San Fernando Valley State College

MOUNTAINS ON MAPS:
Toward an Economical Landform Base

A thesis submitted in partial satisfaction of the requirements for the degree of Master of Arts in Geography

by

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>vii</td>
</tr>
<tr>
<td>Abstract</td>
<td>xi</td>
</tr>
<tr>
<td>1. INTRODUCTION TO THE PROBLEM</td>
<td>1</td>
</tr>
<tr>
<td>1.1 The need for mountains on maps</td>
<td></td>
</tr>
<tr>
<td>1.2 Some current -- and inadequate --</td>
<td></td>
</tr>
<tr>
<td>techniques for satisfying the</td>
<td></td>
</tr>
<tr>
<td>need for mountains</td>
<td></td>
</tr>
<tr>
<td>1.3 Statement of purpose</td>
<td></td>
</tr>
<tr>
<td>2. A BRIEF HISTORY OF MOUNTAINS ON MAPS</td>
<td>14</td>
</tr>
<tr>
<td>2.1 An historical analogy</td>
<td></td>
</tr>
<tr>
<td>2.2 Rudimentary terrain representation</td>
<td></td>
</tr>
<tr>
<td>2.3 The appearance of the vertical</td>
<td></td>
</tr>
<tr>
<td>view in contour lines and</td>
<td></td>
</tr>
<tr>
<td>hachures</td>
<td></td>
</tr>
<tr>
<td>2.4 Introduction of relief shading</td>
<td></td>
</tr>
<tr>
<td>through lithography</td>
<td></td>
</tr>
<tr>
<td>2.5 Overview</td>
<td></td>
</tr>
<tr>
<td>3. PERCEPTION OF THREE DIMENSIONS AND</td>
<td>27</td>
</tr>
<tr>
<td>ITS REPRODUCTION ON A TWO DIMENSIONAL</td>
<td></td>
</tr>
<tr>
<td>SURFACE</td>
<td></td>
</tr>
<tr>
<td>3.1 Psychovisual cues to the</td>
<td></td>
</tr>
<tr>
<td>perception of depth</td>
<td></td>
</tr>
<tr>
<td>3.2 Depth cues based on sensory</td>
<td></td>
</tr>
<tr>
<td>experience</td>
<td></td>
</tr>
<tr>
<td>3.3 The use of shadow as a depth cue</td>
<td></td>
</tr>
<tr>
<td>3.4 The role of technology in the</td>
<td></td>
</tr>
<tr>
<td>reproduction of shaded relief</td>
<td></td>
</tr>
</tbody>
</table>
Chapter
4. THE APPLICATION OF PHOTOGRAPHY TO TERRAIN REPRESENTATION. 50
   4.1 An alternative to "artistic talent" in relief shading
   4.2 The posterization technique
   4.3 Psychovisual justification for the adequacy of posterized terrain depiction
   4.4 Application of posterization to terrain depiction

5. POSTERIZATION TESTED 70
   5.1 A student test of posterized relief
   5.2 Cautionary notes derived from the experiment
   5.3 Conclusions

List of Illustrations. v
References Cited 80
# LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Figure</th>
<th>Illustration</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Inclined contours.</td>
<td>6</td>
</tr>
<tr>
<td>2.</td>
<td>Vertical contours.</td>
<td>8</td>
</tr>
<tr>
<td>3.</td>
<td>Shaded and illuminated contours.</td>
<td>10</td>
</tr>
<tr>
<td>4.</td>
<td>Statistical surface depiction.</td>
<td>12</td>
</tr>
<tr>
<td>5.</td>
<td>Rudimentary terrain representation</td>
<td>16</td>
</tr>
<tr>
<td>6.</td>
<td>Hachures according to Lehmann and Dufour</td>
<td>19</td>
</tr>
<tr>
<td>7.</td>
<td>Geometric relationships in terrain depiction</td>
<td>25</td>
</tr>
<tr>
<td>8.</td>
<td>&quot;Primary&quot; cues to depth.</td>
<td>29</td>
</tr>
<tr>
<td>9.</td>
<td>&quot;Alternative&quot; cues to depth.</td>
<td>32</td>
</tr>
<tr>
<td>10.</td>
<td>Actual lighting effects on a model landscape</td>
<td>36</td>
</tr>
<tr>
<td>11.</td>
<td>Principles behind shaded relief.</td>
<td>37</td>
</tr>
<tr>
<td>12.</td>
<td>Some darkroom techniques</td>
<td>44</td>
</tr>
<tr>
<td>13.</td>
<td>The preparation of tone and halftone</td>
<td>46</td>
</tr>
<tr>
<td>14.</td>
<td>The halftone image and its cost.</td>
<td>48</td>
</tr>
<tr>
<td>15.</td>
<td>A &quot;posterized&quot; portrait</td>
<td>53</td>
</tr>
<tr>
<td>16.</td>
<td>The process of posterization</td>
<td>54</td>
</tr>
<tr>
<td>17.</td>
<td>More examples of posterization</td>
<td>60</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>18.</td>
<td>Posterization as a creative tool</td>
<td>61</td>
</tr>
<tr>
<td>19.</td>
<td>Flow chart for posterized shaded relief</td>
<td>64</td>
</tr>
<tr>
<td>20.</td>
<td>Contour map annotated for posterization</td>
<td>65</td>
</tr>
<tr>
<td>21.</td>
<td>Posterized mountain range</td>
<td>66</td>
</tr>
<tr>
<td>22.</td>
<td>Copy used for the posterized mountains</td>
<td>67</td>
</tr>
<tr>
<td>23.</td>
<td>Posterized terrain as a base map</td>
<td>68</td>
</tr>
<tr>
<td>24.</td>
<td>Additional posterized terrain</td>
<td>69</td>
</tr>
<tr>
<td>25.</td>
<td>A student attempt at posterization</td>
<td>72</td>
</tr>
<tr>
<td>26.</td>
<td>An unsuccessful posterized map</td>
<td>74</td>
</tr>
</tbody>
</table>
PREFACE

"Oh, do let us have some hills. It would be such fun to have hills."

T. E. Lawrence*
Cairo, December, 1914

The statement from Lawrence of Arabia was a reply to one of his draftsmen during compilation of the Cilicia sheet of the quarter million map series of Turkey. The unfortunate cartographer was presented with the problem which had faced mapmakers for centuries before, and has remained to this day; how to represent mountains on maps. What brought about Lawrence's ire was the draftsman's inelegant solution; he had asked Lawrence if he could join tradition by leaving the hills off altogether.

There once was a time when man did not know what mountains looked like from above -- the map view. That period ended when he invented surveying, an end which was reinforced when he took to the air in balloons, airplanes, and spacecraft. When man finally knew what mountains

*Quoted by his former commanding officer, Sir Ernest M. Dowson, KCB, in T.E. Lawrence, by his friends, A.W. Lawrence (ed), London: Jonathan Cape, Ltd., 1937, p. 143.
looked like from above, he still had to figure a way to apply that knowledge to paper so he could communicate his discoveries to others. Certain men were adept at painting. These artists required time, and hence money; and their pictures were not always suitable as a base upon which to apply lettering, roads, boundaries, and all the other symbols that make a map a map. What was needed was some method whereby the illusion of the third dimension -- depth -- could be produced cheaply (so that many different maps could be made); in black and white (because technology dictated that the reproduction of color was prohibitively expensive); and easily (so that long training was not requisite for a successful mountain-maker).

Browsing through the Art Section of the college library, one day, among the literature of graphic design, I found examples of a seldom used process for transforming continuous tone into something that looked as though it had been produced by line techniques. Rather than reproducing the continuous tone of an original photograph, the process, known as "posterization", separated the grays and generalized them into zones of even tone. The highlights on the face in the photograph were white, and the shadows black; and in between were two middle tones, a light gray and a dark gray. The picture did not look at all unnatural;
contrast was enhanced because of the pure whites and blacks. The subject therefore had the appearance of being in bright sunlight.

Working in a darkroom trying to make a similar portrait, I found that posterization as it had been illustrated was far from being a simple replacement for the usual halftone method of reproduction. As it turned out, the example had been done for the four flat tones, not for ease or economy of the process. While experimenting with posterization, I discovered both how to produce the zonal effect without halftoning, and also, using my new method, how to make a final print without starting from a photograph; in other words, how to use this new form of posterization to create an image as well as reproduce one. Applying the process to terrain depiction, I could simulate the appearance of shaded relief from a contour map without either laborious hand shading or expensive halftone reproduction.

