MAPPING DIGITAL DISTANCE MODELS (DDMs)

THESIS

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Brian David Buehner, B.A., B.A.

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ABSTRACT

MAPPING DIGITAL DISTANCE MODELS (DDM)

by

Brian David Buehner, B.A., B.A.

Texas State University-San Marcos

May 2006

SUPERVISING PROFESSOR: J. RONALD EYTON

A published algorithm for producing a new data set called a Digital Distance Model (DDM) extracted from Digital Elevation Models (DEMs) is used in this research. A DDM is a data set consisting of horizontal distance values extracted from the vertical height values in a DEM. A DDM map provides the user with a visual that displays the topographic data as horizontal values with a ground level viewing perspective. Typical mapping media used to display DEMs, such as contouring, classed color, and stereograms, can also be used to map DDMs. This research involves the analysis of three mapping formats, black and white mapping, color mapping, and three-dimensional mapping that were applied to DDMs. A fourth category of mapping is used to compare DDM maps of varying scales and resolutions.

CHAPTER 1

INTRODUCTION

Advancements in computer technologies have helped visualization develop into a subdiscipline within the subject of cartography (Johansson, 2000). Exploring a new visualization technique is the main objective of this thesis. The visualization technique used to display mapped topographic data extracted from Digital Elevation Models (DEMs), a horizontal distance distribution referred to as a Digital Distance Model or DDM (Eyton, 2005). A DDM allows topographic data to be represented as a horizontal distribution rather than a vertical distribution. Maps typically used to represent DEM data, such as contouring, hill shading, stereograms, and color stereoscopic effect are used to display the DDM data. In order to test the effectiveness of this visualization technique with respect to scale and resolution, five data sets of the same location, with resolutions ranging from 1/3 arc-seconds to two arc-minutes, were mapped and displayed using the same mapping technique. The maps generated from each DDM data set in this research were analyzed and evaluated based on potential projected results from future testing.

Elevation data from a topographic map, or DEM is mapped in values based on vertical height distributions with mean sea level as the reference. Some GIS and remote sensing software packages such as *ARCGIS 9.1* (ESRI, 2006) and *ERDAS Imagine* (Leica Geosystems LLC, 2005), allow for various perspective viewing angles including ground level horizontal viewing positions, but the DEM data is still in the vertical height distribution format. An extracted DDM can be viewed in the same ground level viewing perspective, but provides the user with a sense of horizontal depth, similar to how the user would actually view the landscape.

Eyton (2005) in an article titled "Unusual Displays of DEMs" first presented the idea of a DDM and the algorithm needed to extract a horizontal distance distribution (DDM) from a vertical height distribution in a DEM. This research is a continuation of his work and ideas.

The DDM is a raster or grid data set and can make use of all the derivative transformations (slope gradient, slope azimuth, curvature, relative radiance, etc.) and visualization techniques (binary and edge contouring, gray scaling, hill shading, etc.), commonly applied to DEMs. The mapping techniques are broken into three categories. The first category involves black and white DDM mapping, including binary and edge contouring, linear gray scaling, azimuthal circular gray scaling, and hill shaded relief. Each of these visualization techniques produces a unique representation of the topographic data, some of which produces a map that sometimes resembles a photograph or pencil sketch of the terrain. The second category involves color DDM maps using colored classes with and without hill shaded relief. These maps help to represent the horizontal depth of the data through the use of colored 'depth' profiles. The third category involves three-dimensional DDM maps using the color stereoscopic effect, and maps that make use of induced parallax. These stereo representations of the terrain produce maps that give the viewer a feeling of actually standing on the ground and looking at distant landscapes. The data used to map the DDMs covers both physical terrain and urban settings.

The varying scale and resolution of the data can alter the effectiveness of the DDM visualization technique. A fine resolution data set can provide the user with detail, but as the resolution becomes coarser, the detail deteriorates. In order to demonstrate this change, DDM maps were produced from five data sets of the same location and displayed using the same mapping format. The data sets have resolutions between 1/3 arc-seconds and two arc-minutes. The five maps were then compared to each other.

CHAPTER 2

BACKGROUND LITERATURE

DDM Mapping

Eyton (2005) provides the basis for this research involving the extraction of DDMs from DEMs and mapping them. He essentially created a perspective plot from a viewing position of zero degrees altitude with the capability of inducing stereo parallax. To demonstrate the DDM technique, Eyton used terrain data of Mars, from the Mars Orbital Laser Altimeter (MOLA). A hill shade image of Valles Marineris, the Grand Canyon of Mars, was created and used as a guide to bisect the DEM along the canyon floor. Elevation values south of the line were reduced to that of the canyon floor. The extracted DDM and resulting maps show detail in the north walls of the Valles Marineris.

The first of his DDM maps involved slope gradient data, which was displayed with lighter tones representing steeper slopes and darker tones representing gentle slopes. The map was then negated to show steeper slopes with darker tones and gentler slopes with lighter tones. The negated map contrasted the dark outline of the terrain against the white background. Eyton argued that the map not only provided a realistic view of the terrain, but also might be considered a form of cartographic art due to the resemblance of a pencil sketch or a charcoal drawing.

A second map was produced as a stereogram by inducing parallax into the DDM, with a gray scaled slope gradient image used as an overlay. This technique produced a visualization, which gives viewers a perspective that, more than likely, they will never encounter in real life, a view of the Valles Marineris as if they were standing on the canyon floor.

What is Scientific Visualization?

MacEachren (1998, 2001) defines scientific visualization as the use of sophisticated computing technology to create visual displays with the goal of facilitating thinking and problem solving. The emphasis on this undertaking is to not just store knowledge, but is also directed towards knowledge construction. The DDM visualization technique follows MacEachren's definition by producing visual displays from new data extracted from conventional DEM data. These DDM data sets and resulting maps provide the user with new information, such as horizontal slope and contoured distances. Such information can help the user to further facilitate thinking, understanding, and the construction of new knowledge about a particular terrain.

CHAPTER 3

DATA

The original data sources of the eleven DEMs used for this research are the Bureau of Economic Geology at the University of Texas, The U.S. Geological Survey (USGS), and the National Geophysical Data Center (NGDC). Each terrain data set was obtained as four byte, floating-point data, with resolutions ranging between two arc-minutes to one meter DEMs. Following is a brief description of the eleven data sets.

Light **D**etection **a**nd **R**anging (LIDAR) data covering Houston and Austin, Texas, were retrieved online from the Bureau of Economic Geology at The University of Texas (www.beg.utexas.edu). These two LIDAR data sets have a resolution of one meter and were used to illustrate DDM mapping formats applied to an urban environment.

Topography and bathymetry data of Crater Lake, Oregon, downloaded as National Elevation Data (NED) from the USGS website (www.usgs.gov) has a resolution of 1/3 arc-second. Having both topography and bathymetry allows the Crater Lake data set to be used to produce DDM maps with a unique viewing position, looking west from the bottom of the lake bed.

Data sets covering the Grand Canyon, Arizona and Guadalupe Peak, Texas were also downloaded as NEDs from the USGS website. The Grand Canyon data set, with a resolution of one arc-second, was used to produce DDM maps that display sharp vertical drops in a physical setting. The Guadalupe Peak data set, with a resolution of three arc-seconds, is used to illustrate vertical rise in a natural terrain. The vertical rise is easily depicted in the Guadalupe Peak DDM maps due to the flat nature of the landscape south of the peak.

A DEM of the Northwestern United States, with a resolution of thirty arc-seconds, was downloaded from the National Geophysical Data Center (NGDC) website at www.ngdc.noaa.gov. Mt. Rainier, Mt. St. Helen's, Mt. Adams, Mt. Hood, Mt. Shasta, and several other volcanic peaks in northern California, Oregon, and Washington are visible in the DEM. These high elevation volcanoes and peaks, set near the coastline, allow for the production of DDM maps that show elevation change over a large distance.

The final five data sets are of the Hawaiian Islands and surrounding Pacific Ocean. The location was chosen due to the contrasting features of the landscape. The small volcanic islands contain large volcanoes such as Mauna Loa and Mauna Kea, which show sharp elevation rises from sea level, and are riddled with small craters and terrain variations that can be displayed with high resolution DEMs. The coarse resolution DEM still shows the elevation rise in the topography of the islands, but also includes bathymetry.

The five data sets of the Hawaiian Islands each cover different areas depending their specific resolution. A 1/3 arc-second resolution NED of the craters on top Muana Loa on the island of Hawaii is used as an example of fine resolution data. An NED with a resolution of one arc-second of Mauna Kea is used as a mid-level resolution data set. A slightly coarser NED of three arc-seconds, containing Mauna Kea and Mauna Loa, is used as a second mid-level resolution data set. A thirty arc-second resolution data set of the entire Hawaiian Island chain was downloaded from the NGDC website and is used as an example of coarse data. The final data set, with a resolution of two arc-minutes, includes both topography and bathymetry of the Hawaiian Island chain along with much of the surrounding Pacific Ocean. This data set was also acquired from the NGDC website and is used as a second example of very coarse data.

CHAPTER 4

METHODOLOGY

Mapping DEMs and Selecting Subsets

All terrain processing was done using Eyton's unpublished software package, Terra Firma, (Eyton, 2006), and the display and color compositing was done using Paint Shop Pro 7 (Jasc, 2003). Initial processing began by producing a frequency table and histogram of elevation values for each data set. The frequency table and histogram allows the low frequency content to be clipped while the remaining elevation values are stretched between the gray scale values of 0-255. Table 1 shows a tabulation of the elevation values for the Austin data set.

The next step was to produce a relative radiance file for each DEM by calculating the incident solar radiation for each grid cell on a scale of 0.0 – 1.0. A solar azimuth of 360° and a solar elevation of 45° was used. By using the relative radiance file derived from the DEM, a linear gray scaling produced a map with hill shaded relief. The added hill shaded relief gives the DEM map more texture and displays the land features more distinctly. Having sharper detail in the map, allows for a subset to be more easily identified and selected.

Each of the eleven data sets was displayed as a linear gray scale map with hill shaded relief. Relative radiance values are depicted by gray scale values ranging between

Table 1. Frequency Table of the Elevation Values in the Austin DEM

FREQUENCY TABLE AUS CBD LABEL C TXT

CLASS	LOWER CLASS LIMIT	UPPER CLASS LIMIT	FREQUENCY	PERCENT FREQUENCY	ACCUMULATED PERCENT FREQUENCY
1	30 0000	35 0000	1	000	000
2	35 0000	40 0000	0	000	000
3	40 0000	45 0000	0	000	000
4	45 0000	50 0000	0	000	000
5	50 0000	55 0000	0	000	000
6	55 0000	60 0000	0	000	000
7	60 0000	65 0000	0	000	000
8	65 0000	70 0000	1	000	000
9	70 0000	75 0000	1	000	000
10	75 0000	80 0000	2	000	001
11	80 0000	85 0000	2	000	001
12	85 0000	90 0000	3	000	001
13	90 0000	95 0000	4	000	002
14	95 0000	100 0000	6	001	002
15	100 0000	105 0000	31431	3 714	3 716
16	105 0000	110 0000	26341	3 112	6 829
17	110 0000	115 0000	47895	5 659	12 488
18	115 0000	120 0000	205117	24 237	36 725
19	120 0000	125 0000	152146	17 978	54 703
20	125 0000	130 0000	102560	12 119	66 821
21	130 0000	135 0000	89995	10 634	77 455
22	135 0000	140 0000	83600	9 878	87 334
23	140 0000	145 0000	40955	4 839	92 173
24	145 0000	150 0000	20066	2 371	94 544
25	150 0000	155 0000	12419	1 467	96 011
26	155 0000	160 0000	8670	1 024	97 036
27	160 0000	165 0000	6216	734	97 770
28	165 0000	170 0000	3280	388	98 158
29	170 0000	175 0000	3122	369	98 527
30	175 0000	180 0000	2532	299	98 826
31	180 0000	185 0000	1218	144	98 970
32	185 0000	190 0000	1213	143	99 113
33	190 0000	195 0000	1824	216	99 329
34	195 0000	200 0000	2571	304	99 633
35	200 0000	205 0000	1177	139	99 772
36	205 0000	210 0000	509	060	99 832
37	210 0000	215 0000	386	046	99 877
38	215 0000	220 0000	216	026	99 903
39	220 0000	225 0000	163	019	99 922
40	225 0000	230 0000	180	021	99 944
41	230 0000	235 0000	171	020	99 964
42	235 0000	240 0000	212	025	99 989
43	240 0000	245 0000	65	008	99 996
44	245 0000	250 0000	30	004	100 000

Z-MINIMUM 33 936890
Z-MAXIMUM 247 123000

0-255. Determining a subset was the next step. A subset that includes the Astrodome and immediate surrounding areas was obtained from the Houston LIDAR DEM. This subset allowed for the creation of a DDM data set and resulting maps that display a large urban structure without obstruction from surrounding features, due to the large open parking lot surrounding the stadium. Figure 1 shows the Astrodome LIDAR DEM subset as a hill shaded map. A subset selected from the Austin LIDAR DEM includes the Central Business District (CBD), the Colorado River, and a small portion of land south of the river. This subset allowed for the extraction of a DDM data set and resulting maps with the perspective view of looking north over the Colorado River towards the central business district. Figures 2 shows the Austin CBD LIDAR DEM subset as a hill shaded map.

A subset extracted from the Crater Lake DEM includes the western half of the lake and its shoreline. The subset bisects the lake and was rotated 90° clockwise to permit the generation of a DDM data set and resulting maps with a west facing viewing position from the lake bed. Figure 3 shows the Crater Lake DEM subset as a hill shaded map.

The Grand Canyon DEM did not have a subset initially extracted, until the elevation values south of the Colorado River were altered. The goal for this map was to create a visual display of the Grand Canyon with a north viewing perspective from the Colorado River. In order to construct such a map, the DEM needed to be altered so that all values south of the Colorado River were reduced to the same elevation value as the lowest point, just as Eyton (2005) did with the Vallas Marineris data set. This altered the DEM so that only the elevation information comprising the north walls of the canyon was

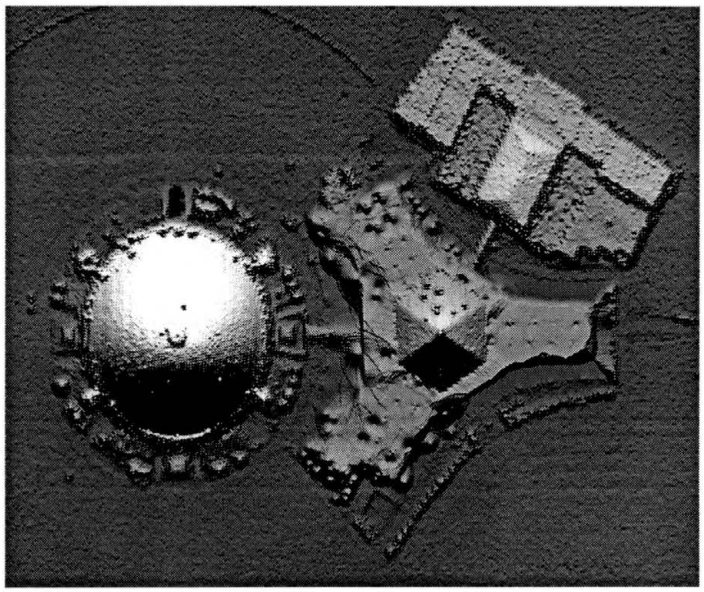

Figure 1. Astrodome LIDAR DEM subset as a hill shaded map (1:8,000).

Figure 2. Austin CBD LIDAR DEM subset as a hill shaded map (1:8,000).

