Terrain Representation Panel

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Peucker: We have been working on relief representations ranging from contour production to the production of lenticular screens of surfaces that give a three-dimensional view. Here I will discuss only planimetric relief representations, which either produce or simulate relief shading.

In my work on relief shading, I simulated a gray tone, which preserves the structure of the surface if observed closely. The first method (fig. 1) is relief contouring, developed for manual use by Kichiro Tanaka in 1950. (These and other methods have been published in the last International Yearbook of Cartography and in Display and Analysis of Spatial Data by Davis McCullough.) The coutour lines to the southeast are thickened to simulate shadow. An alternative method of shading is to thicken white contours to the northwest and use gray as a base tone. You do not have to simulate gray shading as such, but just suggest a certain structure. In a surface with very few contours you can still see the major relief quite clearly.

Another method of relief representation is the inclined contour (fig. 2). The surface is intersected with inclined planes that are parallel to each other and vertical to the sunlight.

Brassel: Most of my research on relief shading (1971-73) has already been published in journals like The American Cartographer (1973). However, some features have been published in German only. My shading model has two roots: traditional manual hill-shading methods and analytical hill-shading methods. The high graphic quality of traditional manual methods is best demonstrated by a painting of Professor Imhof (slide). (Editor's note: Slides not available for publication.) In order to get ahead in automated cartography we should be guided not only by the technical possibilities of available hardware and software, but also by traditional cartography. A good example of analytical hill-shading methods are those of Yoeli (1965-67), who was the first to shade relief by computer; he illuminated the relief from one fixed position.

A special application of constant-illumination shading is shown in figure 1. Since the light source is vertical (at an angle of 89 degrees), this example truly shows relief according to the formula, "the steeper, the darker." In the 19th century when vertical illumination was favored by some scholars, the light source was often slightly tilted in order to improve graphic effects.

(Slide) Here is the same relief portion illuminated from three different directions: northwest, west, and southwest. With these examples we can

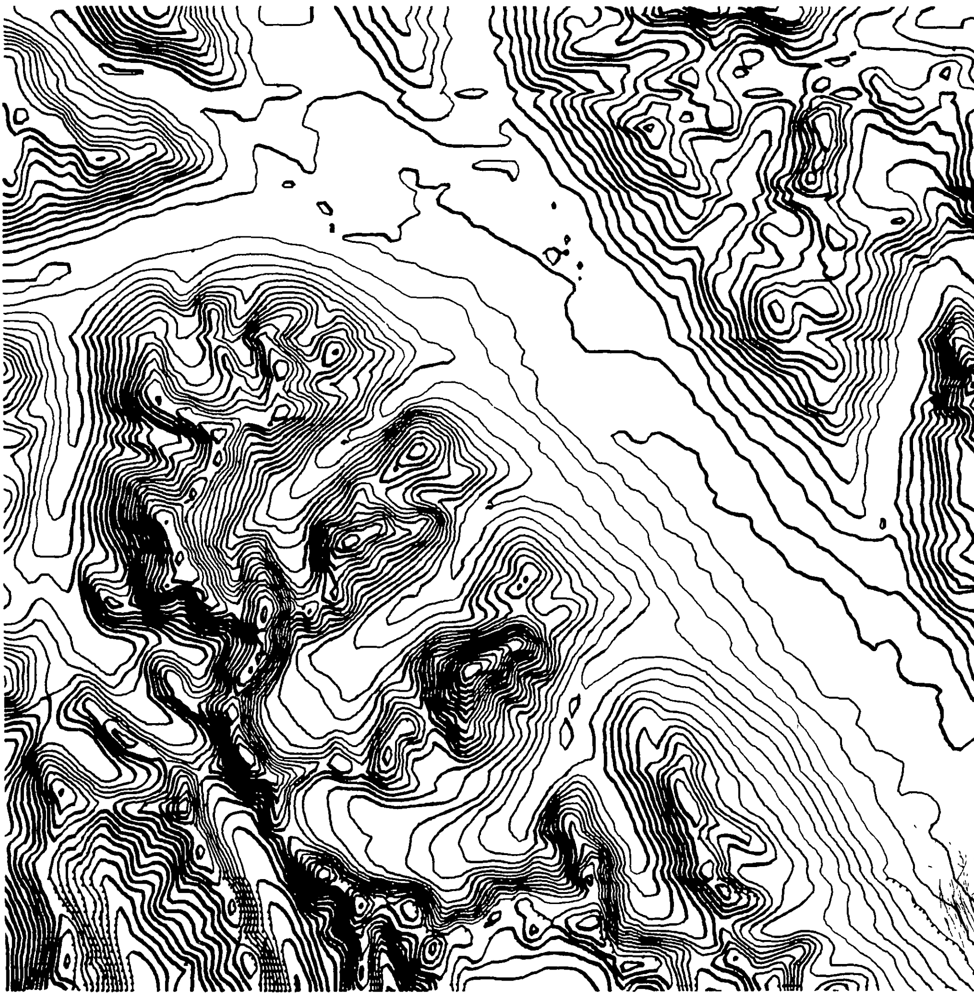

Figure 1
(Peucker)