Acknowledgment must be given to many people for helping me to produce this: To my friends in geography and other places, and faculty also -- especially my thesis committee. Of the latter group, Bill Rutledge deserves special thanks for his imagination during its formative stages, and for his blue-pencilling of the rough draft.
For introducing me to cartography, a great deal of credit must go to a maestro of terrain depiction, Vincent Mazzucchelli. The standards set by his work have been an inspiration to me and others. More recently Scott and Mary Williams have been instrumental in the completion of this work. Scott, for his constant harassment (especially by finishing his thesis before I finished mine) and Mary, for -- among other things -- trying to keep her husband under control. I must thank my parents for their interest; my father especially, for lending his experienced editorial eye.

My wife's picture is figure 15. Most thanks should go to her. Sandy's virtue was impatience.
ABSTRACT

MOUNTAINS ON MAPS:
Toward an Economical Landform Base
by
Donald Allan Ryan
Master of Arts in Geography

Throughout the history of cartographic terrain depiction, new methods have been more a result of incidental technological breakthrough by non-cartographers than a conscious response to a demand for better maps. This situation has existed partly because cartographers have been reluctant to step into an area they consider to be the realm of the artist. Their reluctance is possibly due to inhibition resulting from what many cartographers feel is their lack of "artistic" talent. Although techniques have been proposed over the years to obviate the need for such talent, these too have suffered from inherent drawbacks.

This perceived lack of artistic talent has resulted in the avoidance of one form of rendition that has demonstrably superior eye-catching ability and realistic
appearance: "shaded relief".

A graphic reproduction technique taken from commercial art, known as "posterization", suggests a photomechanical means for producing shaded relief. Instead of an image formed of various-size dots, characteristic of the halftone process, posterization breaks down the light reflected from any given subject into three or four flat gray tone-classes. By scrutinizing where the tones occur in relation to the shape of the subject pictured, the cartographer can learn to predict their arrangement. The tones represent nothing more than shadows, and their quality depends only on the angular relationship between the surface of the subject and the source of light. The cartographer has at his disposal the contour map. All he must do is hypothesize a light source and delineate areas of similar slope -- hence of similar shadow -- with respect to that light. Normal darkroom procedures can then provide a perceptually-sufficient, realistic, shaded map.
CHAPTER 1
INTRODUCTION TO THE PROBLEM

1.1 The need for mountains on maps.

There is a need in Geography for an easy, economical method for the representation of land form -- as a base -- on small size maps. This need is most often felt at the scale of the professional journal or unpublished paper when production must be in black and white and when cost and time involved must be minimized. Such maps supplement text rather than stand alone and are printed in scholarly journals, monographs, theses, and textbooks. They are usually drawn by cartographers who are not professionals, who have no access to elaborate equipment, and who are restrained by limitations of both time and money.

If the lack of mountains on contemporary examples of such maps is any indication, this need has not been met.

Although terrain representation is a common subject of cartographic inquiry, publication in the field has largely been confined to periodic display of new methods. Currently popular cartography texts (books by Greenhood, Monkhouse and Wilkinson, Raisz, and Robinson and Sale) are devoid of
any systematic study or statement upon either the desir-
ability of having mountains on maps or of the principles
which underlie a reader's recognition of three dimensional
forms from lines on a flat surface. The purpose of this
thesis is to explore some current techniques and to suggest
an alternative to the present difficult and expensive pro-
duction process.

Within the economics of cartographic design there is a
balance between the desire to have the mountains and the
economy of leaving them off.

By far the most popular treatment of terrain is to
ignore it. This is a justifiable attitude. It is economi-
cal to leave the land off the map because there is no easy
way to put it on. Since the purpose of the map is to com-
municate space facts, the simpler the map, the less ob-
structed the process of communication. In the process of
eliminating marginally essential information, the mountains
are usually the first to go. Is there, then, any excuse
for such embellishment of the map?

On a map the surface of the paper represents the
surface of the earth. The land's orientation and slope are
therefore aspects common to the base of all maps. If the
purpose of the map is to display some feature whose distri-
bution and variation is influenced by changes in the land
form, then there are obvious reasons for the land to appear. For example, a map may be intended to show variation in the distribution of a plant type. Since the land surface in the mapped area is shown to be flat, the variation in the distribution can be assumed not to be a reflection of the terrain. If the land is hilly, however, then sunlight and shadow, heat and cold, moisture and dryness, and erosion and deposition all vary and influence the distribution of the vegetation. To leave the terrain off the map in this case would rob the reader of the opportunity of making the most obvious mental correlation.

Excuses should be made for omitting hills from the map, but justifications are not needed for putting them on. To paraphrase Sir Edmund Hillary: because they are there. The desire of the geographer to have mountains on his map should be sufficient reason for their inclusion. Study of the land surface as such is unique to geography; if mountains on his maps make the desk-bound scholar feel closer to the earth, however vicariously, the mountains should be there.

1.2 Some current – and inadequate – techniques for satisfying the need for mountains.

Many cartographers lack total confidence in their work, inhibited by what they feel to be a lack of artistic
talent. To counter this real or apparent lack, there are several "recipes" by which terrain maps can be constructed. The following discussion, taken out of historical context, should serve to illustrate the problem of focusing on the flaws found in a few contemporary recipe techniques. (The evolution of terrain representation techniques will be explained more completely in Chapter 2.)

The recipes most often seen are those of the Japanese cartographer, Professor Kitiro Tanaka. Both Professor Tanaka's "Inclined Contours" and his "Illuminated Contours" are widely known in this country and others and have been expounded and modified by Professors Arthur H. Robinson, Norman J.W. Thrower, and others. Though the directions for the construction of these maps are widely known, and the methods are seemingly simple and mechanical, virtually no maps have been published which apply these techniques for other than instructional purposes.

Recognizing their clear pictorial qualities, Professor Tanaka chose to mold the terrain by carefully plotted profiles (Tanaka, 1932). He called these profiles "inclined contours"; they were the surface expression of imaginary planes passing through the earth at a selected inclination. The angle of the planes was related to an assumed angle of illumination and their density, that is, separation was
determined by the scale and contour interval of the source map. Construction, at least as he explained it, was simplicity in itself. It consisted of ruling equidistant lines onto a contour map and then connecting the crossing points of the lines and contours in a systematic fashion. The connecting lines were the inclined contours. (Geometrically there is no difference between contours and profiles, but to remain consistent with accepted cartographic jargon Tanaka should probably have called his lines "inclined profiles", as later cartographers have re-dubbed them). The resulting map was no less abstract than the contour lines from which it was drawn, but it did not look so. It had a pictorial quality that belied its potential uselessness (fig. 1B).

In collaboration, Professors Robinson and Thrower extended the ideas of Professor Tanaka in a series of maps of Camp Hale, Colorado, for the U. S. Army (Robinson and Thrower, 1957). They saw the pictorial quality of the Tanaka method but saw fit to use his inclined contours solely as a base upon which to depict the terrain by sketchy lines, parallel to the profiles. The two geographers created a shaded effect by assuming the traditional northwest source of light and putting more of the sketchy lines on the shade slopes. This furthered the pictorial quality
Fig. 1. The Inclined Contour method of Kitiro Tanaka, and the adaptation by Professors Robinson and Thrower. The horizontal construction lines for Tanaka's map (seen at B) were spaced the same as the contour interval of the map from which it was drawn (A). Thus, since the scale of the contour map was 1:100,000, with a 60-meter contour interval, the construction lines -- and the profiles on the plains at the lower center of his map -- were spaced at 0.6 mm. Through investigation into the quality of light reflected from an undulating surface, Professor Tanaka determined that the width of the profiles should be 0.36 times the spacing of the horizontal construction lines. Thus, in his map, the profiles are 0.22 mm in width. Because of the spacing of the construction lines, Tanaka's map has no vertical exaggeration. Robinson and Thrower widened the spacing of the construction lines and sketched the terrain from the resulting profiles (C).
of the profile map by making it look like a more traditional technique of terrain depiction: the bird's eye view. Therein lay the downfall of their particular method. Whereas Tanaka had pretended to do no more than define a surface, Thrower and Robinson had feigned realism. In a true map view, the information displayed has a distinct appearance: it is not distorted by perspective. The Robinson-Thrower profile map is so strong in its resemblance to a perspective view that the reader has difficulty in reconciling the appearance with reality (fig. 1C).

