usually, the goal in this step is to convert the calibrated images from radiance to model images of surface albedo (and as a function of color for multispectral images sets). These are in turn mosaicked to generate black and white or color mosaics that portray the albedo and color of the surface materials. This is the approach used by McEwen and Soderblom (work in progress, 1993) to generate the regional and color mosaics contained in Volumes 8 through 13 (USGS, 1992a through 1992g) of the CD-ROM series.

When such photometric normalizations are applied to portray the albedo uniformly, they have an adverse effect on the appearance and interpretability of the topography in the mosaic. For example, at high solar-incidence angles (e.g., closer to the terminator), topography is highest in contrast and albedo variations lowest. At lower incidence (closer to the subsolar point), the albedo contrast is highest and that of topography lowest. Consequently, a process that corrects for the illumination effects to present the albedo differences uniformly makes the apparent variation in topographic amplitude even worse! The contrast of a crater near the terminator, which is already very high (relative to the contrast of the same crater viewed at low incidence) is made much higher.

Because a goal in producing the monochromatic (B/W) digital MDIM (compiled at 1/256° scale) was to portray the *topographic relief* as uniformly as possible over the planet, a totally different form of photometric normalization had to be devised. The process effectively involved simply normalizing the image with a high-pass divide filter in which each point in the image was divided by the average of the local average of the 60- by 60-km region around it, leaving the image histograms centered around midrange. Next, a simple model was used to derive a local contrast enhancement within each image that, when applied, would render the topographic contrast uniform across the images. In this way, the contrast of a crater near the terminator was reduced and that of one nearer the subsolar point increased. A more detailed description of the algorithm is contained in the "VOLINFO.TXT" file on the first six volumes that contain this product.

Finally, a seam-removal technique was used in the mosaicking procedure (Soderblom *et al.*, 1978). First, the filtered and stretched images were mosaicked. This mosaic was then filtered with a 51 by 51 low-pass filter (convolved with a 51 by 51 boxcar of unit weight). A 51 by 51 high-pass filter was next applied to each individual image that makes up the mosaic. Finally, this mosaic of high-pass filtered images was added to the low-pass filtered mosaic.

Compilation of the DIM of the entire surface of a planet was the final processing stage, which resulted in a digital global image of uniform resolution. The resolution of Level 2 images used in the compilation was compressed or expanded to match that specified for the DIM. The Viking images were mapped to the Sinusoidal projection using "nearest-neighbor" interpolation (a comparison of resampling interpolation schemes was described in Bernstein *et al.* (1971)).

The dynamic range of the global DIM was designed to accommodate the range of image brightnesses found on Mars. The highest contrast is in the polar region, where the image-density histograms fill the full dynamic range from 0 to 255. Other image files cover low-contrast areas on the planet where density histograms fill only a small part of the range. Thus, most images in the DIM appear very bland when viewed on a display device unless a contrast stretch is applied to the image values. For convenience of image-display applications, the DIM files include a digital version of the image histogram to facilitate display of an image with optimum contrast.

The primary purpose of the frames used in the multispectral DIMs (Volumes 8 through 13), which have lower resolution and more consistent illumination than those used for the medium-resolution DIM, is to display the distribution of surface coloration patterns. The Level 3 (photometric) processing used for these data is, therefore, significantly more complex than that for the medium-resolution DIM.

Data Products

Volume Contents

The present CD-ROM set consists of 22 volumes containing the following:

> *Volumes 1 through 6.* Medium-resolution (1/256°/pixel, or 231 m/pixel) DIMs of all of Mars. These six volumes contain the

highest resolution contiguous coverage of the planet (although higher resolution image maps of scattered areas do exist). Each volume also contains low-resolution (1/4° to 1/16°/pixel) shaded relief index maps, compressed-resolution DIMs, and a gazetteer of feature names. Special polar stereographic projections of DIM images are included on Volumes 1 and 6.

Volume 7. Global DTM at 1/64°/pixel (943 m/pixel) resolution. This model was made by digitizing a series of photogrammetrically compiled contour maps of Mars and then interpolating values on the DTM grid. Although the interpolation scheme did not incorporate maximum and minimum elevation measurements, the selected scale easily captures the resolution and accuracy of the Viking Orbiter topographic data set.

Volumes 8 through 13. Low-resolution (1/64°/pixel) multispectral DIMs, taken in two or more spectral bands. These include individual mosaics made at different seasons, weather conditions, resolutions, and illuminations. Systematic, contiguous coverage of the planet was not collected, complicating the compilation of a photometrically precise planetwide DIM. The work by McEwen and Soderblom will allow production of such a DIM, however, and Volume 14 has been reserved for that product.