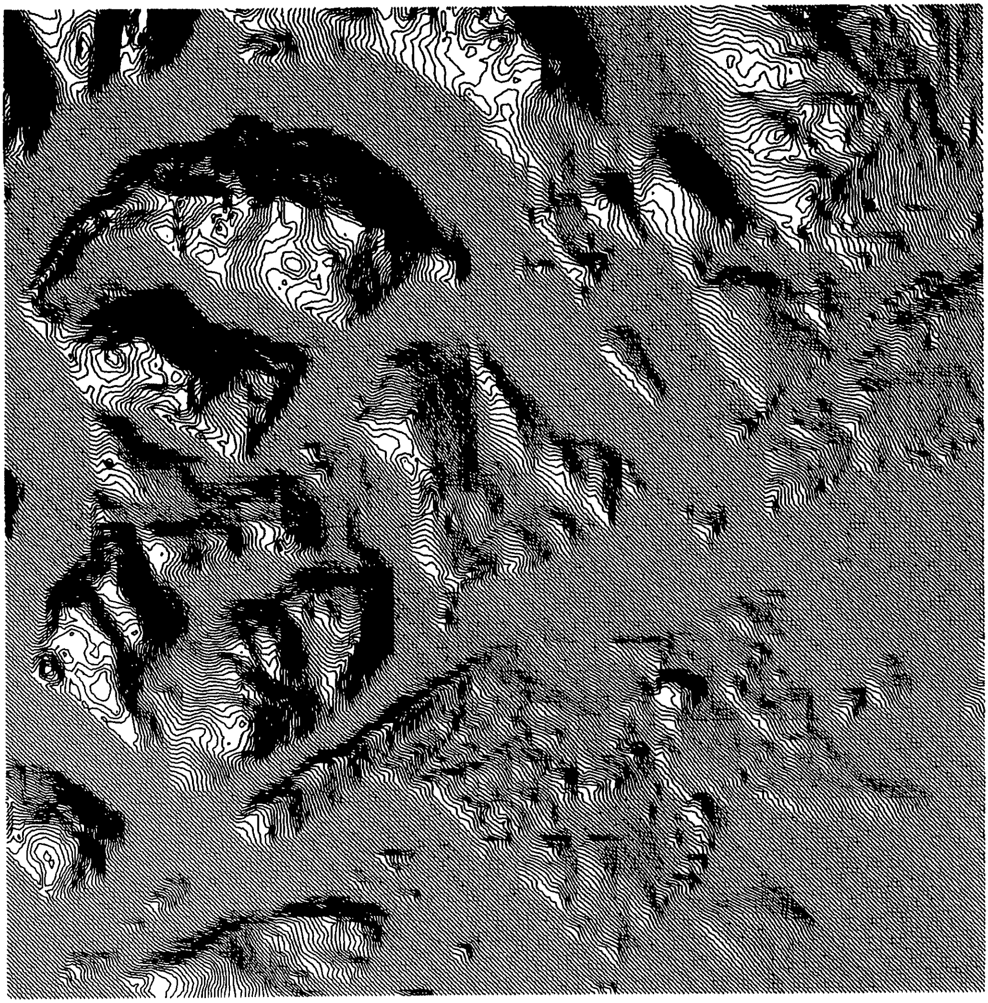

Figure 2
(Peucker)

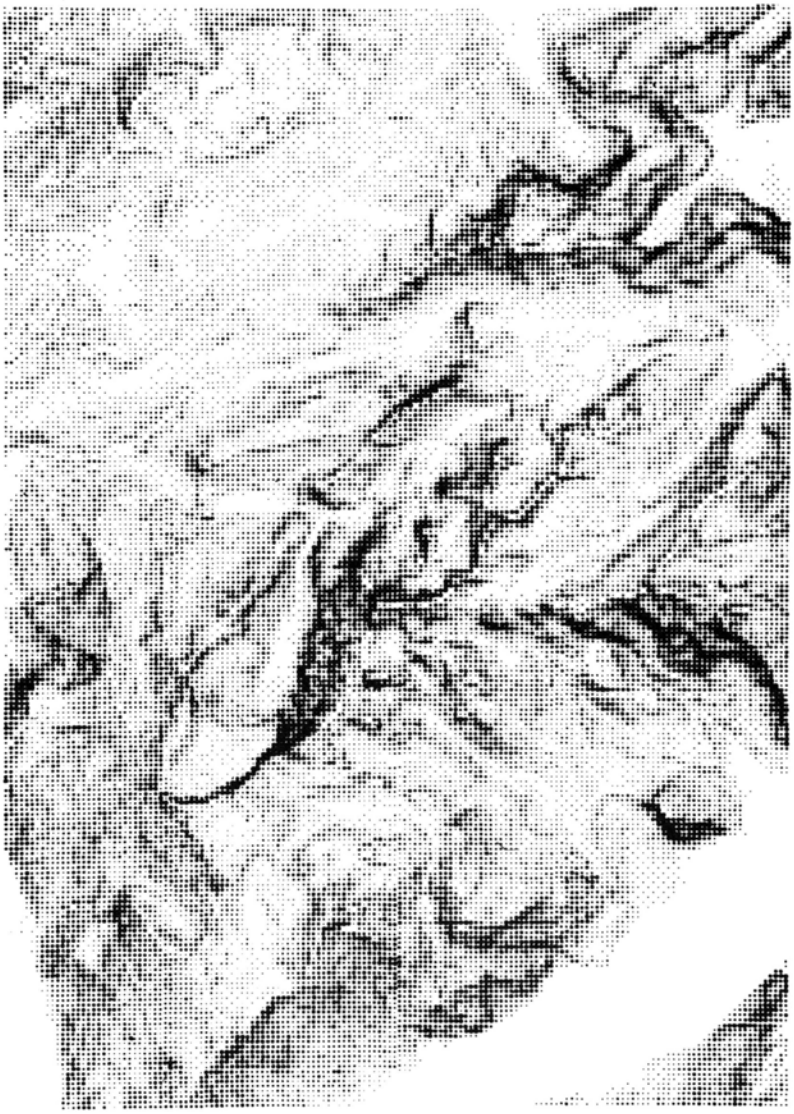

Figure 1

demonstrate that the perception of relief is a function of the direction of illumination. Since the analytical shading model developed by Yoeli does not show the relief realistically, we must search for an extended model. The major difference in my model is an adjustment of the light beam to major land forms. The detailed procedure is described in The American Cartographer (1974). Some ridges are illuminated from southwest and others from northwest (fig. 2); the change in light direction is continuous. Another feature of traditional relief shading used in my model is atmospheric perspective. The amount of gray-tone contrast is increased in high regions and reduced in low regions. (Slide) One shading example is illuminated with atmospheric perspective, the other without.

(Slide) Features other than topographical surfaces may be shaded as well. This slide is a representation of the population density of Zurich, Switzerland. This kind of representation has a lot of problems.

(Slide) This slide shows the line printer for various demonstration displays. With this machine we could change symbols and produce multicolor maps. Modifications in the line printer and the gravure of special symbolism cost about $300. A routine for producing separate layers for different colors allows us to vary the symbolism for different plates and also to turn the screen to avoid moire effects.

The shading model (fig. 3) is a system of algorithms and procedures, grouped in three sections: data, computation, and representation. The actual shading routine is the central procedure in the whole system. It includes the algorithms of Yoeli, the atmospheric perspective algorithms, and the light beam adjustments. The data structures used in the model are old-fashioned--gridded elevation information and a spaghetti file to describe the major ridges and course lines. This second file is compiled by hand: a cartographer interprets the relief, draws edges and river lines, and distinguishes between different categories of lines.