Professor Theodore Oberlander's variation on Tanaka's theme is in quite a different direction, and is more honest in perspective (Oberlander, 1968). He realized the visual conflict within the profile map but wanted to retain the strong visual appeal of the profile. By using vertical rather than inclined profiles, Oberlander lost what had made the Tanaka-Robinson-Thrower methods unique, but he achieved a more acceptable appearance. And the appearance, of course, is what really counts (fig. 2).

A later effort of Professor Tanaka has been called "illuminated contours" (Tanaka, 1950).

Late in the nineteenth century, particularly among surveys employed in the consolidation of the British Empire, cartographers enhanced the appearance of contour maps
Fig. 2. Oberlander's argument against inclined profiles. A through C represent a contoured figure, with vertical and inclined profiles drawn from it. Characteristic of inclined profiles is apparent displacement of the planimetrically correct central prominence. In figure D -- inclined profiles -- some front slopes and slopes normal to the profiles are greatly oversteepened, compared to the actual profiles in figure E. Figure F represents inclined profiles across a symmetrical cone, showing the difference in apparent slope where actual slope remains constant.
to give the effect of shadow by a technique of thickening the printed contour lines on the southeast slopes. Since maps at that time were drafted by hand, very little extra effort was needed for the cartographer to give this effect. Professor Tanaka took this idea one step further: in addition to thickening, and hence darkening, the shade slope contours, he also created the effect of sunlight on the opposite slopes by having the lines there printed in white. For the white lines to show, the whole map had to be rendered upon an even gray background (fig. 3).

Tanaka's maps have a striking effect. The terrain appears to be terraced, with each contour line a retaining wall, the whole landform rising visually from the page on which it is printed. Unfortunately, the 40 percent black "gray" tone on top of which the illuminated contours must be printed is so dark that the loss of contrast obscures any other than the land surface itself. The dark tone of land forms is too much for lettering and line work to overcome.

Both the profile and the illuminated contour methods suffer from faults they have in common. With many bold, curving lines, the finished maps look too busy, especially when roads, boundaries, and lettering are applied upon them. Subtlety is not among their virtues. Their worst feature
Fig. 3. Nineteenth Century British shaded contours and illuminated contours according to the Takala method.
is that the methods are not as simple as their originators would have one believe. Construction of the inclined profiles leaves a considerable responsibility of interpretation to the cartographer, and both this and the illuminated contour map require many tedious hours of line drafting.

Thus two of the most widely known techniques of terrain representation remain little used after almost forty years. The profile technique has enjoyed a recent popularity for the graphic expression of a statistical surface. Interestingly, what appears to be an isometric diagram of such a surface, but what equally might be a piece of landscape, is the trademark for an automated plotter manufactured by the CalComp Company (fig. 4).

The profile has very strong visual appeal. If its quantitative properties satisfy the purpose of the statistical geographer, the question must be asked why it is unsatisfactory for the graphic display of terrain. Similarly, the illuminated contour with its quantitative base still intact has a pictorial quality approaching shaded relief. Undoubtedly, the rapidly increasing application of computer graphics will stimulate the fuller exploration of these and other "automatable" techniques. To prepare for that time it is imperative that the cartographer understand the place of mountains on maps. And, for
A CalComp System

Fig. 4. CalComp’s and other statistical surface representations.
the majority of mapmakers who will never see such elaborate equipment, it is also equally imperative for them to be able to employ conventional materials such as ink, preprinted shading media, and the photographic image.

1.3 Statement of purpose.

The purpose of this thesis is to improve present capabilities for the representation of terrain on low cost maps by suggesting more effective use of conventional materials and known techniques. This purpose will be served through a logical development in four chapters: The first of these chapters, Chapter 2, will explain the alternating roles of technology and the demand for better maps, in an historical context. Chapter 3 will examine the principles which allow the perception of three dimensions from a two dimensional surface and will compare these principles with the technology that can produce such an illusion. Chapter 4 will describe, by example, application of the above principles and technology. Since any new technique is useless if it cannot be applied, and if the results cannot be understood, Chapter 5 will describe a test in which students tried out a process new to them and evaluated its performance.
CHAPTER 2

A BRIEF HISTORY OF MOUNTAINS ON MAPS

2.1 An historical analogy.

The history of the development of terrain depiction may be stated concisely by analogy: Consumers did not ask for electric can openers. Electric can openers were invented, and only then was a market created for them, by means of advertising. If an engineer had invented a technique for portraying land slope and if enough cartographers were exposed to his technique, they might have found it desirable to have that engineer's mountains on their own maps. Like the electric can opener, once the new maps found their way into standard cartographic practice, their users would most likely resist any suggestion to abandon them. In cartographic history, invention has often been the mother of necessity. This chapter will attempt to document the reciprocating demand and response relationship between the mapmaker and technology.

2.2 Rudimentary terrain representation.

It is significant that the earliest known map, often
shown in cartography textbooks, has mountains on it (fig. 5). This reflects on the importance of mountains to the ancients as landmarks, obstacles to easy travel, sources of water, and places of escape from hot climates. The mountains are also significant in that the style of their depiction, simple humped lines, has been handed down to this day unchanged as the most direct and popular representation of elevated land.

Prior to about the fifteenth century, or until the so-called "Renaissance", elevations in the land surface were shown as "sugarloaf" humps if they were mountains, swarms of humps if a mountain range. The hump was a symbol for the hill and not a depiction of it. Thus, each hump commonly looked like any other hump. All mountains must have looked the same to the practical minds of the Roman military engineers, for example; all were obstacles. During the period of general rebirth of the sciences and arts in Europe, and of genuine curiosity about the earth, terrain depiction became just that: an attempt to show what the land surface looked like, not merely whether it was mountainous or flat.

During the earlier part of this period, the oblique perspective, or bird's-eye view of the land that characterized the earlier maps was retained (fig. 5). This was
Fig. 5. Mountain representation on the oldest known map compared with part of a mid-renaissance map of the region near Zurich: more precision accompanied by some loss in simple communicability.
a convenience to both the topographic artist and to the map reader. A mapmaker could select a vantage point from which he could survey the land and draw what he saw from life. The reader, perhaps having been at the same or similar vantage point, (a bell tower or a mountaintop) could easily recognize the forms he saw on paper as having been within his own experience. Although the Renaissance man could have undoubtedly understood a modern well-made shaded relief map, neither he nor the technology of his time demanded the carefully calculated planimetry present within the modern map.

The age of exploration and subsequent discoveries created a need for more accurate maps. While the navigational requirements were met as more accurate instruments and methods were developed, comparable advancement in terrain representation did not occur. Hills were still drawn obliquely on a planimetric base. This lack of advancement in terrain depiction resulted from the absence of any true concept of the vertical view. The artists and cartographers of the day were competent in drawing what they saw but the technology of the time had not produced the means of lifting them above the earth's surface where they could view it from the required angle.
2.3 The appearance of the vertical view in contour lines and hachures.

Contours may have been used as early as 1584 by the geometer Pieter Bruinss to outline the channel of Het Spaarne River in Holland (de Dainville, 1970, p. 392). While subsequently used to record submarine landforms, contours were not immediately applied to dry-land representation and it was the hachure, developed by Colonel Lehmann, an Austrian army officer, that was first widely used to accurately portray terrain (Robinson and Sale, 1969, p. 174). In this technique, by drawing the lines close together following the direction of greatest slope, a map was produced which appeared shaded according to the principle "the steeper the darker". In other words, the land looked as though it had been lighted directly from above (fig. 6).

The greater significance of the surveys undertaken by Col. Lehmann is not the use of hachures but the fact that the shape of the land was probably being recorded for the very first time. The start of the nineteenth century was a time of military activity, particularly in the Austro-Hungarian Empire, and the military establishment realized the usefulness of a vertical view of the landscape. The far sides of mountains were frequently more important
Fig. 6. Hachures according to Lehmann (above) and Dufour.
tactically than the near side that had been shown exclusively on earlier maps. The mountain ranges that had been depicted from only one side could hide armies behind the other. As a result of Lehmann's surveying, military commanders gained the privilege of seeing precisely what the battlefield looked like from above.

Thirty years after Lehmann's introduction of the technique, the Swiss cartographer Dufour applied hachures to a series of topographic maps (Robinson and Sale, p. 175). Unlike the earlier system, hachures on the Dufour maps varied in thickness with compass orientation in addition to steepness and gave the impression of side lighting. While the Dufour system is less precise (in that a sun slope does not look like a shade slope of the very same steepness) it does give a more easily interpreted terrain impression than does the Lehmann technique (fig. 6).

