1986

**Mapping superimposed relief surfaces (SRS)**

Douglas R. Killerud

*The University of Montana*

Follow this and additional works at: https://scholarworks.umt.edu/etd

Let us know how access to this document benefits you.

**Recommended Citation**


https://scholarworks.umt.edu/etd/8359

This Thesis is brought to you for free and open access by the Graduate School at ScholarWorks at University of Montana. It has been accepted for inclusion in Graduate Student Theses, Dissertations, & Professional Papers by an authorized administrator of ScholarWorks at University of Montana. For more information, please contact scholarworks@mso.umt.edu.
MAPPING SUPERIMPOSED RELIEF SURFACES (SRS)

By

Douglas R. Killerud

B. S., University of Minnesota, 1979

Presented in partial fulfillment of the requirements

for the degree of

Master of Arts

University of Montana

1986

Approved by

[Signatures]

Chairman, Board of Examiners

[Signature]

Dean, Graduate School

[Signature]

Date

Feb. 27, 1986
The role of cartography as a discipline is to present the spatial data of reality in a comprehensible easily employed manner at reduced scale. An especially complex problem for the cartographer is the presentation of two or more superimposed surfaces each containing unique relief. The term superimposed relief surface (SRS) is used to identify this situation. The purpose of this thesis is to devise new methods of SRS mapping and to evaluate the effectiveness of these methods compared to one another and compared to two methods which already exist.

Development of a map classification system led to the construction of nine SRS maps. Each map covers the same area in north-central Montana with the earth surface and the Madison limestone geologic structure forming the SRS components. Problems encountered during construction were discussed.

An analysis of the effectiveness of each map was done by interviewing eight professionals. Questions were designed to solicit subjective responses regarding strengths, weaknesses, and other map attributes. A ranking procedure returned ordinal data with which maps could be rated against one another according to visual, metric, and combined criteria.

Results showed that the two SRS maps presently in use, the Hypsometric Contour and Structure Contour maps, were the most effective according to the criteria. The Perspective Stack and Hypsometric Perspective maps did a better than average job presenting an SRS for visual interpretation. The two Shaded Relief Contour maps were the least effective, both visually and metrically. The Multirod and Multirod Profile maps were rated poorly visually and only average metrically. The Profile Fence Diagram provided a satisfactory visual image and offered a limited amount of measurability to place it average in comparison to each of the maps.
# Table of Contents

**Abstract** .................................................. ii

**Table of Contents** .......................................... iii

**List of Figures** ........................................... v

**List of Tables** ............................................. vi

**List of Maps** ................................................ vii

**Acknowledgements** ........................................ viii

1. INTRODUCTION .............................................. 1
   1.1. The Superimposed Relief Surface .................. 2
   1.2. The Problem of SRS Representation ............... 4
   1.3. Methods ............................................. 5

2. DISCUSSION OF THE SRS EXAMPLE AREA ................. 9
   2.1. General Description of the Shelby Surface ....... 12
   2.2. General Description of the Madison Surface ..... 17

3. SRS MAP CONCEPTS AND CONSTRUCTION ................. 23
   3.1. Introduction ....................................... 23
   3.2. Terrain Representation: A Brief History ......... 23
   3.3. Map Classification ................................ 26
   3.4. Classification System Application ............... 34
   3.5. SRS Map Construction ............................. 36

4. ANALYSIS OF EFFECTIVENESS ............................. 77
   4.1. Map Interpretation ................................ 77
   4.2. Interview Background .............................. 79
   4.3. Interview Questions: Types and Breakdown ....... 81
   4.4. Interview Results ................................ 83
   4.5. Assigned Ranking Procedure ...................... 99
   4.6. Assigned Ranking Results ......................... 100
   4.7. Conclusions ....................................... 107

5. SUMMARY AND CONCLUSIONS ............................... 115
   5.1. Suggestions for Further Study .................... 118

Appendix A. RELIEF PRESENTATION TECHNIQUES .......... 120
   A.1. Planimetric ........................................ 120
   A.2. Cross-Sections ..................................... 127
   A.3. Perspective ......................................... 128
   A.4. Photography ......................................... 129
   A.5. Other .............................................. 130
### List of Figures

<table>
<thead>
<tr>
<th>Figure 2-1:</th>
<th>ISOPACH MAP OF THE MADISON LIMESTONE GROUP</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 2-2:</td>
<td>LOCATION MAP OF THE SRS EXAMPLE AREA</td>
<td>13</td>
</tr>
<tr>
<td>Figure 2-3:</td>
<td>TOPOGRAPHY OF THE SHELBY SURFACE</td>
<td>14</td>
</tr>
<tr>
<td>Figure 2-4:</td>
<td>TOPOGRAPHY OF THE MADISON SURFACE</td>
<td>20</td>
</tr>
<tr>
<td>Figure 3-1:</td>
<td>MAP CLASSIFICATION SYSTEM</td>
<td>28</td>
</tr>
<tr>
<td>Figure 3-2:</td>
<td>ASPEX PLOT OF THE MADISON SURFACE</td>
<td>40</td>
</tr>
<tr>
<td>Figure 3-3:</td>
<td>ASPEX PLOT OF THE SHELBY SURFACE</td>
<td>41</td>
</tr>
<tr>
<td>Figure 3-4:</td>
<td>SIMPLE CORRELATION DIAGRAM</td>
<td>61</td>
</tr>
<tr>
<td>Figure 3-5:</td>
<td>TELEVISION SET UP</td>
<td>75</td>
</tr>
<tr>
<td>Figure 4-1:</td>
<td>POSITIVE RESPONSES TO QUESTIONS 1, 2, 3, 4, 7</td>
<td>85</td>
</tr>
</tbody>
</table>
List of Tables

Table 2-1: SEDIMENTS EXPOSED IN THE SWEETGRASS HILLS 18
Table 3-1: SRS MAPS USED IN ANALYSIS 35
Table 4-1: POSITIVE RESPONSES TO QUESTION 1 86
Table 4-2: POSITIVE RESPONSES TO QUESTION 2 86
Table 4-3: POSITIVE RESPONSES TO QUESTION 3 88
Table 4-4: POSITIVE RESPONSES TO QUESTION 4 89
Table 4-5: POSITIVE RESPONSES TO QUESTION 7 90
Table 4-6: RANKING DERIVED FROM QUESTIONS 1, 2, 3, 4, AND 7 92
Table 4-7: FREQUENCY TABLE OF ASSIGNED VISUAL RANKS 101
Table 4-8: FREQUENCY TABLE OF ASSIGNED METRIC RANKS 102
Table 4-9: FREQUENCY TABLE OF COMBINED ASSIGNED RANKINGS 103
Table 4-10: SUMMARY OF ASSIGNED RANKINGS 104
Table 4-11: FINAL T TEST RANKINGS 107
Table 4-12: SUMMARY OF RANKING RESULTS 108
### List of Maps

<table>
<thead>
<tr>
<th>Map 3-1</th>
<th>PERSPECTIVE STACK MAP (PSM)</th>
<th>44</th>
</tr>
</thead>
<tbody>
<tr>
<td>Map 3-2</td>
<td>MULTIROD MAP (MRM)</td>
<td>47</td>
</tr>
<tr>
<td>Map 3-3</td>
<td>MULTIROD PROFILE MAP (MRPM)</td>
<td>53</td>
</tr>
<tr>
<td>Map 3-4</td>
<td>CONTOUR SHADED RELIEF MAP (C/SM)</td>
<td>56</td>
</tr>
<tr>
<td>Map 3-5</td>
<td>SHADED RELIEF CONTOUR MAP (S/CM)</td>
<td>58</td>
</tr>
<tr>
<td>Map 3-6</td>
<td>PROFILE FENCE DIAGRAM (PFD)</td>
<td>62</td>
</tr>
<tr>
<td>Map 3-7</td>
<td>HYPSOMETRIC PERSPECTIVE MAP (HPM)</td>
<td>66</td>
</tr>
<tr>
<td>Map 3-8</td>
<td>HYPSOMETRIC CONTOUR MAP (HCM)</td>
<td>69</td>
</tr>
<tr>
<td>Map 3-9</td>
<td>STRUCTURE CONTOUR MAP (SCM)</td>
<td>72</td>
</tr>
</tbody>
</table>
Acknowledgements

I would like to extend special thanks to the members of my committee; David Alt, Darshan Kang, and especially to Paul Wilson for his kindness and continual confidence in my abilities.

In addition I would like to thank Ken Fielding for video taping assistance, Nancy for shelter from the storm, Daniel for music, Sarah Jane for punctuation, Vicki and Sue for patience, Lakshmi for friendship, Marcia for apricots, Eric for showing me one way, and Jim for keeping me ultimately down to earth.

Most importantly, thanks go to the members of my family Rolf, Barbara, Diana and Scott for never telling me what I should become and simply providing love and support for whatever I was.
Chapter 1

INTRODUCTION

The need to map diverse environmental phenomena has initiated development of a variety of graphic methods.\(^1\) The scale and complexity of the global environment creates numerous roadblocks which impede creation of effective map presentations. The difficulties of geodetic control, land survey, and compilation must be overcome before generalization, symbolization, and presentation can provide a useful map. Cartographers face an especially complex problem when trying to map phenomena consisting of two or more superimposed, three-dimensional surfaces.\(^2\) To date the author has encountered little cartographic literature regarding map construction of this nature.\(^3\)

---


\(^2\) Raisz, *General Cartography*, p. 301.

1.1. The Superimposed Relief Surface

At the time of this writing, there is no term in common use to describe superimposed, three-dimensional surfaces or their method of graphic representation. Surprisingly, the cartographic literature places no emphasis on mapping subsurface relief along with surface relief. There are maps presently in use showing both surface and subsurface relief, but no term accurately describes the concept.\(^4\)

This thesis proposes to use the term, *superimposed relief surface*, to identify the phenomenon. Superimposed relief surface (SRS) is used here to describe multiple surfaces superimposed upon one another: each surface has unique relief which may or may not be affected by the relief of surrounding surfaces. An *SRS map* describes existing and potential mapping methods which portray SRS phenomena.\(^5\)

Although the term, superimposed relief surface, has been defined, the concept may need further clarification. The following example breaks an SRS into its component parts.

Were the earth’s surface stripped of oceans and ice caps, it would appear as a sphere with a stark, continuous ground surface, not unlike the moon’s. The loss


\(^5\)The map definition used throughout this paper is “... a representation of the milieu.” This comes from Barbara Bartz Petchenik and Arthur H. Robinson, *The Nature of Maps*, (Chicago: University of Chicago Press, 1976), p. 15.
of oceans would leave us without a convenient elevation datum. But, if a new
datum were established, the ocean floor could be easily mapped without the
problems caused by great water depths. The new, and previously exposed, terrain
would contain great relief. This is an example of a continuous single relief
surface.

Were the oceans to appear once again, they would fill deep basins and cover
submarine mountain chains. Despite rugged underwater terrain, the ocean surface
would remain topographically featureless. We could envision the water as a
medium filling spaces within the topography, below sea level, as the atmosphere
does above sea level.

From a mapping standpoint, the above example displays two surfaces: the
land surface (either above or below sea level), and the surface of the sea. Because
the surface of the sea (sea level) is essentially a constant, there is no need to
represent it on a submarine topographic map. It simply serves as a measurement
datum. This situation is one of superimposed surfaces with only one surface, 
submarine terrain, having measurable relief.

Should the continental ice caps reappear, the underlying crust would remain
part of the global single relief surface. The ice caps would lie directly above the
continent and represent an additional relief surface. The ice surface undulates at
various elevations in response to differing factors. These two surfaces, the
underlying crust and the ice surface, form the components of an SRS. By
definition, this SRS consists of multiple surfaces, each containing unique relief.
Considering this one example of an SRS, the difficulties of mapping two
independent surfaces become apparent.

1.2. The Problem of SRS Representation

Throughout our daily lives we make “cognitive maps” of phenomena surrounding us. Cognitive, or “mental maps,” guide us through space in addition to storing information about relative locations of perceived phenomena. If we cannot form a cognitive map of certain phenomena, a cartographic map may help us. The use of a cartographic map enables us to stand on more precise intellectual ground while assembling mental images of phenomena not cognitively mapped through sensual input.

An SRS is an excellent example of phenomena that present difficulty in forming a cognitive map. Since at least one of the component surfaces is invisible to sensual perception, the challenge of imagining the spatial relationships of the invisible surface, and the visible surface, is nearly impossible without the aid of a cartographic map. A cartographic solution must offer the user a solid visual image of both surfaces so he can form a clear mental image.

The solution is a difficult one indeed. For centuries cartographers have tried to solve single surface relief presentation problems. Simple relief presentation problems become especially troublesome when attempting to display two surfaces having relief. Essentially, the relief presentation methods used must leave the upper surface somewhat transparent. The map reader will then be able to see through the relief of the upper surface to the relief of the lower. Both surfaces

---

should be discernibly unique. In addition to aiding the reader in forming a clear mental image of the actual phenomena, an effective SRS map will allow measurement of relief and intersurface spatial relationships.

Although two SRS mapping techniques are presently in use, the author contends that the entire spectrum of relief mapping methods have not been applied toward solving this problem. The purpose of this thesis is to devise new methods of SRS mapping and to evaluate the effectiveness of these methods compared to one another and compared to the two methods which already exist. The ability of a map reader to visualize and measure two surfaces will be examined for each technique, and the problems involved in producing the maps will be considered.

1.3. Methods

In order to examine the effectiveness of different SRS map types, several different maps were required for comparison. The cartographic literature was of little help in providing various mapping techniques for SRS portrayal. However, the literature did provide an extensive list of single relief surface representation methods. By using this collection of mapping techniques, the author was able to devise a classification system into which all types of maps, or representation techniques, could be entered.\(^7\) In constructing the new SRS map types, the classification system became an important aid in distinguishing different properties

\(^{7}\)The classification system and complete discussion of design and implementation can be found in Chapter 3.
upon which construction techniques were based. To provide a broad cartographic perspective, representatives from nearly all of the major categories which form the classification scheme were used. The combinations chosen for final map preparation were techniques which seemed to have the most practical SRS mapping application.

As was mentioned earlier in this chapter, there are two types of SRS maps presently in use. One of these types is the hypsometric contour map, exemplified by the *Tectonic/Geological Map of Greenland.* A hypsometric contour map uses contours to display the relief of one surface and hypsometric tints for the relief display of the second surface.

The other type of SRS map is the structure contour map, exemplified by the *Structure Contour Map of the Top of the Madison Surface.* A map of this type uses contour lines to display both surfaces. Differing line weights or colors distinguish between the elevation values of the two surfaces. This map is of particular importance in this paper. It was used as the elevation source map for all the SRS maps described in Chapter 3 and analyzed in Chapter 4.

These two map types, the structure contour and hypsometric contour maps, were constructed and compared along with six new map types devised by the author. All maps were constructed of an area in north-central Montana which

---

8 See footnote on page 2.

9 Ibid.

10 Discussion of SRS map construction along with graphic examples can be found in Chapter 3 beginning on page 36.
has well-documented, superimposed relief surfaces.\textsuperscript{11}

Eight professionals, who work with maps on a daily basis or use them as instructional tools, were chosen as participants in an interview. These individuals were shown the completed maps, associated legends, and interviewed using a prepared set of questions.\textsuperscript{12} Interviewees had an opportunity to study each map for a few moments before and throughout questioning. Upon completion of questioning, they were asked to rank the maps according to their visual effectiveness and metric capability.

Visual effectiveness and metric capability are two extremely important characteristics which will lead to determination of the “best” techniques for SRS mapping. Visual effectiveness, as it appears in this thesis, refers to a map’s ability to visually portray the surfaces which make up a particular SRS. A map would be considered visually effective if the user were comfortable looking at it and felt the image to be a true scaled representation of real phenomena.

Metric capability, or quantitative effectiveness, refers to a map’s ability for use as a measuring tool. If vertical and horizontal measurements can be made without excessive difficulty, the map would have a high metric capability. SRS map measurements must be made vertically between the superimposed surfaces as well as horizontally across either individual surface. The better a representation

\textsuperscript{11}A complete discussion of the SRS example area can be found in Chapter 2.

\textsuperscript{12}The list of questions along with the interview results and analysis can be found in Chapter 4.
is at allowing the user to perform such measurements, the greater its metric capability.