This information is used for light adjustments as well as for a special interpolation of intermediate rows and columns of data points between the existing elevation matrix and can be used to enlarge or to smooth and generalize the relief (fig. 4). Interpolation keeps ridges sharp and smoothes surface portions, thus retaining the characteristics of the original digital terrain model. In some tests, samples of the original data set (1/4, 1/16, 1/64 of all data points) were taken, and the surface was regenerated by interpolation. (Slide) Notice the progressive generalization and deterioration of the relief as the sample size decreases.

Peucker: How can we develop a relief-shading system that will do the whole job in a production shop? There are several problems involved. Since the procedure is still relatively slow, we produced a linear approximation that reduced the cost per point to about 3 percent of what it previously was. We usually have two basic scales for relief-shading--large scales of 1:25,000 or 1:50,000 and small scales of 1:3,000,000. The data problems are very different. With large scales we have data for any grid density that we want. With small scales we do not have such data, but we do have more than the surface structure (e.g. the river and ridge system). We have more indications of the local relief variation than absolute heights.

The problem therefore is to create relative differences. With the

Figure 2.--Automated relief shading. Light source is locally adjusted to land forms.

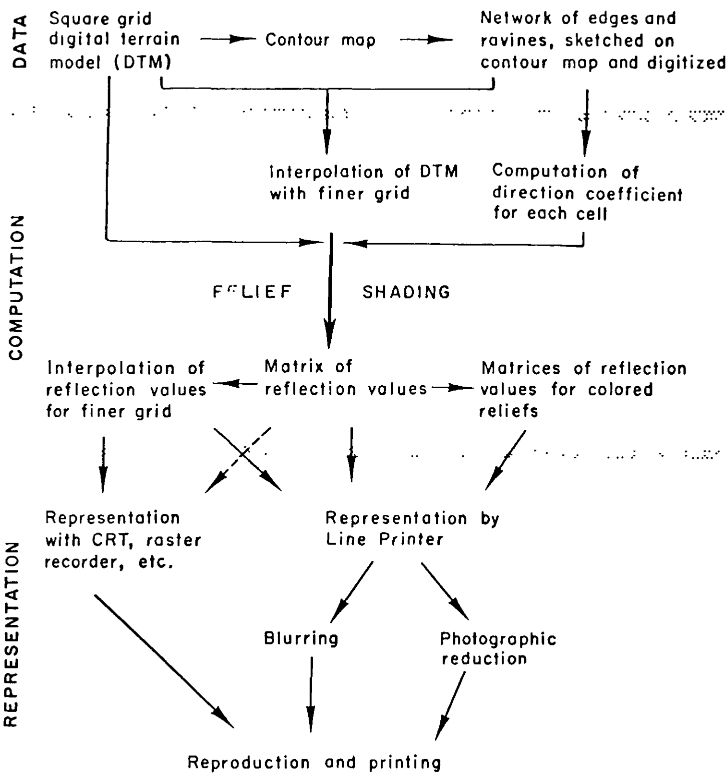

Figure 3.--The basic phases in the production of a computer shaded map. (Courtesy of The American Cartographer)

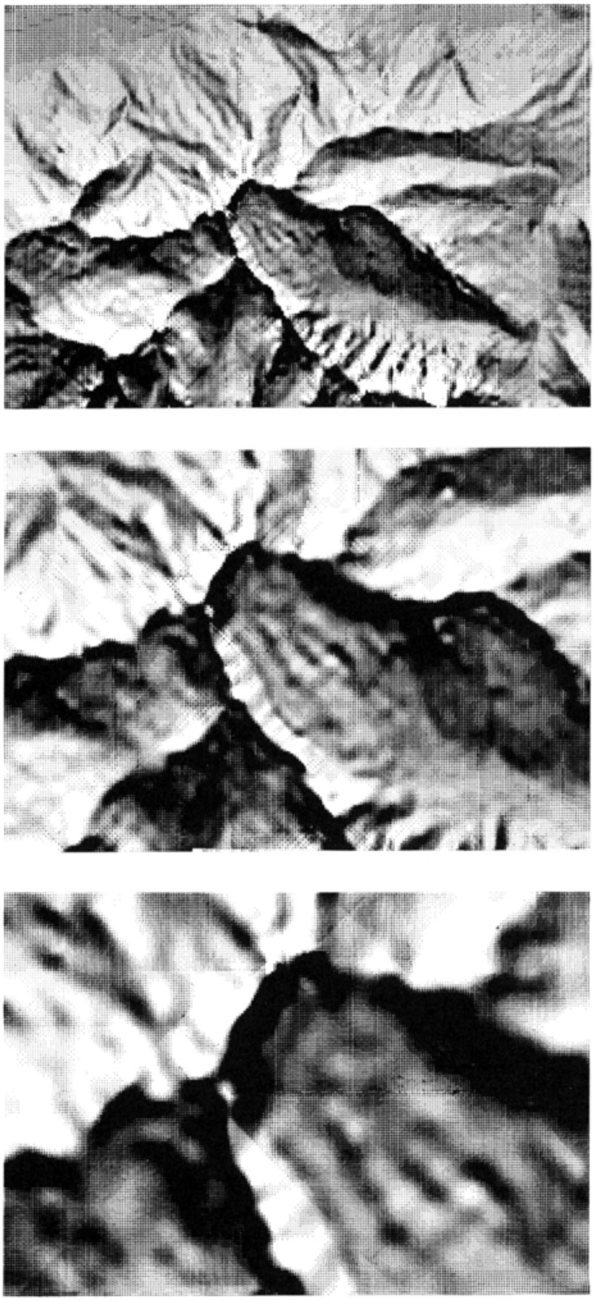

Figure 4.--Interpolation of intermediate rows and columns of data points and subsequent shading with the HILLSHAD program.

whole system on our data structure, we could produce a shading record for each slope and use that record whenever we have to use a map projection at that scale.

Little: The visual methods of automated terrain representation have been adapted to available data and current technology. Automation has stimulated the development of several new methods of display as well as sharpened older methods. Contour maps, long the prevailing style of display, are now produced automatically from various digital terrain models (DTM). Several methods, which were tedious if not impossible by hand, have been programed. Analytical hill-shading (Yoeli) and Swiss relief shading have been handled in programs by Peucker and Brassel, for example. The first may well have been impossible without the computer's aid; the latter, time-consuming. I will discuss a third method, block diagrams or surface relief modeling (fig. 1). Since relief modeling implicitly involves hidden line removal, an expensive process, its use has been customarily restricted to final output of collected data (mostly for display) and to mapping of terrain data. Maps are customarily expected to be printable products. Today the easy availability of terrain data for large regions and the use of graphic terminals (cathode ray tubes, either storage or refresh) offers the possibility of interactive use of relief maps. Since terrain representation by relief modeling provides a simple global view of the shape and variability of the surface, this method can be used not only for display but also for investigation of the data. Relief models can be interpreted easily by casual users as well as trained geographers.