2.4 Introduction of relief shading through lithography.

Throughout most of the history of art, painters have depicted the third dimension by shading, either by assuming the object is illuminated by a particular light source and darkening the side of the mass that falls away from that source, or by highlighting the planes of the mass that lie perpendicular to the line of sight of the
viewer. These are the same principles that govern the visual effectiveness of the Lehmann and Dufour hachures. Until the invention of lithography at the end of the eighteenth century, however, there was no way to transfer this shading to a mass produced series of maps.

For at least a hundred years cartographic artists hand-shaded each individual map. After the popularization of lithography around 1850 by the American printers Currier and Ives, the shading was done on a lithographic stone and applied to paper as a base for other printing -- usually engraved line work and lettering. Technology had caught up with hand painting and the mountains that had always existed in the minds of the cartographic artists could now be translated onto lithographic limestone and printed on paper.

Just before the turn of the twentieth century, photolithography -- a process that mechanized the lithographic principle -- freed the artist from manually drawing the terrain on limestone in reverse. Photolithography allowed anything that could be photographed to be printed on paper. Now those mountains that existed in the artist's minds could be printed in whatever way the artist imagined them, with the most delicate of shading and in full natural colors.
Throughout the history of mountains on maps new methods have been more a result of incidental technological breakthroughs than a response to a demand for better maps. If inventors had sought ways to make better maps when they were needed, we would have had many more novel ways of making maps long ago. The inventions that enabled new methods of landform representation were from fields far removed from geographical cartography. Geography seems to be the only academic discipline that feels a need to represent the three dimensional surface pictorially. Even architecture, that bridge between fine art and engineering, has not produced a body of rendering technique for the depiction of the surface which is the foundation for most of its work.

2.5 Overview.

As the conclusion of a chapter on the history of mountain depiction on maps, it might be a good idea to organize this topic into main traditions and techniques that have accumulated to make up the contemporary cartographer's repertoire.

The progression from the ancient profile of hills to the map's undistorted planimetric view is one of a change in perspective; a change in the relationship of the forms
as they exist to the way they appear. Consider a block of transparent plastic that is a model of a section of the earth's surface. Directly under the peak of each mountain, on the bottom of the block, there is a point which can be seen from above. Anyone looking at any side of the block would get a distorted view. Objects or spaces farther from the viewer are perceived to be smaller than those up close to him, and the bases of the mountains are farther away than the peaks. So, in a vertical view of that transparent piece of land, the points on the base plane that we would expect exactly under the peaks are seen displaced toward the center of the base plane of the block. This is known as central perspective because distortion is equal in concentric zones around the center of the map.

The alternative to central perspective would be the planimetrically correct view which we see in most modern maps. Such a map is said to employ parallel perspective because, instead of the peaks being displaced radially away from their bases on the bottom of the block, they are all lifted perpendicularly from that plane, or parallel to one another. On maps, the central and parallel perspective can be seen in combination with either oblique or vertical views to offer four possible combinations.
Maps from which we hope to take measurements must be vertical views drawn in parallel perspective. The scale from mountaintop to mountaintop will be the same as the scale in the valleys. An aerial photograph can be either vertical or oblique, but it always has central perspective. An oblique view with parallel perspective can be seen in many kinds of block diagrams -- or on Dr. Oberlander's vertical profile maps (fig. 2). Parallel perspective is never seen in nature but is a depiction of the world as it exists; central perspective is the view of the world that is seen by everyone but doesn't really exist at all (fig. 7)

Historically, the three systematic methods for the representation of the earth surface by line pattern (profile, contour, and hachure) were invented at widely different times. None could be said to be the direct result of the discovery of any of the others; their inventions were solitary events. Coincidently, the three line patterns are all geometrically the same as the surface expression of the three axial planes of a solid. The profile is the result of movement on a horizontal plane, the contour is the expression of vertical movement, and the hachure is the expression of torsional movement. Since these represent all of the axial planes of the form, their lineal expressions also represent the only possible surface
The three regular line patterns and four viewpoints.
patterns (fig. 7).

The form of mountains on maps thus far seems to be a product of chance rather than design. Before a more organized attack on the problems of terrain representation can begin, some attention must be given to what makes people perceive three dimensions and also to the technology that allows the illusion of three dimensions to be duplicated on two-dimensional paper.
CHAPTER 3
PERCEPTION OF THREE DIMENSIONS AND ITS REPRODUCTION ON A TWO DIMENSIONAL SURFACE

3.1 Psychovisual cues to the perception of depth.

The immense and immediate popularity of the nineteenth century parlor stereoscope led its inventor, Oliver Wendell Holmes, to write that one no longer needed "...to contemplate with dismay the eventual destruction of the great architectural works since their solid corporeity could be preserved for all time on slides" (Ittelson, 1960, p. 111). To many, the Victorian device had captured the very essence of the real world and stereopsis came to be considered both necessary and sufficient for depth perception.

Scientific terrain representation is based on the fact that stereopsis is not necessary for the perception of depth in the real world. Stereopsis is the effect of depth normally achieved by humans and other animals with overlapping binocular vision. It is best demonstrated when isolated in a stereoscope, a device for viewing paired photographs that have been taken of the same object from different viewpoints. This stereopsis is one of the most
obvious of the visual clues to three dimensionality, but it is only one of many.

Stereopsis is one of four primary "cues" to depth (fig. 8) (to use the psychologist's term). Two of these cues occur within the musculature of the eye, and two within the mind of the perceiver. The muscular cues are "accommodation" and "convergence". Accommodation is the change in the shape of the lens of the eye in order to focus on objects of different distance from the viewer. The change in the curvature of the eye's lens is accomplished by voluntary muscles within the eye and the viewer becomes aware of the difference when he controls the expansion and contraction of the muscles. Convergence describes the rotation of the eyes to follow an approaching object. The viewer can control and feel the pull of the muscles as they turn both eyes inward to follow an approaching object and relax to follow its departure.

The two primary cues of depth that occur in the mind of the viewer are "binocular parallax", the effect that produces stereopsis, and "movement parallax". Movement parallax is the apparent differential motion of objects near and far, when either the head of the viewer or the object are in motion. Familiar objects seen from a moving car are a good example. Objects near at hand, such as a
ACCOMODATION CUE

The muscular effort necessary to flatten the normally curved lens can be perceived by the viewer.

CONVERGENCE CUE

Rotation through about 20° is sufficient to point eyes at objects from infinity to about 5 inches. About 5 inches being the nearest the human eye can focus in bright daylight. The muscular pull necessary to rotate the eye can be perceived by the viewer.

BINOCULAR STEREOPSIS CUE

The left eye sees the man to the right of the tree and the right eye sees the man to the left. The discrepancy between these two retinal images is interpreted by the viewer as depth: the man in front of the tree.

MOVEMENT PARALLAX CUE

The smaller the angle subtended by the lines of sight from the two viewpoints to an object, the more distant that object appears to be.

Fig. 8. "Primary" cues contributing to depth perception.
roadside fence, seem to speed by, distant buildings pass the car more slowly, and far mountains seem to move hardly at all.

Movement parallax experiments involving infant animals including humans, without binocular vision, (one eye covered) show that stereopsis is not necessary for the perception of a depth and suggest that to a small degree, depth discrimination is innate (Walk and Gibson, 1961). Human infants are able to perceive volume visually by the time they are two months old. (Fantz, 1963, in Kidd and Rivoire, 1966). Reinforced by sense of touch, visual volume in infants with one eye covered was as great by six months of age as in infants using both eyes. In other words, prior to a few months of age, infants rely on primary cues of depth, but rapidly acquire enough experience with the world to begin to use certain "alternative cues".

Alternative cues of depth are derived from human experience with the primary cues furnished to them by their movement through the real world. The first of the cues described are largely of doubtful use to cartographers, even though they can readily be simulated on paper and frequently are used by artists. With the exception of color, (which is outside the limits of this paper), they all require distortions of size or relative position that
would conflict with scale and accurate placement of features on a map.

3.2 Depth cues based on sensory experience.

Alternative cues, like the primary cues, are established early in infancy and are based on repeated experience with the sense of touch (fig. 9). Accommodation and convergence, and the alternative cue of increased size would all be learned, for example, when an active infant's hand touched his face. The significance of alternative cues is that they are external to the person and can be manufactured deliberately to suggest depth where none exists. The change in size of the baby's hand as he advances and withdraws it from his face is an important cue. Under experimental conditions, if a large object is placed next to a smaller but otherwise similar one, respondents usually report that the larger object is closer to them. Beyond size, other cues suggested by Weintraub and Walker (1966) are:

**Partial overlap**, in which an overlapping object is reported to appear closer than that which is partly covered. Similarly, an object which casts a shadow appears closer than that on which the shadow is cast.

