Unusual Displays of DEMs

Three procedures for producing new ways to visualize landforms as maps or images derived from Digital Elevation Models (DEMs) are given. One procedure is used to create a highly detailed circular gray scale image from an azimuthal distribution. A second procedure utilizes the principles associated with x-ray tomography for the construction of a volumetric map from DEM cross-sectional 'slices'. The conversion of a DEM to a Digital Distance Model (DDM) comprises the third procedure, to provide 'side-looking' views of the DEM in a variety of map formats including stereograms. DEMs generated from Mars Orbital Laser Altimeter (MOLA) data were used to produce illustrations utilizing the three procedures.

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Introduction

This article describes procedures for producing three unique ways to visualize landforms as images or maps derived from digital elevation models (DEMs). The first of these procedures generates circular gray scale, hillshade-like, images from slope directions (azimuths) without taking into account slope gradients. The resulting gray scale maps are not necessarily a pleasing description of landform but a complex one, showing every nuance of the elevation distribution. This slope gradient invariant method of pseudo hillshading is a useful approach for greatly enhancing landform detail in a gray scale display.

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The second procedure described in this paper is an algorithm for DEM tomographic slicing, which produces a three-dimensional display in the form of a volumetric map (Eyton, 1997). Horizontal cross-sections of landform images derived from DEMs are printed as transparencies and then layered in register to produce a mechanical three-dimensional relief model. This low-cost method allows for the easy production of very effective 3D maps using both black and white, and color, thematic overlays.

A third procedure extracts a horizontal distance distribution referred to as a Digital Distance Model (DDM) from a vertical height distribution or DEM. Although perspective mapping software can sometimes provide an equivalent view as this 'side-looking DEM', the properties of the DDM distribution allows for a number of unique transformations and displays.

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The terrain models used for demonstrating the three methodologies were obtained as DEMs generated from Mars Orbital Laser Altimeter (MOLA) data (sources for the individual data sets are given in later sections of the paper). Mars was chosen as the test site for several reasons. Principal amongst these was a geographer's/cartographer's curiosity, coupled with a compelling need to view new landscapes. Secondly, although

Initial submission, June 2004; revised submission, September 2004; final acceptance, September 2004

earth terrain models may offer familiarity for viewers, the Martian hemisphere chosen contains earth-like features in the form of shield volcanoes and canyon lands, albeit as structures that dwarf their terrestrial counterparts. The third reason is simply an attempt to obtain an 'exploration first', even if only in cartographic form. It would be extremely exciting to be standing on the floor of Mellas Chasma looking north at the walls of the canyon as they flank the entrance to Condor Chasma. If that is impossible, then the next best thing is to provide the 'same' view in the form of an image cartographically derived from the MOLA data; when you are looking at Figures11 and 12, you are 'standing' on Mars!

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Literature Review and Origins

There is no single set of literature that can be pointed to as the background for the derivation of the three disparate methodologies described in this paper. Each is based on completely different principles coming from separate tracks within the evolution of digital cartography and from other fields as well. If an overview of terrain mapping is desired it can be found in Thelin and Pike (1991) under the headings "Visualizing the Landscape", "Machine Images of Topography", and "Application of Digital Landform Maps", within this well written paper accompanying U. S. Geological Survey Map I-2206.

At first glance the circular grayscale mapping methodology appears to be another type of hillshading but is more firmly based on attempts to map directional data in several forms including illuminated contours. Kennelly and Kimerling (2001) present a useful discussion on "Developments in Illuminating Contours" with reference to the relevant work by Tanaka (1950), Horn (1982), Imhof (1982), Gilman (1973), Puecker *et al*. (1975), Yoeli (1983), and Eyton (1984). The approach I used in this paper to produce an azimuthal grayscale image was based on my 1984 digital implementation of illuminated contouring that used three tones; black for those portions of contours with sun-opposing azimuths, white for those portions of contours with sun-facing azimuths, and middle gray for the background. The procedure for circular grayscaling developed here is essentially an expansion of this three-tone technique to a full, continuous tone method for displaying slope azimuths. The results are very detailed, hillshade-like, looking displays.

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The tomographic mapping methodology presented in this paper has its roots in image displays that are referred to as "Slice-Stacking Displays", in Section Ten of The International Society for Optical Engineering Milestone Series, *Selected Papers on Three-Dimensional Displays* (Benton, 2001). Cartographers are more familiar with this methodology in terms of simple landform models constructed by elementary school students from topographic map contour cutouts that are stacked one on top of another. I published (Eyton, 1986b) a simple computer algorithm for generating contour templates from a DEM that could be glued to poster board, and then manually cut out and stacked to produce a solid relief model. Much more detailed volumetric models are now being generated (Sandin, Topmiller, and Weaver, 2002) from laser cut high-density plastic foam with inkjet printed overlays (eg. land use, satellite images, hypsometric tints) although at some expense. The low-cost method for producing three-dimensional maps with black and white or color overlays offered in this paper is based on the algorithm given in my 1986b paper. I have again essentially expanded on an old methodology that produced contour templates (without overlays) in three tones (black, white, and middle gray) to a methodology that uses continuous tones to produce the templates with a monochrome

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or color overlay. The cost to print and assemble each model is less than five dollars.

The third methodology presented in this paper, the transformation of the elevation distribution found in a DEM, to distance distribution called a DDM has tenuous ties to the cartographic literature. It is simply a different method for presenting the information in a DEM and at best is related only to the hidden line algorithm found in a graphical approach called wire frame perspective plotting embodied in programs such as the Laboratory for Computer Graphics and Spatial Analysis SYMVU package (Harvard University, 1971). A program of this type was modified (Masters and Contino, 1983) to produce color separations so that an overlay (annual average temperature in one example and land use in another example) could be generated as wire frame perspective plots (Eyton, 1986b). I was intrigued by a limitation of this particular implementation that prevented the creation of perspectives with viewing altitudes of zero degrees; you could not obtain a display of the terrain model as if you were standing on the ground. In addition to a having a zero degree viewing altitude I also wanted to be able to simultaneously induce parallax in order to view a landscape from a horizontal perspective in stereo. It is these two parameters that set me to thinking about the needed transformation over many years and like many ideas worked on over a long time, the solution just recently presented itself suddenly, and is reported as the DEM to DDM transformation in this paper. The application of the transformation to a DEM produces a new data set (DDM) that can be manipulated (eg. spatial derivatives, lighting models, and parallax induction) and mapped (eg. grayscales, contours, and hillshades).