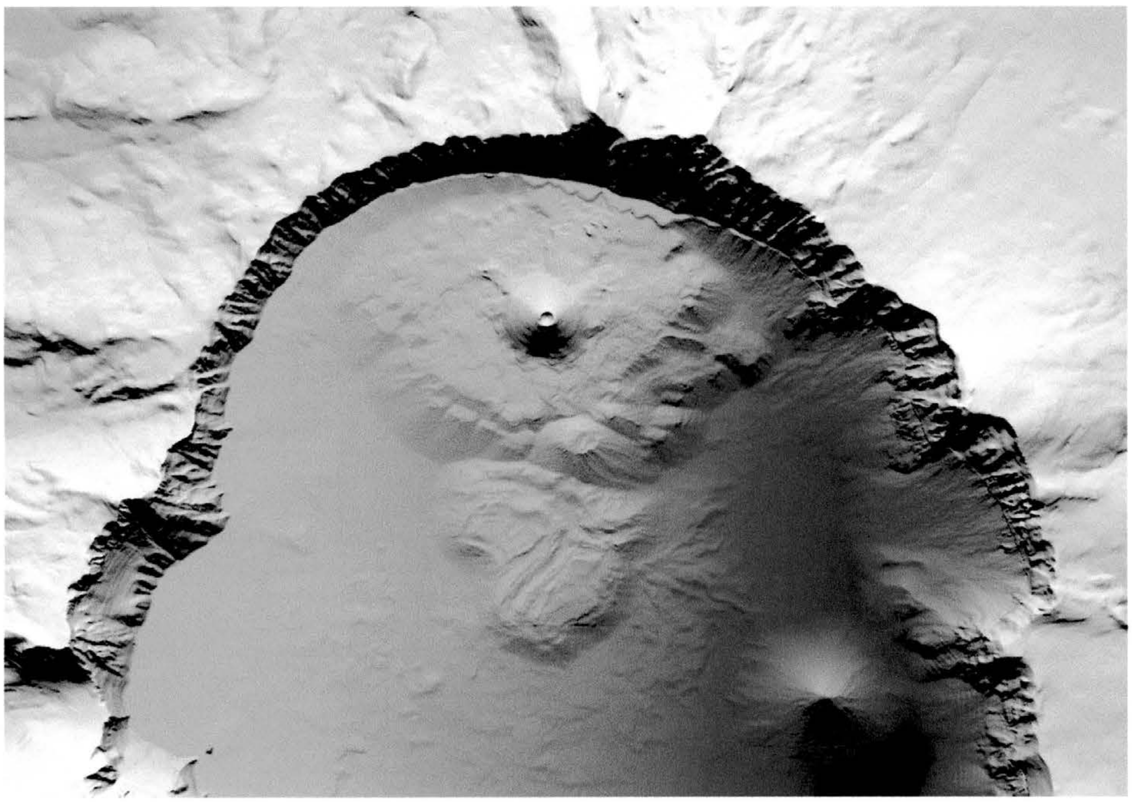

Figure 3. Crater Lake DEM subset including topography and bathymetry. Displayed as a hill shaded map (1:60,000).

retained. A subset was then taken of the Colorado River and north walls of the canyon. Due to the meandering path of the Colorado River, not all of the altered elevation values were able to be eliminated from the subset, but are represented as a slowly changing plane of elevations matching the river elevations in the foreground. Figures 4a and b show the Grand Canyon DEM map before and after the elevation values south of the Colorado River were altered and a subset extracted.

A subset from the Guadalupe Peak DEM (see Figure 5) includes Guadalupe Peak, the surrounding mountains to the east and west, and the small foothills south of the peak. The extracted subset displays relatively flat land trending from the south up to Guadalupe Peak.

A selected subset of the volcanoes and high peaks in Washington, Oregon, and northern California, was separated from the Northwestern United States DEM. The subset was rotated 90° counterclockwise in order to extract a DDM data set with the capability of producing maps with a perspective viewing position of looking east, from the Pacific Ocean, towards the coast. Figure 6 shows the Northwestern United States subset as a hill shaded map.

The 1/3 arc-second resolution Hawaii data set of the craters on top of Mauna Loa, was used to extract a subset that bisects the larger crater and includes the western half of the crater bed and the west walls. The subset was rotated 90° clockwise in order for a DDM data set and resulting map to be created with a viewing perspective of looking east to west towards the crater walls. Figure 7 shows the Mauna Loa craters DEM subset as a hill shaded map. A subset of Mauna Kea, on the island of Hawaii, was chosen from the one arc-second data set. Mauna Kea is also included, along with Mauna Loa, in the

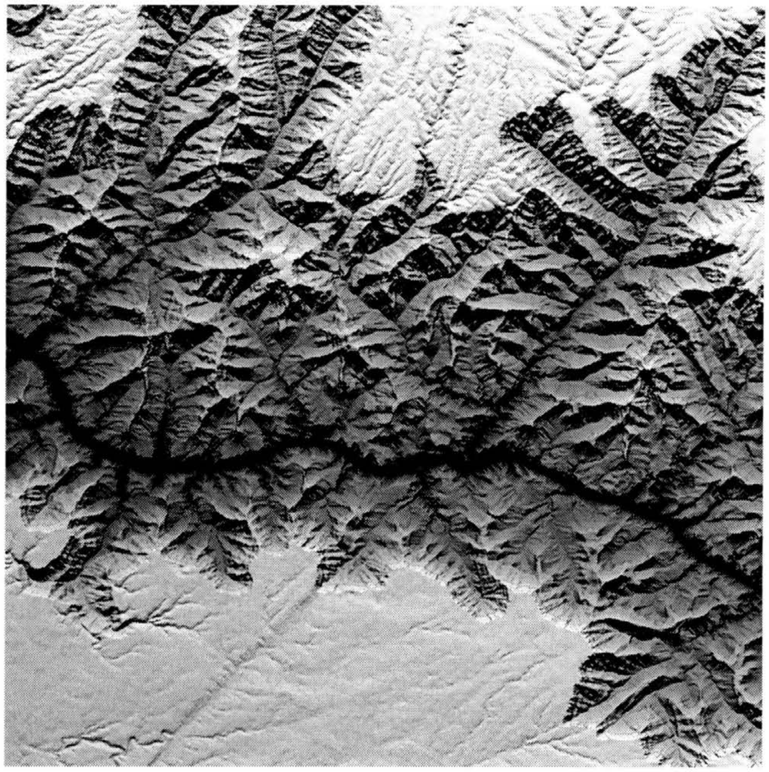

Figure 4a. Grand Canyon DEM hill shaded map before alterations and subset (1:200,000).

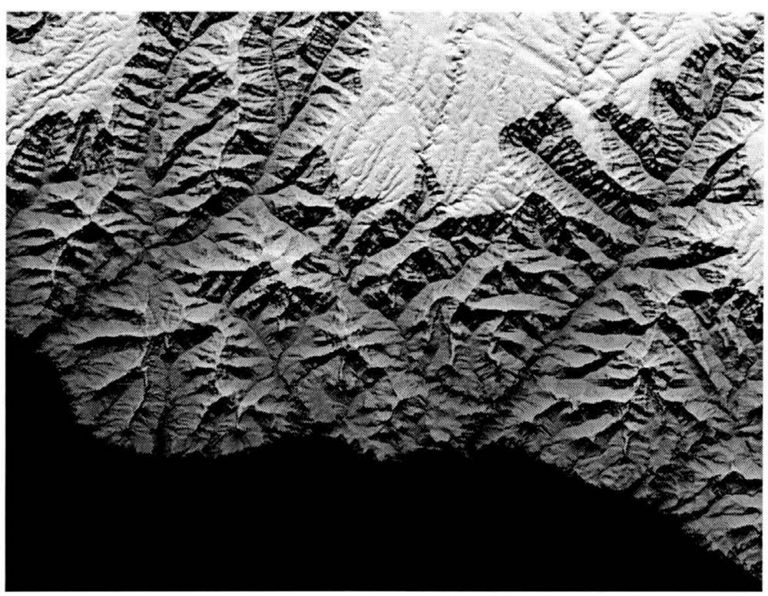

Figure 4b. Grand Canyon DEM hill shaded map after alterations and subset (1:200,000).

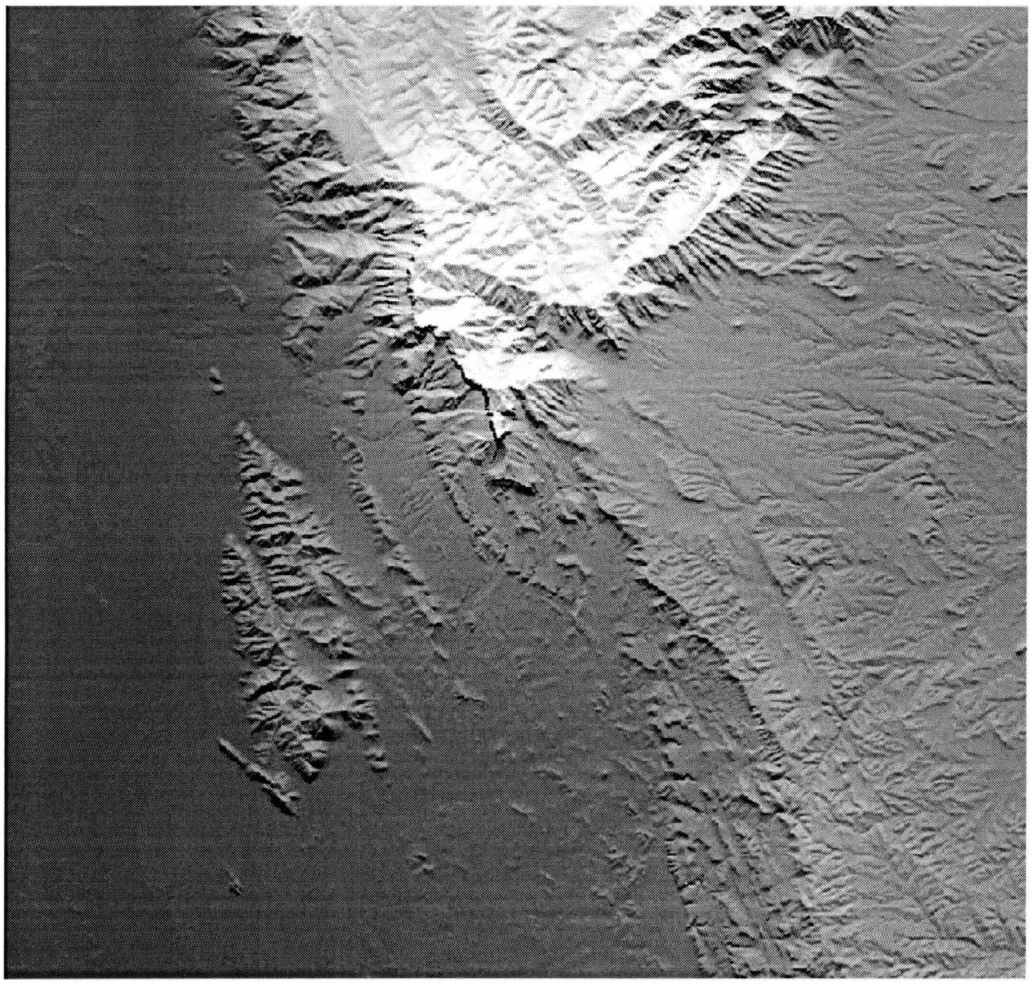

Figure 5. Guadalupe Peak DEM subset as a hill shaded map (1:600,000).

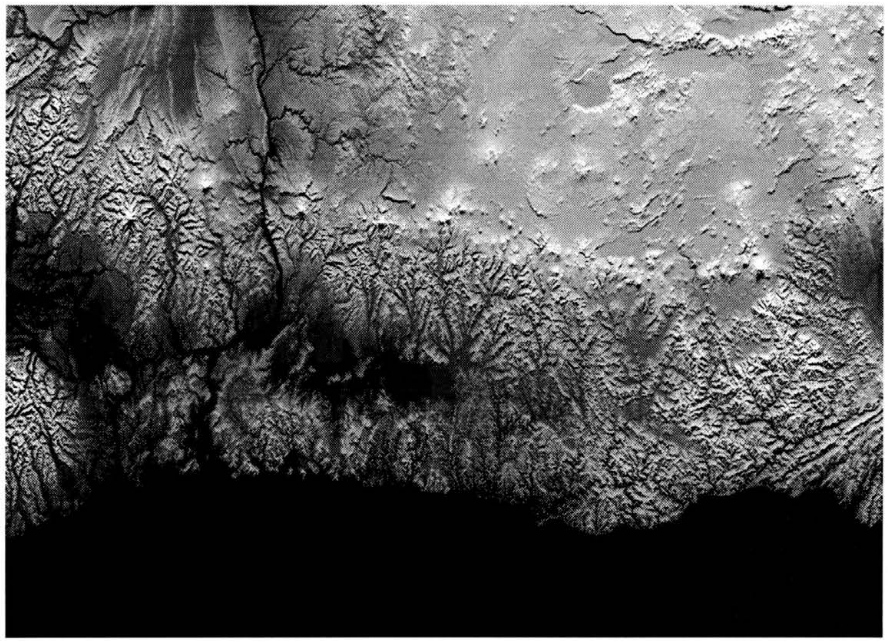

Figure 6. Northwestern U. S. DEM subset as a hill shaded map (1:5,000,000).

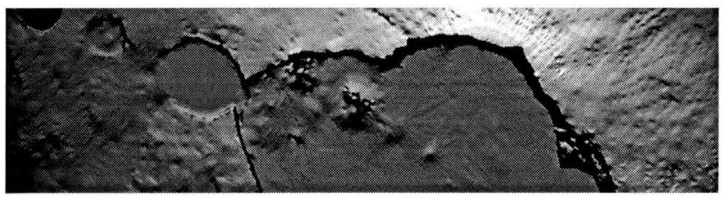

Figure 7. Western half of the craters on top Mauna Loa DEM subset as a hill shaded map (1:75,000).

subset taken from the three arc-second data set. These two subsets were rotated 90° clockwise, in order to produce DDM data sets with the ability to create maps where the land features were displayed consistently among the three higher resolution data sets. Figures 8 and 9 display these two subsets as hill shaded maps.

A subset was selected from the thirty arc-second DEM to include the entire Hawaiian Island chain and the surrounding Pacific Ocean. Lastly, a subset of the two arc-minute DEM was chosen to also include the entire Hawaiian Island chain and Pacific Ocean, but consist of both topography and bathymetry data. Figures 10 and 11 show these two subsets as hill shaded maps.

Extracting a DDM from a DEM

The DDM is extracted from each of the DEMs, using the program 'DDM' within the Terra Firma package. The process starts by grouping each elevation value into classes using a zero distance plane as a reference. These classes are then converted into horizontal distances measured in grid cell units. Figure 12 shows an extracted 10 x 5 DDM taken from a 3 x 5 DEM (Eyton, 2005). Figure 13 illustrates how the DDM extraction is done by showing the relationship between the first column of the DEM and the first column of the DDM (Eyton, 2005).