**Linear perspective** is dependent upon the fact that
SIZE CUE
Among similar objects, the larger appear closer and the smaller more distant.

LINEAR PERSPECTIVE
Linear perspective is the most familiar graphic application of the size and/or overlap cues, and is based on a system of lines radiating from either one or two vanishing points.

OVERLAP CUE
An object overlapping another appears closer than that which is overlapped, even though the far one may be larger.

AERIAL/DETAIL PERSPECTIVE
Loss of detail and reduction in density of tone suggest distance.

Fig. 9. "Alternative" cues to depth perception.
distant objects appear smaller. The cue is most familiar in the apparent convergence of railroad tracks and the shrinking height of a line of telephone poles.

**Color.** It has been observed by artists, but only slightly verified by experiment, that cool colors (e.g. blue or green) tend to recede visually into the background, while warm colors, like red and yellow, appear closer - in relation to a neutral background (Leventhal, 1953, in Ittelson, 1960). Smith found that, when placed against a colored background, the more the color approximated the background, the farther it appeared to recede (unpublished, cited in Ittelson).

The four remaining alternative cues have all been used more or less successfully by cartographers. The last cue is basic to almost all terrain representation, even to contours and profiles.

Two kinds of perspective, in addition to the previously mentioned linear type, do not distort space. They are "aerial perspective" and "detail perspective". Both these cues are closely related to other of the alternative cues, but should be considered separately because of their importance to graphic arts. Aerial perspective appears more frequently in color but can be seen in black and white also. As used by the artist or mapmaker, it is an attempt
to depict the atmosphere as well as the land. The blue or purple cast to distant mountains is an illustration of the effect of aerial perspective. In this case the addition of an ambient hue, the blue haze of the atmosphere, creates the sensation of great distance in the mind of the viewer. The closer the distant object resembles in color the ambient light, the farther away it appears to be. In black and white, the addition of a light gray tone creates the same impression.

In black and white reproduction, aerial perspective looks very similar to what is called detail perspective. To create its illusion, detail perspective is dependent on linear perspective in that it uses the diminishing size of details in the landscape's distance. In optical terms, as any particular detail in a landscape moves farther away, it appears to get smaller. At a certain apparent size the angle subtended by the detail, on the retina of the viewer, becomes smaller than the receptor cell in the eye and the detail disappears. Only the gross land features are represented in the far distance because the smaller features have vanished. In certain of his Alpine maps, the Swiss cartographer Eduard Imhof has added a thin gray tone to the lower elevations. He has described it as a simulation of air perspective but it serves to accomplish
both aerial and detail perspective since it reduces contrast to the point where fine detail is also lost (Imhof, 1959, p. 27). His high mountaintops remain clear and sharp to heighten the illusion. The American cartographer and geologist Hal Shelton uses aerial and detail perspective very effectively for oblique landform representation.

3.3 The use of shadow as a depth cue.

This discussion of the effect of two types of shadow concludes the description of the depth cues (fig. 10).

"Cast shadow" recalls the overlap depth cue in which an object casting a shadow appears closer than the surface upon which its shadow is cast. The shape of a cast shadow serves as a clue to the shape of objects which can be seen from only one angle. Applications of this knowledge range from casual use in our daily routine to the highly sophisticated photo-interpretation techniques used for terrestrial and lunar vertical photographs.

While we can use the shadows cast from ambiguous objects to learn more about them, their application in landform representation generally detracts from the clear appreciation of the forms represented. For instance, a serrated shadow cast by a ridge could be interpreted as a result of either a serrated ridge or of an uneven surface
Fig. 10. Actual lighting effects on a false landscape of wrinkled paper. At A is the most desirable lighting arrangement, with oblique northwest lighting and attached shadow. Nearly horizontal areas are light gray, redding to dark gray as the slope increases on the shadow side and toward white as the slope increases on the lighted side. Changes from the lighted area to the shaded area occur where they should, for instance in the valley bottom to the right of the main ridge. In figure B, shadow cast from the main ridge continues up the valley side toward the next ridge, obscuring features in the valley bottom and offsetting its apparent lowest point to the right. Figure C shows the effect of lighting from directly overhead. Difference between high and low points is not obvious; shading is strictly according to the principle: "the steeper the darker".
Fig. 11. Principles behind shaded relief. A sphere contains all the orientations of slope that can be found on a hillside and therefore can be used as a model for the analysis of terrain shading. If a sphere is lighted from the northwest and from 45° above the horizontal, (as in A) we have a figure with the appearance of B, with one brightly lighted pole as shown, and an antipodal point which cannot be seen but which is in full shadow. Since the pole that is shown contains 0 percent black, and the opposite pole is 100 percent black, it should be easy to conceive the zone halfway between, along the equator, as 50 percent black. A view of the hemisphere facing northeast would look like the view at C. Since the horizontal surface is at the same angle relative to the light as the summit of the hemisphere, it can be also considered to be 25 percent black. This figure can be generalized into D for comparison with the diagrams to the right. In order to separate the hill mass from the flat land, the horizontal surface is often left blank, with no tone, as in the diagram at E. This treatment of hillshading is often seen on maps, particularly where there is lettering printed across the flat areas, and can be seen in this thesis in figures 21 and 23. An alternative technique is to consider the light source to be horizontal, thus rendering the steepest slopes on the light side as white, and the steepest slopes on the shadow side as black, as at F. This is frequently seen on maps since the lessened contrast between the flat land and the hill looks more natural, and can be seen in this thesis in figure 24.
upon which the shadow was cast. Only the American cartographer Richard E. Harrison has used cast shadow to any degree in terrain mapping. Harrison's great skill in modeling the forms by light and shadow has probably saved him the embarrassment of misinterpretation. Judging by negative evidence, we can conclude that terrain mappers generally seem to ignore cast shadows.

The remaining alternative cue of volume is "attached shadow". An attached shadow is on the surface of the object itself and is the single most important of all clues to the shape of the object.

Attached shadow, which will be referred to now simply as shadow for the sake of brevity, is present to some degree in all methods of terrain representation. It is even unintentionally present in profiles and contours. Shadow has been used in either of two ways throughout its history as a graphic technique -- oblique or vertical. Shadow from oblique lighting is currently in fashion, but when first practiced shadow as a result of vertical light was used. Probably part of the popularity of vertical lighting was because its appearance is inherent in so many mechanical techniques. As slope increases, the lines on contour maps become closer together, giving the same darkening effect as Lehmann's hachures. A similar situation results from the
use of profiles.

Although artists had sidelined their landscapes for years, the first shaded maps were drawn as though lighted from above, possibly because that was the easiest way to draw shading from a contour base. Opinions remained divided on whether to light from the side or from above until this century. Some U. S. Government maps remained shaded from zenithal light into the early 1900's while others exhibited oblique lighting before then.

Sometime in the history of landform representation it was decided that if shading were applied to hills as though they were being lighted from the side, that side should be the northwest. This convention reflects the majority of (right handed) people's predilection for having reading light come from above and from the left. Assuming the traditional northward orientation of the top of maps in a reading posture, this light would therefore come from the map's northwest. Most of the inhabitants of the earth, however, never see the sun in the northwest part of the sky. The usually contrary cartographer, Richard E. Harrison, has had many maps published with the light source in the southern quadrants. (South, incidentally, is not always at the bottom of Harrison's maps (Harrison, p. 34).) Professor Imhof regularly switches the light source within
the same map if it serves to heighten the illusion of reality. While a particular ridge might be very well defined by the northwest light source in one part of the map, another part of the same ridge may not show because it curves directly into the light.

Professor Imhof's variation of the direction of light hints at one of the many problems which arise from the use of obliquely shaded relief. While in contemporary practice hachures have degenerated from the carefully calculated Lehmann and Dufour maps of the nineteenth century into much less structured forms, and contour and profile maps are currently being automated, the shaded types of maps are getting more and more complicated as each maker tries to outdo the others in realism. In other words, while some of the methods of land surface representation are becoming more abstract and simplified, the tendency in shaded maps is toward more realistic, pictorial rendition. A possible end to this trend will be the extinction of such maps because they are too difficult to draw and reproduce.