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General Methodology

The three techniques described in this paper have no methodologic commonality other than how each procedure is applied to a data grid. Raster processing (Peuquet, 1979) was used to operate on image grids containing one byte gray level values varying from 0 to 255, or on terrain model grids containing floating point numbers representing elevations, slope gradients, slope azimuths, or relative radiance values. Each grid was processed from top to bottom (first row to last row) and from left to right (first column to last column) on each row; no windowing or neighborhood processing was involved.

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The algorithms were coded as FORTRAN 77/90 executables running under WINDOWS XP and 'styled' so that they could be included in a teaching package of programs (TERRA FIRMA) that have been written for use in undergraduate senior level courses in digital remote sensing and digital terrain modeling at Texas State University (see Table 1). This package accomplishes most of the basic processing needed by students in these principles-driven courses. The learning curve is 'gentle', students can retain a copy of the software after they finish the course, and because the emphasis is on understanding rather than 'button-pushing' students have very little difficulty migrating to the more complex commercial remote sensing and terrain modeling software packages.

"Two map projections that are easily implemented as raster processing algorithms while preserving the circular shapes of craters were utilized to produce the images in this paper."

Two map projections that are easily implemented as raster processing algorithms while preserving the circular shapes of craters were utilized to produce the images in this paper (Snyder, 1987). A simple sinusoidal projection was used to minimize distortions on the hemisphere data sets and involved scaling each row of the image as a function of the cosine of the latitude. An equidistant cylindrical projection was used for the smaller subset and again involved a simple resizing of the image on each row equally.

DATA	
SUBCON	- subsetting and data-type conversion
JOIN	- horizontal or vertical merging of grid data files
FMR	- flipping, mirroring, and 90° rotations of grid data
ENRED	- grid enlargement or reduction
RESOLVE	- ground resolution for arc-data grid cells
RAW	- display of numeric values for a 5x5 neighborhood
MAPPING	
GRAY	- continuous and classed gray scale maps
CONTOUR	- binary, edge, and illuminated contour maps
RGB	- continuous and classed color maps
PALETTE	- color palette generation
MASK	- threshold masking
PROJECT	- equidistant cylindrical and sinusoidal projections
AGRAY[1]	- circular gray scale
ARGB	- complementary color azimuthal class map
VOLMAP[1]	- volumetric maps from tomographic slicing of DEMs
TRANSFORMATIONS	
ALGEBRA	- algebraic, trigonometric, and logical manipulations
CONVO	- 3x3 neighborhood convolution including filtering and differentiation
ACONVO	- 3x3 convolution of circular data including filtering and differentiation
DERIVE	- differentiation (gradient, azimuth) of arc-data
STEREO	- parallax induction
LIGHT	- relative insolation (Lambertian lighting models)
FLOW	- steepest descent DEM flow frequencies
DDM[1]	- conversion of a DEM to a Digital Distance Model
STATISTICS	
COUNT	- frequency table and histogram for grid data
QCOUNT	- display of clipping levels, break points, and extremes
STATS	- descriptive grid statistics
REGRESS	- reduced major axis bivariate grid regression
EIGEN	- principal components analysis; eigen-grid output
ASTATS	- descriptive circular statistics and frequency table
IMAGE PROCESSING	
SIPROC	- special imaging procedures including level-sliced CIR composites, synthetic principal components analysis, and simulated normal color
TRAIN	- unsupervised training-field selection
CLASS	- classification
CONTEXT	- varying window size convolution to produce contextual image files
TRAIN2	- unsupervised training-field selection from contextual image files
CLASS2	- classification of contextual image files

[1] algorithms given in this paper

Table 1. TERRA FIRMA Package of Programs

Circular Gray Scaling

Azimuths as calculated by Eyton (1991) indicate the down-slope direction of the gradient or the direction of the maximum slope magnitude as the elevation changes from high to low. The resulting distribution extracted from a DEM is circular, varying from 0^o - 360^o, and therefore cannot be mapped using conventional linear gray scaling. A simple circular gray scale can be used to map this distribution, so that azimuths pointing directly at an illumination source will be considered fully lit and assigned a gray level value of 255 (white) and those azimuths pointing directly opposite or 180^o from the illumination source are considered unlit and assigned a gray level value of 0 (black). All other azimuths are scaled systematically between 0 and 255 on either 180^o half of the user selected illumination direction (solar azimuth). Figure 1 shows the scaling for both a 360^o illumination source and a 315^o illumination source; the algorithm for producing either of these distributions is given in the following three step procedure:

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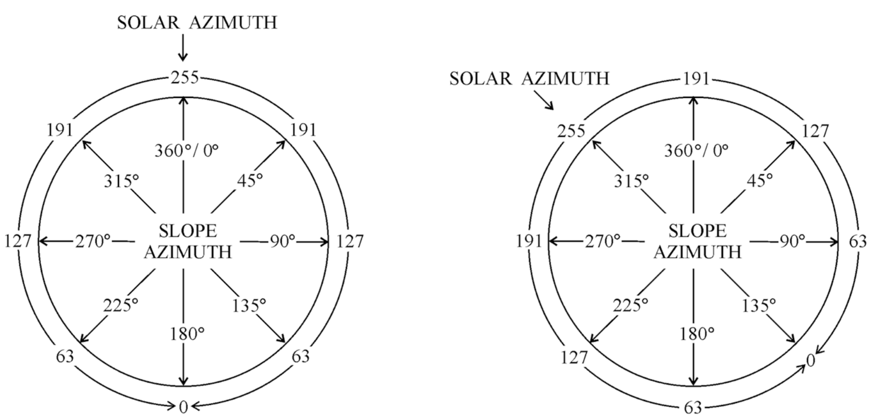

a. Solar Azimuth = 360°   b. Solar Azimuth = 315°

Figure 1. Circular gray scaling (gray level values from 0 to 255) for a 360° illumination source and for a 315° illumination source.