Black and White DDM Mapping

Edge and binary contour maps of the Crater Lake DDM were the first maps produced in black and white. The two contour maps of the DDM were made using a zero

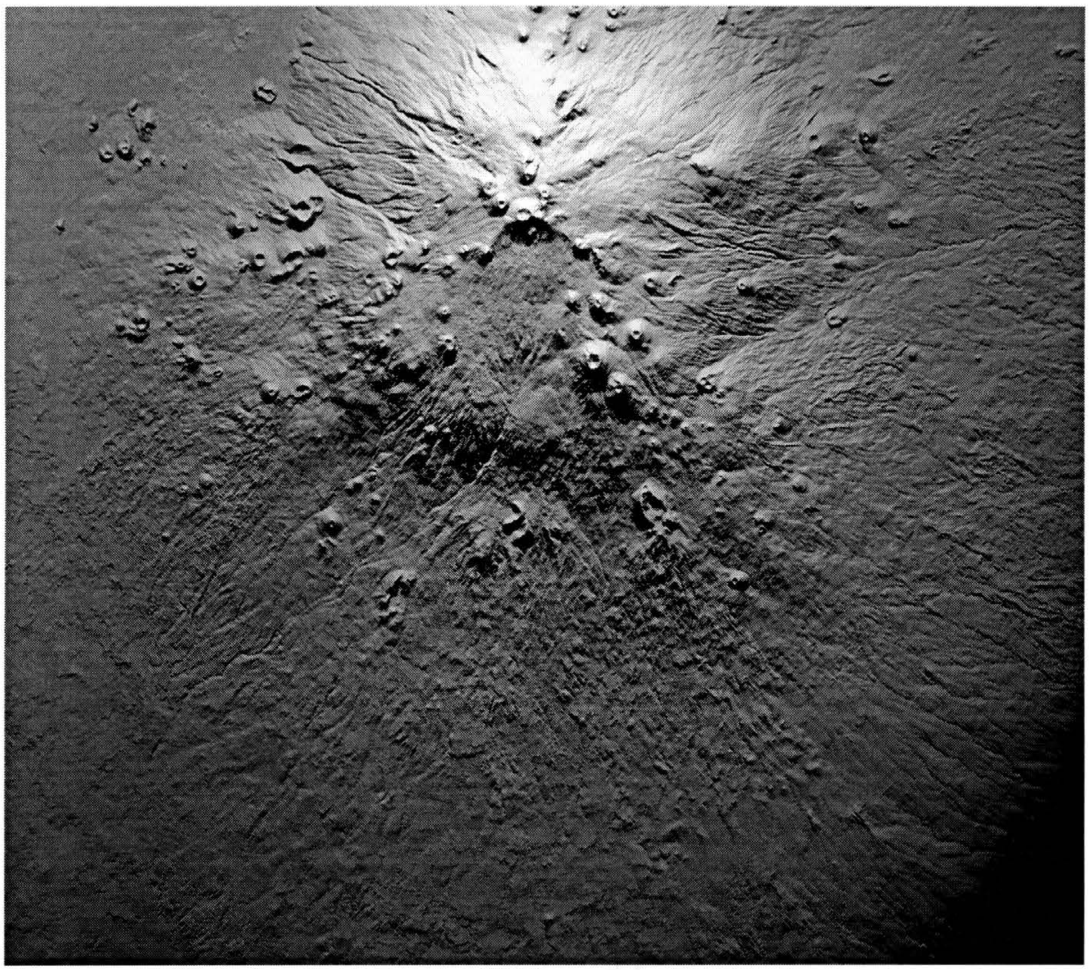

Figure 8. Mauna Kea DEM subset as a hill shaded map (1:200,000).

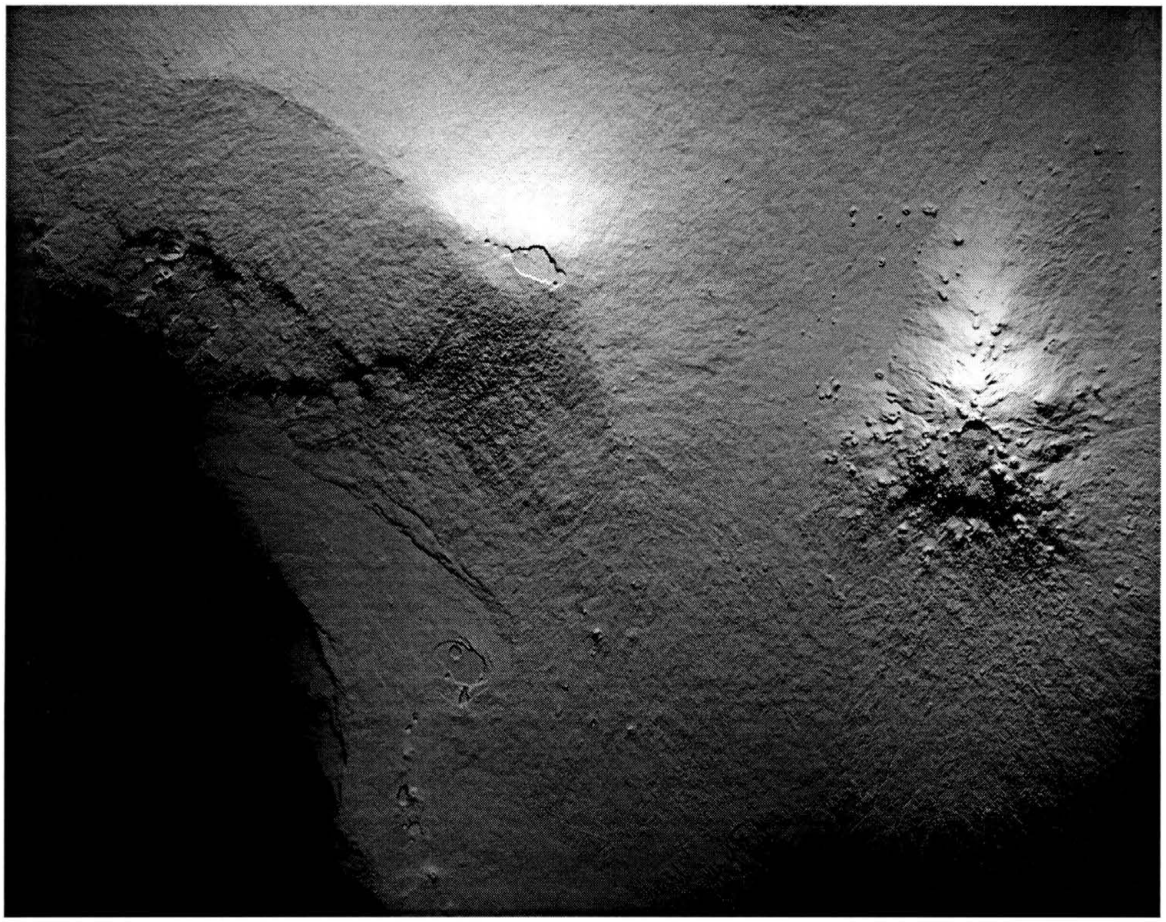

Figure 9. Mauna Loa and Mauna Kea DEM subset as a hill shaded map (1:600,000).

Figure 10. Hawaiian Islands DEM subset as a hill shaded map (1:5,000,000).

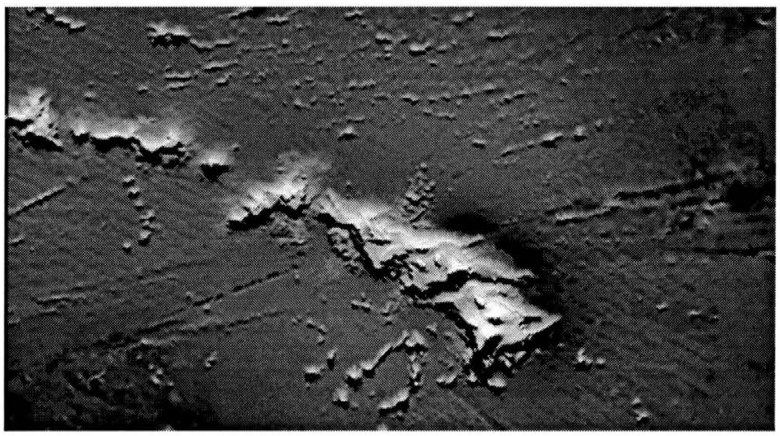

Figure 11. Hawaiian Islands and surrounding Pacific Ocean DEM subset including topography and bathymetry. Displayed as a hill shaded map (1:15,000,000).

GRID CELLS (COLUMNS)

		1	2	3	4	5	
	1	52.	68.	76.	30.	21.	
ROWS	2	36.	53.	32.	25.	21.	DEM (3X5)
	3	23.	34.	42.	21.	21.	

GRID CELLS (COLUMNS)

		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.	
ELEVATION	6	1.	2.	1.	0.	0.	DDM (10X5)
CLASSES	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.	

Figure 12. A 3 x 5 DEM and an extracted 10 x 5 DDM (Eyton, 2005, p. 18).

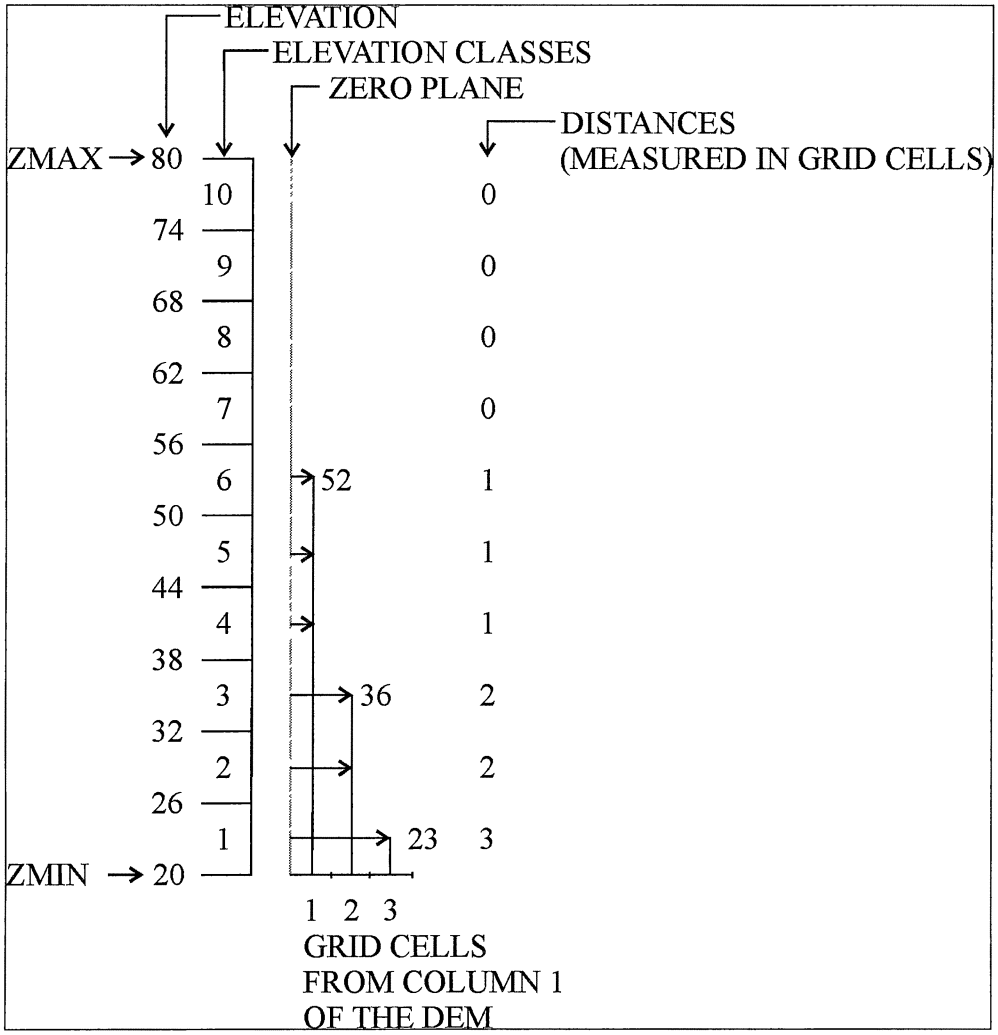

Figure 13. The relationship between the first column of the DEM and the first column of the DDM (Eyton, 2005, p. 19).

value for the reference contour and twenty meters as the contour interval. The second set of contour DDM maps was made using the Astrodome DDM. The contour maps were generated with a zero value for the reference contour and an interval value of ten meters. Both sets of contour maps show cross sectional profiles of the horizontal distance values in the DDMs.

Derivative transformations such as slope gradient, slope azimuth, and relative radiance were used to produce new data sets extracted from the DDMs. Gray scaling and hill shaded relief mapping techniques are used to display these transformed data sets. The Astrodome, Austin CBD, Crater Lake, and the Northwestern U.S. DDMs are used to illustrate these mapping techniques. The slope gradient maps of the four DDMs are displayed with lighter tones representing steeper slopes and darker tones representing flatter areas. These maps were then negated in order to display the landscape's details and variations with darker tones, set against a white background. I believe this tonal contrast produces a more aesthetically pleasing visual. An azimuthal circular gray scale map was also created from the Austin CBD DDM. This map was displayed using a solar azimuth of 270° for the illumination.

A linear gray scale map was produced from the Austin CBD DDM that displays the data as lighter to darker tones, depending on the horizontal distance value. The closer the object is to the viewer, the lighter the tone. The map was also negated in order to provide a white background, which helps bring out sharper detail and depth within the scene.

A hill shaded relief map involves the use of the previously made slope gradient map, and a relative radiance file. The relative radiance file for each of the DDMs was produced with a constant solar elevation of 40°, but with a varying solar azimuth. The variation in the solar azimuth illuminates the terrain from different perspectives, just as the sun would throughout the course of the day. The variation of degrees in the solar azimuth needs to stay between 0° - 90°, or 270° - 360°. If a solar azimuth were given a value between 89° - 269°, then the illumination source in the map would be from under the surface of the terrain. With this in mind, the following solar azimuth values were assigned to each of the three DDMs; 45° for Austin CBD, 270° for Crater Lake, and 90° for the Astrodome. The slope gradients were then modulated by the relative radiance data to produce a slope gradient map with hill shaded relief (Horn, 1982).

Color DDM Mapping

The second category of DDM mapping presented in this research is color mapping and is broken into two sections, classed color with and without hill shaded relief. The Grand Canyon DDM was the first data set used to illustrate color mapping.

A frequency table (see Table 2) was made of the horizontal distance values in the DDM. Using the frequency table as a guide, the values were divided into eight classes. The first six classes were chosen based on closely equivalent equal-frequencies, while the last two classes remained smaller due to the flat foreground of the meandering Colorado River and altered elevation values south of the river (see Table 3). Each class was assigned a color and displayed as a DDM map. In order to accentuate the depth of the canyon, an edge contour map was used as an overlay, with a contour reference of zero and contour interval value of fifteen meters.