The importance of shaded relief as a depth cue suggests that it would be to cartography's advantage to simplify, mechanize, or otherwise expedite the production of that means of terrain representation.
In relation to the above subject, William H. Ittelson (1960, p. 102) has said "...shading is perhaps the most important tool the artist has for conveying the three dimensional character of objects and it is probably an equally important everyday cue as well." John C. Sherman (1964, p. 22) reinforces this view with his statement that "...experience with a wide range of age groups suggests that obliquely lighted shadow simulation (shaded relief) is almost always spontaneously recognized...."

3.4 The role of technology in the reproduction of shaded relief.

The cartographer's job is to become familiar with the visual depth cues which current technology allows to be printed on paper, and to present them to the reader on the map.

While the following advice is intended for workers in the field of commercial design, it can be applied equally to cartographers, since their field should abide by the same standards: "To attempt the practice of graphic design without a good working knowledge of the basic principles of photography is rather like attempting to be a doctor without any training in anatomy: just possible but not to be recommended to either the practitioner or to his prospective client" (Garland, p. c25). The same design
consultant has also pointed out with regard to printing technology, that "...technical advances tend to simplify the input operations which devolve on the graphic designer and his client, so that he is allowed greater flexibility in the kind of material which can be effectively processed for printing. Neither the complexity nor the traditional cageyness of the skilled printer need deter the designer from acquiring an understanding of the basic printing methods around which so many techniques and so much mumbo-jumbo has been erected" (Garland, p. D45). (Of course if money were as much the reward in cartography as it is in commercial design, we would undoubtedly see a vast increase in the speed with which innovations in technology are applied in cartography).

The map reaches the printed page only through the darkroom because press plates for modern printing methods are made photographically. Since the copy is to be photographed anyway, economy dictates that full use should be made of the darkroom time and effort.

Some methods of representation open to the cartographer have been explained elsewhere in this thesis; the fundamentals of the photographic process, including the reproduction of line art and copy for screening, are described here.
When map material is photographed, the relationship of black line on white paper is reversed and the image is fixed on film. This film negative is used either to make a printing press plate for photolithography or photo-engraving (the processes are very similar from the photographer's point of view) or is contacted to light sensitive paper to make a print. During the process of making the negative and the plate or proof (the proof is a print made to check for mistakes on the negative before the more expensive plate is made), several manipulations can change the appearance of the final product (fig. 12). They are described as follows:

**Size.** The photographer can either enlarge or reduce the size of the image in the camera.

**Contrast.** In addition to making a negative from the positive copy, the photographer can produce a positive on film from the negative, and, if needed, a negative on paper.

**Subtraction.** If there is something that the cartographer wants taken off the negative, he can have it painted over with opaque paint and it will not show on the print.

**Addition.** Two or more negatives can be combined on one print. The cartographer can prepare lines on one piece of copy, lettering on another, and area patterns on a third,
Fig. 12. Some darkroom techniques for manipulation of copy.
and then have them photographed and assembled together in register for the print.

**Tone.** The cartographer often uses adhesive-backed patterns for the identification of areal characteristics on the map. The effect of tone can be achieved better at the printmaking stage by the use of screens, which are themselves negatives of very fine dot or line patterns (fig. 13).

**Halftone.** Discussion so far has applied to the production of copy that is solid black -- line, or lettering, or whatever -- on white paper. Customarily, continuous tone, such as shaded terrain, requires a special technique called halftoning (fig. 13).

No type of printing process which prints in commercial quantities can do anything other than lay down solid ink on paper. The press cannot dilute the ink or print it thinner so it will look gray. The effect of continuously graded tone can be simulated by breaking up the light as it is projected onto the film into tiny dots which will vary in size depending on the brightness of the image. On the film negative, the brighter the light, the larger the dots. When the film is printed or made into a plate, the dots on the film become light areas. The larger the dots were on the negative the lighter the appearance of the resulting
A section of laminated plastic halftone screen seen from underneath. In order for them to show, the pyramids of clear plastic projecting from the top surface of the screen have been tinted to differentiate them from the rest of the laminate, which is normally pigmented red. The halftone screen, the photographic negative, and the press plate or print are contacted together as shown below.

A halftone screen mechanically changes the various tones of gray of the negative to dots of different size on the press plate or print.

Fig. 13. The preparation of tone and halftone.
The device that causes this effect is called a halftone screen. Even though how the process works need not be explained here, some mention must be made of halftone's deficiencies (figs. 13 and 14). Since the screen covers the film in the camera, dots appear everywhere on the print. Areas that had been white on the copy are very light tone on the print, thus reducing contrast. Unless the line and lettering elements are prepared as a separate negative, none of the very fine parts of these elements will be maintained after halftoning. Usually fine lines degenerate into dotted lines and edges of solid areas become serrated because they are actually made up of no more than a coalescence of dot images.

The two types of halftone screens are very expensive (fig. 14). Plastic screens that are placed in contact with the film cost between 20 and 300 dollars, depending on size and coarseness of the screen. The cheapest one is a "65 line screen" (having 65 rows of dots per inch) of eight by ten inch size. The typical screen that is used for publication of photographs or continuous tone originals in journals is about 100 to 133 line. The higher priced screen is 200 line and two or three feet on a side. Engraved glass screens, which are not placed in contact with
SCREEN, CONTACT
Magenta or Gray, Regular or Elliptical Dot, 65, 70, 85, 100, 120, 133, 150, 175, 200 lines per inch, Positive or Negative. Not all combinations available in all sizes. Check for availability.

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Fig. 14. Above is a portion of a halftone illustration enlarged 300 percent. The dot structure can be clearly seen, as can the fact that even the highlights contain a very light pattern of dots, and the darkest shadows have some white showing. Below is an excerpt from Read & Co. catalog of graphic arts supplies showing prices of halftone contact screens. These prices can be compared with the $5.95 price for parallel line screens 24 x 24 inches which would be suitable for a process called posterization, which will be discussed in Chapter 4.
the film, are more durable but cost more than one thousand dollars each. The procedure for their use is more involved since they must be placed accurately within a certain plane in the camera's optical system. Their location varies with the size and reduction desired in the copy.

Thus it appears that shaded terrain representation, if it is not discouraged by preparation complexities as it passes across the drafting table, will be stymied in the darkroom down the hall. But cartographic literature does not mention several additional ways for the reproduction of shaded relief, none of which is beyond the capabilities of the average in-house cartographic lab or darkroom. These methods will be explained in the next chapter.
CHAPTER 4
THE APPLICATION OF PHOTOGRAPHY
TO TERRAIN REPRESENTATION

4.1 An alternative to "artistic talent" in relief shading.

Chapter 3 suggested that oblique shading is the strongest means for the simulation of three-dimensionality on paper, yet hardest to produce. As well as demanding the most effort in the interpretation of source data and a somewhat intuitive transformation of contour lines into the play of light and shadow, taxing the draftsman's expertise with different media, it is also expensive and difficult to reproduce. If treated by traditional processes of production and reproduction, shaded relief seems to be out of the question for use on maps that are supposed to be inexpensive and quick to make. Rather than abandon terrain shading because it appears too hard to do, a little effort should be spent on trying to make it easier.

While other methods such as illuminated contours and inclined profiles are practiced in college cartography classes, shading is usually considered to require too much "talent". But the fact that something looks artistic,
does not mean that one must be artistic to do it. For something as practical as a map, the art is in the way it is done, not in the product. While the non-artist may chart his concept on paper by means of a flow diagram or recipe, the artist seemingly does it easily in his head. They both are doing essentially the same thing and the cartographer can take solace in the fact that the artist probably will have a less precise idea of what his map means when it is completed.

The Martin J. Weber art studio in New York City specializes in using more of the potentials of photographic processes than most other commercial art establishments. Among several techniques known collectively as "the Weber Process" is "posterization" (Strauss, 1958, p. 4:34f).

As practiced by Mr. Weber, posterization simplifies the full range of grays found in the conventional black and white photograph into three or four even tones. This is done photographically by consolidating the darkest tones into one and representing them with black; the lightest tones become generalized into white, and middle tones become one or two shades of gray. Since this process results in a simple, bold, high contrast translation of the photograph, it looks like a poster -- hence the name.
As the Weber Studio practices posterization, it cannot be considered a simplification of the halftone process of reproduction. The product is a genuine photographic print (although with only a few tones) and must be halftoned in order to be printed on a press. The process is an addition of some steps to halftoning, and not a substitute for it.

By application of manipulative techniques explained in Chapter 3 (illustrated in figs. 12 and 13), the addition of two or more negatives to make one print, and screening to produce tone, it is possible to make a printable posterized picture directly from a photograph or other continuous-tone original without the necessity for halftoning. It can then be a valid substitute for the existing type of posterization.