Step 1: Determine the absolute difference (AD) between each slope azimuth (SLPA) and the user selected solar azimuth (SOLA).

AD = •SOLA - SLPA•

Step 2: If the absolute difference is greater than 180, then redefine AD by subtracting the absolute difference from 360.

IF (AD > 180.) THEN AD = 360. - AD

Step 3: Calculate the brightness value as a gray level value (GLV from 0 to 255).

GLV = 255 - [(AD/180) x 255]

The algorithm works for all user selected solar azimuths and all DEM derived slope azimuths including 0° and 360°. For perfectly flat terrain

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". . . flat areas often are not truly flat and consist of very gently sloping regions that show only very small variations in gradient while exhibiting an irregular distribution of down-slope directions or azimuths. The result is a rough or 'bumpy' looking plain when displayed as a circular gray scale image. A comparison of an azimuthal circular gray scale image to a conventional hillshaded image explicates this point."

(slope gradient = 0°) that have no slope azimuth, a gray level value of 127 is arbitrarily assigned to produce a mid-level gray tone in the image.

Figures 2 and 3 show gray scale maps of the slope components (gradient and azimuth) for one half (180°E to 360°E) of the 1/16° x 1/16° resolution DEM (2880 x 2880) found in the Initial Experimental Gridded Data Records (IEGDR) as data file IEG0062T.IMG (Planetary Data System Geosciences Node, 2002) derived from the Mars Orbital Laser Altimeter (MOLA) data.

The slope gradient map (Figure 2) was produced by transforming the gradient component values to a gray scale of 0 (black for flat land) to 255 (white for the steepest slopes). The algorithm for producing the circular gray scaling scheme shown in Figure 1 was used to produce the image of the azimuth distribution shown in Figure 3 that displays all changes in relief, large or small, with approximately the same amount of detail. For example, flat areas often are not truly flat and consist of very gently sloping regions that show only very small variations in gradient while exhibiting an irregular distribution of down-slope directions or azimuths. The result is a rough or 'bumpy' looking plain when displayed as a circular gray scale image. A comparison of an azimuthal circular gray scale image to a conventional hillshaded image explicates this point. The hillshaded

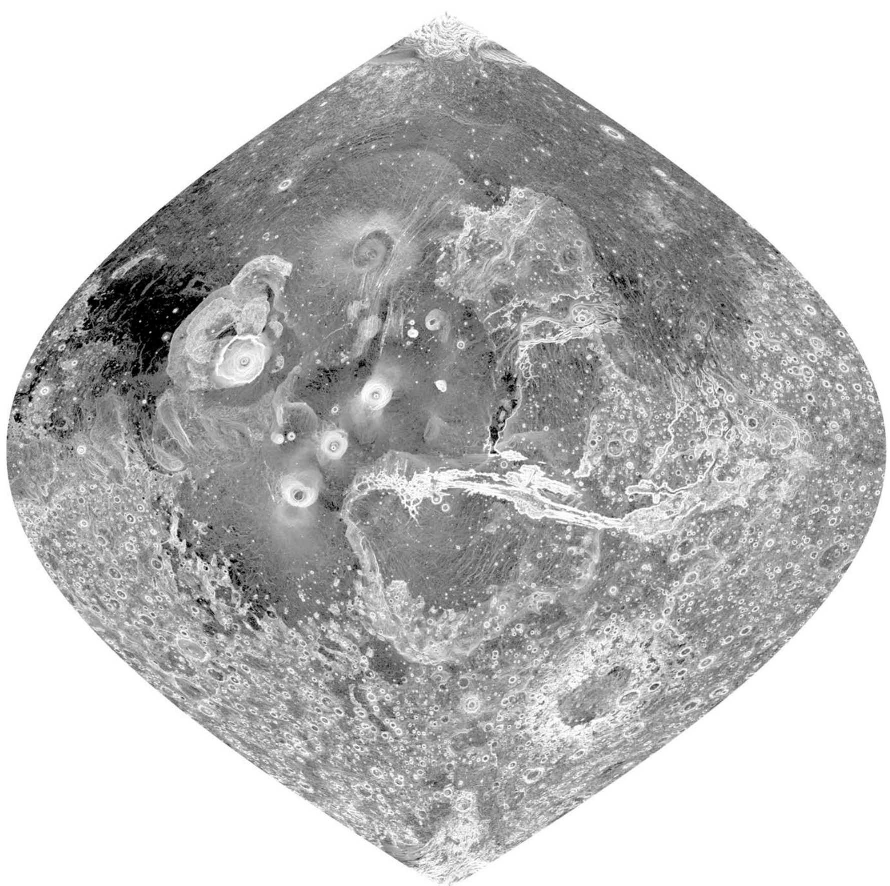

Figure 2. Linear gray scale image of the slope gradient distribution for the 180°E to 360°E hemisphere of Mars. Low slopes are dark toned and high slopes are light toned. Olympus Mons appears in this image as the west-most shield volcano with a circular cone (excluding the lava field) roughly 550 km (342 mi) in diameter. Valles Marineris, the 'Grand Canyon' of Mars, begins just east of the three southwest to northeast (Arsia Mons, Pavonis Mons, and Ascraeus Mons) aligned volcanoes and ends 4300 km (2672 mi) to the east. Projection is Sinusoidal.