Table 2. Frequency Table of the Classed Elevation Values in the Grand Canyon DDM

FREQUENCY TABLE GCB DDM LABEL GCB TXT

CLASS	LOWER CLASS LIMIT	UPPER CLASS LIMIT	FREQUENCY	PERCENT FREQUENCY	ACCUMULATED PERCENT FREQUENCY
1	0000	20 0000	20961	9 295	9 295
2	20 0000	40 0000	1607	713	10 008
3	40 0000	60 0000	2800	1 242	11 250
4	60 0000	80 0000	2607	1 156	12 406
5	80 0000	100 0000	3025	1 341	13 747
6	100 0000	120 0000	2444	1 084	14 831
7	120 0000	140 0000	5447	2 416	17 247
8	140 0000	160 0000	4413	1 957	19 204
9	160 0000	180 0000	3062	1 358	20 561
10	180 0000	200 0000	3778	1 675	22 237
11	200 0000	220 0000	4353	1 930	24 167
12	220 0000	240 0000	5921	2 626	26 793
13	240 0000	260 0000	8504	3 771	30 564
14	260 0000	280 0000	7831	3 473	34 037
15	280 0000	300 0000	4432	1 965	36 002
16	300 0000	320 0000	6617	2 934	38 937
17	320 0000	340 0000	8602	3 815	42 751
18	340 0000	360 0000	10421	4 621	47 373
19	360 0000	380 0000	9586	4 251	51 624
20	380 0000	400 0000	9479	4 204	55 827
21	400 0000	420 0000	7585	3 364	59 191
22	420 0000	440 0000	7677	3 404	62 595
23	440 0000	460 0000	5336	2 366	64 961
24	460 0000	480 0000	7991	3 544	68 505
25	480 0000	500 0000	12100	5 366	73 871
26	500 0000	520 0000	13576	6 020	79 891
27	520 0000	540 0000	15563	6 902	86 793
28	540 0000	560 0000	9227	4 092	90 885
29	560 0000	580 0000	4838	2 145	93 030
30	580 0000	600 0000	2947	1 307	94 337
31	600 0000	620 0000	1401	621	94 958
32	620 0000	640 0000	2369	1 051	96 009
33	640 0000	660 0000	2046	907	96 916
34	660 0000	680 0000	1959	869	97 785
35	680 0000	700 0000	412	183	97 968
36	700 0000	720 0000	4583	2 032	100 000

Z-MINIMUM 000000
Z-MAXIMUM 700 000000

Table 3. Input File Designating the Eight Classes, Their Associated Color, and the Percent Frequency for the Grand Canyon DDM

CLASS	LOWER CLASS LIMIT	UPPER CLASS LIMIT	COLOR NUMBER-COLOR (within Terra Firma's color palette)	PERCENT FREQUENCY
1	0	100	3-BLUE	13 747
2	100	200	11-LIGHT BLUE	8.490
3	200	300	4-CYAN	13.765
4	300	400	2-GREEN	19.825
5	400	500	10-LIGHT GREEN	18.044
6	500	600	6-YELLOW	20.466
7	600	640	22-ORANGE	1 672
8	640	720	1-RED	3.991

8-COLOR OF UNCLASSED VALUES-BLACK

The second classed color map was generated using the Astrodome DDM. A frequency table of elevation values was produced in order to help determine class limits (see Table 4). The horizontal distance values were then, divided into six classes to represent varying depths in an urban environment. Due to the uneven distribution pattern of elevation values, the six classes were not created based on an equal percent frequency. Instead, the class limits were determined with the goal in mind of creating a visual that represents the depth and shape of the Astrodome and surrounding structures in the scene (see Table 5).

The second set of maps was made with the same color classing and edge contouring, but with modulated hill shaded relief to show more texture in the maps. The Astrodome DDM used the previously made relative radiance file and the Grand Canyon DDM used a relative radiance file having 90° as the solar azimuth and 20° as the solar elevation.

Three-Dimensional DDM Mapping

The third category of DDM mapping produced for this thesis is three-dimensional DDM mapping. This category is divided into two sections, color stereoscopic effect mapping (Eyton, 1990) and induced parallax anaglyph mapping. The Grand Canyon DDM was used to produce a map that displays the color stereoscopic effect. Instead of producing a classed color map, the internal color palette of 1021 colors in Terra Firma was utilized to produce a continuous color map. The colors range from blue to red, where blue appears furthest away from the viewer and red appears closest to the viewer.

Table 4. Frequency Table of the Classed Elevation Values in the Astrodome DDM

FREQUENCY TABLE AST DDM LABEL A TXT

CLASS	LOWER CLASS LIMIT	UPPER CLASS LIMIT	FREQUENCY	PERCENT FREQUENCY	ACCUMULATED PERCENT FREQUENCY
1	0000	10 0000	86848	60 311	60 311
2	10 0000	20 0000	0	000	60 311
3	20 0000	30 0000	0	000	60 311
4	30 0000	40 0000	0	000	60 311
5	40 0000	50 0000	0	000	60 311
6	50 0000	60 0000	0	000	60 311
7	60 0000	70 0000	0	000	60 311
8	70 0000	80 0000	0	000	60 311
9	80 0000	90 0000	0	000	60 311
10	90 0000	100 0000	0	000	60 311
11	100 0000	110 0000	0	000	60 311
12	110 0000	120 0000	49	034	60 345
13	120 0000	130 0000	0	000	60 345
14	130 0000	140 0000	11	008	60 353
15	140 0000	150 0000	144	100	60 453
16	150 0000	160 0000	293	203	60 656
17	160 0000	170 0000	216	150	60 806
18	170 0000	180 0000	291	202	61 008
19	180 0000	190 0000	599	416	61 424
20	190 0000	200 0000	864	600	62 024
21	200 0000	210 0000	975	677	62 701
22	210 0000	220 0000	670	465	63 167
23	220 0000	230 0000	672	467	63 633
24	230 0000	240 0000	486	338	63 971
25	240 0000	250 0000	137	095	64 066
26	250 0000	260 0000	503	349	64 415
27	260 0000	270 0000	480	333	64 749
28	270 0000	280 0000	487	338	65 087
29	280 0000	290 0000	7	005	65 092
30	290 0000	300 0000	75	052	65 144
31	300 0000	310 0000	161	112	65 256
32	310 0000	320 0000	62	043	65 299
33	320 0000	330 0000	150	104	65 403
34	330 0000	340 0000	74	051	65 454
35	340 0000	350 0000	524	364	65 818
36	350 0000	360 0000	1011	702	66 520
37	360 0000	370 0000	2741	1 903	68 424
38	370 0000	380 0000	1949	1 353	69 777
39	380 0000	390 0000	2120	1 472	71 249
40	390 0000	400 0000	2325	1 615	72 864
41	400 0000	410 0000	4095	2 844	75 708
42	410 0000	420 0000	5518	3 832	79 540
43	420 0000	430 0000	3600	2 500	82 040
44	430 0000	440 0000	3431	2 383	84 422
45	440 0000	450 0000	3977	2 762	87 184
46	450 0000	460 0000	3052	2 119	89 303
47	460 0000	470 0000	605	420	89 724
48	470 0000	480 0000	709	492	90 216
49	480 0000	490 0000	1861	1 292	91 508
50	490 0000	500 0000	813	565	92 073
51	500 0000	510 0000	241	167	92 240
52	510 0000	520 0000	251	174	92 415
53	520 0000	530 0000	83	058	92 472
54	530 0000	540 0000	145	101	92 573
55	540 0000	550 0000	168	117	92 690
56	550 0000	560 0000	127	088	92 778
57	560 0000	570 0000	224	156	92 933
58	570 0000	580 0000	114	079	93 013
59	580 0000	590 0000	115	080	93 092
60	590 0000	600 0000	168	117	93 209
61	600 0000	610 0000	9779	6 791	100

Z-MINIMUM 000000
Z-MAXIMUM 600 000000

Table 5. Input File Designating the Six Classes, Their Associated Color, and the Percent Frequency for the Astrodome DDM

CLASS	LOWER CLASS LIMIT	UPPER CLASS LIMIT	COLOR NUMBER-COLOR (within Terra Firma's color palette)	PERCENT FREQUENCY
1	0	10	18-DARK BLUE	60.311
2	10	270	17-DARK GREEN	4.438
3	270	370	2-GREEN	3.675
4	370	410	6-YELLOW	7.284
5	410	470	22-ORANGE	14.016
6	470	610	1-RED	10.276

8-COLOR OF UNCLASSED VALUES- BLACK

A continuous color stereoscopic effect map makes use of a continuous spectral sequence of colors, which is defined (Eyton, 1990) by four sets of gray level values (**1** blue to cyan; **2** cyan to green; **3** green to yellow; **4** yellow to red – see Figure 14). A graphic video display has 256 tones of gray level values, but because the end of one step is the beginning of another, a total of 1021 (4 x 256 – 3) color positions are present. Each horizontal distance value in the DDM is scaled from 1 – 1021 using the equation shown in Figure 15 (Eyton 1990).

The visual perception of color depth using the color stereoscopic effect, allows for the creation of a map that can be viewed in three dimensions. This effect is greatly increased with the aid of glasses constructed from plastic with holographic optical prism elements that are embedded in the lenses. The Astrodome DDM is used to illustrate the color stereoscopic effect for an urban terrain. Both of the color stereoscopic effect maps used the previously created relative radiance files and edge contour maps for add hill shaded relief with a contour overlay.

Another three-dimensional mapping technique was used to induce parallax (Eyton, 1984) and create an anaglyph. Crater Lake and Guadalupe Peak DDMs were used to produce these maps. The process began by inducing parallax into each DDM data set. The maximum induced parallax shift selected for the Guadalupe Peak DDM was sixteen grid cells and a maximum shift of eight grid cells for the Crater Lake DDM. Stereo pairs were then generated from each DDM. The Guadalupe Peak DDM stereo pairs were displayed as negated linear gray scaled slope gradient images. Using a viewing program such as Paint Shop Pro 7, both right and left views were opened and

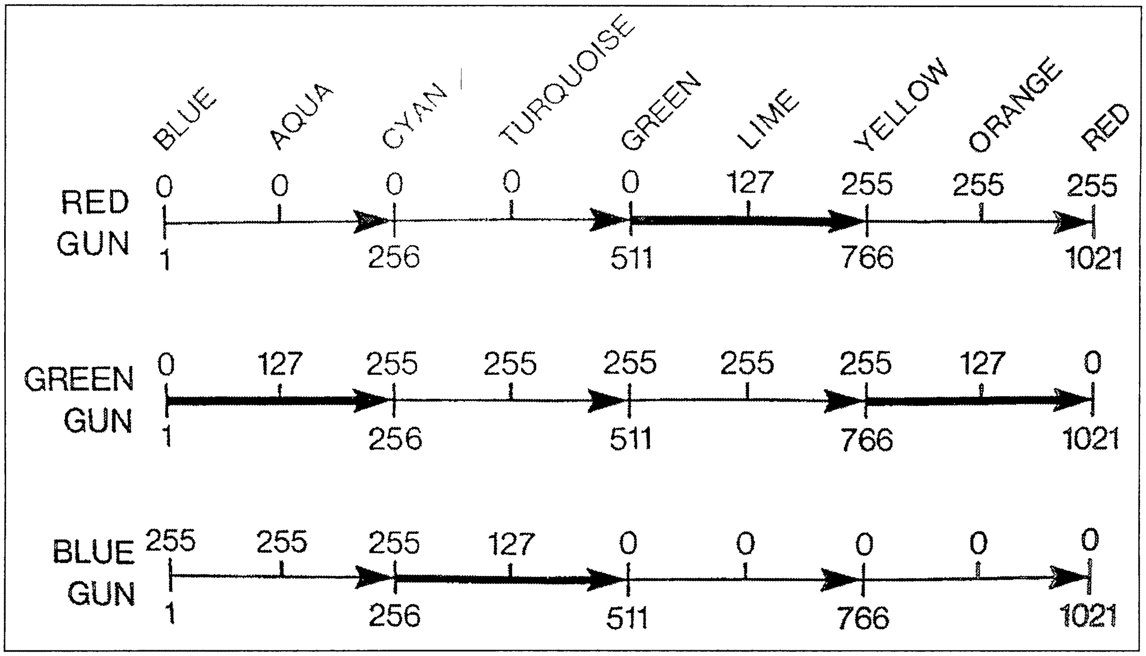

Figure 14. A tabular representation of a continuous spectral sequence of colors. The numbers below the lines indicate the color position (1 – 1021); the numbers above the lines display channel settings in gray level values. Bold arrows show where gray level values are changing from 0 – 255 or 255 – 0 (Eyton, 1990, p. 25).

$$CP = \left(\frac{Z - Zmin}{Zmax - Zmin} \right) \times 1020 + 1$$

where:

CP = color position on a scale of 1 – 1021

Z = horizontal distance value in DDM

Zmin = minimum horizontal distance value in DDM

Zmax = maximum horizontal distance value in DDM

Figure 15. The scaling equation used to determine color position for horizontal distance values in DDMs (Eyton, 1990, p. 25).

then assigned to the appropriate video channels. The right image was assigned to the red channel and the left image was assigned to the green and blue channels, creating a red and cyan (green + blue) anaglyph. This enables the viewer to see the map in stereo using red and cyan viewing glasses.

A hill shaded relief anaglyph map was produced from the Crater Lake DDM by using a relative radiance data set as the modulating file instead of the slope gradient gray scale map. The hill shaded relief displayed the terrain features with darker tones and shadows, which I believe added texture and depth to the stereogram, making for a more realistic rendition.

Scale and Vertical Exaggeration

Vertical exaggeration is the ratio between the horizontal scale and the vertical scale in a DDM. Increasing vertical exaggeration occurs when the vertical scale is increased with respect to the horizontal scale. Garrity (2004) found that a modest vertical exaggeration of 5-10x produced satellite images that had blocky shadows and appeared unsightly. This is not the case for maps created from DDMs. The vertical exaggeration of the DDM maps produced in this research remained within the range of 1-30x. This range of vertical exaggeration shows the landforms in a more detailed fashion allowing the viewer to see small differences in the distribution of the terrain.

Horizontal scale is found by measuring the width of the map, and then dividing it by the number of pixels in a row, multiplied by the resolution at that specific latitude. In order to determine the resolution of each data set, latitude is entered into the program 'RESOLVE' within the Terra Firma package. The program calculates a specific resolution based on an algorithm developed by Maling (1989). Once the resolution is calculated, it is entered into the equation referenced above, to determine horizontal scale. For example, if a map is 10 inches wide, and there are 1060 pixels in a row, and the resolution is 318 meters at a latitude of 70° north. The horizontal scale will equal:

$$(10in \times 2.54cm/in) / (1060 \times 318m \times 100cm/m) = 1{:}\ 1327087$$

The vertical scale is found by measuring the image height, on the printed map, and then dividing it by the vertical distance. Image height is the 'map' height, and the vertical distance is the vertical rise of the actual terrain in the DEM. The vertical rise is determined by subtracting the highest vertical elevation from the lowest elevation. For example, if the image height is 1.25 inches and the vertical distance (Zmaximum - Zminimum) is 4000 feet, then the vertical scale will equal:

$$1.25in / (4000ft \times 12\ in/ft) = 1{:}\ 38400$$

Once the horizontal and vertical scale is determined, the horizontal scale is divided by the vertical scale to get the vertical exaggeration. The two previous scale calculations will yield a vertical exaggeration of:

$$1327087 / 38400 = 34.6x$$

Comparison of DDM Resolutions

As with most visualization techniques, possible limitations of effectiveness may occur due to the various attributes of the data. A limitation of effectiveness with DDM mapping involves coarse resolution and small scale. The previously mapped DDMs ranged between fine resolution LIDAR DEMs, and a coarse thirty arc-second DEM. In order to more easily compare fine to coarse resolution DDM maps, five DDMs of the same location were mapped using the same mapping format.

The location is the Hawaiian Islands, and the resolutions range between 1/3 arc-seconds to two arc-minutes. Each map was displayed using a negated gray scale map of the slope gradient. The 1/3, one, and three arc-second resolution data sets were mapped in a west facing perspective, with a consistent vertical exaggeration of 3x. The two coarser data sets were mapped in a north facing perspective with a higher vertical exaggeration of 20x.

Chapter 5

RESULTS AND ANALYSIS

The DDM data sets and resulting maps display the elevation values as a horizontal distance distribution, instead of as a vertical height distribution. The extracted DDMs have been mapped using conventional mapping techniques that are used to produce DEM maps. The following are the results of DDM mapping of a single location with varying resolutions and DDM mapping using the three categorized techniques, black and white, color, and three-dimensional mapping.

Black and White DDM Mapping

The negated slope gradient, azimuthal circular gray scale, and negated slope gradient with hill shaded relief maps of the Austin CBD appear as pencil or ink sketches of the city's skyline (see Figures 16a-c). While the negated linear gray scale map resembles that of a film negative or a black and white photograph (see Figure 16d).

The Crater Lake and Astrodome slope gradient and hill shaded relief maps show much of the same artistic qualities. I believe by reversing the tones in the slope gradient maps, the landscape is displayed in a more naturally accepted representation. The dark outline of the urban structures and physical landscape is contrasted against the white background, which helps to elaborate the shape, depth, and variations in the terrain.