Questions were designed to solicit subjective responses regarding visual impressions and quantitative effectiveness. Yes and no responses were tabulated and comments regarding strong and weak attributes were recorded. Statistical analysis was done to determine significance of ranked data and indicate the most effective SRS presentation.

The newly developed maps discussed in Chapter 3 should be considered first steps toward expanding the imagination and breaking down preconceived cartographic limits. The SRS mapping problem is an unusual one which requires an unusual solution. Once a proven method has been worked out, it would be beneficial to:

* Hydrogeologists—interested in locating water tables in relation to ground surface or local strata
* Stratigraphers—for correlation between different relief surfaces
* Geomorphologists—for examining ancient processes in underground surface formation and subsequent events causing overlying structure and relief
* Glaciologists—for studying ice burden, isostacy, and identification of subglacial geomorphology
* Geographers—in the continual quest to properly locate phenomena in correct horizontal and vertical space
* Educators—in providing imagery for their students as part of a total environmental understanding
* Engineers—for determining cut and fill during construction
* Curious people
Chapter 2

DISCUSSION OF THE SRS EXAMPLE AREA

Figure 2-1 shows the known extent and thickness of the Madison limestone group throughout parts of the western United States and Canada. The SRS example consists of the surface formed by the top of the Madison group and the earth surface directly above it. An actual SRS was chosen, as opposed to a hypothetical case, to assure the usefulness of newly developed mapping techniques.

For ease of identification during discussion, the surface formed by the top of the Madison limestone group will be termed the Madison surface. The earth surface forming the other component of the SRS will be referred to as the Shelby surface.

A series of 1:2,500,000 maps published by the Montana Bureau of Mines and Geology provides topographic data for the Madison surface. From the Shelby Quadrangle of that series, a nine-by-fourteen-inch map area, covering approximately a 35 x 55 mile ground area, was chosen to serve as the SRS example. Bounded on the north by the U.S.-Canada border at 49° N latitude and

---


14 See R. D. Feltis, Madison Group, footnote on page 2.
ISOPACH MAP
OF THE
MADISON LIMESTONE GROUP

Figure 2-1

Isarithm Interval = 250 ft.

Thicknesses of more than 3000 ft. are shown with 1000 ft. contours isarithms.

— — — Dashed lines indicate approximate isarithm position.

Scale

on the west by 112° W longitude, the area forms a rectangle with the long dimension east-west. A number of interesting geomorphologic features are found on both surfaces and will be discussed below. A location map of the example area can be found in Figure 2-2.

2.1. General Description of the Shelby Surface

Located on the plains, about 100 miles east of the Rocky Mountain Continental Divide, the Shelby surface is characterized by gently sloping terrain, highly dissected by gullies and stream eroded coulees.\(^\text{15}\) Elevations on the plain range from 3,000 to 3,600 ft, averaging 3,400 ft. The land generally slopes to the southeast. A topographic map of the Shelby surface is shown in Figure 2-3.

The high rolling plain is considered part of the Great Plains geographic region. It is covered with a shallow layer of drift laid down by the Keewatin ice sheet during Wisconsin glaciation. The depth of drift ranges from 10 to 25 ft and "... forms a rolling to billowy, hummocky topography, with shallow lake depressions and low mounds and ridges."\(^\text{16}\) Most drainages remain as they were before Wisconsin glaciation. The larger streams continue to follow their ancient stream beds. Erosion has its greatest effect along the deeply entrenched perennial streams, carving up the shallow drift covered divides. Major drainages include

\(^{15}\) Stream profiles made across the Lakey Ranch, Montana, 1:24,000, USGS 7 1/2' series, topographic quadrangle, of the Cottonwood-Government Creek drainage system, shows a slight 0.62% slope.

Topography of the SHELBY SURFACE

Figure 2-3

Contour Interval = 200 ft.

Source: Configuration of the top of the Madison Group, Shelby 1 x 2° Quad, Montana, by R. D. Feltis.
Willow, Cottonwood, and Sage creeks. The Marias and Milk rivers collect these and eventually empty into the Missouri River.

The climate is semiarid with average precipitation ranging from 10 to 12 inches annually. Because of its central continent location, the area experiences great temperature extremes. Summer occasionally offers 100° F with very low relative humidity. Winter temperatures can drop to -50° F with wind chills reaching -70° F.

Most of the sparsely populated northern portions of Toole and Liberty counties are included in the example area. The two larger towns are Shelby, Montana, with a population of approximately 3,100 and Sunburst, Montana, with a population slightly fewer than 500. In addition to these towns, there are a number of small rural villages. The area is primarily agricultural; however, in 1922, petroleum was discovered in the Kevin-Sunburst field, located just north of Shelby. Petroleum and natural gas found in commercial quantities has resulted in great geologic interest, providing data from which the Madison structural contour map was constructed.

2.1.1. Sweetgrass Hills

An interesting topographic feature in the example area is the Sweetgrass Hills. Three adjacent laccolithic centers form these igneous buttes. They rise over 3,000 ft above the surrounding plains to elevations of 6,983 ft at West Butte

---

and 6,958 ft at East Butte. The third of the three main buttes, Middle Butte, is slightly lower at 6,500 ft. East Butte, while not the highest, is the largest of the three in terms of areal extent. These buttes are isolated formations over 100 miles from either the Bear Paw Mountains to the south or the Rocky Mountains to the west. While the Bear Paw Mountains consist of an eroded volcanic center, the Sweetgrass Hills are purely laccolithic, composed of sills, dikes, and uptilted sediments.\(^\text{18}\)

Surface erosion, occurring after up tilting caused by the laccolith, has exposed sediments in the Sweetgrass Hills ranging in age from Pleistocene glacial till to the Mississippian Madison limestone group. The base of the Madison group, or sediments below that, are not exposed. Table 2-1 identifies the various exposed sediments and their thicknesses.\(^\text{19}\) Further discussion of the Madison group is found in the next section.

2.2. General Description of the Madison Surface

The name Madison is used to describe the limestone sequence of lower Mississippian rock in Montana and Wyoming. According to Hamblin and Sloss, the Madison limestone is "... part of an enormously widespread series of lower Mississippian sediments deposited in the Cordilleran geosyncline and adjoining

\(^{18}\)Ibid.

\(^{19}\)Ibid., p. 466.
### Table 2-1: SEDIMENTS EXPOSED IN THE SWEETGRASS HILLS

<table>
<thead>
<tr>
<th>Age</th>
<th>Formation</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleistocene</td>
<td>Glacial Moraines</td>
<td>(variable)</td>
</tr>
<tr>
<td></td>
<td>Glacial Till</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Judith River</td>
<td>top eroded</td>
</tr>
<tr>
<td></td>
<td>Montana Group</td>
<td>500'</td>
</tr>
<tr>
<td></td>
<td>Claggett</td>
<td>150'</td>
</tr>
<tr>
<td>Upper Cretaceous</td>
<td>Colorado Group Upper Member</td>
<td>1000'</td>
</tr>
<tr>
<td></td>
<td>Lower Member</td>
<td>800'</td>
</tr>
<tr>
<td>Lower Cretaceous</td>
<td>Kootenai Formation</td>
<td>450'</td>
</tr>
<tr>
<td>Jurassic</td>
<td>Ellis Formation Unconformity</td>
<td>200'</td>
</tr>
<tr>
<td>Mississippian</td>
<td>Madison Limestone</td>
<td>base not exposed</td>
</tr>
</tbody>
</table>

[the] western part of the continental interior.  

The Madison surface, shown in Figure 2-4, exhibits characteristics indicating it was once an erosion surface. An extended break in sedimentation, caused by the withdrawal of limestone depositing seas, allowed subaerial erosion and solution to form the existing Madison surface and limit its geographical extent. The following geologic history is taken from Hamblin and Sloss:

1. Local withdrawal of Devonian sea and marked changes in sedimentation

---


and fauna
2. Deposition of organic shale transition beds in shallow isolated basins
3. Invasion of Paine sea from west into shallow east–west trough through central Montana. Deposition of Paine beds in sea subject to periodic influxes of clastic matter from west. No deposition in southeast over an area also lacking Silurian and Devonian strata
4. Farther spread of sea north and south, and uniform deposition of Woodhurst beds. Clastic material diminishes and indirect stratification active with concentration of crinoid and brachiopod fragments in thick beds
5. Farthest spread of sea and deposition of Mission Canyon limestone. Complete absence of sand and silt except in southwest margin of basin
6. Withdrawal of sea. Exposure to subaerial erosion and solution action during part of middle and late Valmeyer time
8. Deposition of later Paleozoics (and Triassic in south)
9. Early Mesozoic erosion north of present Big Snowy and Belt mountains, Montana, to form karst topography on the Madison where exposed. Madison completely removed in northern Alberta and northern Saskatchewan
10. Deposition in Jurassic of Fernie, Ellis, Sundance

The Madison surface is also affected by the Sweetgrass Hills laccolith. Across the example area, Madison surface depths and elevations from the mean sea level datum range from −300 ft on the eastern edge to over 6,800 ft in the Sweetgrass Hills area. The Madison surface actually breaks the Shelby surface on East Butte. This break point aided Billingsley and Kemp in compiling the information in Table 2–1. The Kevin–Sunburst Dome is apparent in the southwest corner of Figure 2–4.

The Madison source information was compiled by R. D. Feltis of the U.S.G.S. from drill hole data. The holes are located primarily on the plain. A few holes
Topography of the

MADISON SURFACE

Figure 2-4

Contour Intervals:

lower elevations = 100 ft.
higher elevations = 500 ft.

Source: Configuration of the top of the Madison Group, Shelby 1x2° Quad, Montana, by R.D. Feltis.
were drilled on the lower slopes of the Sweetgrass Hills, but not enough to form an accurate contour map of those areas. The source map shows incomplete elevation data for the upper slopes and tops of the buttes formed by the Madison surface. The need for two continuous surfaces required the author to extrapolate elevation data for areas lacking data. The difficulty of finding complete elevation data for an invisible surface necessitated the extrapolation for examination purposes.

Despite the need to extrapolate occasional elevation values for the Madison surface, the SRS example is effective in portraying the concept. It is a relatively simple example because of the close correspondence between the two surfaces. Although the two display many similar features, there is enough variation in relief to clearly identify unique surfaces. Completed SRS maps and design considerations for each map are presented in the following chapter.
Chapter 3

SRS MAP CONCEPTS AND CONSTRUCTION

3.1. Introduction

In his book, The Look of Maps, Robinson points out that "... our ability to gather and reproduce data has far outstripped our ability to present it." Cartographic relief presentation is no exception to this statement. From the late seventeenth century Swiss topographic masterpieces to present day computer perspective plots, all topographic mapping attempts have been valuable contributions toward alleviating presentation inadequacies. SRS mapping, necessarily, has a foundation consisting of existing cartographic relief presentation techniques. A historical review and a classification of techniques follows. Technique combinations will then be illustrated and discussed regarding their suitability for SRS mapping.

3.2. Terrain Representation: A Brief History

The earliest known maps still in existence were produced by the Babylonians on clay tablets approximately 2500 B.C. These maps were used for taxation purposes and contain symbols indicating property boundaries and relief. The

---


symbols representing hills consist mainly of smooth domes as seen from the side. This symbolization is referred to as "mole hills". Mole hills were drawn with their bases parallel to the direction of the mountain range axis. This technique left images of mountains lying on their sides and, in some cases, even appearing upsidedown.

Around 130 A.D., Ptolemy was mapping the known world. Of his major contributions to the foundation of geography and cartography, the most important was his advancement of cartography as a science. In his map of the Mediterranean and Black Sea, he identifies mountain ranges with a series of slightly overlapping triangles. These triangles are all oriented with their peaks to the north and relief shading on the northeast slope. Further advances led to mountains portrayed from a "birds eye" perspective. Valleys and mountain ranges were easily identified in this perspective, but the similarity of mountain symbols created an unattractive fish-scale pattern.

Improvements in the "birds eye" perspective view naturally led to more artistically rendered mountains, which began to take on the shape of the terrain being symbolized. In the fifteenth century, Henricus Martellus showed the relief of

---

26Imhof, Relief Presentation, p. 1.


28Ptolemy is credited with providing the geographic data and details for cartographic construction of many maps. Whether he actually produced any maps by his own hand is not known at this time.

29Neal, Of Maps and Men, pp. 22–23.
the Alps (based on Ptolemy) with elaborate shading in brown, white, and green.\textsuperscript{30}

Mountain symbols produced by shadow hachuring first appeared in the sixteenth century. In 1503, Leonardo da Vinci was the first to actually show the terrain in its entirety with his \textit{Map of Tuscany}.\textsuperscript{31} Maps had previously shown the terrain with discontinuous symbols; da Vinci showed each hill individually in its correct relation to adjacent hills. Streams, houses, and relief shading were employed for clarity in this birds eye perspective. This was an important step in the representation of a continuous relief surface.

In 1667, the first accurate planimetric map displaying relief was Hans Conrad Gyger’s \textit{The Canton of Zurich}.\textsuperscript{32} This map was based on a dense pattern of survey points. The mountains were accurately located in the plan view and relief shading with natural colors made it not only accurate, but beautiful.

Slope and shadow hachures were used throughout the 1800’s. At the same time, contours were coming into use. The principle of the isobath was in use as early as 1585, but the topographic contour was not extensively used until the 1800’s due to lack of accurate land survey information. The use of contours expanded rapidly and accuracy increased through the aid of photogrammetric plotting.

Advances in production and reproduction processes have led to a variety of


\textsuperscript{31} Imhof, \textit{Relief Presentation}, p. 3.

\textsuperscript{32} Ibid., p. 5.
relief presentation forms. Combinations of the techniques mentioned, new color schemes, and the advent of computer graphics bring us to the methods in use today.

Appendix A contains brief descriptions of most types of relief presentation found in the literature. They are presented there for quick reference, as an introduction to new techniques, and as a supplement to the map classification system introduced in Chapter 1 and discussed below.

3.3. Map Classification

Many natural sciences have foundations based upon classification systems. Grouping phenomena according to similar properties or relationships is important for identifying new phenomena and organizing concepts. Once a classification system is developed, characteristics of groups or subgroups can be studied and conclusions drawn regarding specific class levels.

Although cartography is not a natural science, it is possible to utilize a classification system to organize the products of cartographic research. When studying mapping techniques, one is left to seek out bits and pieces of presentation methods scattered throughout the literature. These methods should be consolidated into easily identifiable, structured groups. There are an infinite number of ways to present spatial phenomena, but no single system for identifying mapping methods according to common graphic properties.

In an attempt to identify and organize the spectrum of relief presentation, the author has developed the classification system shown in Figure 3-1. It is based on
a logically subdivided population where maps are separated into groups according to common graphic properties.\textsuperscript{33} A hierarchy exists in map types which lends itself to categorization into distinct subdivisions based on the form of the map (flat map, block diagram, aerial photograph, etc.) and the types of symbols employed. The divisional approach was used as opposed to the agglomeration technique since all of the types of maps which may ever exist are not currently known.\textsuperscript{34} The divisional approach initially requires all of the known members of a population to be grouped into one category. Subsequently, the population is broken down into increasingly specific segments based upon various differentiating criteria. Figure 3–1 shows the similarity tree for the classification of general maps subdivided according to the divisional approach. As one moves across the classification scheme from left to right, increasingly specific examples of representation methods are found. Eventually, the most specific descriptions of the presentation method can be broken down no further. This is exemplified by the Special Versions of Symbols category displayed in the column to the far right.

Because this paper is primarily concerned with relief presentation, further classification of thematic maps will be left for another study. The Intended Use category, which includes single surface relief presentation and SRS maps, will not be subdivided further for other map types. The few examples included in the


\textsuperscript{34}The agglomeration approach to classification works best when all of the members of the population being classified are known and are included in the classification. Abler, Adams, and Gould, \textit{Spatial Organization}, p. 155.
Figure 3-1: MAP CLASSIFICATION SYSTEM

UNIVERSE | GENERALIZED PHENOMENA | INTENDED USE | VISUAL FORM | SYMBOLIZATION | SPECIAL VERSIONS OF SYMBOLS
--- | --- | --- | --- | --- | ---
Thematic | Air Charts | Planimetric * | Hachures |
Thematic | Road | Planimetric | Shading * |
Thematic | Cadastral | Planimetric | Physiographic |
Thematic | Water Charts | Planimetric | Inclined Contours |
Thematic | Others | Planimetric | Hypsometric *

General | Single Surface Relief Presentation | Cross Section * |

SRS | Planimetric | Profile Fence *

Universe | General |

* marked maps indicate their use as components of SRS maps.
scheme are presented to demonstrate a logical division under \textit{Intended Use}.