To produce surface maps quickly in an interactive environment, the Laboratory for Computer Graphics and Spatial Analysis, Harvard University, has developed the program ASPEX. Gridded data storage remains the most popular storage method for surface data although such methods as local polynomial surface patches and triangular networks are presently in use. However, because of the availability of grids and the possibility of interpolation from other forms, ASPEX deals with grids stored in matrix format. Currently many block-diagram programs are available--SYMVU of the Laboratory of Computer Graphics, Calcomp's, Douglas's VIEWBLOK, and many others. Most are constrained by the size of the grid matrix of data, up to a typical maximum of 130 by 130 as in SYMVU. Many data bases today are much larger. Thus to produce a relief map, cumbersome techniques were used to split the data into manageable sections, requiring cutting and splicing to assemble the finished product. Against this constraint, ASPEX adopts a strategy which partitions the grid as it is input, spooling data onto secondary storage and handling sections within the core. In this way the amount of data to be modeled can be limited only by the size allotted to pointers marking the sections. Since the size of the sections can be altered at compilation time, the total size of the program can be tailored to suit the time/space tradeoffs at the installation.

Within an interactive situation, complete graphic representation often must be balanced against speed and storage constraints. For storage tubes, like a Tektronix graphics terminal, the drawing time is directly proportional to the number of line segments in the image. For refresh tubes, the storage required is also proportional to the number of vectors. For a block diagram of a digital terrain model in a 100 by 100 grid, the number of visible line segments can be up to 10,000. On a slow speed line the transmission time can easily be 15 to 20 min. To solve this logjam, ASPEX has a generalization feature using a routine

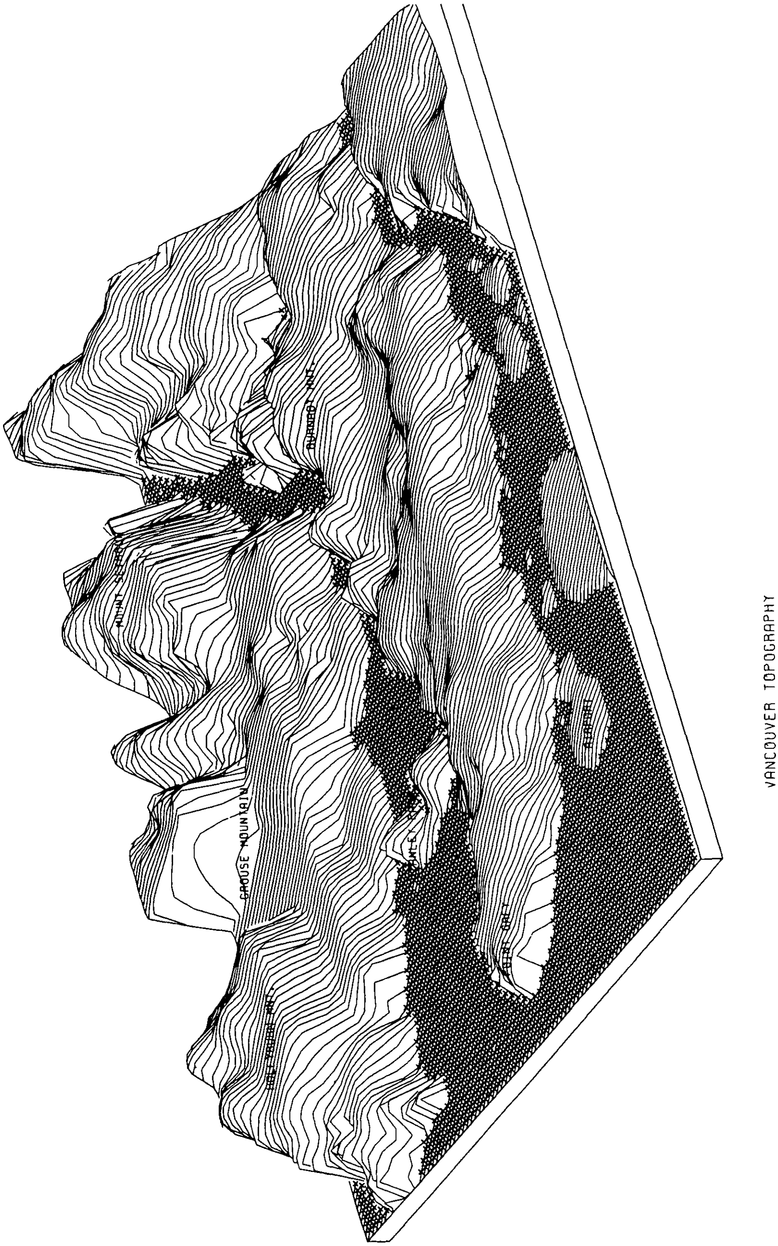

Figure 1

written by Douglas (1973). The points in relief that deviate less than a user-specified minimum from the general trend of the line are removed. Figure 2 shows an ungeneralized plot. At the resolution of a typical CRT, or 0.01 in, across a drawing approximately 7 by 9 in, generalization can cut the plotting time in half and thus reduce the storage requirements (fig. 3). Using a larger minimum, 0.02 in, reduces the drawing time still further to 35 percent of the original (fig. 4). With a minimum of 0.03 in, the detail is again reduced (fig. 5). This process has a practical limit at which the major relief is altered by generalization, but at lower levels the process still reveals its usefulness.

Similarly the plotting time can be reduced by dropping every second or third relief line within the image. By combining this technique with line generalization, the image buildup time can be considerably reduced without much information loss. A map in which every third line has been skipped (fig. 6) takes two-thirds as long to create as a full image (fig. 5), and when every second has been removed (fig. 7), half as long. Not only is this technique time-efficient, but elimination of some of the lines often clarifies the global trends of the surface and eases identification of the major relief features. The relief components of high frequency can essentially be eliminated, removing what is often a noise component. Whether the smaller relief, however distinguishing, is in fact significant is a decision for the analyst using the program, not for the program itself. We have merely opened the option to examine data in this manner.