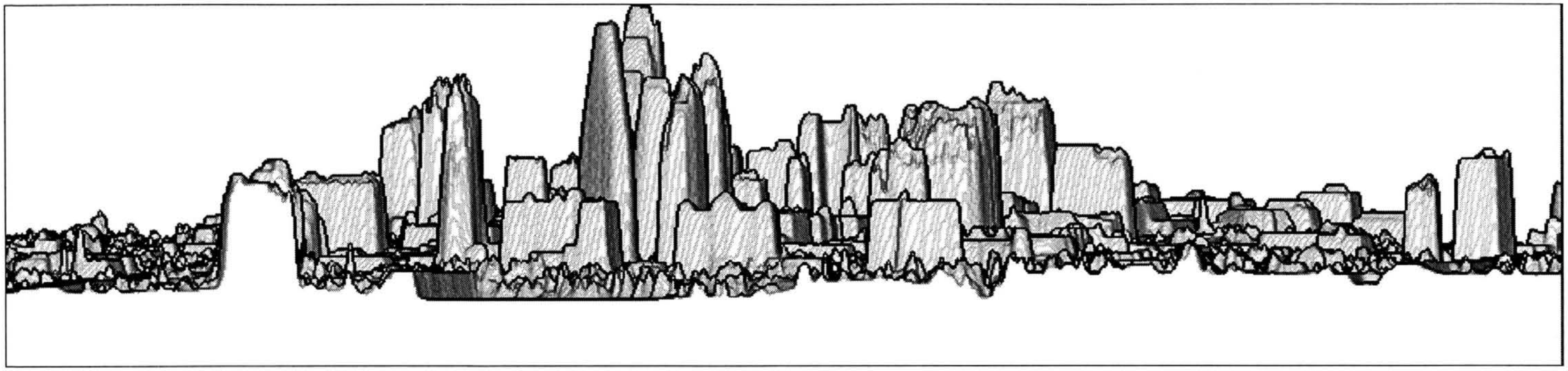

Figure 16a. Negated slope gradient map of the Austin CBD (vertical exaggeration of 1x).

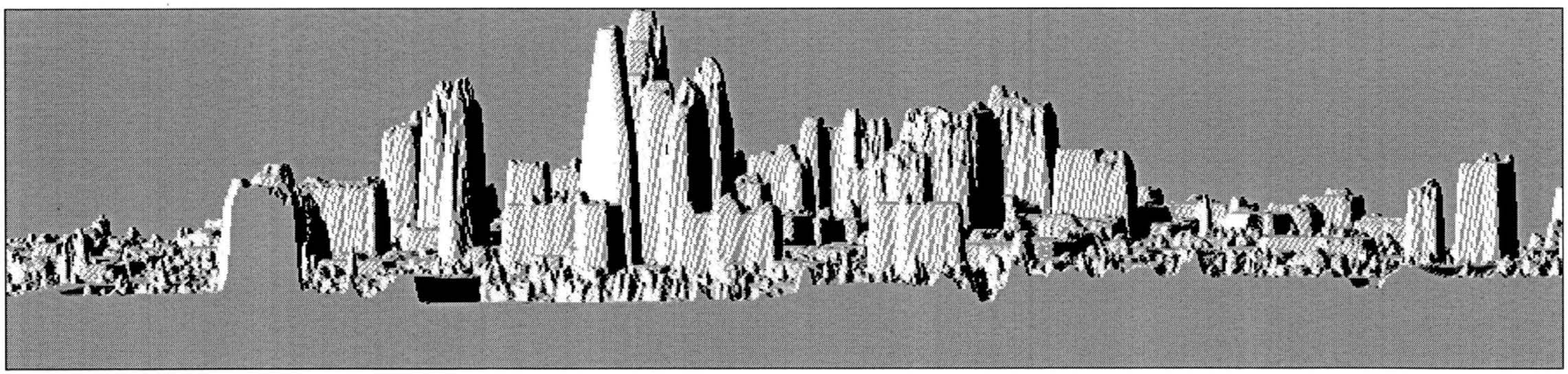

Figure 16b. Azimuthal circular gray scale map of the Austin CBD (vertical exaggeration of 1x).

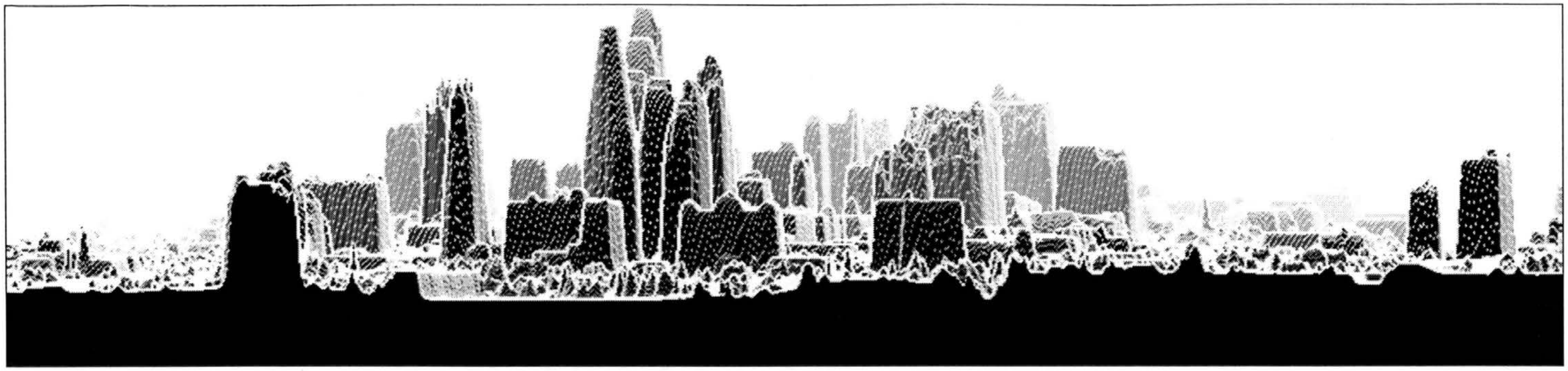

Figure 16c. Negated slope gradient map of the Austin CBD with hill shaded relief (vertical exaggeration of 1x).

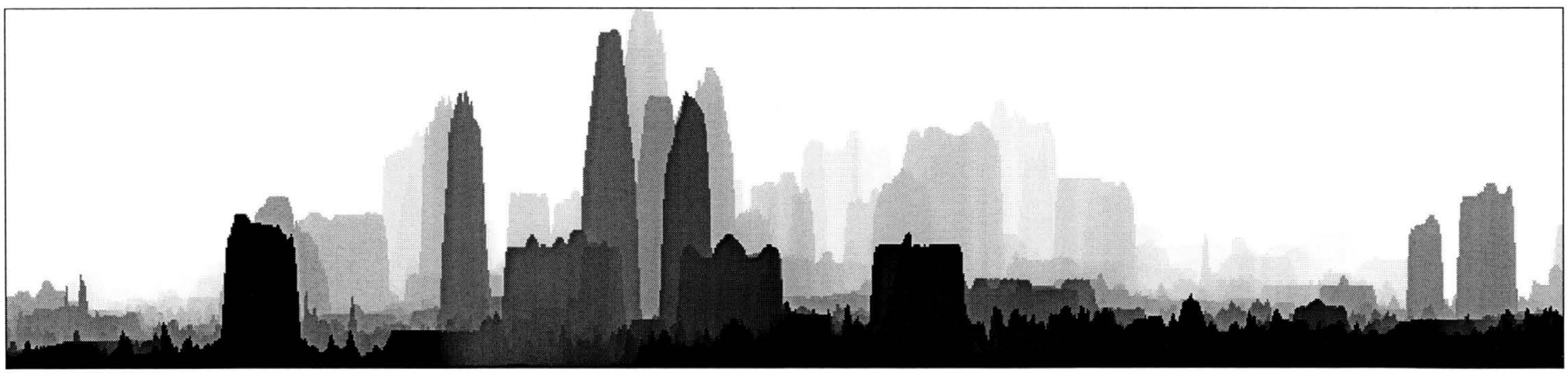

Figure 16d. Negated linear gray scale map of the Austin CBD (vertical exaggeration of 1x).

These maps might be considered a bridge between the art and science of cartographic representation.

Due to the addition of bathymetry data, the Crater Lake map is able to display formations within the lake bed. The two large cinder cones, Wizard Island (233 meters above lake level) and Merriam Cone (30 meters below lake level) (Wood and Kienle, 1990) are easily seen rising from the lake floor, and are displayed to the user from a viewing perspective of standing on the lake bed. This perspective gives the viewer a sense of the size of the cinder cones in comparison to the lake itself. The vertical steepness of the banks and flat nature of the lake bed are also clearly depicted in the maps (see Figures 17a and b).

The Astrodome maps display detail in the same fashion as the Crater Lake maps. The darker tones help to distinguish the structures, while the lighter tones display the structures' shape and orientation. The large size and spherical form of the Astrodome can be seen in contrast with the surrounding smaller structures that have sharper edges and angles (see Figures 18a and b).

The contour mapping was broken into two sections, binary and edge contouring. The binary and edge contour maps of the Astrodome and Crater Lake DDMs show the contours as representing horizontal profiles as they would be measured away from the viewer along the ground (see Figure 19a-d). The contour interval values varied depending on the range of horizontal distances and the nature of the terrain, and slope gradient. The four contour maps of the Crater Lake and Astrodome DDMs, have contour interval values of twenty and ten meters, respectively. These values show the depth of each data set without cluttering up the contours.

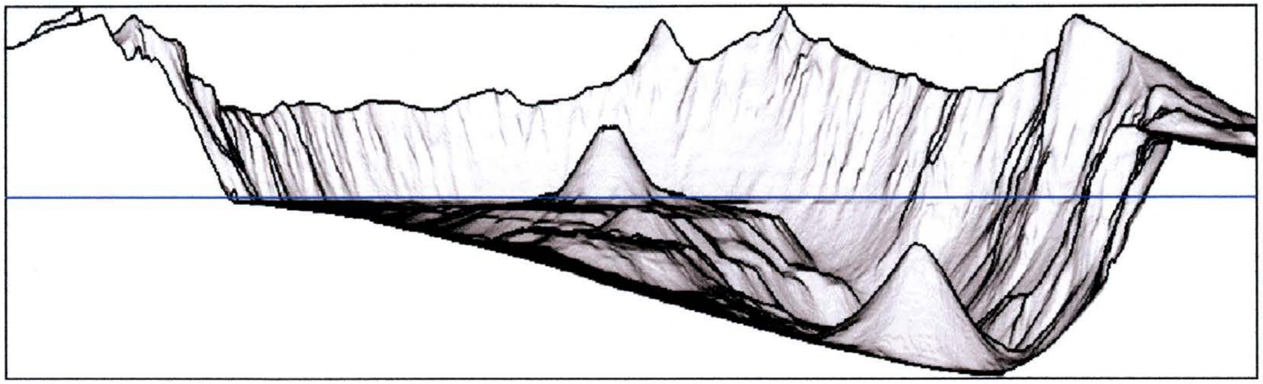

Figure 17a. Negated slope gradient map of Crater Lake (vertical exaggeration of 2x). Lake level is indicated by the blue line.

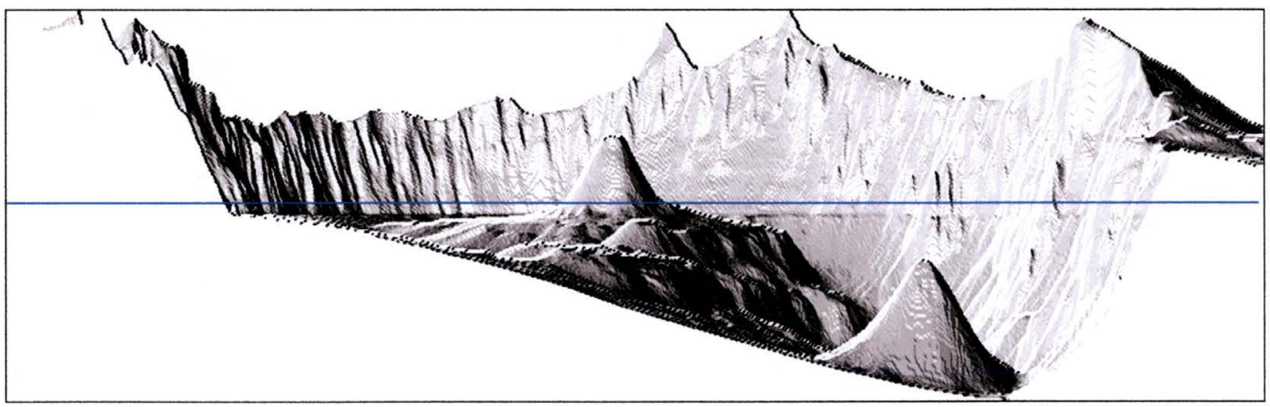

Figure 17b. Negated slope gradient map of Crater Lake with hill shaded relief (vertical exaggeration of 2x). Lake level is indicated by the blue line.

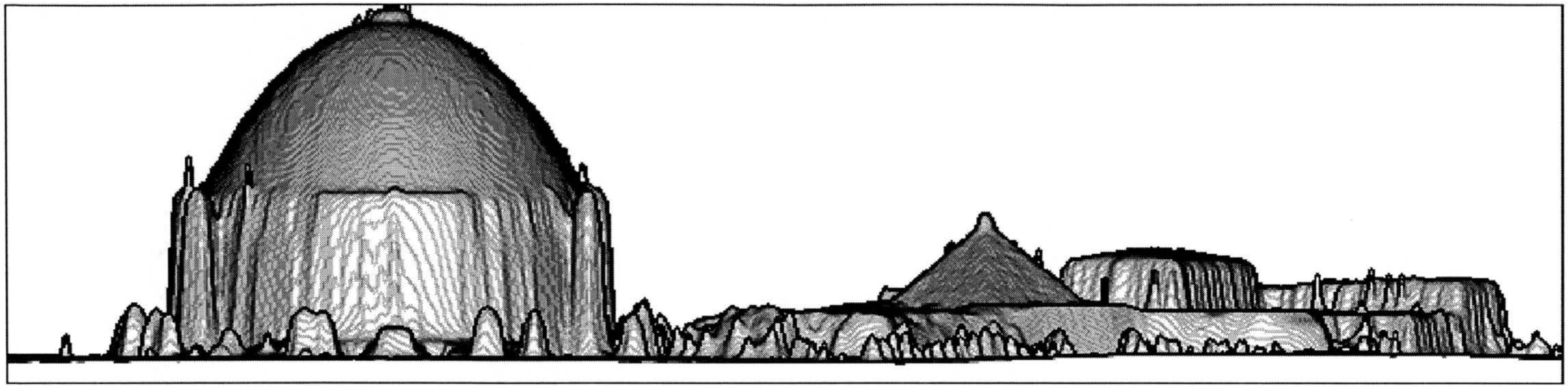

Figure 18a. Negated slope gradient map of the Astrodome (vertical exaggeration of 3x).