The techniques shown in Figure 3–1 include only those the author has encountered in cartographic and geographic literature. Undoubtedly, there are more relief presentation techniques from the past which have been overlooked. There are certainly techniques being developed presently which could not be included. The intent was to design the classification system carefully enough to allow entry of absent techniques.

A research project involving map production of all possible combinations of known techniques is beyond the scope of this paper. In seeking the most effective technique for SRS presentation, however, it is important to analyze as many as feasible. The classification system was a direct aid in deciding which techniques showed promise for developing new SRS maps.

3.3.1. Classification Design

The hierarchy existing in the population of maps is seen in the terms identifying each of the six subdivisional levels. These terms are shown in the diagram below; they name characteristics which serve as guidelines that help determine a map's entry into one division or another.

\begin{verbatim}
Universe ---> Generalized Phenomena ---> Intended Use ---> Visual Form ---> Symbolization ---> Special Versions of Symbols
\end{verbatim}

Each of the guideline levels have special characteristics that distinguish it from the others. The sections below discuss each of the six subdivisions and identify the criteria a map must meet to enter any particular level.
3.3.1.1. The Universe

The only criterion required at this point of the classification system is that the object be a map. There are many definitions for the word "map"; however, this paper will consider only two.

The first definition comes from the traditional ideas of cartography:

The art, science and technology of making maps, together with their study as scientific documents and works of art. In this context maps may be regarded as including all types of maps, plans, charts, and sections, three-dimensional models and globes representing the Earth or any celestial body at any scale.\(^{35}\)

From this, one can see how the word map is so intimate to cartography that it must be defined at the same time. The context qualifier for maps, from the International Cartographic Association’s definition of cartography, allows for a broad range of graphic interpretations to be considered a map.

The second definition comes from Petchenik and Robinson’s interpretation of a map being a "representation of the milieu."\(^{36}\) This is license to a limitless range of graphic manipulations. Under these definitions, map construction is limited by the cartographer’s imagination, not a rigid definition. In the classification system presented, the Universe exists as all things considered a map by the definitions above.


\(^{36}\) Petchenik and Robinson, Nature of Maps, p. 15.
3.3.1.2. Generalized Phenomena

The second level of the classification is identified as Generalized Phenomena. Morrison et al. divide all maps into two classes—general maps and thematic maps. General maps portray the spatial association of geographical phenomena. Thematic maps portray the areal distribution of phenomena, or relationships between a limited number of different but related phenomena. These two broad categories comprise the initial subdivision of the universe. A map meeting the criteria defining general maps will fall into that branch and enter lower class levels from there. It is easy to foresee all map types falling into either of these two general categories.

3.3.1.3. Intended Use

The further subdivision of general maps is based on the intended use of the map. The mapped geographical phenomena, mentioned in the preceding section, is usually aimed at a specific audience often to be used for specific purposes. The map provides the user with required spatial-locational information. Examples from the classification system show clear differences of intended use. Navigation on land, sea, and air, public land surveys, topography, and SRS's are all maps possessing special features dictated by their intended use.\(^{38}\)

---


\(^{38}\)Under this category in the classification system, the term "relief representation" is used instead of topographic maps. One usually thinks of a topographic map as a USGS quadrangle using contour lines to display relief. Relief representation is used in an attempt to nullify any prejudice associated with the narrower perspective of the other term.
3.3.1.4. Visual Form

At this point, the criteria which define the next lower level of the classification changes from the types of information maps are attempting to portray and now considers their physical form or appearance. *Visual Form*, as it relates to relief presentation, refers to the viewing angle, or projection, of the object image. Examples from the classification system include:

* Planimetric—the viewing angle for a planimetric map is vertical. The horizontal scale is constant in all directions across the map and all angles are preserved as they are in reality
* Cross-Section—the viewing angle of a cross-section is 90° from vertical. An imaginary vertical slice is made through an object and viewed perpendicular to vertical. Often cross-sections will use vertical exaggeration to highlight relief
* Perspective—a perspective image is one that appears three-dimensional, or, as the eye would view something stereoscopically. There are two angles involved in viewing a perspective; altitude and azimuth
* Photography—photography can be made at any angle and utilized in a number of different forms

3.3.1.5. Symbolization

Maps are abstractions of reality. The generalization involved in producing a useful map forces the cartographer to use esoteric and abstract symbolization. Ideally, the effort of the map maker is to produce an image of reality which can be immediately recognized and understood by all who use it. One map user may find the collection of symbols more beautiful or aesthetically appealing than another user might; but, the functional message contained within the map should remain the same in each instance. For example, skeletal line and spot height symbols may not be as attractive as planimetric relief shading, but both techniques are an
attempt to display the relief of a given area.\textsuperscript{39} Despite the fact that the different techniques display relief with varying degrees of accuracy, the functional message remains one of spatial-locational relationships of phenomena (relief, in this case) within the mapped area.

The fifth level of the classification, under the heading \textit{Symbolization}, finally reaches the stage where individual map types begin to appear. However, some of the map types listed here can be further subdivided; accordingly, they are not individuals. Although they are not differentiated in Figure 3-1, the maps listed under the heading \textit{Symbolization} are actually of two varieties: one is maps with individualized symbols which cannot be broken down into more subvarieties; the other is maps which have conceptualized symbols capable of being broken down further. Those with conceptualized symbols branch once again in Figure 3-1 into the individual map types listed in the last column under \textit{Special Versions of Symbols}.

3.3.1.6. Special Versions of Symbols

Because some symbols exist as concepts, as mentioned above, another class level is required for the further subdivision of conceptualized symbols. These divisions are found in the column to the far right of Figure 3-1. One example from the classification of a conceptualized symbol that has special versions is the hachure. Simply identifying a symbol as a hachure would be incomplete. "Hachure" is actually a generic term describing a symbol that exists in one of three

\textsuperscript{39}Definitions of these symbolization forms may be found in Appendix A.
forms: horizontal, slope, or shadow hachures. Each of these forms use slightly different techniques in obtaining the same goal, but are nonetheless considered hachures.

3.4. Classification System Application

The main reason for developing the classification system was to produce a comprehensive list of relief presentation techniques from which mapping types appropriate for SRS display could be chosen.

Figure 3-1 contains a number of terms which have been underlined or otherwise noted. This was done to identify the map types, or techniques, selected for SRS map construction and analysis. As can be seen from the figure, the map types selected encompass a broad range of potential methods. From various combinations of these types, nine SRS maps were made and analyzed. They are defined in the following section on taxonomy. In choosing these particular map types, the intent was to achieve a fair representation of relief presentation methods. Limitations, in the form of cartographic and financial resources, were also a factor in choosing these maps for construction and examination.

3.4.1. Taxonomy of SRS Maps

Development of new mapping methods requires finding names which will help identify and describe new map types. Table 3-1 shows the names assigned to the SRS maps that were examined in this paper. Each map type shown in the table was given a definition and an abbreviated title. These shortened titles (acronyms) will be frequently referred to in the analysis found in Chapter 4.
<table>
<thead>
<tr>
<th>Map Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perspective Stack Map (PSM):</td>
<td>Two or more three-dimensionally appearing perspective surfaces vertically superimposed</td>
</tr>
<tr>
<td>Multirod Map (MRM):</td>
<td>Vertical rods drawn to scale displaying the surface elevations associated with selected geographic locations</td>
</tr>
<tr>
<td>Multirod Profile Map (MRPM):</td>
<td>Vertical rods drawn to scale displaying surface elevations associated with selected geographic locations; with profile lines connecting the rod tops along a selected orientation</td>
</tr>
<tr>
<td>Contour Shaded Relief Map (C/SM):</td>
<td>Contours indicate relief of the upper surface; shaded relief displays the lower surface</td>
</tr>
<tr>
<td>Shaded Relief Contour Map (S/CM):</td>
<td>Shaded relief displays the upper surface; contours indicate the relief of the lower surface</td>
</tr>
<tr>
<td>Profile Fence Diagram (PFD):</td>
<td>Any number of profiles that indicate the location and relationship between surfaces and a datum along profile lines</td>
</tr>
<tr>
<td>Hypsometric Perspective Map (HPM):</td>
<td>A hypsometric tint map superimposed upon a three-dimensional perspective surface</td>
</tr>
<tr>
<td>Hypsometric Contour Map (HCM):</td>
<td>A hypsometric tint map superimposed upon a contour map</td>
</tr>
<tr>
<td>Structure Contour Map (SCM):</td>
<td>Two sets of contours, each displaying the relief of a surface</td>
</tr>
</tbody>
</table>

Of the nine maps listed in Table 3-1, the first seven maps were developed by the author. Although they number seven maps, they represent only six map types. These six types were named using components which produce a particular map type. The contour shaded relief and shaded relief contour maps use identical techniques in their construction and are considered to be of the same type. A
reversal of the techniques representing the surfaces is the only difference between the two.

Two maps which were not developed by the author are found at the bottom of Table 3-1. No title reference was found for the SRS combination of hypsometric tints and contours. The term "hypsometric contour map," used earlier in this paper to describe that particular mapping technique, was necessarily derived by the author. It was named using logic similar to that applied to the preceding seven maps. The term "structure contour map" is in common use and will be used throughout.

Two of the abbreviated titles contain slashes. This was done for two reasons. First, the structure contour map initials are identical to the shaded relief contour map. Second, the slashes identify maps of the same type and make it easier to determine which relief technique applies to each surface. The first letter indicates the upper surface representation form.

3.5. SRS Map Construction

3.5.1. Perspective Stack Map (PSM)^40

Three-dimensional maps, or perspective block diagrams, are an excellent alternative to normal planimetric maps. Most map readers, regardless of experience, can utilize perspective diagrams because the cartographer can

---

^40Abbreviated versions of map titles are included to familiarize the reader. They will be relied upon heavily during discussions in the following two chapters.
communicate surface detail more effectively.\textsuperscript{41} Lobeck\textsuperscript{42} and Raisz\textsuperscript{43} were influential in developing block and physiographic diagrams. In addition to topography, their diagrams include symbolization indicating land cover.

Computer generated perspective plots do not yet have the capability of showing land cover type as a physiographic diagram might. Presently, most software is capable of accepting elevation data and outputting a plot based upon various parameters chosen by the user. This is the method used for compilation of the perspective stack map.

Two computer mapping packages supported by the University of Montana Computer Center and used to construct the perspective plots are Synergraphic Mapping (SYMAP)\textsuperscript{44} and Automated Surface Perspectives (ASPEX).\textsuperscript{45} They exist in a Digital Equipment Corporation (DEC) System 2065 mainframe computing environment at the University of Montana. SYMAP output is in the form of a high-speed, lineprinter map using vectors created from \(x,y\) coordinates as input. ASPEX utilizes a raster matrix created during a SYMAP run, with the properly requested

\begin{footnotesize}
\begin{itemize}
\item[\textsuperscript{42}] Lobek, \textit{Block Diagrams}.
\item[\textsuperscript{43}] Raisz, \textit{General Cartography}, pp.149–55.
\end{itemize}
\end{footnotesize}
For output, ASPEX processes each pixel in the matrix according to parameters assigned by the user. Conditions set include viewing altitude and azimuth, resolution level, height as a ratio of length, and number of diagonal lines used to display the surface. Guidelines concerning perspective orientation and viewpoints can be found in Crawford and Jenks, Rowles, and Crawford and Marks. Output displays include CRT images on a Tektronix 4014 Graphics Terminal, hardcopy plots on a Tektronix 4662 Flatbed Plotter, and a Calcomp Drum Plotter.

The computer perspective SRS map was compiled from elevation data found on the Structure Contour Map of the Madison Group by Feltis. The source map contains the location of drill hole sites for water and petroleum. The Madison surface was mapped using drill hole data by interpolating the elevation between sites and constructing isarithms at 100 ft contour intervals. The Shelby surface consists of photogrammetrically plotted contour lines from the USGS 1:250,000 Shelby Quadrangle.

The Madison surface was digitized using approximately 90 points distributed across the surface of the map. An elevation was established for each point, and the SYMAP program interpolated elevation values for the entire surface based on the Structure Contour Map of the Madison Group by Feltis. The source map contains the location of drill hole sites for water and petroleum. The Madison surface was mapped using drill hole data by interpolating the elevation between sites and constructing isarithms at 100 ft contour intervals. The Shelby surface consists of photogrammetrically plotted contour lines from the USGS 1:250,000 Shelby Quadrangle.

---

46 Crawford and Jenks, Viewing Points, p. 25.


upon the assigned points. Although 90 points seems like a small number for such a large area, the low resolution of source data and the topographic character of the Madison surface hardly justified a denser pattern of digitized points. An example of the ASPEX output for the Madison surface is shown in Figure 3-2.

Conversely, the Shelby surface was digitized using approximately 300 points. The intent was to increase the detail level of the Shelby surface. This was made possible by the higher resolution provided by the source map. The source map indicated many gullies; the 300 digitized points allowed some of these to be shown. The computer plot for the Shelby surface is shown in Figure 3-3.

The next step in preparing the SRS map was to join the two surface images so that both could be seen simultaneously. The difficulty encountered at this point was in limiting the amount of visual obstruction caused by the upper surface. A number of attempts were made using ASPEX to plot the surfaces together on the same piece of paper. No amount of parameter variations or pen color choices would allow for an acceptable map using two ASPEX runs on one plot. ASPEX size limitations are directly controlled by the relationship between vertical exaggeration and plotter size. Differences in digitized data between the Madison and Shelby caused different horizontal and vertical scaling that could not be forced to coincide.

Due to the innate scaling and registration problems encountered in this situation with ASPEX, two different plots were made— one of each surface on separate sheets of paper. The parameters were set for each plot with a viewing
Figure 3-2: ASPEX PLOT OF THE MADISON SURFACE

Source: Configuration of the top of the Madison Group, Shelby 1 x 2° Quad, Montana, by R.D. Fettis.
Figure 3-3: ASPEX PLOT OF THE SHELBY SURFACE

Source: Configuration of the top of the Madison Group, Shelby 1 x 2° Quad, Montana, by R.D. Feltis.
altitude of 40° and azimuth of 35°. The height parameter for the Madison surface was 0.25 of the image length corresponding to a vertical exaggeration of approximately 11x. Height for the Shelby surface was 0.40 of image length corresponding to a vertical exaggeration of approximately 36x.

To assure dimensional integrity, isometric plots were produced. An isometric plot creates an image with no vanishing points. Parallel lines remain so and angles are constant across the image. A true perspective represents a three-dimensional object on a plane surface as it would appear to the eye. Since a true perspective has vanishing points, the plots presented here are not true perspectives.

The Madison surface was plotted in red with a diagonal line density equal to one. The high density of lines creates a strong three-dimensional image with good contrast and the highest level of resolution attainable.

The Shelby surface was plotted in black, with a diagonal line density equal to four. The lower density of lines was a happy medium discovered through trial and error. It allowed a great deal of transparency while keeping much of its own

---

49 Altitude refers to the viewing angle, or height, in relation to a plane. A viewing angle, or altitude equaling 90° would place the viewer directly above the center of the plane. An altitude of 0° would be a view from "ground level". Azimuth sets the viewing angle with regard to north. North is customarily oriented towards the top of a map. An ASPEX azimuth angle will rotate the map in such a manner that the assigned azimuth will be oriented toward the top.

50 Rowles, "Perception of Block Diagrams," p. 34.

51 The diagonal line density value corresponds to the desired number of lines to be plotted. A value of 1, means each line processed by ASPEX will be displayed. A value of 4 means every fourth line of all possible lines will be displayed. In this manner one controls the output resolution.
surface structure visible. The Shelby plot now needed to be joined to the Madison. Because the Shelby plot was not produced to the same scale, it had to be photographically reduced to allow registration of the two images. The Shelby plot was reduced onto a film positive. The final step was to register the two images and make a color photocopy. The final result is the map shown in Map 3-1.\textsuperscript{52}

The registration was done by projecting vertical lines upward from the block formed by the Madison image. Desire to show the relationship of relief between surfaces, required the Shelby to be placed on top at some distance, thus allowing the eye to perceive a point to point correspondence. The vertical distance is somewhat arbitrary, but guided by these needs.