Volumes 15 through 21. High-resolution (1/1024°/pixel to 1/8192°/pixel, or 58 m/pixel to 7 m/pixel) DIMs of selected areas of special scientific interest. High-resolution imaging could not be targeted accurately during the Survey Mission. Coverage by these DIMs is, therefore, inconsistent and non-contiguous. Furthermore, the 5-km standard error in map control becomes much more obtrusive in the high-resolution DIMs than in those of lower resolution. Thus, the high-resolution DIMs were made internally consistent, but they show large discrepancies with the medium-resolution base.

Directory Structure
The volume and directory structure of the CD-ROM volumes conform to the Level-1 standard specified by the International Standards Organization (ISO). This standard is also known as the ISO-9660 standard, and it was used so that the disks can be accessed on a wide variety of computer systems.

The image files are subdivided into directories on the basis of image file type (DIM, DTM, shaded relief), resolution of the image file, and, for 1/256° and 1/64°/pixel image files, the center latitude of the image. For 1/4° and 1/16°/pixel images, the first two characters of a file name followed by six 'X' characters make up the directory name. Volumes 1 and 6 contain a special directory, called POLAR, that contains Polar Stereographic projection images from 80° to 90° latitude.

The DIM images, shaded relief index maps, DTM files (Volume 7 only), supplemental files, documentation, and software are located in separate directories.

Image Label Area
The label area of a image file contains descriptive information about the image. The label consists of keyword statements that conform to Version 2 of the Object Description Language (ODL) developed by NASA's PDS project (Davis, 1990; Cribbs and Wagner, 1991).

Image Index
Each CD-ROM contains an image index file (IMGINDEX.TAB) with catalog information about all DIM image files in the collection. The image index file and its associated PDS label file (IMGINDEX.LAB) are located in the INDEX directory. The catalog information in the index table includes the file names, CD-ROM volumes containing the DIM image files, and data on the mapping parameters. The image index file has fixed-length records of 512 bytes in ASCII character representation. Each record (row in the table) contains the information for a single DIM image file.

Gazetteer
Planetary nomenclature, like terrestrial nomenclature, uniquely identifies a feature on the surface of a planet or satellite so that the feature can be easily located, described, and discussed. The gazetteer on Volumes 1 through 21 of the CD-ROM volume set contains detailed information about all named features on Mars that the International Astronomical Union (IAU) has named and approved from its founding in 1919 through its triennial meeting in 1991. Ancillary files in the GAZETTER (*sic*) directory are for users of the WordPerfect® word processor. (The name of the directory is intentionally misspelled to accommodate PC/DOS 8-character directory-naming limitations.) The diacritical marks on some feature names in the gazetteer can be converted with the macros included in this directory. Work on a comprehensive gazetteer is in progress by Batson and Russell. A recent version of the Mars Gazetteer is contained in Batson and Inge (1994).

Software
Software is provided on each DIM CD-ROM to facilitate access to the image files. The included routines provide display, contrast enhancement, and zoom and pan capability; histograms; and a movable cursor with pixel-parameter display. The software is located in subdirectories within the SOFTWARE directory, which contains the subdirectories MAC (Macintosh software), PC (PC/DOS software), SUN (SUN Sparcstation), and VAX (VAX/VMS workstation). Within each subdirectory is a file called SOFTINFO.TXT that tells how to use the software.

Summary
We have completed the digital synthesis of available cartographic data for the planet Mars collected by the Viking Orbiter missions between 1976 and 1980. The database is designed for use not only with mainframe and minicomputers, but also with small desktop work stations. It is expected to provide a foundation for the continuing exploration of Mars.

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The Mars digital models were compliled at USGS/Flagstaff under the direction of R.M. Batson, L.A. Soderblom, and Sherman S.C. Wu, Principal Investigator and Co-Investigators, respectively. Wu provided the technical management and supervision of a team of photogrammetrists who compiled the topographic control and the topographic maps used to make the DTM. Kathleen Edwards developed the technical procedures and standards for DIM compilation, and she provided the technical management and supervision of a team of technicians who compiled the medium-resolution DIM. Her procedures are used for all DIM compilation. L.A. Soderblom and A.E. McEwen developed the photometric and multispectral processing techniques. Our thanks go to R.L. Kirk and L.A. Soderlom, who reviewd this paper and rewrote several paragraphs. The design, layout, and production of the CD-ROMs was performed by E.M. Eliason at the USGS and M. Martin and J. Hyon at JPL.

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