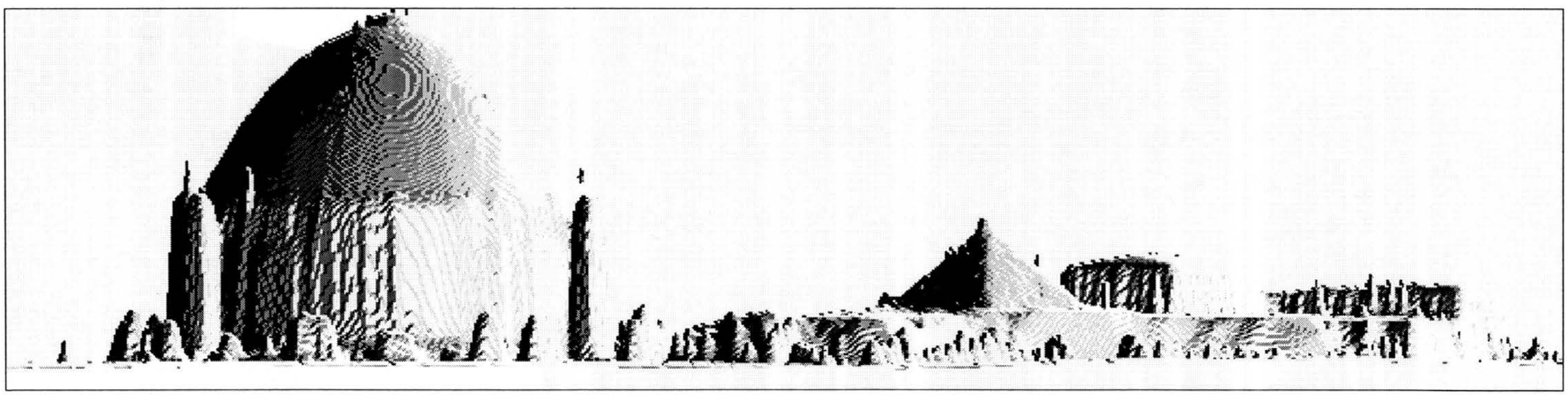

Figure 18b. Negated slope gradient map of the Astrodome with hill shaded relief (vertical exaggeration of 3x).

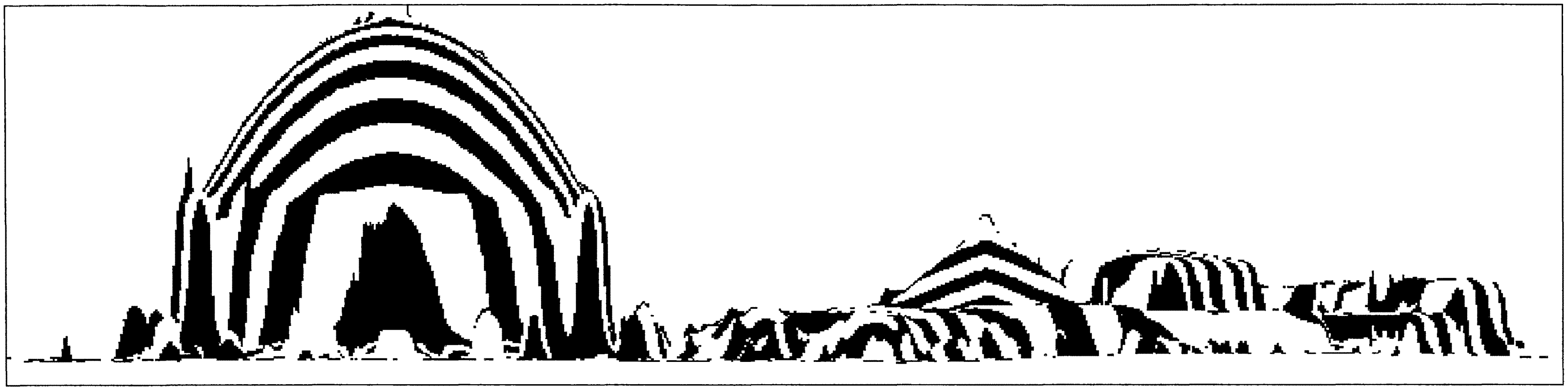

Figure 19a. Binary contour map of the Astrodome (vertical exaggeration of 3x).

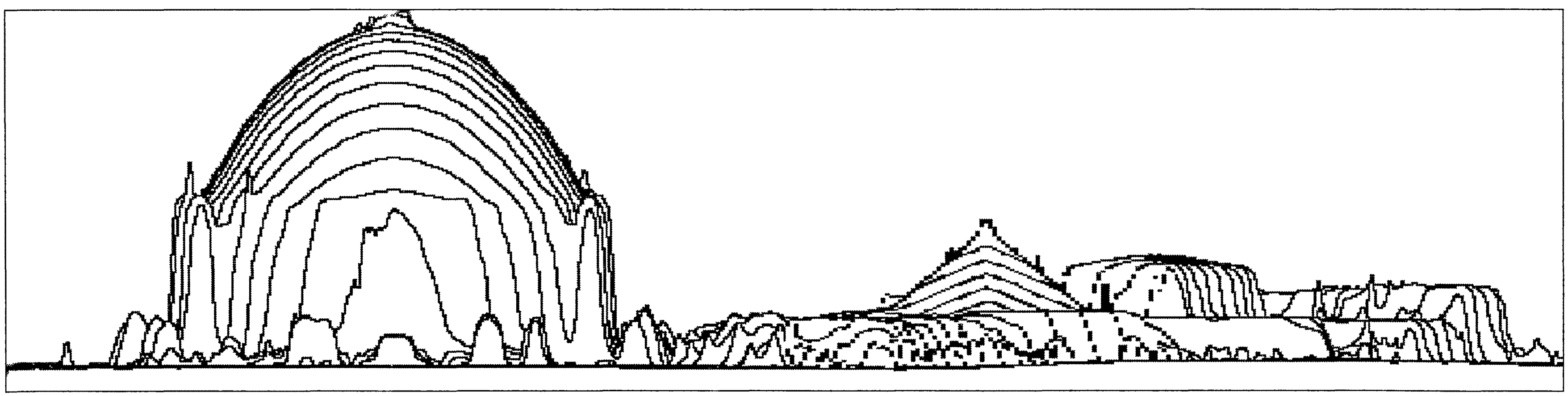

Figure 19b. Edge contour map of the Astrodome (vertical exaggeration of 3x).

Figure 19c. Binary contour map of Crater Lake (vertical exaggeration of 2x).

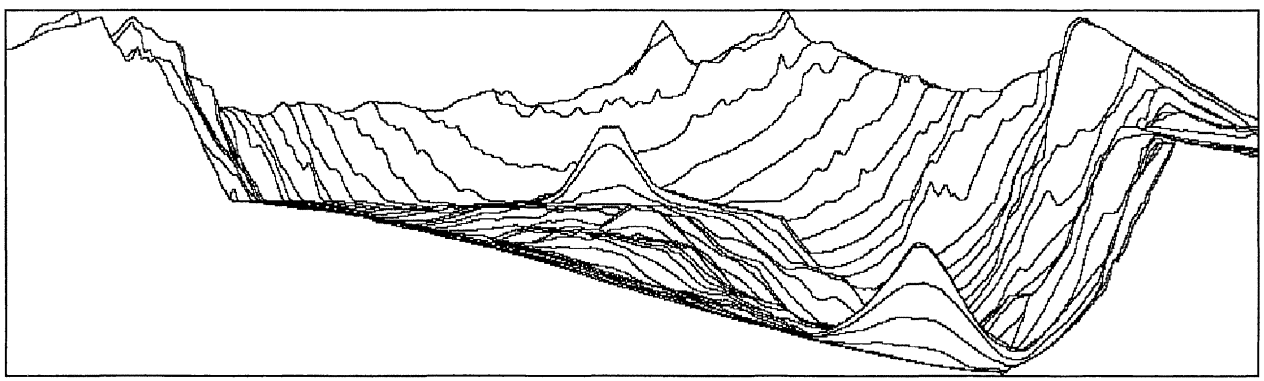

Figure 19d. Edge contour map of Crater Lake (vertical exaggeration of 2x).

A final slope gradient map was produced from the Northwestern U.S. DDM. The map displays a larger area at a coarser resolution, thirty arc-seconds. The high peaks (moving north to south or left to right across the map) of Mt Rainier, Mt Adams, Mt St. Helen's, Mt. Hood, Mt. Jefferson, Three Sisters, and Mt. Shasta, are easily depicted, but are distorted due to the higher vertical exaggeration of 30x. The terrain is displayed with a blocky appearance because of the coarse resolution, and doesn't include much detail. I believe this loss of fine detail is acceptable because of the scope and size of the area mapped. The goal of this map was to display the high peaks and volcanoes in the Northwestern U.S. as they are seen from a Pacific Ocean viewing perspective. The small terrain variations are sacrificed in order to create such a map (see Figure 20).

Color DDM Mapping

The color mapping of DDMs is represented with maps produced from the Grand Canyon and Astrodome DDMs. Two maps were created from each DDM, a classed color map with hill shaded relief and a classed color map without hill shaded relief. The Grand Canyon classed color map offers the user an unobstructed view of the north walls of the canyon from the perspective of standing at the same elevation as the Colorado River. To accentuate the classes and represent measurable horizontal distances, an edge contour image was used to overlay the map (see Figure 21a). The hill shaded relief dulled the colors, but added texture and dimension to the terrain. Sections of the canyon walls and other distributions in the landscape that were not distinguished by the contour overlay, are now able to be seen (see Figure 21b).

The Astrodome classed color map displays the stadium to the user, from a

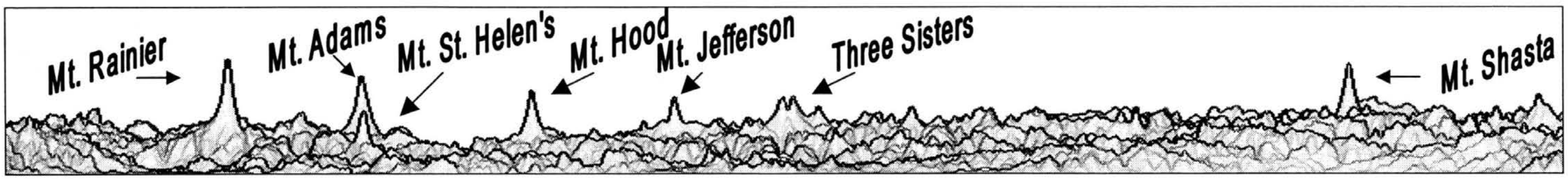

Figure 20. Negated slope gradient map of the Northwestern U.S. (vertical exaggeration of 30x).

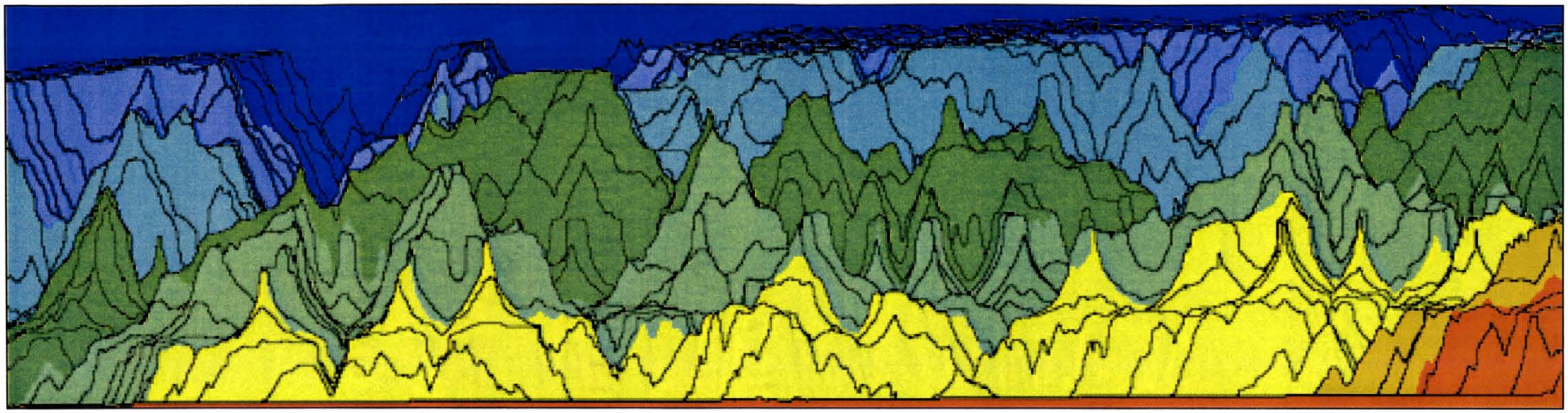

Figure 21a. Classed color map of the Grand Canyon (vertical exaggeration of 3x).

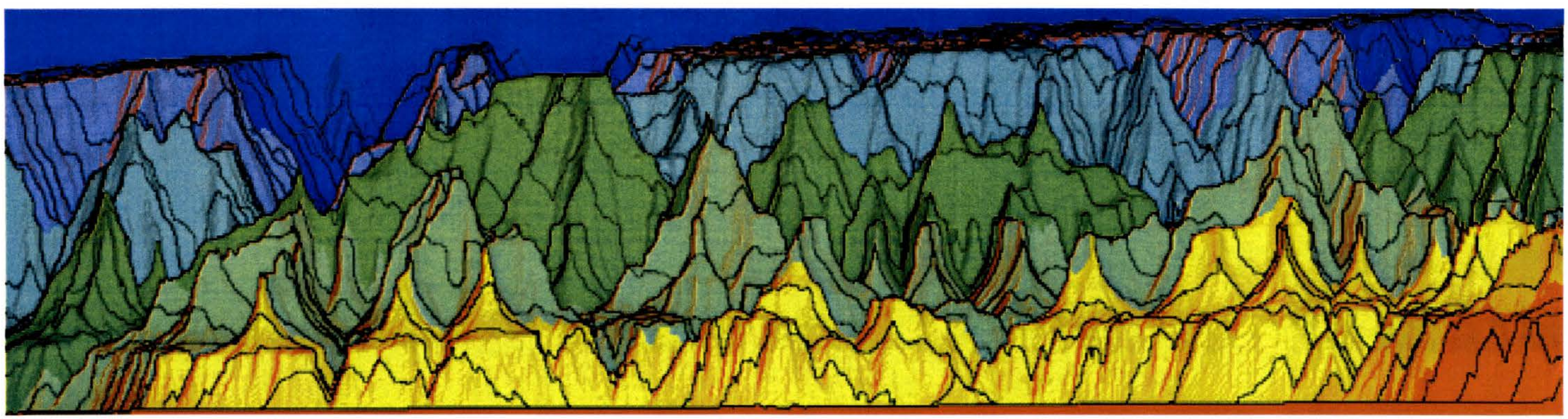

Figure 21b. Classed color map of the Grand Canyon with hill shaded relief (vertical exaggeration of 3x).

viewing perspective that is similar to that of the Grand Canyon DDM maps, an unobstructed, ground level view. With no obstacles in the line of sight between the user and the Astrodome, the colored classes easily illustrate the shape and depth of the stadium. An edge contour image was overlaid to help define the form of the structures (see Figure 22a). The addition of hill shaded relief helps to portray the urban structures in a more realistic rendition by emphasizing detail and shape of the stadium. The colors lost some of the intensity in the shaded areas, but the classes are still easily distinguishable due to the contour overlay (see Figure 22b). Both of these maps have colored classes of horizontal profiles, which display more pronounced detail and represent the distance values more explicitly than the black and white contour maps alone. I believe future testing would show that a typical map user would be able to more easily determine horizontal distances and structure shapes in this classed color DDM map, because the horizontal profiles have already been grouped and are easily identifiable due to the variation in colors. A black and white contour map displays horizontal distances, but the map user may need more time to determine specific distance values or shape of a structure due to lack of easily identifiable classes.