Besides speeding up the drawing process for interaction, ASPEX implements virtual image methods and windowing and clipping techniques prevalent in many interactive applications. Explanation of these methods can be found in <u>Principles of Interactive Computer Graphics</u> by Neumann and Sproull (1973). Most block diagram programs, such as SYMVU, restrict the viewer to a vantage point outside the surface for scanning the entire surface. In ASPEX the vantage point can be placed anywhere above or outside the surface, and the central point of the image can be anywhere. Using this option one can zoom in on portions of the data of special interest and produce a map showing the relief at larger scale and unobscured by surrounding relief. In a closeup view, parts of the image must necessarily extend outside the range of the tube plotting area. We must clip these parts as they leave or the lines will wrap around the scope, entering on the other side. The windowing routines in ASPEX handle this difficulty without significant expense.

In figures 8 through 11 we zoom in on a model of the relief of the conterminous United States, from the Northeast to Denver. The sequence gives a vivid impression of the changing landforms across the country, adding a new dimension in display techniques. The generalization, zooming, and windowing options are applicable to maps on a pen plotter and in a batch environment.

The sum of these techniques in ASPEX provides many of the features of interactive display for block diagrams. Generally these methods are making an impact in geographic data manipulation and display, most significantly in the manipulation of regional data bases for social, economic, and legal land-use planning. The combination of several sources of data where the regions overlap (e.g. housing data with job statistics) is currently a feature of many regional data base systems, and we expect that this combination will also be true with DTM's and