Figure 3. Circular gray scale image of the slope azimuth distribution for the 180°E to 360°E hemisphere of Mars. Lighting is from the north (solar azimuth=0°). Projection is Sinusoidal.

image shown in Figure 4 uses an incident insolation calculation (Donker & Meijerink, 1997) to determine the relative radiance (0.0 - 1.0) for each grid cell in the Martian DEM. The slope gradient and the slope azimuth of each grid cell along with the user selected solar azimuth (0^o - 360^o) and solar elevation (0^o - 90^o) are used to calculate the relative amount of solar radiation striking the Martian surface for any grid cell of the DEM. A linear scaling of the relative radiance distribution from minimum (GLV = 0 or black) to maximum (GLV = 255 or white) produces a Lambertian hillshaded image in which the plains now appear smooth and flat.

Other characteristics of the circular gray scale image shown in Figure 3 include the 'plastic-like' appearance of those regions, such as the flanks of the Tharsis shield volcanoes, where there is a systematic and smooth change in azimuth that defines the sides of the cones. Emphasis on every break or edge in the landforms, regardless of magnitude, is the hallmark of the circular grayscale display; no other mapping transformation that I have used produces this level of detail.

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Tomographic Mapping

Tomography is a technique usually associated with medical X-ray scans of the human body. The New World Dictionary of the American Language (1984) offers this derivation - "*Tomo* is from the Greek *tomos* which means *a piece cut off*", and definition - "a technique of X-ray photography by

Figure 4. Hillshade image created by the linear gray scaling of the relative radiance distribution for the 180°E to 360°E hemisphere of Mars. Lighting is from the north with a solar azimuth=0° and a solar elevation=45°. Projection is sinusoidal.

". . . the additive density of the material makes it difficult to see detail on the bottom layers. The limiting number of sheets controls the number of elevation classes that are selected and in order to add contour lines equal interval classes are required."

which a single plane is photographed, with the outlines of structures in other planes eliminated". A procedure based on this definition was used to construct cardboard landform relief models (Eyton, 1986b) from computer-generated templates. This procedure has been modified to produce images generated from DEMs as horizontal transparent slices of the earth's surface that can be stacked in a three-dimensional volumetric black and white, or color, display.

Figure 5 shows a hillshaded image of Olympus Mons derived from the 1/64° x 1/64° DEM (1000 x 1200) subset obtained from the Mission Experimental Gridded Data Records (MEGDR) as the MEGT45N090G. IMG data file (Planetary Data System Geosciences Node, 2002). The elevation range for the DEM was divided into nine equal-interval classes and those portions of the hillshaded image that fell into each elevation class were printed as separate images (see Figure 6) onto overhead transparency media. About nine or ten sheets appear to be the maximum number of transparencies that can be used in a stack; any more, and the additive density of the material makes it difficult to see detail on the bottom layers. The limiting number of sheets controls the number of elevation classes that are selected and in order to add contour lines equal interval classes are required. Table 2 shows the classes I chose to slice the elevations from the Olympus Mons DEM while adding contour lines at a 3000 m interval.

The overhead transparencies were attached to overhead transparency cardboard mounting frames and then stacked on top of each other in

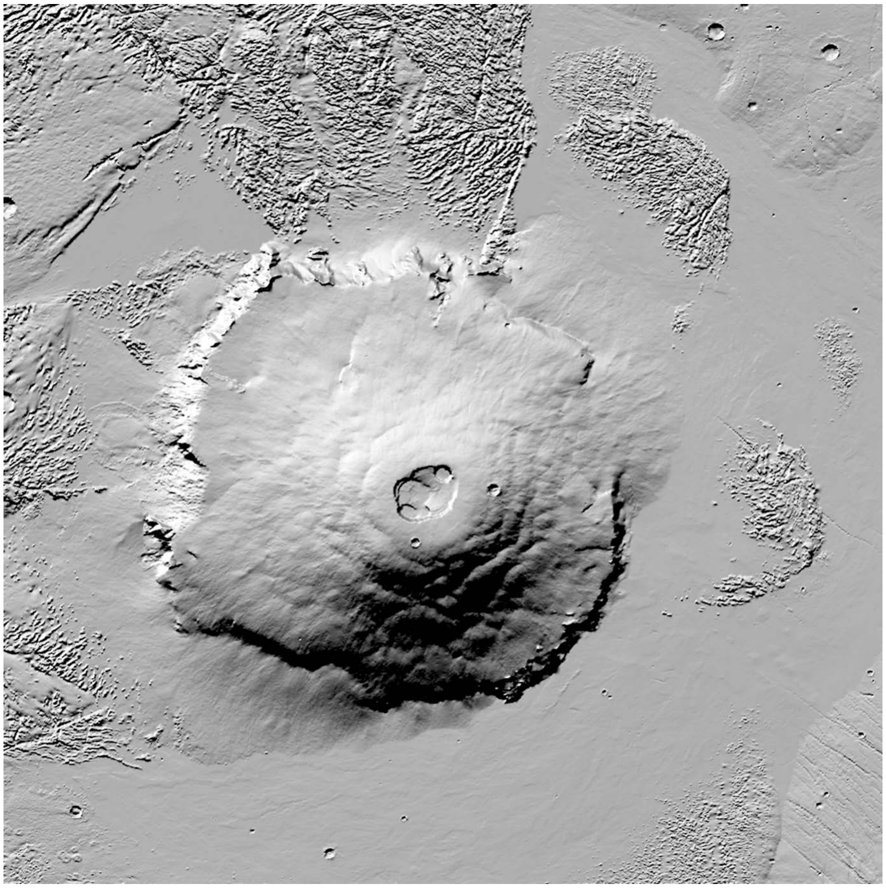

Figure 5. Hillshade image of Olympus Mons derived from the 1/64° x 1/64° resolution DEM. Lighting is from the northwest (solar azimuth=315°) with a solar elevation of 45°.

register to produce a mechanical volumetric model. Persistence of vision blends the individual layers into a continuous three-dimensional display that can be examined from any direction without the use of special viewing aids. The same procedure can be applied to other images, such as satellite scenes, land use maps, temperature distributions etc., registered to a DEM, to produce volumetric maps with black and white, or color, thematic overlays.