Three-Dimensional DDM Mapping

The Grand Canyon and the Astrodome DDMs were used to generate three-dimensional maps that make use of the color stereoscopic effect. Both maps are similar to the classed color maps, in that the maps contain colors that represent horizontal depths in the scene. The difference is that these maps have continuous color, which allows the viewer to see the map in three-dimensions, with the aid of viewing glass. The addition of

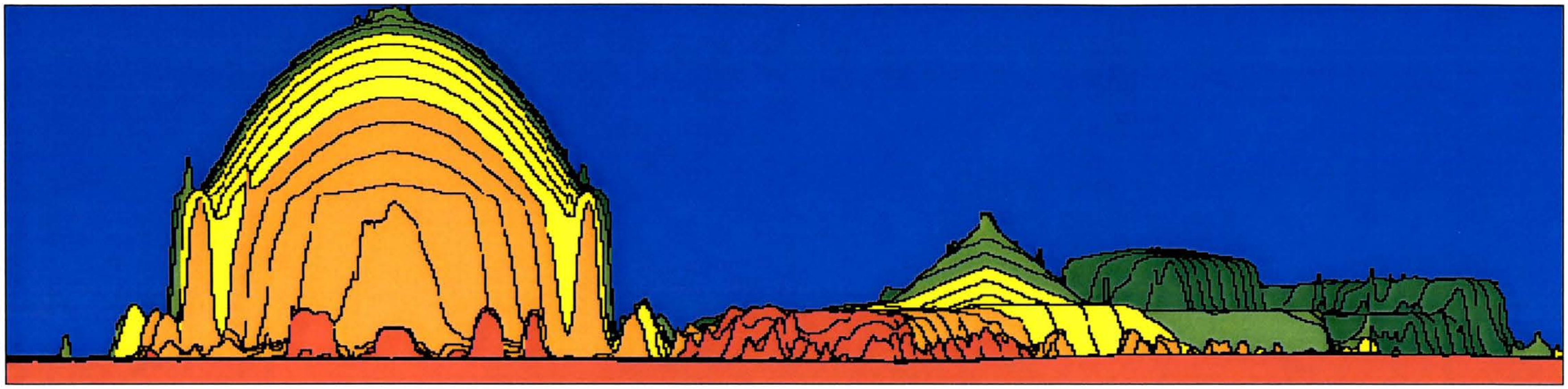

Figure 22a. Classed color map of the Astrodome (vertical exaggeration of 3x).

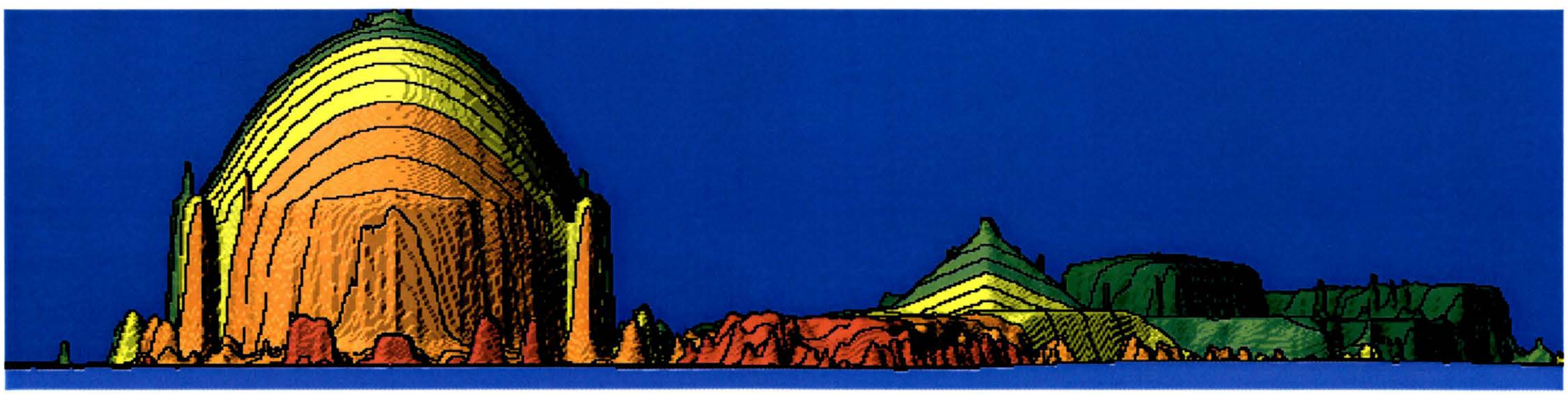

Figure 22b. Classed color map of the Astrodome with hill shaded relief (vertical exaggeration of 3x).

an edge contour overlay helps the user to depict distances, and makes the three–dimensional effect more distinct. A smaller contour interval value was used with both DDMs in order to accent the detail and variations of the landscape (see Figures 23a and b). A hill shaded relief map was also produced from both DDMs. The addition of hill shaded relief decreased the sharpness of the colors, thus slightly reducing the three-dimensional effect. The loss of color intensity in the shaded areas makes the maps appear darker, but gives the viewer a more realistic display due to the visible detail in the scene (see Figures 23c and d).

The induced parallax anaglyph DDM maps of Crater Lake and Guadalupe Peak also display the data to the viewer from a ground-based human perspective in three-dimensions (see Figures 24a and b). The Crater Lake anaglyph map used a relative radiance image as an overlay in the production of the stereo pairs, which adds hill shaded relief and gives the map a distinct gray tone.

The Guadalupe Peak anaglyph map used a negated slope gradient image as the overlay. The slope gradient image shows the outline and steep cliffs of Guadalupe Peak and surrounding mountains as they are displayed from the foreground to the background. The flat nature of the foreground allows for the more pronounced three-dimensional view of the peak. Much like the Grand Canyon and Astrodome DDMs, the view is unobstructed which allows for the prominent object in the map, to be viewed in a clear, broad, and unimpeded fashion.

Comparison of DDM Resolutions

The Hawaii DDM maps show a limitation in data resolution with respect to detail.

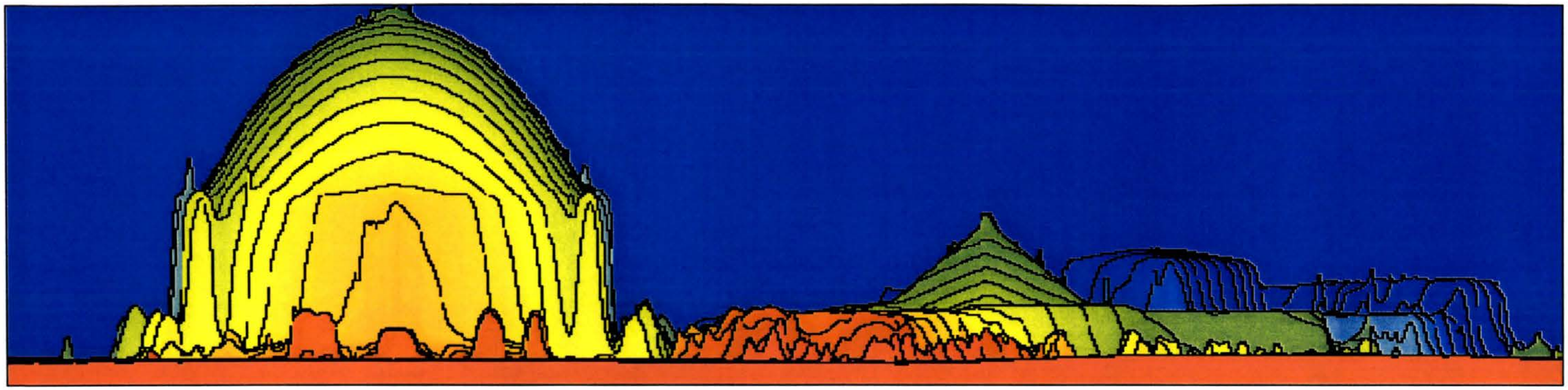

Figure 23a. Color stereoscopic effect map of the Astrodome (vertical exaggeration of 3x).

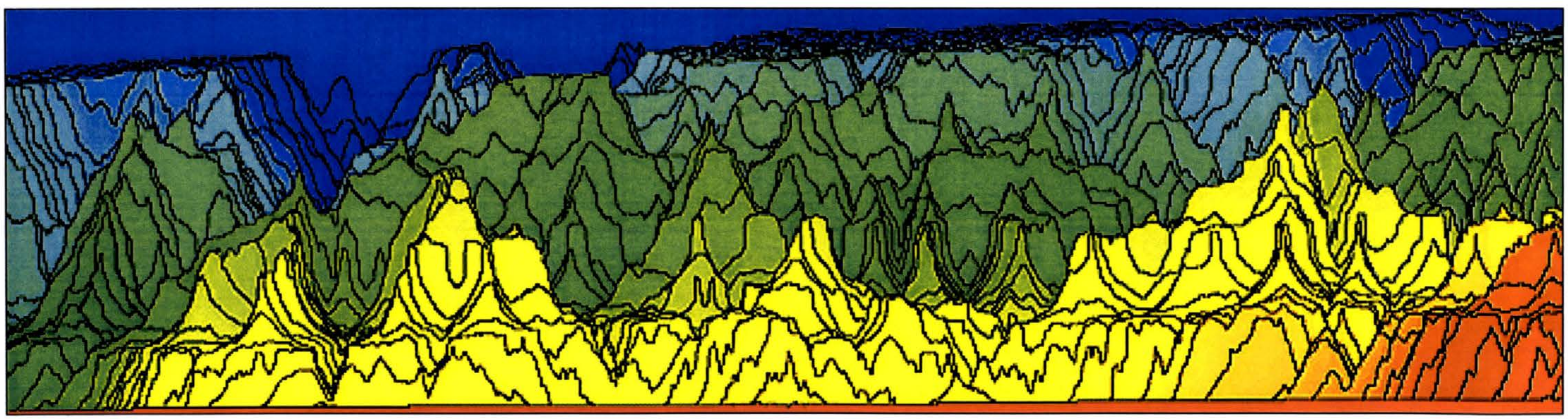

Figure 23b. Color stereoscopic effect map of the Grand Canyon (vertical exaggeration of 3x).

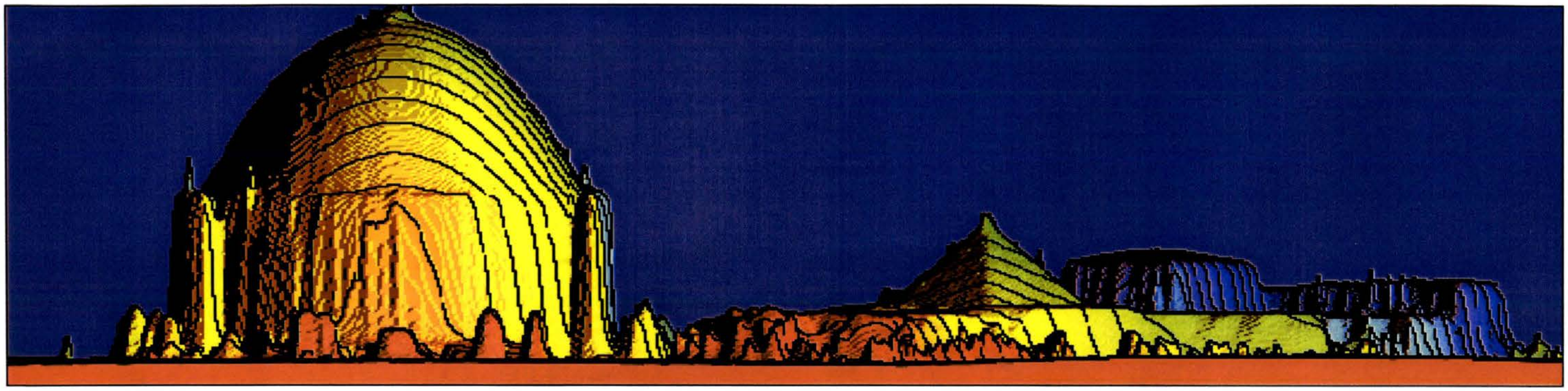

Figure 23c. Color stereoscopic map of the Astrodome with hill shaded relief (vertical exaggeration of 3x).

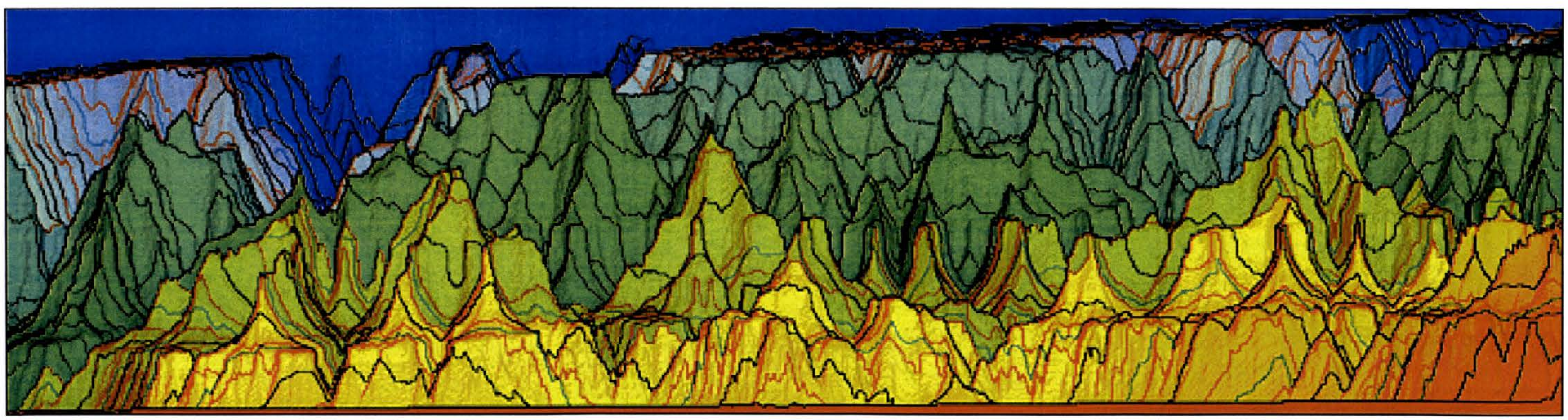

Figure 23d. Color stereoscopic map of Grand Canyon with hill shaded relief (vertical exaggeration of 3x).

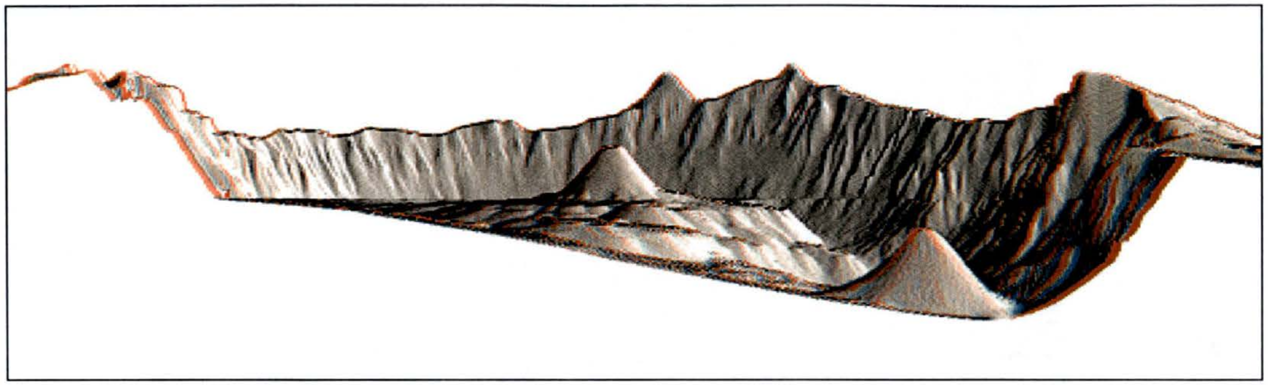

Figure 24a. Induced parallax anaglyph map of Crater Lake (vertical exaggeration of 2x).