\textsuperscript{52}A note of clarification: All of the SRS maps compiled and presented for examination and analysis are identified as Maps in the illustrations. All supporting maps and diagrams are designated as Figures. This is done for referencing ease and to emphasize the importance of the SRS maps in further discussion.
PERSPECTIVE STACK MAP (PSM)

Superimposed Relief Surface Map of the
Madison Limestone and Shelby Ground Surfaces

Map 3-1

Madison Surface

Shelby Surface

Vertical Exaggeration ≈ 11x

Vertical Exaggeration ≈ 36x

Horizontal Scale (along isometric lines)

Source: Configuration of the top of the Madison Group, Shelby 1 x 2° Quad, Montana, by R.D. Feltis.
3.5.2. Multirod Map (MRM)

The multirod map, presented in Map 3-2, is based upon the construction of a scale relief model. In an actual model, the construction material at any point would be built to the appropriate height in relation to surrounding terrain and to scale. Once completed, the surface could be viewed from any angle. The rod map is essentially the same thing without a physical surface. The rods can be considered supporting members for an imaginary surface.

To begin construction, two grids must be drawn; one on the planimetric source map and another on what will be the rod map. The grids must be identical, except that the scale may vary if the cartographer wishes to make the finished map larger or smaller. From the source map, each intersection contains an elevation value for both the Madison and Shelby surfaces. These values are assigned to the corresponding intersection on the rod map.

With this information transferred to the rod map, one can begin to graphically represent the elevation values at the intersections. Once a vertical scale is decided upon, vertical lines are drawn to indicate the height of each surface. Using the grid plane as a datum, the lines can be drawn quickly and accurately.

When producing a multirod map, several problems concerning their design must be overcome. The design considerations listed below will be discussed in detail throughout the remainder of the multirod map section:

* Density of grid intersections
* Map orientation
* Vertical scale
MULTIROD MAP (MRM)

Superimposed Relief Surface Map
of the
Madison Limestone and Shelby Ground Surfaces

Map 3-2

Vertical Scale

MSL

Shelby elevation

Madison elevation

Grid Datum = MSL

Vertical Exaggeration ≈ 14x

Horizontal Scale
(along isometric lines)

Source: Configuration of the top of the Madison Group,
Shelby 1 x 2° Quad, Montana, by R.D. Feltis.

drkilled 2/86
* Line weights and thickness
  * Line color
  * Use of elevation points not falling on an intersection

3.5.2.1. Density of Grid Intersections

This is probably the most difficult of the design considerations. In order to provide the map user with enough points upon which to infer a surface, the map maker runs the risk of creating an unintelligible clutter of little lines. This, of course, would inhibit the visual interpretation of the surfaces. In terms of measurement, or metric capability, unless one line physically interferes with another, any number of lines would be acceptable; however, visual interpretation requires that the quantity be limited to some numerical optimum.

The procedure for selecting an optimum number of rods is subjective at best. The character of the surfaces has much bearing upon the density needed. Mountainous, hilly, or gullied terrain would require a higher density of points than would flat plains or desert. There is no formula with which to calculate such a value. Having a good feel for the capability of the graphic and a good idea of surface topography to be displayed, plus some trial and error, will be the only guide.

Very few, if any, intersections on the source map will fall directly on a contour line. When assigning a value to an intersection, one simply does a straight line interpolation between known elevation values on either side of the desired point.
3.5.2.2. Map Orientation

The importance of orientation can be recognized if one imagines the entire range of azimuths and altitudes from which the surfaces could be viewed. The azimuth angle must be set so that a vertical line from one point will not collide with any adjacent lines or points. This requires azimuth adjustment based upon average line length. The multirod map, Map 3-2, is based upon a grid orientation provided by an ASPEX isometric plot where: azimuth = 35°, altitude = 40°. None of the lines projecting from an intersection interfere with another grid intersection. The angles also give an impression of depth which is extremely important in any three-dimensional representation.

3.5.2.3. Vertical scale

The vertical scale should be identical for both surface representations. The scale chosen for this map was 1:36,000 which amounts to a vertical exaggeration of 14x. All vertical lines can be quickly measured using the 1:30 scale on an engineer's scale.

If the vertical scale is too large, the map will appear top heavy. It will be more difficult to make a visual connection between the surface and the datum base because of the increased line lengths. A scale too small will give little impression of relief. Visual comparison of two elevations at one point becomes

---

53 See footnote on page 42 regarding azimuths and altitudes.

54 For further discussion on principles of perspective plot orientation, please refer to footnotes on page 38.
increasingly difficult with a decrease in scale.

3.5.2.4. Line Weight and Thickness

Through trial and error a number of different line widths were tried. The map presented here consists of 0.30 mm vertical lines and 0.25 mm grid lines. That is not to say these are the optimum widths. The main problem is the need to hold the image together visually with the grid, yet make the grid as inconspicuous as possible. The grid might have been screened back to 75 percent black which would eliminate some of the confusion existing between it and the blue Madison rods. If one data set was to be emphasized, the line weight and thickness could be correspondingly larger.

3.5.2.5. Line Color

Contrasting colors seem to be the key in an SRS multirod map. Both data sets must be recognized as unique. Reproduction by color photocopy is not the most suitable method for retaining original coloration. Much work still needs to be done to determine the appropriate coloration.

3.5.2.6. Elevation Points Not on Grid

The grid will not intersect in every desirable place on the map. If one were restricted to the grid, many important features might be left out. The solution is to include an occasional point not on an intersection. Any point can be located by x–y coordinates on the planimetric source map. The rod maps used here are isometric, so x–y coordinates can be measured from any two grid lines. Once properly located on the rod map, scaled rods corresponding to the new data point
may be drawn.

A serious cause of confusion occurs when rods interfere with surrounding data points. Some cartographic license may be required to eliminate certain intersections deemed less important. Generalization in cartography allows for adjustments which will produce a more effective image of reality.

A situation not encountered on this map occurs when an important feature has elevations falling below the datum, but not falling upon a grid intersection. A couple of possible solutions include locating the datum with a cross drawn parallel to grid lines at the point of intersection, then proceeding to draw the rods. Another is to let the contrasting colors do the work of identifying the datum at the intersection point. The upper surface rod could be followed to its terminus at the datum. The lower surface rod would then begin at the same point. Care would be required to assure recognition of the lower rod's relationship to surrounding rods.

3.5.3. Multirod Profile Map (MRPM)

The multirod profile map, shown in Map 3-3, is a natural progression from the multirod map. The multirod map requires the eye to move unaided from rod to rod while constructing surface impressions. The multirod profile map shows a straight line interpolation between the tops of each rod and allows one to easier visualize ups and downs along a profile. Any rod not falling on a grid intersection or a profile line is left to stand alone. The interpolation allows for increased metric ability. A perpendicular drawn from the grid to a profile becomes a rod which can be measured the same as any other. Design considerations are virtually identical to the multirod map.
MULTIROD PROFILE MAP (MRPM)

Superimposed Relief Surface Map of the Madison Limestone and Shelby Ground Surfaces

*Map 3-3*

Vertical Scale

- 6000 ft.
- 3000
- 1500
- 0

Grid Datum = MSL

*Vertical Exaggeration = 14x*

Horizontal Scale (along isometric lines)

10 0 10 20 30 km.

Source: Configuration of the top of the Madison Group, Shelby 1 x 2° Quad, Montana, by R.D. Feltis.
3.5.4. Contour Shaded Relief Map (C/SM) and Shaded Relief Contour Map (S/CM)

These two maps are discussed together because they use the same construction techniques. C/SM, Map 3–4, uses contours to display the upper Shelby surface while S/CM, Map 3–5, uses planimetric shaded relief for the Shelby surface.

Contour lines and planimetric relief shading are two popular methods of relief presentation. Contours give a good impression of topography as well as excellent metric capability. Shading gives an effective visual impression of topography but is very weak metrically. The two contour–shaded maps attempt to create a strong one-to-one planimetric correspondence between the surfaces. Impressions of relief on one surface can be compared to the other by switching one’s attention back and forth between the presentation methods. A continual switching of one’s attention will provide the reader with a good visual impression of both surfaces and measurability on the surface displayed by contours.

Maps 3–4 and 3–5 were drawn using a black pastel pencil on smooth bristol board paper. Pencil marks were rubbed by hand to create the tonal gradations. The Shelby contours were drawn on mylar from which a film positive was made. The Madison contours were negative scribed and a film positive was made from that. The appropriate map components were registered and exposed in a vacuum frame printer onto diazo paper, then developed.
CONTOUR SHADED RELIEF MAP (C/SM)

Superimposed Relief Surface Map
of the
Madison Limestone and Shelby Ground Surfaces

Map 3-4

Madison Surface

Shaded Relief Indicates the
Madison Surface

Contour Interval = 200 ft.

3400

SCALE

Source: Configuration of the top of the Madison Group,
Shelby 1 x 2° Quad, Montana, by R D Feltis.

2/86
SHADEDS RELIEF CONTOUR MAP (S/CM)

Superimposed Relief Surface Map of the Madison Limestone and Shelby Ground Surfaces

Map 3-5

Madison Surface

Contour Intervals:

lower elevations = 100 ft.

higher elevations = 500 ft.

Shelby Surface

Shaded Relief Indicates the Shelby Surface

500 ft. index contours

N

SCALE

Source: Configuration of the top of the Madison Group, Shelby 1 x 2° Quad, Montana, by R.D. Feltis.
3.5.5. Profile Fence Diagram (PFD)

In geology, stratigraphers are faced with the task of demonstrating the continuity of invisible, underground stratigraphic units through a process called "correlation." Put briefly, the stratigrapher takes data sets from drill holes or outcrops and tries to develop the stratigraphic picture existing between known points. By logically matching identical units from drill hole data, he is able to project the occurrence or disappearance of rock-stratigraphic, time-stratigraphic, or bio-stratigraphic layers.

Probably the stratigrapher's most important tool is the correlation diagram. A simple example is shown in Figure 3-4. A completed correlation diagram presents a profile of the area between two points with all possible solutions shown.

A fence diagram takes the correlation diagram into the third dimension by adding depth. This allows any number of drill hole sections to be correlated. The desired sections are planimetrically located and profiles drawn between them. It is on this principle that the profile fence diagram SRS map is based. The purpose is to display as much structure as possible with a minimum number of profiles.

The key to construction of an effective fence diagram is the location of profile starting and ending points, or fence posts. Begin by locating profile lines on the source map. These straight lines become the datum from which surface elevation data will be measured at the chosen vertical scale. At the beginning and

55 See page 9 for discussion of source map.
Figure 3-4: SIMPLE CORRELATION DIAGRAM

Sections

Possible Profile Solutions

Junctions of each profile is a vertical fence post. The surface elevation at a fence post location is determined from the source map. The post is drawn to the correct vertical scale indicating the height of the two surfaces from the datum. In like manner, elevations at points along a profile, or fence line, are determined and vertically scaled from their location on the datum. The completed profile fence diagram is shown in Map 3-6. This map has a vertical exaggeration of 7x. The two sets of profile lines connect points identifying their respective surfaces.
PROFILE FENCE DIAGRAM (PFD)

Superimposed Relief Surface Map
of the
Madison Limestone and Shelby Ground Surfaces

Map 3-6

Vertical Scale

Vertical Exaggeration ≈ 7x
All horizontal measurements must be
made along baseline; vertical measurements
parallel to vertical fence posts. Posts are
perpendicular to bottom neat line.

Source: Configuration of the top of the Madison Group,
Shelby 1 x 2° Quad, Montana, by R.D. Feltis.

2/86
The shading and pattern symbols aid in identification of surface relationships between each other and the datum. A stratigraphic fence diagram is usually drawn with opaque fence lines. Opaque fence lines block whatever is directly behind. This is done to decrease the confusion caused by the large number of stratigraphic units. The assumption is that during interpretation blocked features can be inferred by the surrounding visible structure.

Because there are only two layers of interest in this SRS map, it is beneficial to leave the fence lines transparent. The design allows all surface profiles to be viewed and measured despite their position relative to fence lines in the forefront.

Part of the purpose of the map is to give a visual impression of relief for both surfaces and at the same time present the surfaces in such a way as to be measurable. Measurements can be made at any point along the datum by scaling a vertical line to the desired surface. Elevation comparisons can be made between surfaces at a point by simply subtracting heights along a vertical line. Since the datum is planimetrically correct, horizontal measurements can be made between points on any other profile.

The nature of the fence diagram requires considerable visual interpolation to be used to imagine the surface topography in the spaces between fence lines. If correctly chosen, profiles should illustrate all of the important relief features, leaving relatively uncomplicated terrain to fill in gaps.

The datum for Map 3–6 was set at mean sea level. For displaying the Madison and Shelby surfaces, the datum works well. Where the Madison surface drops below the datum it is still easily identified by the structure symbol extending
to the surface line. Examples of this situation can be seen at the ends of the fences to the far right of Map 3-6. Measurements below sea level are simply made along the vertical as before.

3.5.6. Hypsometric Perspective Map (HPM)

This SRS map uses the powerful image created by a computer perspective and hypsometric tints displayed on an isometric plane, as shown in Map 3-7. The blending of these representation types offers a clear view of the Madison surface through a colorful, transparent hypsometric map of the Shelby.

The perspective image of the Madison surface uses the same data as the perspective stack map. The only difference is the increased scale of the HPM. The Shelby plane was constructed by using the similar squares technique of changing scale or projection.\(^{56}\) Selected contours for elevation ranges were transferred from the source map to the correctly scaled isometric plane. Hypsometric tints were then applied to elevations occupying these ranges.

The effectiveness of hypsometric tints in portraying elevation zones depends on the color relationship between the map and reality. As we observe the earth in daily life we come to associate certain colors with different land areas or cover types. The hypsometric map must utilize earth tones that will be recognized and associated with a progression in elevation. This selection of effective colors presents a difficult problem. Imhof suggests that the aim of color selection is to

HYPSOMETRIC PERSPECTIVE MAP (HPM)

Superimposed Relief Surface Map
of the
Madison Limestone and Shelby Ground Surfaces

Map 3-7

Madison Surface

Shelby Surface

Elevation in feet:

- over 6000
- 5000-5999
- 4200-4999
- 3800-4199
- 3400-3799
- 3200-3399
- 3000-3199

Note: height of hypsometric plane above perspective surface is arbitrary

Source: Configuration of the top of the Madison Group,
Shelby 1 x 2° Quad, Montana, by R.D. Feltis.
give "... the greatest possible three-dimensional impression." Many schemes have been developed toward that goal, but none have become standard. The Modified Spectral Scale, utilized in this and the following map, is probably the most widely used method.

A real limitation of hypsometric tints is resolution. The number of elevation intervals are limited to the number of colors which can be easily distinguished on a color scale. The highest number of intervals is approximately ten.

3.5.7. Hypsometric Contour Map (HCM)

The hypsometric contour map, shown in Map 3-8, is a map type presently in common use. It will be analyzed in the same manner as the newly developed maps previously discussed.

The map was constructed by making a diazo print of the Madison surface contours. Selected contour ranges from the Shelby surface were superimposed directly above the Madison surface. These elevation ranges were colored following the Modified Spectral Scale.

---

57 Imhof, Terrain Representation, p. 300.

58 The Modified Spectral Scale is based upon the following color designations, beginning with the highest elevation through the lowest: deep brown or reddish-brown, medium brown or reddish-brown, light yellowish-brown, yellow, light yellowish-green, green, blue-green, deep blue grey-green. This comes from Imhof, Terrain Representation, pp. 302-3.

59 Ibid., pp. 300-11.

60 See preceding section.
HYPSOMETRIC CONTOUR MAP (HCM)

Superimposed Relief Surface Map of the Madison Limestone and Shelby Ground Surfaces

Map 3-8

Madison Surface

Contour Intervals:
- lower elevations = 100 ft.
  - 100
- higher elevations = 500 ft.
  - 1500
- 500 ft. index contours

Shelby Surface

Elevation in feet:
- over 6000
- 5000-5999
- 4200-4999
- 3800-4199
- 3400-3799
- 3200-3399
- 3000-3199

Source: Configuration of the top of the Madison Group, Shelby 1 x 2° Quad, Montana, by R.D. Feltis.
3.5.8. Structure Contour Map (SCM)

The second of two types presently in use, the Structure Contour Map, is shown in Map 3-9. The structure contour map is used often by geologists to study the underlying structure topography only. In this case, both Madison and Shelby topographic information are provided. Feltis describes an important cartographic technique used in structure contour map production: "The presentation of more than one parameter or surface on a map can be accomplished by using various line weights and by screening of the base map as well as contour lines." The object is to provide as much information as possible without causing confusion. The use of colors may also improve readability. This map was made by simply registering the contour film positives mentioned and making a diazo print.