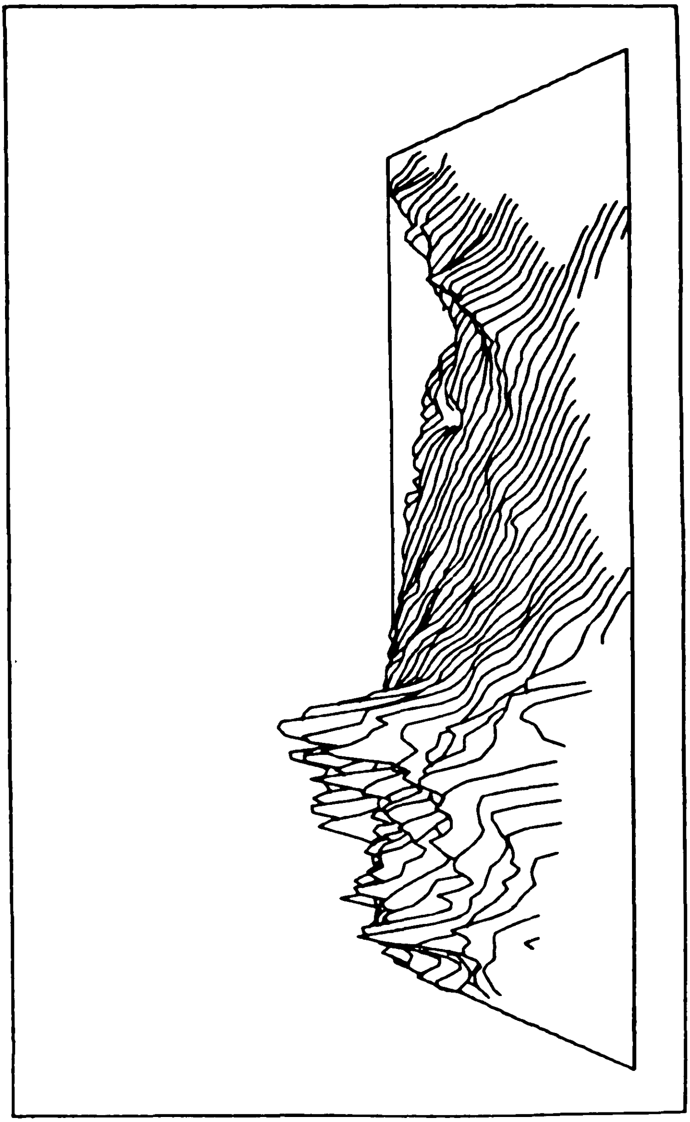

Figure 2

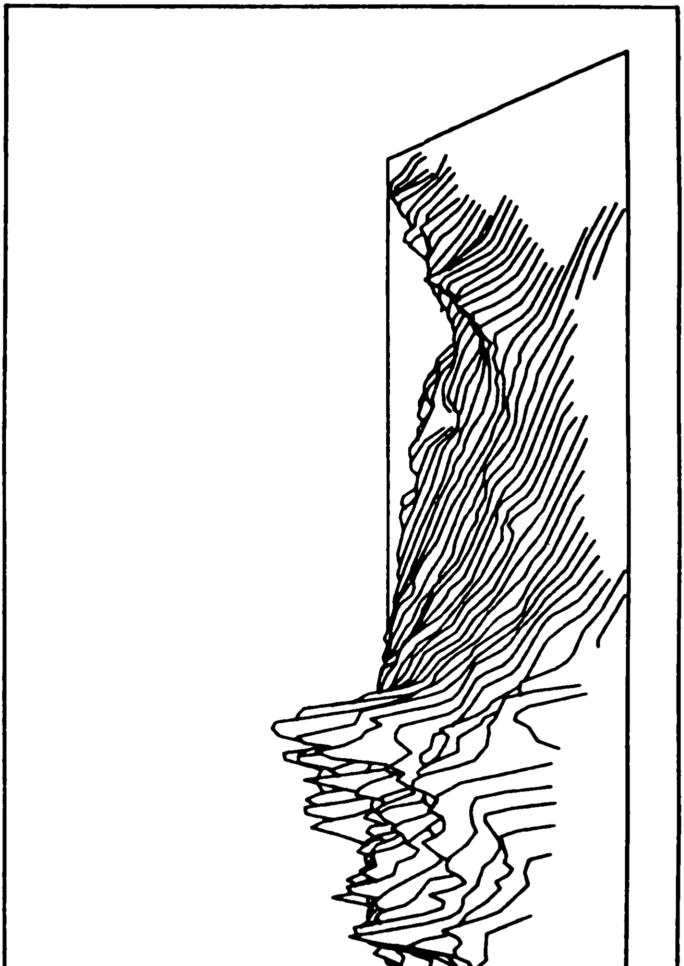

Figure 3

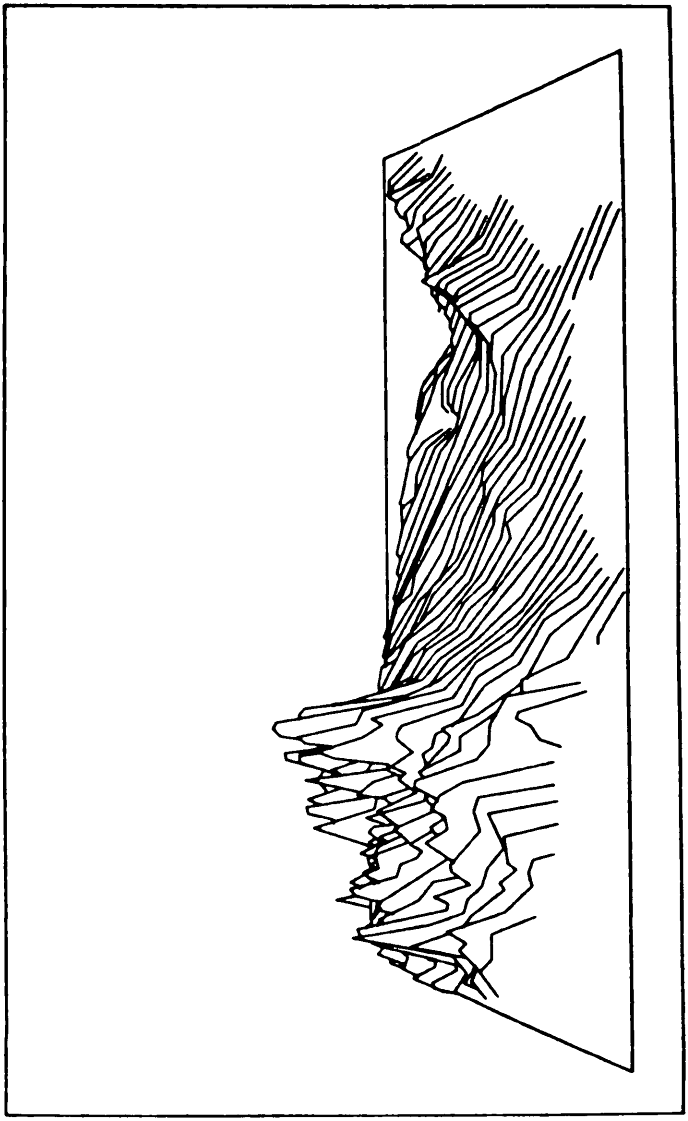

Figure 4

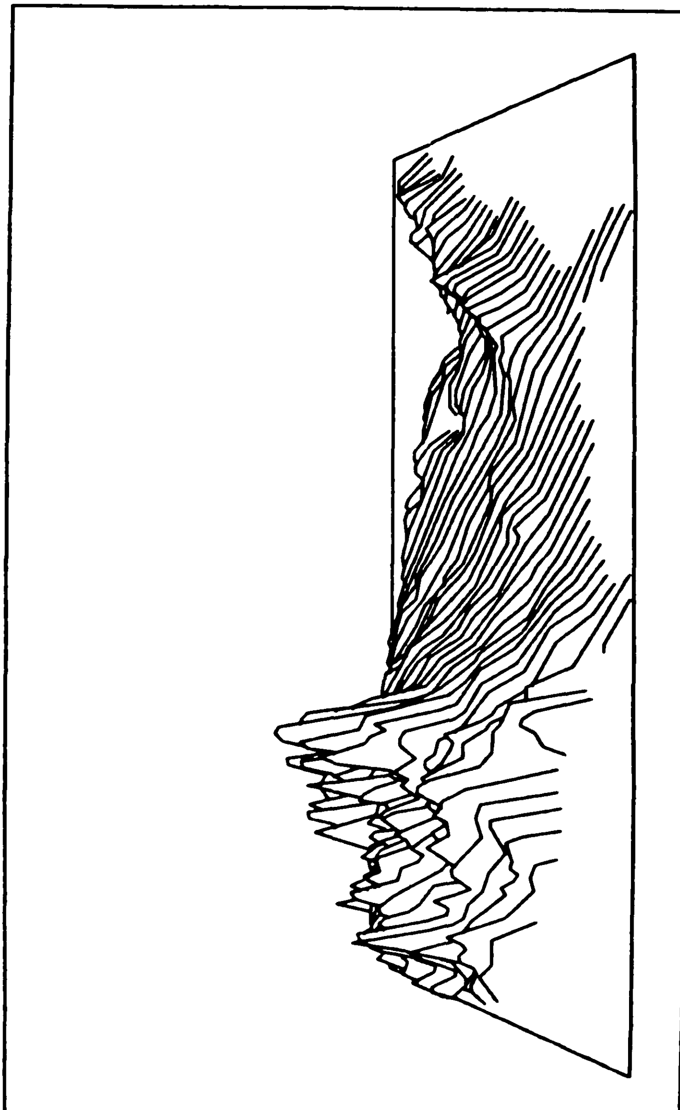

Figure 5

Figure 6

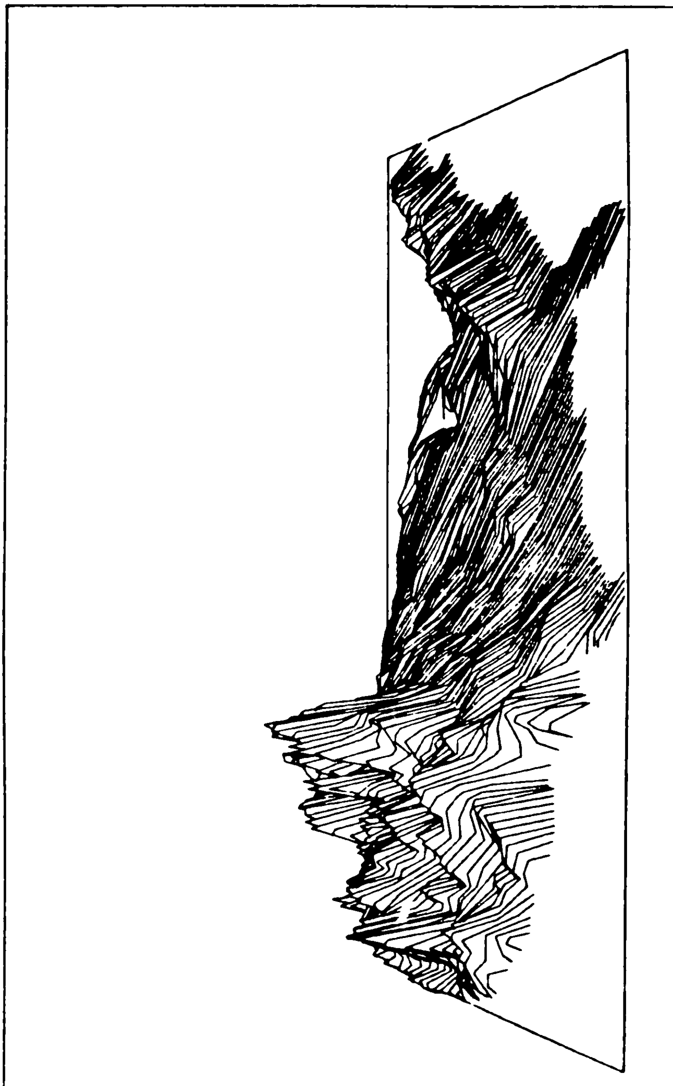

Figure 7

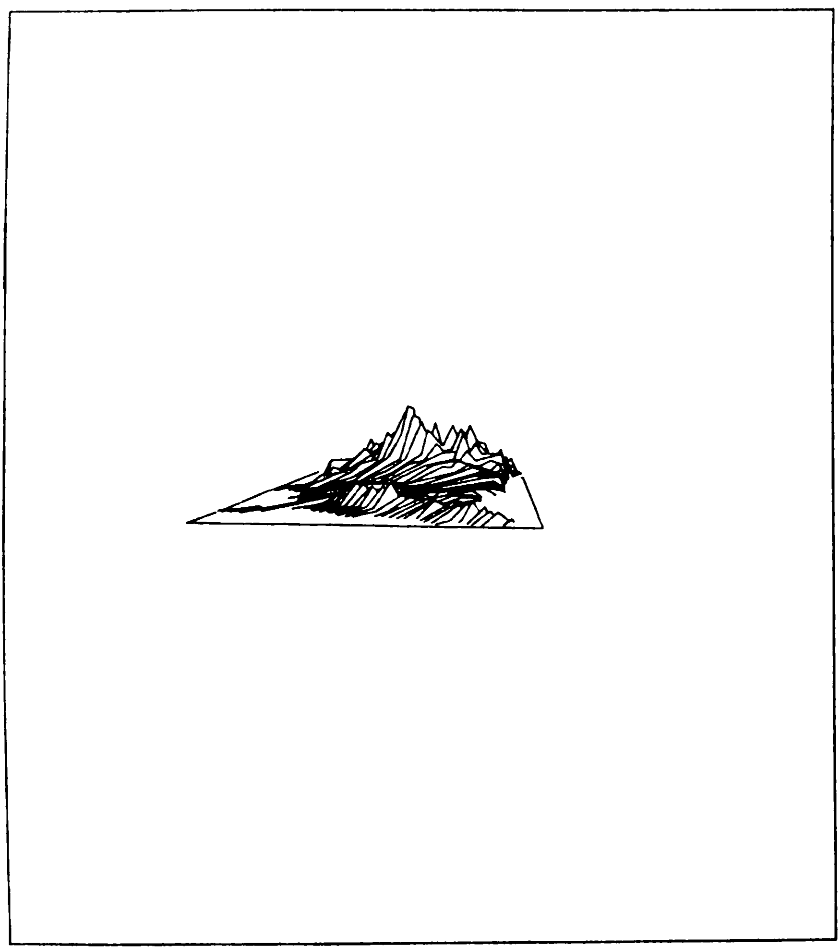

Figure 8

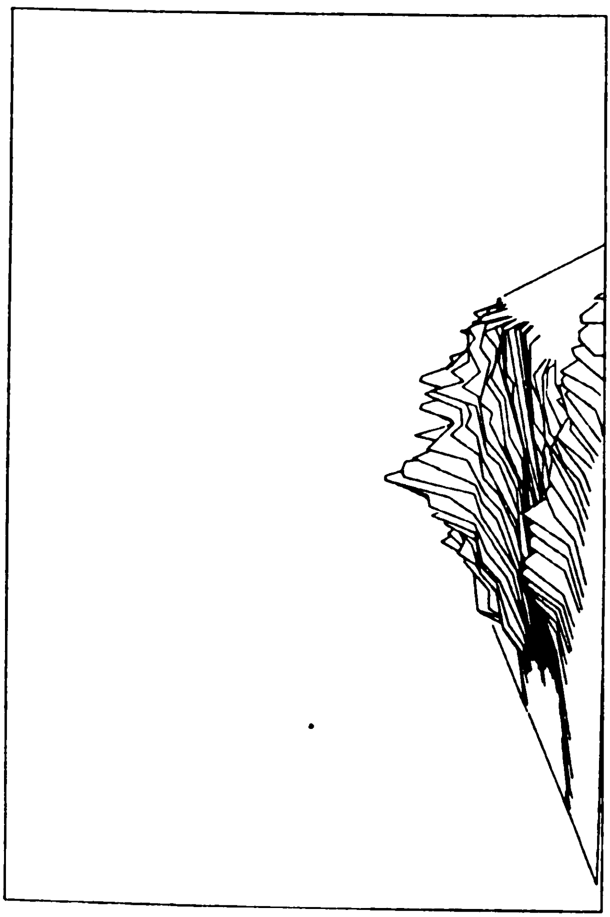

Figure 9

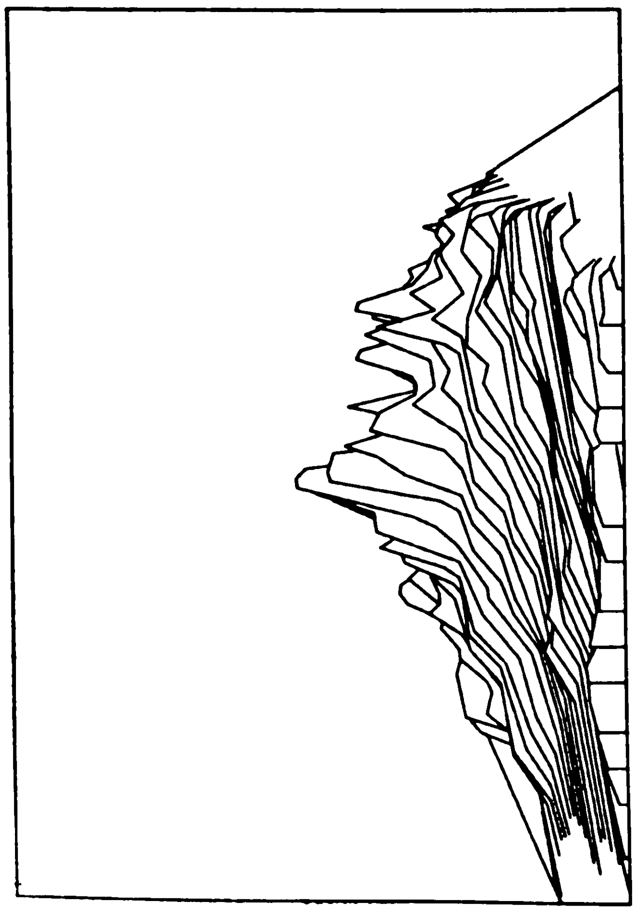

Figure 10

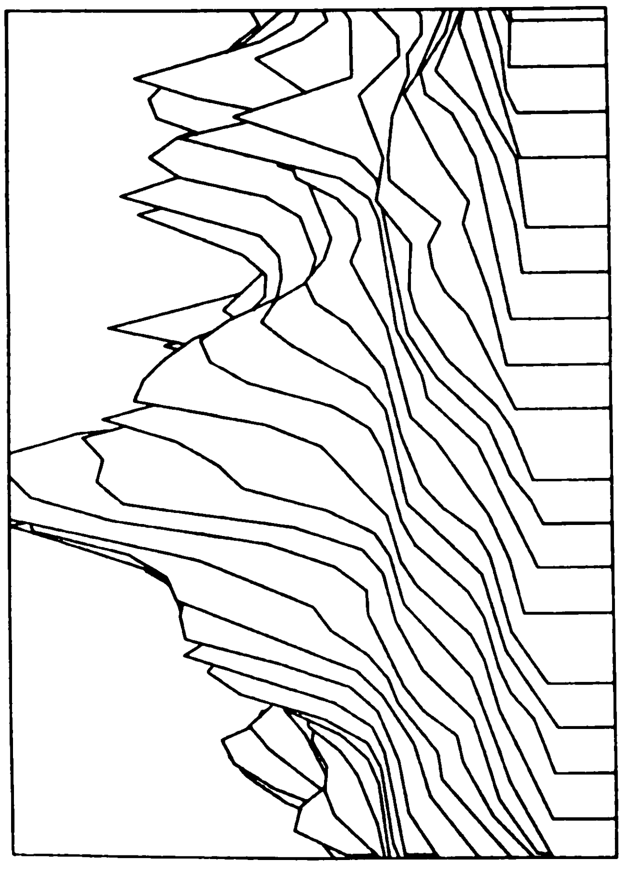

Figure 11

regional data. These overlays can be displayed in several fashions, including color separations of the varying data groups. Figure 12 shows the forestation of Dentes de Morcles, Switzerland, produced by plotting the forested and unforested land groups separately and then combining them in the printing process.

Further development envisioned for ASPEX involves plotting cultural features as lines on the surface and drawing polygonal data, such as land-use types, on the relief and overlay of contour