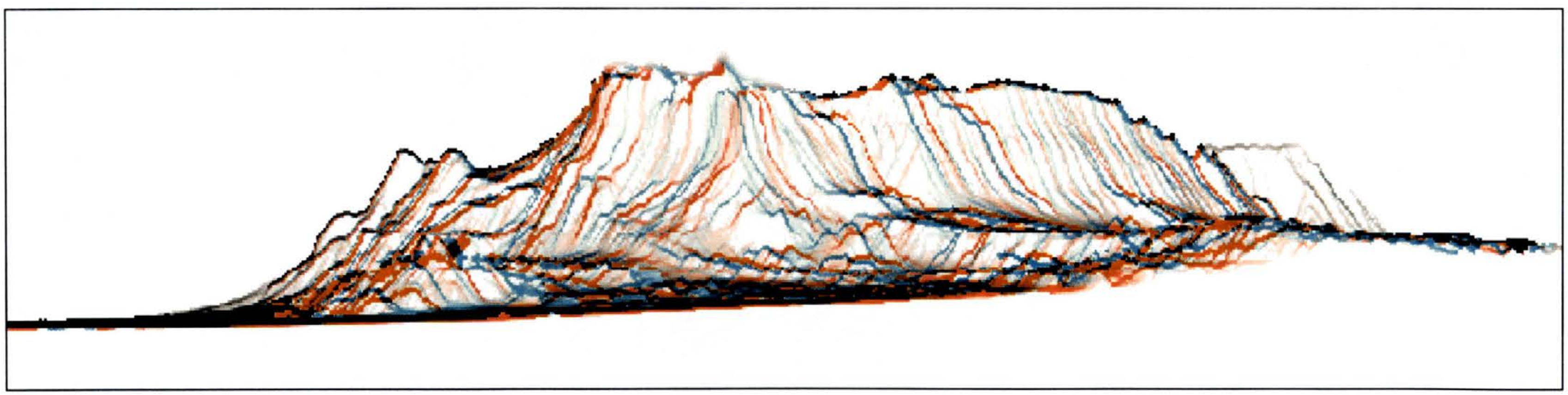

Figure 24b. Induced parallax anaglyph map of Guadalupe Peak (vertical exaggeration of 15x).

The fine resolution data produced DDM maps with sharp detail at a large scale. As the data becomes coarser, the DDM maps included a larger area but lost detail. These coarse resolution maps are small scale, and thus the Hawaiian Islands have been reduced to a small feature showing little to no detail.

The three finest resolution Hawaii DDMs were the 1/3 arc-second, one arc-second, and three arc-second data sets. The DDMs were generated and displayed with a west facing viewing perspective and a vertical exaggeration of 3x. Each of these maps displayed enough detail to give the viewer an idea of the landscape and distribution of the terrain. The 1/3 arc-second map displayed the crater on top of Mauna Loa. The flatness of the crater floor and steep slopes of the crater walls are clearly seen (see Figure 25a). The one arc-second map displays Mauna Kea, from sea level to the peak. The detail in this map is enough to demonstrate the rounded shape and rugged sides of the volcano (see Figure 25b). The three arc-second map shows both Mauna Loa and Mauna Kea. Terrain variations in this map are clearly depicted as well. The jagged sides of Mauna Kea are still visible and are contrasted against the relatively smooth, flowing terrain of Mauna Loa (see Figure 25c). All three of these maps display terrain detail of specific landscape features on the island of Hawaii. The fine detail is slowly lost as the resolution becomes coarser (1/3 arc-second to three arc-seconds), but the specific terrain variations, such as the contrasting trends of slopes between the two volcanoes, are still easily depicted.

The two coarse resolution maps display the landscape in a fashion similar to the Northwestern United States DDM map. The vertical exaggeration is high, 20x, and fine

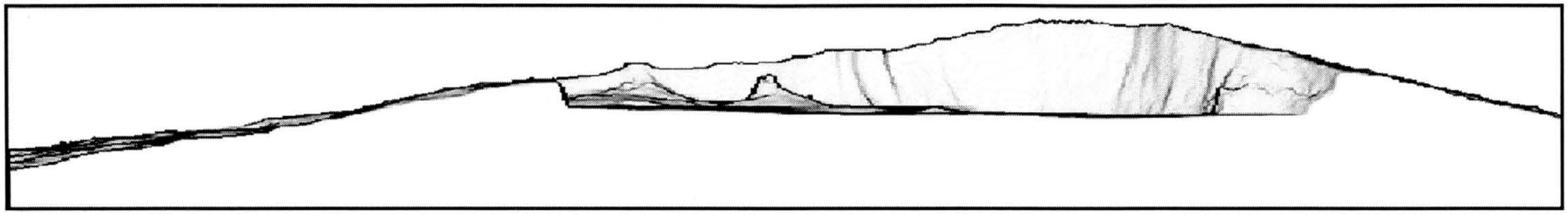

Figure 25a. Slope gradient map of crater on top Mauna Loa (vertical exaggeration 3x). DEM resolution of 1/3 arc-second.

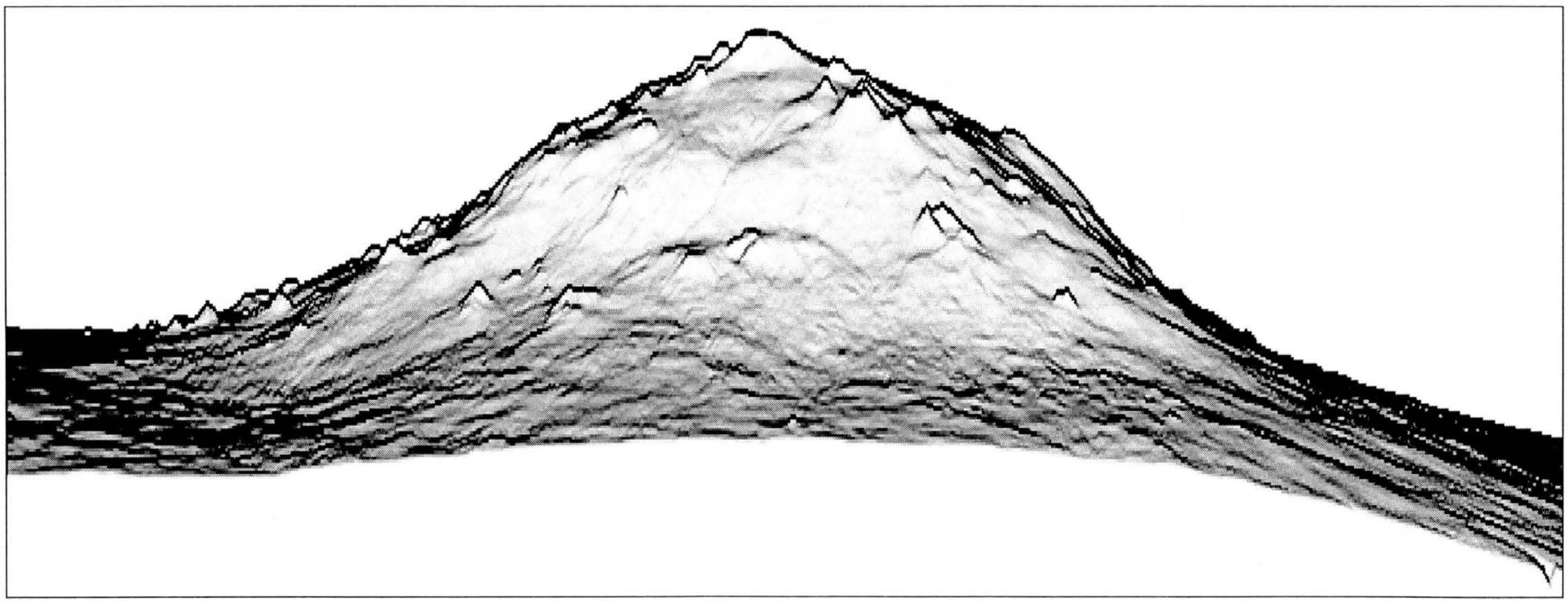

Figure 25b. Slope gradient map of Mauna Kea (vertical exaggeration of 3x). DEM resolution of one arc-second.

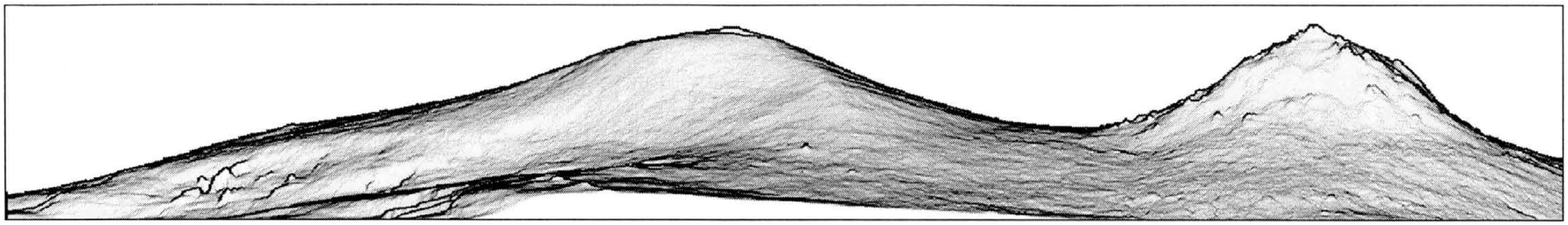

Figure 25c. Slope gradient map of Mauna Kea and Mauna Loa (vertical exaggeration of 3x). DEM resolution of three arc-seconds.

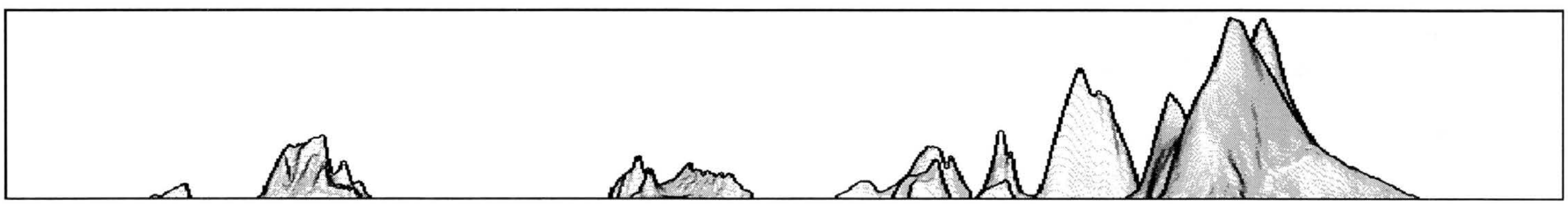

Figure 25d. Slope gradient map of Hawaiian Island (vertical Exaggeration of 20x). DEM resolution of thirty arc-seconds.

detail is lost. Although detail is lost, the advantage of these two visuals is the large amount of land and ocean area covered. The thirty arc-second map shows the entire Hawaiian Island chain with a viewing perspective of looking north. Each island is visible, but subtle terrain differences are not (see Figure 25d). The coarser DDM is the two arc-minute DDM, which also contains bathymetry data. This DDM and resulting map was also created with a north facing viewing perspective and included the Hawaiian Island chain and the bathymetry of the surrounding Pacific Ocean. The map displays the Hawaiian Islands as small features compared to the deep bathymetry of the Pacific Ocean (see Figure 25e). The rigid and blocky appearance of the map makes detecting detail a problem. This rough appearance might be reduced if the area mapped were increased to the entire Pacific Ocean.

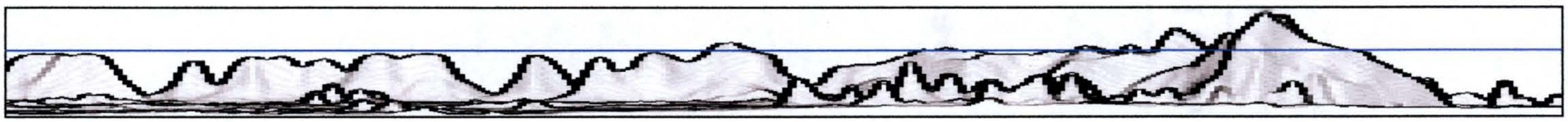

Figure 25e. Slope gradient map of Hawaiian Islands and surrounding Pacific Ocean bathymetry (vertical exaggeration of 20x). DEM resolution of two arc-miuntes. Sea level is indicated by the blue line.

Chapter 6

SUMMARY AND FUTURE WORK

The DDM visualization technique was presented and demonstrated using typical DEM mapping formats. Eleven DDMs were extracted from the DEMs, and mapped using a format that was designated in the three mapping categories, black and white, color, and three-dimensional mapping. An attempt was made to use urban and natural terrain DDM, to show that each of the common mapping techniques used to display DEM data can also be used to display DDM data of various geographic landscapes. This was true for all of the techniques used, except the induced parallax anaglyph map. The Austin CBD and Astrodome DDMs were unable to be displayed in such a way. These data sets both contain urban structures that have very sharp angles and slopes; inducing parallax in these data sets produces folded over edges – an unacceptable artifact resulting from the 90° vertical slopes of the building sides.

The comparison of single location DDM mapping showed the limitation of effectiveness with the DDM technique. The loss of detail comes at the price of area mapped. The fine resolution DDM maps would be of value to someone who needs to know the variations of a specific terrain, such as hikers, land surveyors, or architects. The coarse resolution maps display a broad scope of land area, but with little detail. This lack of specific terrain detail isn't a complete disadvantage. Not all detail is lost; the general nature of the terrain is still visible, which could make the map useful to people such as navigators or military personnel.

The benefits of the DDM technique include a more realistic ground-based human viewing perspective, artistic purposes, and the ability to gain new knowledge from a transformation of a familiar data set, a DEM. Viewing the data as a horizontal distance distribution provides the user with the ability to see the terrain as an individual would typically see it from the ground. A viewing perspective such as this, similar to the user's normal viewing stance, provides the user with a display that can represent data of a place that they may never be able to actually visit.

Many of the black and white DDM maps resemble that of an artistic rendering of a landscape. Although these maps do have an aesthetic appeal, they still have scientific value and can be used to gain knowledge of the form and changes in form of the features in the terrain.

The DDM maps display elevation data differently than you would see in a DEM map of the same terrain. The vertical values have now been converted to horizontal values. By using a DDM map in combination with a DEM map, the user would not only have height represented, but also distance. This added information would give the user a sense of depth and structure of the landscape.

A drawback with the DDM technique is the loss of visible surfaces in the landscape from a particular viewing perspective. The land area in the DEM is mapped from a viewing perspective of high altitude, allowing for more visible surfaces to be displayed in the image. It may be possible to extract and map a DDM that displayed the same amount of landscape as in the DEM, if the DEM only covers an area that has an increasing slope. If this were the case, the DDM would have to be extracted and mapped in an up-slope facing perspective. Usually the terrain isn't distributed in such a fashion. The drawback of losing visible surfaces, that are included in a DEM from a particular viewing point, is taken as a trade off for the ability to create maps with unique viewing perspectives, such as from the canyon floor or lake bed.

In order to determine the benefits and drawbacks from a map user's perspective, a testing program would need to take place. Test subjects would preferable be people who are familiar with elevation data, either in an academic or professional setting. The testing would need to involve a DEM and a DDM mapped in the same format and displayed side by side. The test subject could then analyze both maps to see which one benefits their needs more and why. This testing should be task oriented involving, for example, interpretation of typical landform processes for characteristic regions (mountainous or arid lands) from both a DEM and a DDM. DDMs could then be generated and mapped with specific needs and users in mind.

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VITA

Brian David Buehner was born in Louisville, Kentucky, on December 26, 1977. Following one year of undergraduate work at Bellarmine University, he entered the University of Louisville in 1997. In 2001 he graduated with the degree of Bachelors of Arts in Philosophy. In 2003, he entered into the geography undergraduate program at the University of Kentucky, and in 2004 earned a degree of Bachelors of Arts in Geography. In august 2004 he entered the Graduate School at Texas State University, serving as a teaching assistant in the Department of Geography.

Permanent Address: 7713 Circle Crest Drive
Louisville, Kentucky 40241

This thesis was typed by Brian David Buehner.