The principal drawback to this mapping approach is that the images printed on the overhead transparency material, when stacked, become difficult to see due to the additive density of multiple layers. A simple solution is to attach a white sheet of paper to the bottom of the stack and hold the display up to a light source. A better solution is to fix the display onto a small light box that is mounted at eye-height on a wall. Figure 7 shows a photograph of the Olympus Mons hillshade volumetric map attached to a 9 inch x 12 inch light box.

Several alternative production methods can be used to enhance, or solve problems, with these displays. For example, vertical exaggeration can be increased by simply adding a blank transparency frame between each image layer or slice; adding two or more blank transparency mounts between each image layer will produce a display with bright spacing that appears the equivalent of white contour lines. Problems with seeing the gaps between the layers can be reduced by adding black contour lines to the hillshaded image (or other images) with a contour interval equal to the elevation class interval used for slicing. Slightly overlapping slices with

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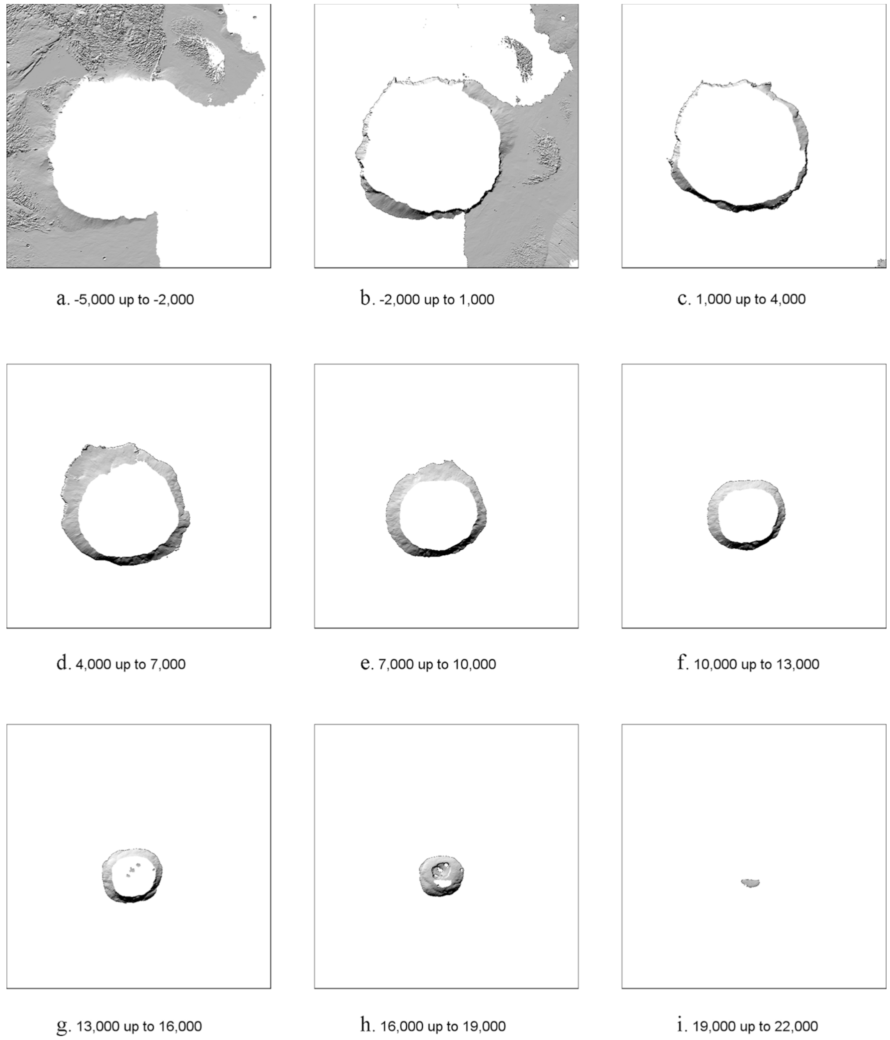

Figure 6. Slices of the hillshade image shown in Figure 5 using a reference location= -5000m and an elevation class interval=3000m were used to produce these nine images.

Elevation Class	Lower Class Limit	Upper Class Limit
1	-5000	<-2000
2	-2000	<1000
3	1000	<4000
4	4000	<7000
5	7000	<10000
6	10000	<13000
7	13000	<16000
8	16000	<19000
9	19000	<22000

Notes
The actual extremes for the Olympus Mons DEM are as follows:
Z-minimum = -3264 m
Z-maximum = 21229 m
The class interval for the tomographic slicing was set at 3000.

Table 2. Elevation Classes for the Olympus Mons Tomographic Map

feathering at the edges is another alternative for creating a smooth transition between the image segments of the display.