---

STRUCTURE CONTOUR MAP (SCM)

Superimposed Relief Surface Map
of the
Madison Limestone and Shelby Ground Surfaces

Map 3-9

Madison Surface
Contour Intervals:
lower elevations = 100 ft.

higher elevations = 500 ft.

500 ft. index contours

Shelby Surface
Contour Interval = 200 ft.

Source: Configuration of the
Shelby 1 x 2° Quad,
3.5.9. Video Images

One final note concerns an SRS mapping technique based upon the use of television cameras and videotape. This experiment was inspired by J. W. Thrower when, in 1959, he urged cartographers to take the lead in utilizing animation for mapping purposes. Movement is perceived due to the eye's ability to retain "... an image of an object momentarily after the object has been removed." Therefore, a series of images slightly different from the preceding image will give the impression of smooth, continuous movement of the object.

The concept of the eye retaining an object image momentarily after it has been removed lead the author to consider taking relief maps of two surfaces, exposing them one after another in rapid succession, to create a SRS image.

To produce a video tape, the planimetrically shaded relief maps used in the shaded relief contour SRS maps were used. Each was mounted in front of a television camera and carefully registered on a television monitor. The system is shown in Figure 3-5.

Each map being scanned by its own camera enables the monitor to accept the image of either camera through the use of a controlling switch. Superimposed dissolving or flicker switches were used to change from image to image. The dissolving switch replaces one image by filling in with a new image as the old one gradually "dissolves" from the screen. The flicker switch simply turns one camera

---


63 Ibid., p. 10
on and the other off. The flicker transition is not as smooth as a dissolve, but it is quicker.

A number of attempts were made to create an image that would leave solid impressions of a previous relief image while viewing another. The method was unsuccessful with respect to images being imprinted in our memory and relating it to another flashed in front of the viewer.

It was successful in allowing the user to study one map at a time and quickly see a feature on either surface and its relation to another.

Due to the unavailability of video tape players during interview sessions, this
attempt at SRS mapping was not included in the analysis of Chapter 4.

3.5.10. Other Possibilities

The importance of video technology, holography, and real time computer animation should not be overlooked. Dutton claims that computer map animation provides four dimensions of reality, including time. The usefulness of animation for the presentation of temporal information cannot be denied.

When viewing a complex three-dimensional surface, there are a number of viewpoints offering important information. Animation allows the surface to be exposed from any angle through a series of continuous changes. "Real time" animation describes the ability to manipulate the image while it is being processed. The user has control of the image and can view it from angles determined interactively. The potential for SRS applications are numerous using this technology.

---


65 Rowles, "Perspective Block Diagrams," p. 34.

Chapter 4

ANALYSIS OF EFFECTIVENESS

4.1. Map Interpretation

A certain amount of education is required to understand any map. Robinson and Petchenik discuss interaction between sensory organs and intellect for the reconstruction of reality from a map. An observer’s senses are bombarded with unordered stimuli. It is up to the observer’s intellect to organize the sensual input. Often the complexity of actual phenomena, added to the complexity of a map representation, can cause the frustrated map user to give up mentally. Confusion arises out of the difficulty involved in organizing the sensual input.

The user’s inability to form a solid intellectual image of phenomena, even with the help of a map, may lead him to question the existence of the phenomenon. He may simply treat incomprehensible map symbols as irrelevant, despite their importance. This does not imply that the map user, who does not comprehend a highly complex map, is intellectually deficient. Perhaps the

67 Petchenik and Robinson, Nature of Maps, p. 69.

68 Ibid., p. 70.

69 An excellent discussion of why our eyes scan a map as they do and associated intellectual steps involved in viewing can be found in Henry W. Castner and J. Ronald Eastman, “Eye Movement Parameters and Perceived Map Complexity,” American Cartographer 11 (October 1984): 107-17.
cartographer is at fault. The map is such a powerful a tool for representing reality that, when it fails, we should expect the user to doubt reality.\textsuperscript{70}

Wright claims, "The qualities of integrity, judgment, critical acumen, and the like are as much required in the interpretation of maps as in preparation of them."\textsuperscript{71} This clearly indicates the need for education and sensitivity when interpreting a map. Responsibility for producing an effective map does not lie solely with the cartographer.

Map users not familiar with the concept of contours for relief display may not be able to use a topographic quadrangle map effectively during cross-country travel. However, after a short explanation of contour principles, most users are apt to be much better prepared for their back-country trip. The same holds true regarding SRS maps. Faced with an unfamiliar SRS map to interpret, users may be able to utilize the map to its fullest capacity, but probably not.

Interviews used to determine the effectiveness of the SRS maps presented in the preceding chapter utilized participants with little or no background in SRS map reading skills. It is important to note that interview participants had very little time to familiarize themselves with the SRS maps. Their comments regarding an SRS map's effectiveness are based upon previous map reading experience and first

\textsuperscript{70} Misconceptions about the actual areal extent of Greenland is an excellent example of how maps are taken for face value by most people. The average reader of Mercator's projection will not perceive the incredible enlargement in scale occurring as one approaches the poles as anything unusual. Confusion and disbelief appear when the reader is tutored on the actual size relationships between Greenland and countries located near the equator.

impressions of the new technique combinations.

4.2. Interview Background

To determine the effectiveness of the various SRS presentations, interviews were done using professors and other professionals who work with maps on a daily basis. Professionals were chosen because of their map reading expertise and their ability to express themselves in a manner providing helpful comments and constructive criticism. The nature of the problem requires a solution that would be clearly perceived only by a select audience. Geologists and hydrogeologists are particularly suited to thinking in terms of superimposed relief surfaces. The intent behind choosing this sample population was to select map users who clearly understand the SRS mapping problem or are familiar enough with mapping techniques and capabilities in general to understand the problem with only a quick explanation. This strategy eliminated users who might not know how to read contour lines or comprehend other concepts employed in SRS mapping.

Interview participants are listed as follows:

* Professor David A. Alt, Geology, University of Montana, Missoula, Montana
* Stan Bain, Supervisor, Geometronics Division, Flathead National Forest, Kalispell, Montana
* Clinton D. Crider, Mapping Supervisor, Montana Department of Highways, Helena, Montana
* Gerald Daumiller, Cartographer, Montana Department of Highways, Helena, Montana
* Carl H. Key, Research Geographer, Glacier National Park, Montana
* Professor Robert Taylor, Earth Sciences, Montana State University, Bozeman, Montana
* Kurt Tueber, Remote Sensing Specialist, College of Forestry, University of Montana, Missoula, Montana
Each participant was interviewed separately. Interviews took place wherever it was convenient for the participant, usually in their office or an adjacent room with a table.

To begin the interview, the following introductory statement was read concerning the objectives of the thesis and the definition of an SRS:

The purpose of this thesis is to examine the visualization problems involved in superimposed relief surface maps. In addition, it will compare the effectiveness of graphic methods now in use to alternative methods presented by the author.

The term, superimposed relief surface describes any number of surfaces superimposed upon one another where each surface has its own relief which may or may not be affected by the relief of surrounding surfaces. A superimposed relief surface map is simply any representation, in map form, of an SRS.

If any confusion remained after this introduction, further explanation was given using an actual example of an SRS. An oral description of the situation existing between the Madison and Shelby surfaces proved to be enough to clarify the terms and their intent. A clear understanding of the mapping problem was necessary before materials presentation and actual questioning began.

Participants were given the perspective stack map and its associated legend, then allowed a few moments to study the presentation. The following questions were then asked regarding the map in hand:

1. Does the legend and map provide enough symbolization for you to mentally construct two surfaces? In other words, can you recognize the existence of two unique surfaces?
2. Is it simple to determine which surface is the upper and which is the lower surface?
3. Is the detail great enough to examine the spatial relationship between a feature on one surface and the corresponding point above or below?
4. Are the scales helpful and easily applied?
5. What would you say were the strong points of the presentation?
6. What would you say were the weak points of the presentation?
7. Is this visual presentation especially irritating or pleasing?

Each of the maps were presented in this manner and responses recorded by the author.\textsuperscript{72}

After all the maps had been studied and questions asked, the maps were laid out in plain view for ease in recalling each of the presentations. Participants were then asked to rank each map according to two criteria: first, according to its visual effectiveness, second, its metric capability.\textsuperscript{73} This completed the interview. Each interview lasted approximately one to one and one-half hours. Participants were encouraged to comment on all aspects of the presentations.

4.3. Interview Questions: Types and Breakdown

The seven questions asked during the interviews can be divided into groups based either on the form of the response or whether they are oriented more toward the visual or metric attributes of the map. "Form of response" refers to whether a question can be answered with a positive, negative, or neutral response (Questions 1, 2, 3, 4, and 7); or, by an open-ended discussion (Questions 5 and 6). "Visual or metric attributes" refer to questions which pertain to either the visual or metric qualities of the maps. The following paragraphs identify which way each of

\textsuperscript{72} Responses such as "I don't know" or "undecided" were entered as negative responses.

\textsuperscript{73} For operational definitions of visual effectiveness and metric capability see page 7 in Chapter 1.
the questions is oriented, along with a brief discussion of each.

Question 1 is visually oriented and very basic. It asks the reader if the map supplies him with the minimum amount of data required for recognition of more than one surface. This is very important because an image that does not help the reader distinguish between two unique surfaces would be practically useless for visual SRS study. Although the reader may not be able to mentally "see" two entire surfaces, the portions of the presentation he is able to decipher may allude to the existence of two surfaces. With this knowledge, he may still be capable of some practical measurements. A participant may have answered "no" to Question 1 because of confusion arising out of a kind of initial "shock" received from viewing an unusual, unfamiliar map. As questioning continued, participants may have begun to recognize two surfaces. If so, answers to the remaining questions would become more objective.

Question 2, like Question 1, is visually oriented. In addition, it expands upon simple visualization of two surfaces by asking if the reader can easily identify the vertical relationship regarding each plane's location in space. This question is further acknowledgement of the existence of two recognizable surfaces. If the reader identifies a distinction between a lower and upper surface, the map becomes increasingly useful.

Question 3 is metrically oriented. If a user is provided with enough detailed information, he should be able to recognize a point-to-point relationship between surfaces. Without this quality, the map will not allow intersurface measurements to be made. Unless one is studying an SRS map on a casual basis, measurability
is very important.

Question 4, like Question 3, is metrically oriented. Scales are an integral part of a map’s metric capability. Without appropriate scales, a map might be rendered completely ineffective.

Questions 5 and 6 are open-ended questions that are neither visually nor metrically oriented. They were designed to allow participants to elaborate on their impressions of the SRS maps.

The final question, before the participants were asked to rank each map, was Question 7. It is a visually oriented question and deals with the attractiveness of the SRS maps. A map not aesthetically appealing may alienate potential map users, despite the usefulness of the map.

4.4. Interview Results

The remainder of this chapter is divided into four sections. The first presents results from Questions 1, 2, 3, 4, and 7. The second is a discussion drawn from the results of Questions 5 and 6, pertaining to a map’s strong and weak attributes. The third section contains the results of the rankings which concluded the interviews. The final section offers a discussion that compares results from each of the previous analyses.
4.4.1. Responses to Questions 1, 2, 3, 4, and 7

Figure 4-1 graphically shows the complete results of Questions 1, 2, 3, 4, and 7. As the results for each question are discussed, a condensed table is presented for that particular question. This is done as a quick reference aid to the reader. Comparison of results between the questions may be done through the use of Figure 4-1.

4.4.1.1. Question 1: Does the map display two surfaces?

Table 4-1 shows the number of positive responses to question one for each of the map presentations. The maximum number of positive responses equals the number of participants (eight).

Results in Table 4-1 show the HPM and the SCM to be very effective in presenting two distinguishable surfaces. The strength of the HPM comes from the two completely different relief presentation methods combined into one map. The obvious three-dimensionality of the Madison surface computer plot clearly distinguishes it from the Shelby hypsometric plane above. The SCM uses a mapping technique found in geology and familiar to most earth scientists. This familiarity undoubtedly was a factor involved in the high scores received by this map.

Another high scoring map is the PFD, providing the user with a number of profiles. The profile technique offers visible and measurable vertical displacement.

---

74 Please note that each of the maps discussed has been given an abbreviated title. These abbreviations will be used throughout this chapter and Chapter 5. As a reminder, a table of definitions can be found on page 35. Graphic examples of each SRS map can be found from the List of Maps in the front matter.
Figure 4-1: POSITIVE RESPONSES TO QUESTIONS 1, 2, 3, 4, 7

SRS Map Types

<table>
<thead>
<tr>
<th>PSM</th>
<th>MRM</th>
<th>MRPM</th>
<th>C/SM</th>
<th>S/CM</th>
<th>PFD</th>
<th>HPM</th>
<th>HCM</th>
<th>SCM</th>
</tr>
</thead>
</table>

Number of Positive Responses

0 1 2 3 4 5 6 7 8

Question Numbers

1 2 3 4 7

Visually Oriented Questions (1, 2, 7)

Metrically Oriented Questions (3, 4)
between the surfaces. Where the surfaces intersect or where a number of fence lines arrive simultaneously at a fence post, there is a possibility of some confusion. However, seven positive responses indicate the presentation as being very capable for allowing surface differentiation.

The PSM, also with seven positive responses, draws its strength from the apparent three-dimensionality of the computer plots and their appealing color combinations.

The MRM, with only two positive responses, did a poor job of creating images with two different surfaces. It is interesting to note that the addition of profile lines in the MRPM was a great improvement upon this visual attribute.

4.4.1.2. Question 2: Which is the upper and which is the lower surface?

Results for Question 2 are shown in Table 4-2.

Table 4-2: POSITIVE RESPONSES TO QUESTION 2

<table>
<thead>
<tr>
<th>PSM</th>
<th>MRM</th>
<th>MRPM</th>
<th>C/SM</th>
<th>S/CM</th>
<th>PFD</th>
<th>HPM</th>
<th>HCM</th>
<th>SCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>6</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>7</td>
<td>7</td>
<td>8</td>
<td>7</td>
</tr>
</tbody>
</table>

The two highest scoring maps for this question were the PSM and the HCM. The impression of the Shelby surface “floating” above the Madison undoubtedly is the reason the PSM received the maximum number of positive responses. Also, with eight positive responses, the HCM was proven just as effective. The
landscape character of the two surfaces are very different, shown by the detail level of the contours. The combination of tints and contours in the HCM apparently made it easy to place the Shelby surface above the Madison.

Similar to the results in Question 1, the PFD, HPM, and SCM all remain as high scorers. The PFD, with its mean sea level datum, helps considerably in identifying vertical-locational relationships. The HPM remains strong because, similar to the PSM, it gives the impression of one surface “floating” above another. The SCM remains high scoring probably because of the familiarity of the presentation method.

The MRM improved considerably from Question 1. By studying the surfaces in an isolated area of one to four grid intersections, the length of the colored lines clearly indicates which surface is higher. Despite not being able to easily see two entire surfaces, determination of vertical relationships at many points across the image contributed to its improved scoring. The addition of profile lines, as in the MRPM, caused some confusion in the vertical dimension by slightly interfering with rods on other grid lines. However, the MRPM only lost one positive response as a result.

Two maps were very confusing in terms of the vertical position of the surfaces: the C/SM and S/CM. The S/CM is slightly less confusing since the relief shading emphasizes the presence of stream beds. This indicates that this surface has been exposed to the forces of erosion and helps to identify it as the Shelby surface.
4.4.1.3. Question 3: Is there a clear point-to-point relationship between the surfaces?

Results from Question 3 are shown in Table 4-3.

Table 4-3: POSITIVE RESPONSES TO QUESTION 3

<table>
<thead>
<tr>
<th>PSM</th>
<th>MRM</th>
<th>MRPM</th>
<th>C/SM</th>
<th>S/CM</th>
<th>PFD</th>
<th>HPM</th>
<th>HCM</th>
<th>SCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>2</td>
<td>8</td>
<td>7</td>
</tr>
</tbody>
</table>

The most noticeable change from the first two questions is the failure of the PSM and HPM to provide a one-to-one, intersurface relationship. The arbitrary placement of the upper surface causes great difficulty in visually tracing vertical lines between surfaces. Although the maps are isometric projections, the vertical undulations of the relief makes it nearly impossible to locate the coordinates of any particular point on the surface relative to the datum base. Only a very general correspondence is apparent in small sections of the image.