4.2 The posterization technique.

Posterization may be done in the following manner, using the portrait in figures 15 and 16 as an example: This is a continuous-tone original which has been photographed with high contrast film, the kind usually used for the reproduction of line copy. For this portrait, three exposures were made; one at a speed normal for line copy of the same size, one twice that exposure, and one four times
Fig. 15. A "posterized" portrait. The effect of three negatives can be clearly seen in this enlargement due to the coarseness of the line screen used. This picture was made from a wallet-size photo and involved photographing the original three times: once at "normal" exposure (normal for the degree of enlargement, lighting, and sensitivity of the film); once again at twice the normal exposure (either twice the time or twice the lens opening); and a third time at four times the exposure. Each increase in exposure enlarged the area on the film that became opaque when developed. A diagram of the process appears in the following figure.
Fig. 16. The process of posterization. The negatives are all exposed on the same print, with the screen oriented appropriately. In the case of this portrait, the negative from the longest exposure – hence greatest black area – has been printed without a screen to enhance contrast.
as long. The first negative is clear in all the areas but the brightest highlights and the background, the third negative is clear only where the deepest shadows had been, and the second negative is in-between. These negatives were then placed in register and a print made. A press plate could just as well have been made from the negatives.

The negatives were then screened. A screen for very light tone was placed under the first negative and exposed, then that negative was removed and the second put in its place. If the print had been developed at that stage a light tone would have covered all but the highlights and the background. The second negative was exposed with the same screen beneath it as had been under the first. A print made at that point would have shown the addition of a darker pattern to the middle tones by the addition of the two screens. The third negative was exposed with no screen and added the black of the shadows and the girl's dark hair.

This experiment could not have been completed successfully without the use of a special screen. If a dot screen had been used, the addition of the two images by the second exposure would have resulted in the familiar interference pattern known as a "moire'. This pattern is always present, although it can be minimized, where one regular dot pattern
is laid over another. This would have given the darker of the two middle tones a very peculiar and bold appearance which would have destroyed the illusion of continuous tonal gradation in the resulting print. The special screen was made for this study by photographing a sheet of lined "Zipatone" pattern. The lines were chosen as they were to appear on the final print; the pattern could have been enlarged or reduced if desired. For the two exposures of the tonal areas the lines were used at right angles to one another. If three middle tones had been desired another negative would have been made and the screens oriented 60 degrees apart.

4.3 Psychovisual justification for the adequacy of posterized terrain depiction.

Why the abstract posterized image is sufficient for terrain depiction can be explained by experimental psychology. Perception studies in cartographic symbology have shown that when symbols are taken out of series or context it is very hard for their place in that series to be judged. This was discussed by Meihoefer (1969) with regard to circle size, by Ekman, Lindman, and William-Olsen (1961) with respect to volume symbols, and by Jenks and Knos (1961) in relation to a graded series of shading patterns. These studies suggest that, given a minimal complexity in
the pattern or appearance of equal tones (as in posterization) the viewers do not perceive, and therefore do not care, that the tone they see does not model the figure at all. Apparently a perceptual "set" triggers the recognition of the form before one realizes that the depth cues are not all present. Gregory (1967) experienced evidence of the same set (pre-conditioned response) during experiments with illusion figures in which subjects "recognized" shapes that were not there but which had been suggested by certain lines and angles. Possibly, after a certain amount of experience with the real world, people build up a sort of vocabulary of familiar forms. Eventually it takes only a suggestion to trigger recognition of these forms whereas it might take many depth cues for them to perceive volume in a shape that had never been seen before.

The moon photos which flood the media whenever a spacecraft nears that heavenly body have introduced a proof of perceptual set with regard to appreciation of land features. Moon craters look like moon craters to even the least sophisticated television watcher, no matter what the light source. (Reversal of light source is traditionally thought to reverse the land feature; hills become holes and valleys become ridges).
4.4 Application of posterization to terrain depiction.

The application of posterization as an alternative to hand shaded relief presents another problem, for the same reason that aerial photographs are undesirable for depicting land forms from above. Although surface patterns from color or clothing do not conflict in a portrait of a person, they do conflict with the perception of volume in the representation of terrain. Relief must be depicted solely through the modulations of light and shadow.

A near-precedent exists for posterization in cartography. Certain series of British Ordnance Survey maps use photographic reproductions of terrain models as a base. It was found that the normally gray terrain map produced by photography could have its three dimensional effect enhanced by the application of an overprint to the areas of darkest shadows. This was done by preparing another halftone negative in the same manner as the first but with greater exposure, so that a print from that negative would show only the small areas of darkest shadow. This negative was then printed in purple over the gray halftone terrain base. This is not actual posterization. The result is halftone (not flat tone) but the logic of the system is similar even if the mechanics are not. Of course, the
necessity for preparing terrain models removes this method from contention as an economical means of landform representation.

Further experiments with posterization have shown that for application to landform representation, the effect can be produced without having to make a toral original; it can be accomplished directly from a contour map in the following manner:

After examining a half dozen posterized prints, it becomes fairly easy to predict where the zones of shade will occur when looking at a photograph as potential copy (figs. 17 and 18). Anyone familiar enough with topographic maps to see ridges and valley bottoms and their relative sizes can learn to predict where the zones would occur if the map were a finished rendering.

A sheet is furnished to the photographer with an area of uniform slope represented as a solid patch of black or red. The photographer then prepares a negative which will have a window where the solid color was. (Figures 19 through 23 illustrate the posterization process and should be referred to along with the following description).

For terrain representation, a negative is made for each tone desired -- a very light tone for areas of gentle slope, another for steeper slopes and a third for the
Fig. 17. More examples of posterization.
Original posterized illustration showing form of mountains in a wrinkled paper landscape.

Key drawing showing tone areas based on angular relationship between slope units and hypothetical angle of illumination.

Posterized illustration based on above key drawing. An oblique form of shaded relief, this depiction was made from the key drawing's ridge and valley lines alone.

Fig. 18. The transition from posterization as a copying method to posterization as a creative tool.
steepest. In this instance, slope refers to the orientation with respect to light, as well as to the horizontal (as in fig. 11). The light source can be selected by the cartographer to suit the grain of the landscape. This technique requires some familiarity with contour lines that shading does but no rendering with brush or pencil. Illustrations for this thesis were drawn with a red nylon-tip pen. The red photographed as though it were black, yet remained transparent to reveal contour lines underneath the tracing.

The negatives for this posterization can be used to prepare a print on which to draw the other map elements, or instead may be exposed for a print or plate at the same time as the negatives for roads, boundaries, and lettering. The lines in the screening patterns used should be fine enough that they appear as a tone, to avoid the unpleasantly busy confusion of illuminated contours and profiles. The various screens used in the preparation of illustrations for this thesis appear slightly coarse because they were all homemade. Finer commercial screens are available at quite reasonable cost (fig. 14); a 20 percent, 100 line, parallel line screen is recommended.

Pinhas Yoeli has proposed a shading technique similar in derivation to posterization, in that the map is covered
with a fine grid of squares containing gray tones. The steeper the land, the darker the tone. In theory, a contour map would be scanned by machine and gray values selected square by square, based on orientation and density of contour lines. The technique is presumably automatable although presently there is no method for printing the squares (Yoeli, 1965 and 1966).

Posterization is similar both in spirit and appearance to "Impressionism", a popular movement in art during the latter part of the nineteenth century. Impressionist artists were stimulated in their work by the beginnings of experimentation into the nature of light and color, and frequently emulated photography to achieve certain effects. Impressionist paintings are characterized by the modeling of forms by light, sometimes in dots or dabs of paint, and thereby suggesting, rather than depicting solid forms.