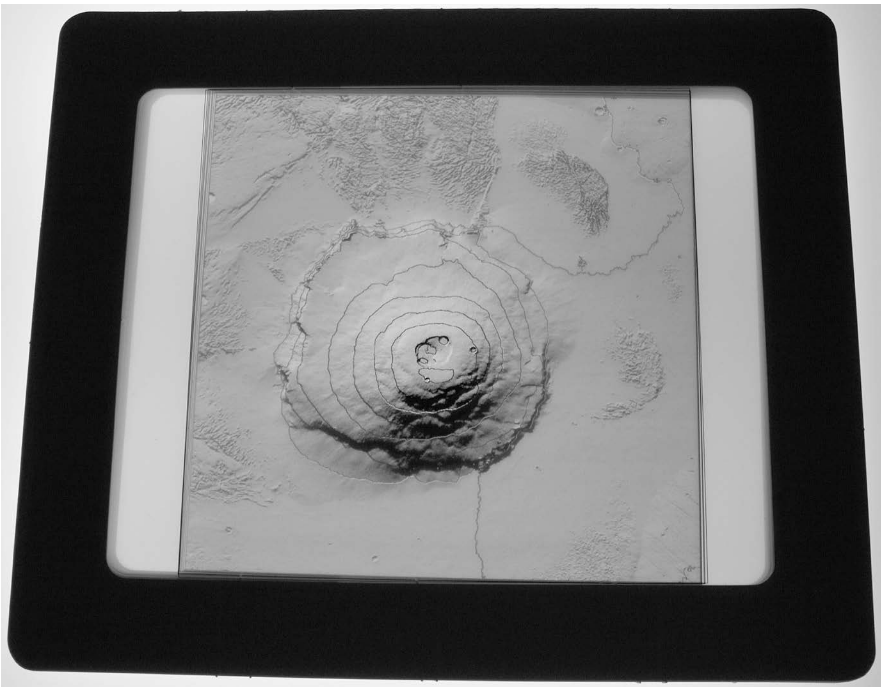

Figure 7. The nine image slices shown in Figure 6 have been attached to overhead transparency frames, interleaved with blank frames, and stacked in register to form the volumetric map displayed above.

Digital Distance Models

A transformation that converts the vertical height distribution of a DEM into a horizontal distance distribution that I call a digital distance model (DDM) provides the basis for a number of unique measurements and displays. Figure 8 illustrates how the process works using a small 3 x 5 DEM and the resulting 10 x 5 DDM. The small amount of easy to read FORTRAN code used to extract the DDM from the DEM is given as well. The algorithm may be more readily understood as a graphic (see Figure 9) that illustrates the relationship between the DEM and the DDM for the transformation of the first column of elevation values in the DEM, to the first column of distance values in the DDM. A subset of the Mars 1/64^o x 1/64^o DEM (1000 x 1200) found in the Mission Experimental Gridded Data Records (MEGDR) as the MEGT00N270G.IMG data file (Planetary Data System GeosciencesNode, 2002) centered on the Melas Chasma region of Valles Marineris was converted to a DDM (150 x 1200) then displayed as gray scale images to illustrate the process. Figure 10 shows a hillshaded image with a white line bisecting the valley walls that contain the Mellas Chasma where it opens to the north into Condor Chasma and then into Ophir Chasma. In order to obtain an unobstructed view of the valley wall north of the line, all elevations in the DEM south of the line were set to the elevation value occurring at the intersection of the line. The DDM was created by looking from the south of the modified DEM to the north. A slope gradient transformation was used on the DDM before gray scaling to produce the horizontal view shown in Figure 11a. The slope gradient

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GRID CELLS (COLUMNS)

ROWS	1	2	3	4	5
1	52.	68.	76.	30.	21.
2	36.	53.	32.	25.	21.
3	23.	34.	42.	21.	21.

DEM (3X5)

GRID CELLS (COLUMNS)

ELEVATION CLASSES	1	2	3	4	5
10	0.	0.	0.	0.	0.
9	0.	0.	1.	0.	0.
8	0.	1.	1.	0.	0.
7	0.	1.	1.	0.	0.
6	1.	2.	1.	0.	0.
5	1.	2.	1.	0.	0.
4	1.	2.	3.	0.	0.
3	2.	3.	3.	0.	0.
2	2.	3.	3.	2.	0.
1	3.	3.	3.	3.	3.

DDM (10X5)

```
C FORTRAN PROGRAM TO TRANSFORM EXAMPLE DEM TO DDM
C
      REAL*4 DEM(3,5),DDM(10,5)
      DATA DEM/52,36,23,68,53,34,76,32,42,30,25,21,21,21,21/
C
C ASSIGN PARAMETERS
      NROWS=3
      NCOLS=5
      NCLASS=10
      NCLASS1=NCLASS-1
      ZMAX=80.
      ZMIN=20.
      ZRANGE=ZMAX-ZMIN
C TRANSFORM DEM TO DDM
      DO I=1,NROWS
        DO J=1,NCOLS
          NZR=(ZMAX-DEM(I,J))/ZRANGE*NCLASS1+1.5
          DO II=NZR,NCLASS
            DDM(II,J)=I
          END DO
        END DO
      END DO
C WRITE OUT DISTANCE VALUES FROM DDM(II,J)
      DO I=1,NCLASS
        WRITE(*,'(5F5.0)') (DDM(I,J),J=1,NCOLS)
      END DO
      STOP
      END
```

Figure 8. The relationship between a DEM and an extracted DDM is presented using a small example data set. The FORTRAN code used to create the 10 x 5 DDM from the 3 x 5 DEM is listed below the diagrams.

for the DDM was determined using the zero distance plane as the base reference. For areas that show no terrain (above the top of the valley) the slope gradient as measured against the zero distance plane will be zero