The HCM and SCM are effective because they are planimetric and depend upon contours. Elevations at any point on either surface can be quickly determined by a straight line interpolation.

Responses to the remaining maps tended to be marginal. Neither the MRM, MRPM, nor PFD provide information for the entirety of either map surface; large areas remain vacant. Where mapped information does exist, it displays good intersurface relationships. Indeed, for those particular points, the vertical displacement of the two surfaces can be measured precisely.

A major fault with the C/SM and S/CM, despite the planimetric representation of both surfaces, is that exact elevations are available only for the contoured
surface. However, one is able to view many relief features on both surfaces. A hill displayed by relief shading on one surface is obviously unique if there are no contours indicating a hill on the other surface.

4.4.1.4. Question 4: Are the scales helpful and easily applied?

This question was asked without requiring a task to be performed. The results would undoubtedly be different if the interviewees had actually attempted to make measurements. As it stands in most cases, however, participants found the scales necessary, helpful, and easily applied. Results from Question 4 are shown in Table 4-4.

Table 4-4: POSITIVE RESPONSES TO QUESTION 4

<table>
<thead>
<tr>
<th></th>
<th>PSM</th>
<th>MRM</th>
<th>MRPM</th>
<th>C/SM</th>
<th>S/CM</th>
<th>PFD</th>
<th>HPM</th>
<th>HCM</th>
<th>SCM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
<td>8</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>8</td>
<td>7</td>
</tr>
</tbody>
</table>

Scoring the lowest was the HPM with six. This is probably because of the difficulty anticipated in measuring between two completely different relief presentation methods. The most surprising result from Question 4 is the eight, scored by the PSM. The author felt that the difficulty of measuring on a three-dimensional, isometric projection, and the rather arbitrary placement of the upper surface would make this the most difficult map for taking measurements. Participants considered this, but recognized the scales as general guides, not as precise measuring tools.
4.4.1.5. Question 7: Is the map irritating or pleasing?

This question deals with the attractiveness of the presentations. A beautiful map creates a more willing audience; viewers tend to be more receptive to the message being sent. A map that was found pleasing received a positive designation. Results are shown in Table 4-5.

Table 4-5: POSITIVE RESPONSES TO QUESTION 7

<table>
<thead>
<tr>
<th>PSM</th>
<th>MRM</th>
<th>MRPM</th>
<th>C/SM</th>
<th>S/CM</th>
<th>PFD</th>
<th>HPM</th>
<th>HCM</th>
<th>SCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>7</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>

Interestingly, none of the maps received eight positive responses. Of the two maps receiving seven positive responses, the PSM results were anticipated. This map seems to hold a fascination because of color and three-dimensional appearance. The interplay of shadow and light, and smooth character of contour lines on the S/CM caused it to perform higher than the remaining seven.

Interpretation of an overwhelming number of little lines was the main reason behind the low scores aquired by the MRM and MRPM. These lines create frustration and clearly affect the attractiveness of the maps. Some participants expressed their difficulty in holding the map images together visually. Occasionally, they would apparently invert, causing a great deal of confusion.

The PFD and SCM also had very poor showings. The lack of color was a debilitating factor for both maps. Confusion because of line quality and the sheer volume of data contained in the SCM were probable causes of its poor performance.
4.4.2. Ranking Developed from Questions 1, 2, 3, 4, and 7.

Recall from page 81 the discussion on question orientation. Using the average number of positive responses from the visually oriented and metrically oriented questions, the rankings shown in Table 4-6 were developed. There are three rankings: the first ranks the collective evaluations of the participant's concerning the visual effectiveness of the maps (Questions 1, 2, and 7); the second ranks their evaluation of the metric effectiveness (Questions 3 and 4); and the third ranks their evaluation of the overall effectiveness based on all of the questions, with the exception of the open-ended ones. It must be emphasized that these rankings represent only the responses to the visual and metric questions. Later, the respondents were asked to produce their own ranking of the maps. This ranking will be dealt with shortly. Comparisons between the results presented in Table 4-6 and the participants own rankings can be found in the Conclusion section of this chapter.

4.4.3. Interview Questions--Open-Ended

Questions five and six were open-ended questions allowing participants to elaborate on their impressions of the presentations. Each map received comments regarding strong points and weak points. A complete listing of the responses would be impossible to include here. What follows is a collection of brief comments by interview participants, edited by the author to avoid redundancy.

---

75 Maps with identical averages indicate a tie.
Table 4-6: RANKING DERIVED FROM QUESTIONS 1, 2, 3, 4, AND 7

<table>
<thead>
<tr>
<th>Rank</th>
<th>VISUAL Map</th>
<th>VISUAL x</th>
<th>METRIC Map</th>
<th>METRIC x</th>
<th>COMBINED Map</th>
<th>COMBINED x</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PSM 7.3</td>
<td></td>
<td>HCM 8.0</td>
<td></td>
<td>HCM 7.2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>HPM 7.0</td>
<td></td>
<td>MRM 7.0</td>
<td></td>
<td>PSM 6.4</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>HCM 6.7</td>
<td></td>
<td>SCM 7.0</td>
<td></td>
<td>SCM 6.4</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>SCM 6.0</td>
<td></td>
<td>PFD 6.5</td>
<td></td>
<td>HPM 5.8</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>PFD 5.3</td>
<td></td>
<td>MRPM 6.0</td>
<td></td>
<td>PFD 5.8</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>S/CM 5.0</td>
<td></td>
<td>C/SM 5.5</td>
<td></td>
<td>S/CM 5.2</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>MRPM 3.7</td>
<td></td>
<td>S/CM 5.5</td>
<td></td>
<td>MRPM 4.6</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>C/SM 3.3</td>
<td></td>
<td>PSM 5.0</td>
<td></td>
<td>MRPM 4.6</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>MRM 3.0</td>
<td></td>
<td>HPM 4.0</td>
<td></td>
<td>C/SM 4.2</td>
<td></td>
</tr>
</tbody>
</table>

The discussion has been organized with every map discussed individually in regard to its strengths and weaknesses.

4.4.3.1. PSM Strengths

Initially, one is struck by the bright colors which make this map pleasing to view. Once the reader begins to focus on the function of the image, it is relatively easy to distinguish two unique surfaces. The topography of both surfaces is displayed well and leaves a very good impression of how the separate surfaces are related. The vertical exaggeration of both is effective; it creates a clear distinction between them. The line weights and densities provide solid image planes, yet allow enough transparency to view both planes simultaneously. The legend is well-prepared and an effective aid in map interpretation. This map is considered very effective visually.
4.4.3.2. PSM Weaknesses

The most glaring weakness of this presentation is the lack of metric capability. The absence of a datum is a severe disadvantage and makes any measurements quite inaccurate. Because it is not in planimetric form, it is difficult to observe a one-to-one correspondence between the surfaces. For this reason and because of confusion occurring as a result of each surface having different vertical exaggerations, it is not possible to gain an accurate impression of the spatial relationships between the surfaces.

A problem inherent in any type of three-dimensional perspective is blocking. Blocking occurs when relief, existing between an observer and a point of interest, obscures the view because of its height or the viewing angle of the image. Despite following guidelines to provide the "best" view, there will always be areas hidden behind relief features located toward the front of the image. One respondent felt the line density on the Madison surface was too high.

4.4.3.3. MRM Strengths

The grid is very effective in providing a solid datum from which to work. Each location containing a rod provides an exact one-to-one correspondence; this allows for quick vertical comparison. All rods can be measured exactly, both vertically and horizontally, by following lines parallel to the grid. The detail level, or the number of grid intersections, was agreed upon as being appropriate for an image of this scale.
4.4.3.4. MRM Weaknesses

Most of the participants felt the MRM's visual capability was very poor. Reasons for this ineffectiveness include weak color contrast, inferior line quality, and a tendency for the image to invert optically. Trying to interpret the relief over large areas was difficult because the high density of lines overload the reader's visual sense. Another weakness was the ability to obtain measurements only at grid intersections. This only allows single-point interpretation as opposed to continuous-surface interpretation.

4.4.3.5. MRPM Strengths

Many of the comments made regarding this map can be found above in the strengths section of the MRM. Additional comments mostly concerned the increased quantitative capability resulting from the ability to perform interpolations between the profile lines and the datum base. Several of the participants seemed to enjoy the colorful presentation.

4.4.3.6. MRPM Weaknesses

Like the MRM, the MRPM provided surfaces which were difficult to visualize. One respondent commented that the diagram looked like a series of telephone or power lines. The line thickness directly affects the strength of the colors and was considered ineffective. Confusion was the general consensus.
4.4.3.7. C/SM Strengths

This map employs the standard mapping techniques used for creating contours and shaded relief. Contours give a good impression of vertical displacement, and shading adds to the overall attractiveness of the map. Because it is planimetric, a one-to-one correspondence between the surfaces exists across the map. This mapping technique enables the cartographer to emphasize one surface by using contours, yet provide general information on another surface by using shaded relief.

4.4.3.8. C/SM Weaknesses

The most apparent weakness of the C/SM is its failure to provide quantitative data for the shaded relief surface. This eliminates the possibility of metric comparison between the surfaces. There is also no visual relationship to guide the user in determining which surface is the upper or lower. This must be determined through the use of a legend. The character of the Madison surface makes the shading incomprehensible in some parts of the map. The lack of detail in these areas makes the Madison topography difficult to distinguish. This contrasts with the Shelby contours which were considered too detailed for the users needs by some of the participants.
4.4.3.9. S/CM Strengths

It is easier to see two surfaces on this map, compared to the C/SM. It seems more natural to look at shading occurring on an exposed erosion surface than it does to see it representing a subterranean surface. The shaded stream beds aid in two ways: first, they give the user an idea of the general slope; and second, they clearly identify the shaded Shelby surface as the upper surface. It is easy to interpret the planes on an individual basis. Both surfaces are planimetric so the horizontal spatial relationships are preserved. As in the C/SM, the result is pleasing to the eye.

4.4.3.10. S/CM Weaknesses

Lack of metric ability is the most obvious weakness. There is some confusion caused by the occasional contour which is left disconnected. It was felt that considerable preknowledge of the area was necessary to correctly interpret this map.

4.4.3.11. PFD Strengths

The interviewees generally found it easy to distinguish between the two surfaces of this map. Along any fence line, vertical measurements can be accurately made. The ability to visually examine the vertical relationships clearly, although limited to fence lines, is very helpful.
4.4.3.12. PFD Weaknesses

To some, the map was confusing due to the absence of a geographic reference, ineffective patterns used to distinguish the surfaces, and optical inversion of the image. An inherent weakness in a fence diagram is the nonexisting detail in the large areas which fall between fence lines. One can infer a continuous surface, but it is not measurable at any point not along a profile.

4.4.3.13. HPM Strengths

The strongest feature of this map is its artistic quality. It is colorful, simple, clear, and provides a nice impression of both surfaces and their vertical relationship. Two surfaces are obvious; and, if the Madison surface was of primary interest, one could gather much information from this presentation. Respondents seemed to find this the most attractive of the maps discussed.

4.4.3.14. HPM Weaknesses

Again, deficient metric capability was a major fault. Poor correlation between surfaces confounded some of the viewers and made it difficult to establish vertical relationships both visually and metrically. Two respondents found this particular combination of relief presentation methods especially confusing. The Shelby surface appears flat because the tints are restricted to a plane.
4.4.3.15. HCM Strengths

This map has excellent point-to-point correspondence. It is easy to recognize two surfaces. Colors and contours clearly show information pertaining to different surfaces. The vertical scaling in the tints is effective. Simplicity, clarity, and coloration work to the benefit of this presentation.

4.4.3.16. HCM Weaknesses

Without the use of a legend, it is difficult to determine which surface is above or below. Broad elevation tint ranges obscure the detail of the lower surface, especially at higher elevations, and makes for difficult terrain interpretation. Some participants found the presentation too colorful; others found it boring.

4.4.3.17. SCM Strengths

This map uses contours to display both surfaces. Contour lines are the most common method of showing relief at present. The technique is widely understood and has the advantage of displaying elevations in a quantitatively precise manner. The SCM displays intricate detail for both surfaces in precise correspondence with one another.

4.4.3.18. SCM Weaknesses

No coloration, excessive detail, and continual crossing of contour lines, all contributed to reader confusion. This map could not be casually read. Two levels of contour resolution illicited the comment that only skilled users could effectively interpret this map.
4.4.4. Notes Regarding Map Attributes

All of the comments found in the preceding section are based on a relatively short exposure time to each of the maps. It is only natural for the participants to miss certain attributes that contribute to, or decrease, the effectiveness of a map. As mentioned at the beginning of this chapter, education or familiarity with a mapping technique is the best preparation for understanding a map's true capabilities or flaws.

There were a number of cases in which respondents contradicted one another. Criticisms from some, such as "too colorful," "too much vertical exaggeration," or "too much detail" would be interpreted by others as satisfactory. In an attempt to arrive at conclusions based upon this vast amount of subjective data, participants were asked to rank each map twice: once in relation to its visual effectiveness in portraying an SRS and again in terms of its metric capability.

4.5. Assigned Ranking Procedure

The purpose behind having the participants do a ranking of the maps was to obtain objective data for comparison with the more subjective results presented in earlier sections. It is much more practical to claim one map is "better," or "more effective," than another by using ordinal data derived from a ranking procedure than it is to depend upon a simple discussion of impressions.

The eight interview participants who did the ranking represented a population consisting of people well-aquainted with the use of maps. The ranking was the

---

76 For further discussion of participant selection criteria and a list of participants, please refer to the discussion on page 79, of this chapter.
final step of the interview. By this time, participants had studied each map for at least five minutes. In the course of that time, they had been asked seven questions concerning various aspects of the maps. They were considered fairly well-aquainted with the maps. The ranking was done in a manner described in the following paragraph.

All of the SRS maps were laid out in plain view. Interviewees were asked to first rank them with regard to visual effectiveness. They ranked the maps in order from most effective to least effective. The ordinal ranking was based upon a scale from one to nine, with one map occupying each slot. In this scheme, each map could be identified by its effectiveness in relation to all of the others. In this same manner, the metric ranking proceeded.

4.6. Assigned Ranking Results

Tables 4–7 and 4–8 show the frequency of rank responses for each map. As an example of how to interpret these tables, please refer to Table 4–7 during the discussion below:

Each rank assigned by a participant was given a weighted score. A map that received a first place rank would obtain a score of nine. A map receiving a second place rank would obtain a score of eight, and so on down to a ninth place rank, with a score of one. In this way, the more high rank responses a map received, the higher its cumulative score. For example, the PSM results from Table 4–7 show five participants ranked it first, two ranked it second, and one ranked it fifth. The cumulative scores combining the rankings of all of the participants were
Table 4-7: FREQUENCY TABLE OF ASSIGNED VISUAL RANKS

<table>
<thead>
<tr>
<th>ASSIGNED RANK</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAP Weighted Scores ($x_i$)</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>PSM</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRM</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRPM</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C/SM</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/CM</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PFD</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HPM</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCM</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCM</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Score: $\sum f_i \cdot x_i$

where: $f_i$ = the frequency of responses

$x_i$ = the weighted score determined by an assigned rank

An average was then taken by dividing 66 by the number of participants (eight). Hence, the PSM under the visual category received an average ranking of 8.25 out of a possible nine. All of the average values in Tables 4-7 and 4-8 were calculated with the following formula:

$$\text{score} = \sum f_i \cdot x_i$$

For the PSM this translates into a final score of:

$$(9 \times 5) + (8 \times 2) + (5 \times 1) = 66$$
It is interesting to note the vast differences of opinion exhibited in a few cases. These differences created an absence of central tendency; or, in other words, a high variance in the data. The variance ($s^2$) and the estimated mean standard deviation ($s_{\bar{x}}$) are shown in the final two columns of Tables 4-7, 4-8, and 4-9. The variance is calculated using

$$s^2 = \frac{SS}{n-1}$$

where: $n=8$

$$SS = \frac{\sum f_i \cdot x_i^2 - (\sum f_i \cdot x_i)^2}{n}$$

The value $s_{\bar{x}}$ is required for calculation of the Student's $t$ test used later in this chapter. It is derived from the following formula:
Examples of data showing high variance include the PFD, SCM, and HPM from Table 4-7. Table 4-8 shows high variance for the MRPM, MRM, SCM, and S/CM.