Illustrations of posterization and the steps in its production will conclude this chapter. Chapter 5 describes a test of the posterization process by beginning cartography students and offers concluding remarks.
Fig. 19. Flow chart for posterized shaded relief.
Fig. 20. The original contour map with some of the main ridges overlain. The drafting of the following maps from this original leaned heavily on the overlay because the contour map was not very clear when seen through the tracing paper. More contrast or greater contour interval would have obviated the need for the ridge-line overlay.
Fig. 21. Posterized shaded relief of part of the Panamint Range, Death Valley, California. Base map used was USGS 1:250,000 Death Valley Quadrangle from the previous illustration. The terrain here has been greatly generalized and stylized by the cartographer. Drafting took about one and a half hours. Reduced 20 percent from original scale.
Fig. 22. The three pieces of copy used to make the mountain range in the previous illustration. At A is the copy used to produce the highlights. Flat land and land facing directly into the sun has been left white, with everything else in shadow. To the right of this copy is that which was used for the deepest shadow. Only the steep southeast slopes were colored on this copy. At B is the copy which was used to produce the shading for the main mass of the mountain. All slopes to the south or east of ridges were colored to give continuity to the main spurs. After a proof was made it was determined that the valley bottoms needed accentuation to tie them together; this was done with stream lines on the copy for the deepest shadow. Reduced 50 percent from original.
Fig. 23. Shaded relief is not usually an end in itself. Here some other information has been added to the mountain. The terrain has been depicted lightly enough that lettering and 50 percent gray roads can be easily seen. This was a test of the two types of screening to see if a moire was produced, and to see if the roads would be lost in the gray tone of the slopes.
Fig. 24. This is the first experiment with leaving the flat land in gray tone. The gray is desirable in some instances because it is easier to differentiate between highlighted slopes and flat ground. The gray flat land is also more logical if the light is assumed to be coming from a source about 45° above the horizon -- only the highlights on the slopes should appear white. The drawing took about two hours and was deliberately done roughly to test the effect of sloppy work. Some areas have suffered but parts of the San Gabriel mountains and the long ridge of the Santa Monicas came out fairly well. Drawn from USGS 1:250,000 Los Angeles Quadrangle, and reduced 15 percent from original scale.
CHAPTER 5

POSTERIZATION TESTED

5.1 A student test of posterized relief.

Posterization was tested by the fourteen members of a second-semester cartography class in the Geography Department at San Fernando Valley State College in the Spring of 1970. Although this was their second semester in cartography, none of the students had any previous training in landform representation and only one had ever tried it on his own. That student had experimented with the Robinson-Thrower inclined profile technique but had abandoned that exercise because he was frustrated by the ambiguities inherent in the profile construction process.

An introductory talk of about an hour and a half explained the development of the process of posterization. No attempt was made to teach the principles behind terrain representation in general, or relief shading in particular. From xerox copies of part of the USGS 1:250,000 Death Valley, California quadrangle, the students were asked to derive their own zones of shadow intensity and produce the copy necessary to make a posterized map. Previously, a
map of the same area had been made by the author using
three pieces of copy. The students were asked to try using
three also, but could make as many as they thought neces-
sary.

Of the fourteen examples produced in the darkroom from
the students' efforts, only one was of publishable quality
(fig. 25). Four more were well received by readers and
were deemed recognizable as mountains, but had minor
faults. An additional four were obviously mountains, but
only because they could have been little else; and the five
remaining were -- for one reason or another -- entirely
unacceptable.

The time they spent in drafting ranged from about four
hours down to less than two, with the more successful
appearing examples having taken longer. The time factor,
however, may be more a reflection of a student's work
habits than the demands of the process. The student with
a short attention span will become impatient and frus-
trated by not being able to see the product of his work
while he is doing it, and may not make the effort to do the
job right. The more meticulous student will spend too much
attention on details, and forget the purpose of the process
or the nature of a terrain base. The maps which took
longest uniformly showed too much detail at the expense of
Fig. 25. Part of the Panamint Range as depicted by a student in a cartography class. This was made using six pieces of copy as opposed to the three used in figure 21. Its author chose southwest lighting for this range, which conflicts with the normal reader's predisposition toward northwest light. The wavy line on the eastern margin of the range was an attempt to depict the alluvial fans in that area; neither the author nor the students were successful in attempts to depict such areas of comparatively low relief on the same map with high rugged mountains.
the larger forms.

Experience seemed to have little to do with the success of the individual experiments. While the person who did the very best job was the one previously mentioned who had tried the Robinson-Thrower method, the second best map was produced by a woman who, prior to the exercise, could not read a map with contour lines (fig. 26). Most of the others in the class were similarly inexpert.

Since this was an upper division course with some college seniors in it, it had been assumed that all of the students were thoroughly indoctrinated into the intricacies of contour line interpretation and would be able to picture -- in their mind's eye -- what the form should look like. This assumption proved to be fallacious. Many students could not tell ridges from canyons at all and needed coaching to recognize concave and convex slopes, summits and saddles, and differences in elevation.

After seeing the results of their work, every one of the students said he could do a better and faster job if given another chance. This is undoubtedly because they could not picture how their mountains would look until the darkroom processing had been finished. Once the finished product has been seen, the draftsman's curiosity may be satisfied and he can gain enough from that single experience
Fig. 26. Another student's attempt at depiction of the
Puna Mint Range. Unlike the rendition in the previous
figure, this is an example of mountains made by a student
inexperienced in contour line interpretation and terrain
representation. The very prominent ridgeline is a little
misleading since some of the high peaks are more insular
than they are represented. If shown in a map context,
with roads and other symbols and names overprinted, this
representation would probably be recognized as a mountain
by the average reader, despite its primitiveness.
that he does not need to see his mountains as he works. Once a few terrain maps have been made by this method, a draftsman should have no trouble in imagining how his depiction will look when finished.

5.2 Cautionary notes derived from the experiment.

The cartography class experience permitted the formulation of a set of directions, or a recipe, by which the process of posterization can be carried out from contour maps. Three steps are important: contour comprehension, location of key topographic features, and the stacking of overlays to approximate the appearance of the photographed map.

A person preparing copy for the darkroom must be familiar with the nature of contour lines. Forms which are most important in the process of posterization are ridges and valleys. Although precise orientation of slope is not necessary, the general shape is important. For instance, the darkest shadow in concave slopes is near the ridge, while convex slopes are shaded near the base. One premise of posterization is that only three or four tones are necessary to convey to the reader the impression of mass; when so few tones are used, attention need be paid only to relative shading within each part of the hill mass. This
means that although the tone on one slope might be the same as that on another part of the mountain the two slopes cannot be inferred to have the same angle. Accuracy is only relative to other parts of the same slope -- to the right or left and upslope or down. A reader cannot accurately relate two slope areas on far separate parts of the map, and will not assume that they are similar.

Drawing in the ridge and the valley lines on the contour base may be helpful before outlining the tone areas. Generally these lines will be more easily seen through the overlays as the map is being constructed. Care must be taken, however, to be sure that the ridge and valley lines do not become the only guides for the tone areas, as steepness and orientation of the slope units may vary without being reflected in these lines. Where there are no prominent ridges, the drainage network is often found to be pronounced and will therefore suffice for the same purpose.

Finally, for the draftsman who would like to see the mountain as he constructs it, the appearance of the final map can be approximated by stacking the overlays. This should be done in register, with the largest shadow area on the bottom and a cover sheet to lessen the intensity of the overlay on the top. If the overlays are made on translucent paper, the light gray tones produced by stacking
will give some indication of what the final product will look like. If pin registration is used, deficiencies can be corrected and viewed immediately by lifting and replacing the individual flaps.

5.3 Conclusions

Results of psychological testing suggest that shading is the most quickly and consistently recognized cue to the third dimension. But shaded relief on maps is considered by many cartographers to be so difficult to execute that they have invented several mechanical techniques, such as the use of profiles and illuminated contours, to circumvent what many feel is a necessity for innate artistic talent.

Rather than being an easy way to shaded relief, however, profiles and illuminated contours become something else altogether. The busy line patterns of both these techniques preclude the possibility of overprinting very much data. They never become shaded maps because they cannot escape their obvious coarse pattern of lines. Additionally, these techniques are often just as confusing and tedious to execute as hand shading. What has been needed is an easily completed process which results in the appearance of tone rather than lines. Shadows can be convincingly portrayed only with tone and only a tonal base
map allows dot and line patterns and printing to be easily read.

Examples from history show that techniques from fields other than cartography can often profitably be applied to cartographic problems. Too often this application has come many years after a process has become routine in another field. A technique from advertising art, called posterization, is one of probably many which can be used in cartographic terrain representation.

Experiments by students who were trying posterization for the first time confirmed that the process is relatively fast; drafting times for a journal-size base map took about two to four hours. At the end of this time, only a few of the images were recognizable as mountains, but all of the students said that they thought that they could have mastered posterized terrain representation on a second try. Their mistakes showed that none of their problems were conceptual ones and there is no doubt that most of the second maps would have been successes.

Aside from producing a finished base map, the posterization class was equally valuable for educational purposes. In posterizing from contour lines, the student must learn to perceive the third dimension from the lines on the map, without taking any great time thinking about it. Although
none were asked to try, it is likely that most of the
students would have been able to render relief by tradi-
tional hand shading with little trouble, because of their
experience with posterization.
REFERENCES CITED