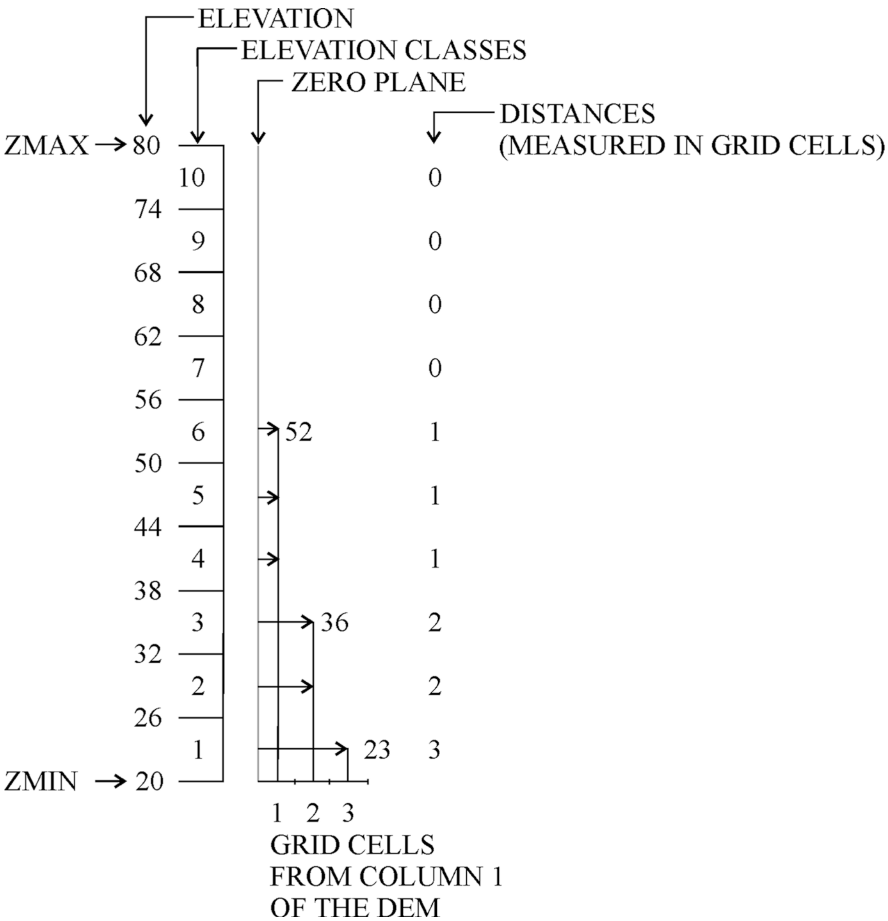

Figure 9. This graphic shows the relationship between the first column of the 3 x 5 DEM and the first column of the 10 x 5 DDM from a left side, horizontal point of view.

degrees and appears dark toned (black) in a gray scale map; slopes greater than zero will appear light toned.

The resulting display, which has an abnormal appearance, similar to that of a film negative image, can be altered by reversing the tones to produce the 'positive' image shown in Figure11b. Flat (as measured against the zero distance plane) or nearly flat areas will now be light toned and steeper areas will now be dark toned. This image has an ink-sketch quality that I believe portrays the landscape in a more normally accepted rendition.

Other transformations and mappings of the DDM can provide useful displays as well. Contouring the DDM will produce a series of cross-sectional profiles; gray scaling the DDM will produce a display that is reminiscent of the actual view, paintings, and photographs of the various foreground to background planes of terrestrial foothills and mountains when observed from afar. Parallax induction is another transformation that can be easily applied to a DDM to produce a unique graphic in the form of a stereogram. North and south looking DDM subsets (150 x 290), centered on the arrows visible in Figure 10 were used to produce left and right parallax induced DDMs before transformation into the slope gradient gray scale stereograms shown in Figures 12a and 12b. The parallax induction algorithm is exactly the same as the one used to generate stereograms from DEMs as given by Eyton (1984).

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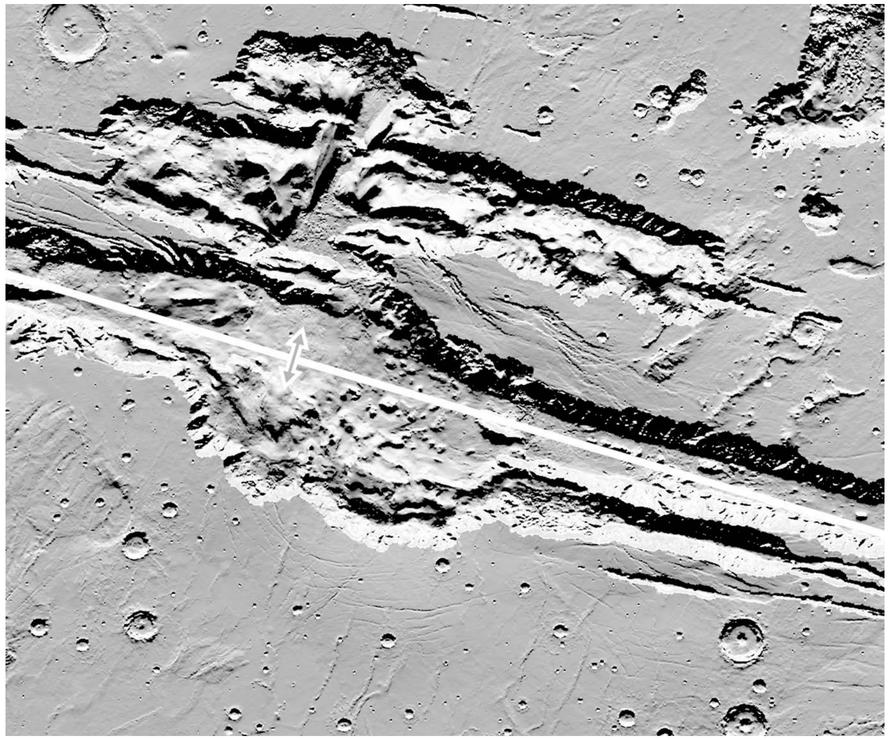
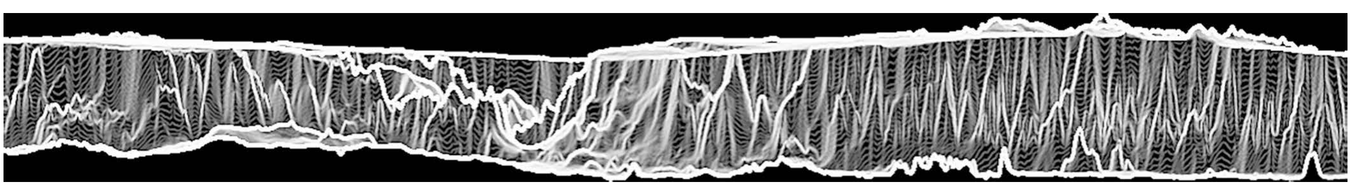