It was not feasible to have interviewees calculate, or weigh in their minds, the many factors necessary to determine a ranking combining visual and metric criteria. Therefore, to determine a combined ranking, the frequencies of responses and the assigned rankings appearing in Tables 4-7 and 4-8 were combined, producing the results presented in Table 4-9. Table 4-9 uses identical techniques for the calculation of scores, but the combination of frequencies doubles the number of participants to sixteen. This new value becomes \( n \) in any further calculations where combined data is used.

<table>
<thead>
<tr>
<th>RESPONSE FREQUENCY ( f_i )</th>
<th>MAP</th>
<th>PSM</th>
<th>9 8 7 6 5 4 3 2 1</th>
<th>Weighted Scores ( x_i )</th>
<th>( \Sigma f_i x_i )</th>
<th>( \bar{x}_i )</th>
<th>( s_i^2 )</th>
<th>( s_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSM</td>
<td>5 2</td>
<td>1 1 3 3 1 1 94</td>
<td>5.88</td>
<td>7.85</td>
<td>0.70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRM</td>
<td>2 2 3</td>
<td>2 2 5 72</td>
<td>4.50</td>
<td>10.53</td>
<td>0.81</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRPM</td>
<td>1 1 2 2 3 5 2</td>
<td>64</td>
<td>4.00</td>
<td>7.20</td>
<td>0.67</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C/SM</td>
<td>2 2 4 1 5 2</td>
<td>53</td>
<td>3.31</td>
<td>1.86</td>
<td>0.34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/CM</td>
<td>1 2 2 2 2 2 5</td>
<td>52</td>
<td>3.25</td>
<td>4.33</td>
<td>0.52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PFD</td>
<td>3 3 3 1 4 1 1</td>
<td>73</td>
<td>4.56</td>
<td>3.60</td>
<td>0.47</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HPM</td>
<td>1 2 1 3 5 2 1 1</td>
<td>88</td>
<td>5.50</td>
<td>3.33</td>
<td>0.46</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCM</td>
<td>4 4 4 1 2 1 1 16</td>
<td>116</td>
<td>7.25</td>
<td>2.47</td>
<td>0.39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCM</td>
<td>3 5 2 2 1 1 2</td>
<td>108</td>
<td>6.75</td>
<td>4.20</td>
<td>0.51</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4-10 is a summary with the maps placed in rank based upon the average values calculated in Tables 4-7, 4-8, and 4-9. For example, the PSM is ranked first visually, seventh metrically, and third combined.

Table 4-10: SUMMARY OF ASSIGNED RANKINGS

<table>
<thead>
<tr>
<th>RANK</th>
<th>VISUAL</th>
<th>METRIC</th>
<th>COMBINED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PSM</td>
<td>SCM</td>
<td>HCM</td>
</tr>
<tr>
<td>2</td>
<td>HCM</td>
<td>MRM</td>
<td>SCM</td>
</tr>
<tr>
<td>3</td>
<td>HPM</td>
<td>HCM</td>
<td>PSM</td>
</tr>
<tr>
<td>4</td>
<td>SCM</td>
<td>MRPM</td>
<td>HPM</td>
</tr>
<tr>
<td>5</td>
<td>S/CM</td>
<td>PFD</td>
<td>PFD</td>
</tr>
<tr>
<td>6</td>
<td>PFD</td>
<td>HPM</td>
<td>MRM</td>
</tr>
<tr>
<td>7</td>
<td>C/SM</td>
<td>PSM</td>
<td>MRPM</td>
</tr>
<tr>
<td>8</td>
<td>MRPM</td>
<td>C/SM</td>
<td>C/SM</td>
</tr>
<tr>
<td>9</td>
<td>MRM</td>
<td>S/CM</td>
<td>S/CM</td>
</tr>
</tbody>
</table>

The combined rank column of Table 4-10 shows the HCM and SCM occupying the top two positions. This is noteworthy because they use the two SRS mapping techniques presently in common use. The PSM and HPM filled the third and fourth positions. They primarily relied on color and three-dimensionality to achieve such a high ranking. The PFD finished in the middle of the rank. As one approaches the bottom of the rank, he sees the two types of rod maps edging out the higher spots over the two shaded relief maps.

The calculation of averages used to determine the ranks in Table 4-10 are very straightforward. However, the validity of these ranks needs to be tested because of the small sample population and unusual variance found in some cases. It must be shown whether or not a map falling into a certain rank is significantly different from any other map.
4.6.0.1. Testing Average Rank Significance

The statistic used to determine the significance of data is the "two-tailed Student's t test". Although the t test is theoretically based upon sample data from a normal population distribution, it is considered robust. This means its validity is only slightly affected by moderate deviations from a normal distribution.77

Application of the Student's t test requires a null $H_0$ and alternate $H_A$ hypothesis. The null hypothesis, $H_0: \mu=5$, states that the hypothesized mean rank of each map will equal 5. The value 5 is chosen to represent the average value of the rankings because of its central location within a range of 1 to 9. The t test is applied to each map in an attempt to prove or disprove $H_0$. If the t test result agrees with $H_0$, this means there is no significant difference between the average value calculated for that particular map (from Tables 4-7 and 4-8) and 5. The map in this case would be considered average.

If, however, a significant difference is found to exist between $\mu=5$ and the average for a given map, the $H_0$ is rejected and the alternate hypothesis, $H_A: \mu=5$, is accepted. If $H_A$ is accepted, the map in question is considered either significantly above or below average. It is above average if the average from Tables 4-7, 4-8, and 4-9 is greater than 5. The opposite holds true for below average.

The formula for the Student's t test is as follows: \[ t = \frac{x - \mu}{s_x} \]

where:
- \( \mu = \bar{y} \) = hypothesized average for entire population
- \( x = \bar{X} \) = sample population average
- \( s = \bar{s} \) = estimate of mean standard deviation

The calculated \( t \) is compared to an assigned value obtained from a table of critical values of the t distribution. It is in this manner one can determine whether a map is above or below average in relation to \( \mu \). The value used here is:

\[ t_{0.05(2)} = 2.365 = \text{critical value} \]

where:
- \( 0.05 = \) the assigned level of significance
- \( (2) = \) indicates a two-tailed t test
- \( 7 = n - 1 = \) the degree of freedom

The result of this will cause each of nine maps to fall into one of three divisions: above average, average, or below average, for both visual and metric criteria. Table 4-11 shows these results, plus the combined results. The combined results were determined using the same techniques.

An excellent example of how the results of the Student's t test, appearing in Table 4-11 establish the significance, or insignificance of the rankings from Table 4-10, is the MRM. In Table 4-10 this map is ranked second metrically, while the HCM is ranked third. Table 4-11, on the other hand, places the HCM in the above average column, while leaving the MRM average. This seems unusual until one

---

\textsuperscript{78} Ibid., p. 98.

\textsuperscript{79} The potential for \( t \) to fall on either side of the critical value makes this test "two-tailed". 
Table 4-11: FINAL T TEST RANKINGS

<table>
<thead>
<tr>
<th>VISUAL</th>
<th>Above Average</th>
<th>Average</th>
<th>Below average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PSM</td>
<td>C/SM</td>
<td>MRM</td>
</tr>
<tr>
<td></td>
<td>HPM</td>
<td>S/CM</td>
<td>MRP</td>
</tr>
<tr>
<td></td>
<td>HCM</td>
<td>PFD</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SCM</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>METRIC</th>
<th>HCM</th>
<th>MRM</th>
<th>PSM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MRPM</td>
<td>MRPM</td>
<td>C/SM</td>
</tr>
<tr>
<td></td>
<td>PFD</td>
<td>PFD</td>
<td>S/CM</td>
</tr>
<tr>
<td></td>
<td>HPM</td>
<td>HPM</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COMBINED</th>
<th>HCM</th>
<th>MRPM</th>
<th>C/SM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MRPM</td>
<td>MRPM</td>
<td>S/CM</td>
</tr>
<tr>
<td></td>
<td>HPM</td>
<td>HPM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PFD</td>
<td>PFD</td>
<td></td>
</tr>
</tbody>
</table>

examines the frequency distribution for the MRM found in Table 4-8. The ninth rank offered by a single respondent carried enough statistical weight to pull it out of the above average category.

Most of the other results of Table 4-11 fall as expected when compared to Table 4-10.

4.7. Conclusions

Table 4-12 was developed for the purpose of aiding the reader in the following discussion. It contains all of the ranking results determined in the preceding sections of this chapter. Unless otherwise noted, the discussion of maps and rankings in the remainder of this chapter is based upon Table 4-12.
Table 4-12: SUMMARY OF RANKING RESULTS

<table>
<thead>
<tr>
<th>Rank</th>
<th>Visual</th>
<th>Metric</th>
<th>Combined</th>
<th>Visual</th>
<th>Metric</th>
<th>Combined</th>
<th>Visual</th>
<th>Metric</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PSM</td>
<td>HCM</td>
<td>HCM</td>
<td>PSM</td>
<td>SCM</td>
<td>HCM</td>
<td>PSM</td>
<td>HCM</td>
<td>HCM</td>
</tr>
<tr>
<td>2</td>
<td>HPM</td>
<td>MRM</td>
<td>SCM</td>
<td>HCM</td>
<td>MRM</td>
<td>SCM</td>
<td>HPM</td>
<td>SCM</td>
<td>SCM</td>
</tr>
<tr>
<td>3</td>
<td>HCM</td>
<td>SCM</td>
<td>PSM</td>
<td>HPM</td>
<td>HCM</td>
<td>PSM</td>
<td>HCM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>SCM</td>
<td>PFD</td>
<td>HPM</td>
<td>SCM</td>
<td>MRPM</td>
<td>HPM</td>
<td>C/SM</td>
<td>MRM</td>
<td>PSM</td>
</tr>
<tr>
<td>5</td>
<td>PFD</td>
<td>MRPM</td>
<td>PFD</td>
<td>S/CM</td>
<td>PFD</td>
<td>PFD</td>
<td>S/CM</td>
<td>PFD</td>
<td>MRPM</td>
</tr>
<tr>
<td>6</td>
<td>S/CM</td>
<td>C/SM</td>
<td>S/CM</td>
<td>PFD</td>
<td>HPM</td>
<td>MRM</td>
<td>PFD</td>
<td>HPM</td>
<td>PFD</td>
</tr>
<tr>
<td>7</td>
<td>MRPM</td>
<td>S/CM</td>
<td>MRPM</td>
<td>C/SM</td>
<td>PSM</td>
<td>MRPM</td>
<td>SCM</td>
<td>MRPM</td>
<td>MRM</td>
</tr>
<tr>
<td>8</td>
<td>C/SM</td>
<td>PSM</td>
<td>MRM</td>
<td>MRPM</td>
<td>C/SM</td>
<td>C/SM</td>
<td>C/SM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>MRM</td>
<td>HPM</td>
<td>C/SM</td>
<td>MRM</td>
<td>S/CM</td>
<td>S/CM</td>
<td>MRM</td>
<td>S/CM</td>
<td>PSM</td>
</tr>
</tbody>
</table>

(brackets indicate a tie)
4.7.1. Perspective Stack Map (PSM)

This map was designed with an emphasis on visual effectiveness. The results shown by the rankings, in addition to strengths mentioned in Question 5, indicate that this goal was achieved. A first place rank was attained from Questions 1, 2, 3, 4, and 7, as well as in the assigned visual ranking. These ranks were significant, as shown by the final t test ranking of above average visually. Metrically, the map was very poor. It had ranks of eighth and seventh from Questions 1, 2, 3, 4, and 7 and assigned metric ranking, respectively. The final t rank of below average metrically was expected.

The exceptional visual effectiveness, coupled with poor metric capability, left it not significantly different from average in the combined t rank.

4.7.2. Multirod Map (MRM)

The MRM, not surprisingly, scored the worst visually in all cases. It takes some imagination to visualize an actual surface fitting across the tops of the rods. Imagination should not be required to this degree on the part of the map reader.

Metrically, the MRM ranked much higher. It tied for second with the SCM in Questions 1, 2, 3, 4, and 7 and held second place in the assigned rankings. Despite its high rank based upon frequency scores, it only received an average metric t rank. This indicates the high rankings derived from Questions 1, 2, 3, 4, and 7, and assigned rankings to be insignificant. If they had been significant, a

---

80Reference to results determined by t tests are made as “final t ranks” or simply “t rank.”
corresponding above average metric t rank would surely have occurred. The HCM, with a slightly lower average, was able to attain an above average t rank, edging out the MRM.

It is obvious, looking at the map, that it was designed with measurability as its main objective. Interview participants noticed this obvious point, but did not feel it excelled at its intended objective. To an untrained eye, the map appears terribly confusing. The confusion destroyed any possible visual effectiveness and severely hampered its metric capability.

4.7.3. Multirod Profile Map (MRPM)

Similar to its cousin, the MRM, the MRPM faired poorly across the rankings. The added profile lines made it better visually, but worse metrically when compared to the MRM. The highest position attained by the MRPM was fourth place metrically in the assigned ranking.

Some participants were baffled by the presentation. It was the only map which received a first and last rank under the same criteria as shown in Table 4–8. The extreme differences of opinion metrically gave it a variance of 7.92. With only eight respondents, the variance could not have been much higher. As a final result, the MRPM was considered average according to the combined t ranks.
4.7.4. Contour Shaded Relief Map (C/SM)

The results indicate the C/SM slightly stronger visually than metrically. The C/SM and its counterpart, the S/CM, did not do well in the metric ranks, scoring below average in every category. Correction of some design flaws would increase the value of this map type. A better shaded relief rendition might possibly help. Colors and spot heights would make it even more useful in many respects.

Perhaps we can blame the poor results of this map on the experimental nature of the final graphic product—not the concept. The author felt the concept to be one of the best offered in this paper. Despite the results, he still sees great potential in this type of mapping. Planimetric in design, beauty in shadow and light, and the three-dimensionality one "sees" in a good shaded relief are all positive factors which can lead to an effective presentation.

4.7.5. Shaded Relief Contour Map (S/CM)

The problems facing the S/CM are similar to the C/SM. The ranks from Questions 1, 2, 3, 4, and 7 place the S/CM sixth in all respects. It was as high as fifth in the visual assigned ranking, which gave it an average rank. It was last metrically which translated into a below average combined rank. Many of the comments found in the preceding section pertaining to cartographic improvements can be reiterated for the S/CM.

It is interesting to note the reaction of the interviewees when presented with this map. It was shown immediately after the C/SM. Nearly everyone breathed a sigh of relief when presented with it. They actually recognized the earth surface
because of the shading in stream channels. This made them much more comfortable with the map. The character of the Madison contour lines are much less threatening than those found on the C/SM. For this reason it was ranked higher than the C/SM in Questions 1, 2, 3, 4, and 7 and in the assigned ranking.

4.7.6. Profile Fence Diagram (PFD)

The PFD was the essence of average. Nobody loved it, and only one respondent really hated it. What the PFD diagram did was provide a satisfactory visual image of the SRS. It also offered a reasonable amount of measurability to make it acceptable in that regard as well.

4.7.7. Hypsometric Perspective Map (HPM)

As in the case of the PSM, the HPM scored high visually and low metrically. It was ranked last metrically in Questions 1, 2, 3, 4, and 7, but fared better at sixth in the assigned ranks. It was a firm sixth place because it was able to remain average in the t ranks metrically, while the PSM, ranked seventh, fell to a below average metric t rank.

The SRS image presented is very striking. It gains attention and sparks interest; its benefits are primarily visual. Because the visual and metric criteria scores essentially cancelled one another out, the HPM remained average in the combined t rank.
4.7.8. Hypsometric Contour Map (HCM)

If any map of those presented can be considered the "best" in all respects, it would have to be the HCM. Scanning Table 4-12, one can see this map occupying the first three places in every column. These places are proven significant by the map's inclusion in each of the above average t rankings. It is not surprising that this map ranked so highly or that it was one of the two SRS maps previously in existence. It is a high quality, accurate, pleasing map.