lines. Both developments should significantly enhance the readability of these maps. By setting surface modeling in an interactive system and enhancing the possibilities of thematic mapping over DTM's, we hope to increase the geographer's understanding.

Rockwell (New Jersey Dept. of Community Affairs): How much core does it take to operate ASPEX?

Little: We were working on a Digital Equipment Corp. computer, PDP-10. It takes 24 k right now, but we have an overlay that goes down to about 16 k. You can make it as small as you want.

Rockwell: Could you run ASPEX on a PDP-11 or a large -8?

Little: Certainly.

Broome (Census Bureau): I noticed that you were talking about how long it took to plot data on the tube. Is this time a function of computation time or transmission time?

Little: Transmission time.

Broome: What bar were you operating at?

Little: 300 bars, which is typical.

Rhind (Univ. of Durham): For many users of big machines in an interactive system, the time that you wait for the data has increasingly less to do with the central processing time or even the transmission time. Virtual memory machines are often working until the page comes through. You can't do anything about this situation except organize the data structure in a way that minimizes the number of pages needed.

Little: On a virtual memory machine you should act as if you were on a PDP-8.

Broome: Virtual memory machines are unpredictable with our programs. This strategy allows us to reduce the size and work as if we were in a few pages.

Rhind: I do wish that you would stop calling that thing the Tanaka Method. It was used by the British Army in the 1840's.

Peucker: The method is attributed to Tanaka because he was the first to formalize it mathematically. Incidentally, about the transmission time, 3 years ago I was happy to have a turnaround time of half a day. Now people are nervous if they have to wait a few seconds.

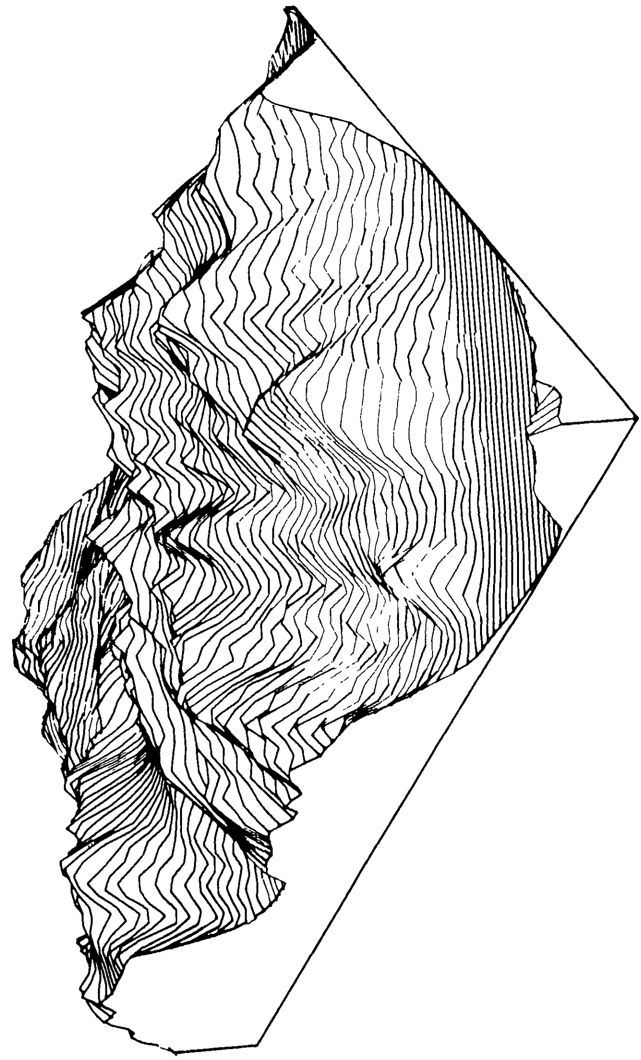

Figure 12