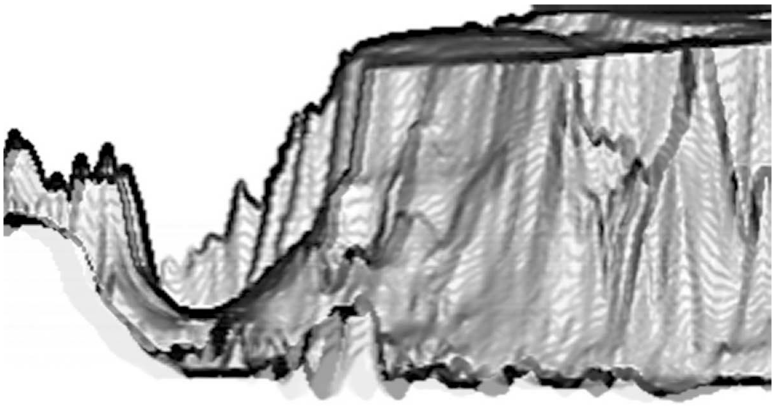
Figure 10. This hillshade image of the central region of Valles Marineris was created from a subset of the Mars 1/64° x 1/64° DEM. The white line bisecting the image into north and south halves corresponds to the location in the DEM where all elevations to the south of the line (along the columns in the DEM) were set to the elevation value occurring at the line. The DDM and resulting images (Figure 11) constructed from this altered DEM shows only detail north of the line. The arrows, located roughly at the center of Mellas Chasma, show the middle location of two additional DDM subsets that were used to create the stereo images shown in Figure 12. The north arrow points to the entrance of Condor Chasma and following the arrow's direction also points to the entrance of Ophir Chasma located immediately north of Condor Chasma. The area covered by this subset is approximately 1093 km (679 mi) west to east and 920 km (572 mi) south to north. Grid cell size at this latitude is about .91 km in longitude and .92 km in latitude. Projection is Equidistant Cylindrical.



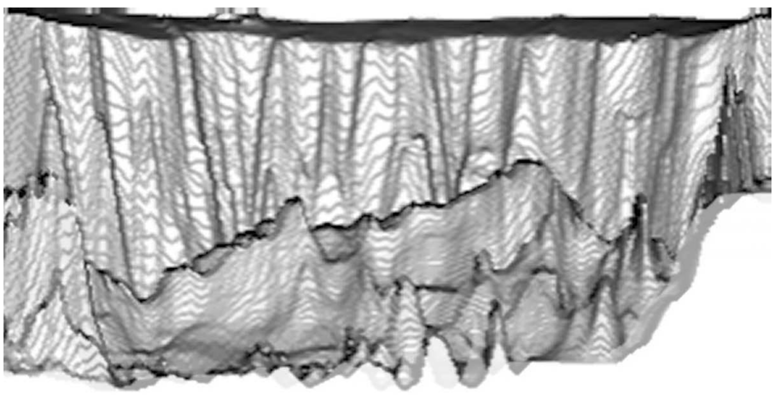
a. Linear gray scale of slope gradients with flat or gentle slopes shown as dark tones and steep slopes shown as light tones.

b. Linear gray scale of slope gradients with flat or gentle slopes shown as light tones and steep slopes shown as dark tones.

Figure 11. Images showing gray scales of slope gradients relative to the DDM zero plane.



a. Subset looking north through the opening into Condor Chasma.



b. Subset looking at the south wall of Mellas Chasma

Figure 12. Subsets of the Valles Marineris 1/64° x 1/64° DEM centered on the arrows shown in Figure 10 were converted to DDMs and induced with parallax before creating the left and right perspective slope images in the form of anaglyphs displayed above. Red-cyan glasses with red over the right eye are needed to view these images. (see page 60 for color version)

Discussion

Three new ways to visualize surface geometry using DEMs, with and without thematic overlays, has been presented. Circular gray scaling of a slope azimuth distribution should be of value to investigators interested in examining landform structures in great detail. However, their use as a means for popular depiction of landscapes may be limited because of the harshness of the image brought about by the same overabundance of detail that makes the displays useful for landform analysis. It is possible to mix the plastic-like image of the circular gray scale with the more diffuse-looking image resulting from Lambertian hillshading to produce enhanced hillshaded products. This is a subject of further research.

Tomographic maps have potential as teaching aids, and for providing inexpensive 3D displays that are suitable (requires no viewing aids) for public presentations in information centers. These displays, in both black and white as well as color, require no special equipment to produce but are limited in size (10 in x 12 in) to conventional overhead transparency material that can be printed on inkjet printers. Larger size models could be constructed from transparent films (50 inches wide in long rolls) avail-

"Circular gray scaling of a slope azimuth distribution should be of value to investigators interested in examining landform structures in great detail."

able for large format printers, but the mechanics of separating and stacking large images then becomes the principal problem. Layering the film between thin sheets of clear Plexiglas or acrylic plastic sheets is possible, however the resulting display would be extremely heavy.

Images from DDMs not only provide a unique horizontal view of land surfaces but also provide displays that might be considered a form of cartographic art. Their principal advantage is that the same data transformation and mapping manipulations that can be applied to a DEM can also be applied to the extracted DDM. More work needs to be done on the methodology for determining the 'height' or number of rows needed for the DDM. From my limited experience with producing these models, it appears that about ten to twenty percent of the number of grid cells or columns in the row of the initial DEM used as the number of rows to be extracted in the DDM, results in an acceptable DDM display. Application of the DEM to DDM transformation to elevation models generated from LIDAR data may produce a better balance between the horizontal resolution (not accuracy) and the vertical resolution in the DDM with the potential for creating outstanding horizontal displays from vertically gathered data.

"Images from DDMs not only provide a unique horizontal view of land surfaces but also provide displays that might be considered a form of cartographic art."

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