Elevations can be found for every point to an accuracy of one-half the contour interval. The colors of the hypsometric tints make the map very comfortable for viewing as opposed to the more sterile graphics of the SCM. Although some metric precision is lost due to broad elevation ranges on the hypsometric plane, this characteristic lends itself to the overall high quality of the presentation by reducing confusion.

4.7.9. Structure Contour Map (SCM)

Besides the HCM, the next closest competitor for the top position is the SCM. It was the only other map to receive an above average t rank. It was perceived as excellent metrically, but only average visually. That slight flaw was the only factor which kept it from sharing "the best" status with the HCM.

The SCM's importance actually exceeds the others. Despite some visual confusion associated with criss-crossing of contour lines, it provides the most thorough elevation data possible for both surfaces. This was agreed upon by
interview participants, as is shown by the first place attained in the metric assigned rank.
Chapter 5

SUMMARY AND CONCLUSIONS

Technological advances in earth surveys have provided interested persons with vast amounts of data. These data come from sources as varied as orbiting satellites, to explosions deep underground. In order for a researcher to utilize these data, it must be transformed into a useable medium. For the researcher interested in sharing information with the public, the data, or results, must be reduced to the layman’s level. Often these alterations of the original data set do not result in concise, understandable products.

Cartographers face the data transformation problem in every map they produce. One especially complex problem for the cartographer is the representation of a superimposed relief surface (SRS). This thesis introduced terms in an attempt to identify the problem. In addition, it presented nine maps which were designed to alleviate SRS presentation inadequacies.

The development of each map was discussed. Following map construction, they were analyzed by eight professionals. The analysis was in the form of interview questions. The professionals were also given an opportunity to rank the maps. Questions were designed to solicit subjective responses regarding strengths, weaknesses, and other map attributes. The ranking returned ordinal data with which maps could be rated against one another according to visual, metric, and combined criteria.
The significance of the rankings mentioned above were tested using the Student’s t test. Results from this testing produced a final ranking. This final ranking placed maps in categories of above average, average, and below average for the three criteria: visual effectiveness, metric capability, and their combination.

The results presented in Chapter 4 are a clear indication of some of the challenges facing the cartographer in SRS presentation. Providing visual comprehension and measurability in this multidimensional problem is the goal. The mapping techniques discussed in this paper were limited to two-dimensional sheets of paper. Of the examples presented, each had their strengths and weaknesses.

The four maps that stood out throughout the testing were the PSM, HPM, HCM, and SCM. Of these four, the PSM and HPM were developed by the author. They utilized the power of three-dimensional computer plotting, which gave them their striking visual appeal. Despite their lacking metric quality, they help develop a firm intellectual picture of superimposed relief surfaces in the mind of the reader.

Often we are interested in relatedness. The PSM and HPM provide the user with three-dimensional imagery in which generalized surfaces are displayed relative to one another. These maps have done well to provide for the visual needs of the user. Their use as illustrative aids in a classroom or text is warranted for explanation of geologic concepts. At this point in their development, they are metrically ineffective. Introduction of a datum, spot heights, hypsometric tints, or patterns on the perspective plots will likely increase the versatility and
value of these maps as metric tools.

The HCM and SCM exemplify SRS mapping techniques presently in use. The HCM is the strongest of all the maps, being above average in both visual and metric categories. Taking all the maps and their rankings into consideration, the HCM is considered the best combination of techniques for SRS presentation. The combination of contours and hypsometric tints provide a versatile image satisfying visual and metric needs. These techniques are universally understood by earth scientists—undoubtedly an advantage when comparing them to some of the more unfamiliar techniques used in SRS mapping. The colors clearly identify elevation ranges on the Shelby surface. A direct correlation exists between the surfaces. Every point is measurable to an accuracy of one half the contour interval or tint range. This metric capability is exceeded only by the SCM.

The resolution of the SCM increases the measurement accuracy over the HCM. Although it did not obtain an above average t rank visually, it ranked fourth visually in both Questions 1, 2, 3, 4, and 7 and assigned rankings. This is good considering its lack of graphic quality. The large number of crossing contour lines, differing contour intervals, line quality, and lack of color contribute to its average visual standing. Improvements in design may possibly increase its visual value.

The PFD remained average in all categories. It offers the reader a reasonable visual perspective of the SRS as well as limited metric ability.

The MRM and MRPM were very poor visually. Improvements in color combinations and line quality might be able to bring them into the average t ranks. The MRM was given high ranks metrically which helped elevate it into a combined
rank of average. Metrically, the MRPM did not do as well as the MRM; however, it also received a combined ranking of average. Perhaps the improvements mentioned above, along with increased use and reading ability, would cause more appreciation for these maps.

The C/SM and S/CM were considered average visually but below average metrically. The final result gave them a combined rank of below average. They were probably considered the most unusual of the maps presented. Very flat or gently sloping terrain is difficult to portray using shaded relief. Much of the area of both surfaces contains this type of terrain. Only general impressions of relief can be seen. This, coupled with direct correlation between the two surfaces, gives them their average visual rank. The shaded relief provides information that is secondary to contour information, yet important to the user. Improvements could include spot heights on the shaded relief, higher quality shading, and contrasting colors.

5.1. Suggestions for Further Study

The maps presented are the result of trial and error and were produced with very limited finances. Any further studies to expand cartographic knowledge of SRS mapping should probably be limited to one or two methods at a time. A careful breakdown of each of the map types presented here would be valuable.

The two methods already in use could be improved upon as well. Despite their obvious superiority over other SRS maps, they still have weaknesses. Perhaps a philosophical discussion of why they work well will expose areas in
need of improvement.

As mentioned at the beginning of Chapter 4, education is an important factor in map comprehension. A study of the improvement of map reading ability following explanations of varying detail could guide the cartographer to include additional legend information as an aid to reader education.

The maps presented were not made with specific applications in mind other than simply representing two surfaces. Special visual or metric requirements would lead to technique combinations designed to solve individual needs. This, in turn, would expand general knowledge of SRS mapping.

There are many other possible combinations of relief presentation which could be attempted. As was mentioned in Chapter 1, this is only a beginning step into a realm of many possibilities.
Appendix A

RELIEF PRESENTATION TECHNIQUES

This appendix is provided as reference material to the relief mapping portion of the classification scheme presented in Chapter 3. The various subdivisions contain terms which may not be familiar to some cartographers much less laymen. The list of terms and brief descriptions of each should help the reader identify mapping techniques and understand their location in the classification.

The categories *Universe* and *General*, found to the far left of Figure 3-1, are discussed in detail in the Classification Design section of Chapter 3. Also discussed throughout Chapters 3 and 4 are SRS maps and their components. What is included here is the breakdown of single relief surface maps into members which comprise the lower three subdivisions in the classification.

A.1. Planimetric

A planimetric map refers to a map that displays an area viewed vertically. There is no change in scale across the map. All features fall precisely in relation to one another on the map just as they would in reality. For a map to be planimetric, the area it covers must be small enough so the curvature of the earth will cause only minimal distortion.
A.1.1. Hachures

"Hachure" is a generic term that identifies a mapping technique that indicates slope by drawing closely set parallel lines in the direction water would run on that surface. Hachures are based on a generalized contour system. The length of a line segment is determined by the distance between two contour lines.

A.1.1.1. Slope Hachures

This method is based upon 'the steeper, the darker' theory of relief portrayal. The hachures are drawn to form an image resembling the surface as it would be seen with vertical illumination. In depiction of slope gradient, line thickness is the controlling factor: the steeper the slope, the thicker the line.

A.1.1.2. Shadow Hachures

These are drawn to resemble the terrain as it would look under an oblique illumination source. Many of the same rules for slope hachures apply for shadow hachures. The main difference is that shadow hachure lines are drawn finely on an illuminated surface. This gives little indication of the relative steepness in illuminated areas.

A.1.1.3. Horizontal Hachures

Also called "form lines," the horizontal hachure is related to both contour lines and hachures. Lines are sketched so they remain perpendicular to the fall line. Because they are sketched they do not necessarily portray a continuous line of elevation. The impression of relief is gained from changes in line width.
following the principles of oblique lighting and the relationship of ‘the steeper, the darker’.

A.1.2. Shading

Shading is one of the most important tools for conveying impressions of relief. The human eye is so accustomed to the interplay of shadow and light, it seems quite natural to imagine three-dimensionality from two-dimensional graphics using this principle.

A.1.2.1. Combined Relief Shading

Any relief surface will cast shadows when struck by light from an oblique angle. When observing an area under these conditions from a vertical position, one sees an image of ridges and peaks rising upward with shadows falling away from the ridgetops. It is termed “combined” because it relies upon two principles: oblique illumination and the steeper, the darker.

A.1.2.2. Slope-Zone Maps

In seeking ways to eliminate individual interpretation when making a landform map, Miller and Summerson in *Slope-Zone Maps*, suggest using a technique which relies on slope angle to indicate relief. This method, in some ways, is like a hypsometric map. Four to eight classes are assigned to slopes between 0 to 90 degrees. These classes are given a color from a continuous grade tint scale (i.e. light grey . . . dark grey). Viewing this map it is easy to see areas with steep or flat slopes. The grey shades emphasize slope as an element of relief as opposed to elevation.
A.1.3. Physiographic Diagrams

Physiographic diagrams offer the map reader a pictorial rendition of relief.

A.1.3.1. Raisz Style Physiographic Diagrams

Erwin Raisz pioneered this type of relief presentation. A standardized set of symbols for various types of landforms and land cover are drawn within an area boundary. Features such as rivers and political boundaries are placed in the correct planimetric location. The pictorial symbols simply identify the existence of mountains, canyons, jungles, plains, etc.

A.1.3.2. Proportional Relief

As with Raisz, this method uses pictorial symbols; however, more features are planimetrically correct, such as mountains, valleys, and drainages. Mountains cannot be drawn planimetrically because of vertical displacement. Ridd in his article *The Proportional Relief Landform Map*, uses a local base as a datum instead of sea level. The base of a mountain is located correctly in the plan view and its peak is displaced northward by a given proportion. In this manner the peaks shown have a locational and elevational consistency across the map.

A.1.4. Contours

The contour is probably the most useful and versatile method for relief presentation. It does an excellent job on its own merit and becomes even more powerful in combination with other techniques. Contour lines connect points of equal elevation with reference to a datum. A lake shore is an excellent example of a natural contour line.
A.1.4.1. Common Topographic Contours

This type of contour is used in the production of U.S. Government topographic maps. It is usually photogrammetrically compiled, and the contour interval is set depending upon the map scale and severity of relief.

A.1.4.2. Tanaka Method

This method utilizes the planimetric and hypsometric accuracy of contours in addition to the principles of oblique lighting. Introduced in the July 1950 issue of the *Geographical Review* Kitiro Tanaka describes a system of contours drawn on a grey background, with varying thicknesses, white or black. The line thickness and color at any point is determined by the angular relationship between the light source and the point location. The final result creates an image of relief that looks as if it is terraced.

A.1.4.3. Variable Line Weight Contours

The contour lines are increased in thickness on southeast facing slopes in order to convey the image of relief.

A.1.4.4. Shaded Relief Contours

This technique is similar to the Tanaka method in that it simulates the results of an obliquely lighted surface. It differs in that the transition between illuminated or shaded slopes is done with greys rather than an abrupt white to black change.
A.1.5. Inclined Contours

This type of relief representation method is based upon contours produced from numerous equidistant, parallel, inclined planes which intersect the ground surface in an east-west direction.

A.1.5.1. Orthographic

Presented in the Geographical Journal 79, Kitiro Tanaka did the original work on this method in 1932. Readers are referred to that particular work, noted in the Sources Consulted section, for an explanation of construction steps and graphic examples.

A.1.5.2. Robinson-Thrower Style of Inclined Contours

These two well-known cartographers attempted improvements to Tanaka’s method. For a discussion of their work see Robinson and Thrower, Geographical Review 47.

A.1.6. Hypsometric Maps

Hypsometric maps show relief by employing distinguishable shades or colors between contour lines. The shades or colors may be changed between every successive pair of contours or they may be changed less often at some chosen interval of contours.
A.1.6.1. Tints

In the case of tints, colors or shades are assigned to the various elevation ranges. Colors are chosen in an attempt to imitate earth tones associated with types of vegetation or ground surfaces at different elevations.

A.1.6.2. Patterns

The same principles regarding division into elevation zones apply as above. This method uses patterns as opposed to colors to identify elevations across an area.

A.1.7. Spot Heights

Spot heights simply locate a point on a map and indicate its exact elevation in relation to a datum. The map reader is not required to do any interpolation. They are quickly and easily read and provide a great deal of information about an area. Spot heights are almost always used in association with other relief presentation methods.

A.1.8. Skeletal Lines

These lines are essentially indicators of watershed or ridge networks. One naturally assumes streams to be lower than ridges. Identifying these features is the skeletal line’s function.
A.2. Cross-Sections

This presentation type shows relief in the form of a portion of the earth which has been "sliced" and removed for viewing.

A.2.1. Profile

A profile is simply a diagram indicating the relationship of a surface to a datum along a given line. The profile is on a vertical plane instead of a horizontal plane. This severely limits the areal extent of relief which can be displayed. Vertical exaggeration is normally involved.

A.2.2. Series

A series is a number of profile models placed in their proper planimetric location, creating an actual structure. This can be done on paper as well, but the horizontal scale does not allow for easy measurement.

A.2.3. Fence Diagram

This type of diagram displays a number of cross-sections connected in a three-dimensional appearing graphic. Horizontal and vertical measurements can be made if a datum is established.
A.3. Perspective

This group of map types uses the principles of displaying dimensionality as our eyes would see an actual surface from some angle above or below.

A.3.1. Rod

A rod map uses rods drawn to scale to indicate the elevation at a particular point. The base of the rod is in the correct planimetric location for that data point. An extensive discussion of rod maps can be found beginning on page 46 of this paper.

A.3.2. Block Diagram

Block diagrams are freehand perspective drawings of geomorphological features. In addition to the surface view, parts of the underground structure can be seen in profile. Block diagrams essentially lift out a section of the earth and shows the terrain features of the earth surface from a "bird’s eye" perspective, and geologic strata in cross-section.

A.3.3. Elevated Contours

To understand this graphic, one can try to imagine looking at the earth’s surface from a bird’s eye perspective and seeing the ground covered with contours. The elevated contour map is the pictorial version of this concept.
A.3.4. Computer Perspective

This is simply a computer plotted version of the terrain. The computer processes elevation data provided by the user and outputs a three-dimensionally appearing surface plot.

A.4. Photography

This branch contains types of relief presentation derived from photographic processes.

A.4.1. Orthophoto

Orthophotos are the result of digital terrain mapping technology developed by the U.S.G.S. They are planimetrically corrected photos of 7 1/2 minute quadrangles.

A.4.2. Vertical Air Photos

Most contour maps are constructed using vertical air photos. These photos are taken from a platform located directly above a point on the earth which is the center point of the photo. Vertical displacement becomes increasingly severe as one moves away from this point.
A.4.3. Oblique Air Photos

The platform for the oblique air photo is at some angle, other than 90 degrees, from a point on the earth to be photographed. One can think of the oblique photo as a "panoramic view" of the surface.

A.4.4. Stereo Pair

Using adjacent vertical air photos and a stereoscope, one can see a three-dimensional image. Numerous calculations are required for measuring vertically and horizontally because of vertical exaggeration and displacement.

A.4.5. Photographed Models

These are simply photographs of terrain models constructed from various materials.

A.5. Other

A.5.1. Hologram

Holograms are recent inventions which allow three-dimensions of an object to be viewed. Holograms of landscape scenes could be built to display relief as it might be viewed from a number of angles.
A.5.2. Raised Relief

These maps are commonly constructed of molded plastic and colored using hypsometric tints.

A.5.3. Anaglyph

This method uses slightly offset, identical images produced with blue-green and red color filters. The resulting anaglyph is viewed with glasses constructed with a blue-green lens on one side and a red lens on the other.
SOURCES CONSULTED


Crawford, Paul V. and Jenks, George F. Viewing Points for Three-Dimensional Maps. Lawrence, Kansas: Department of Geography, University of Kansas, [1967].


Lobeck, A.K. Block Diagrams and other Graphic Methods Used in Geology and Geography. Amherst, Mass.: Emerson-Trussell, 1958.


Morrison, Joel; Robinson, Arthur; and Sale, Randall. Elements of Cartography. 4th


