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Digital Cliff Drawing for Topographic Maps: Traditional Representations by Means of New Technologies

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Abstract

On topographic mountain maps, cliff drawings are among map elements that are most difficult to produce. However, they belong to some of the most spectacular representations on maps. This paper gives a short historic overview of the development of cliff drawing and describes the most common styles of cliff representations. New techniques are presented in detail for the generation of simplified ridge-line representations in an entirely digital and effective manner. The paper shows examples of mountain maps produced using this semi-automated method and suggests further developments.

Cartographic Cliff Representation and the Historic Development of the Swiss Style

Large parts of mountainous areas throughout the world are covered with scree or solid rock. These areas have critical importance to human activity, particularly the natural hazards associated with mountaineering. For human activity to be conducted safely in these rocky domains, precise maps are required. When the first complete large-scale surveys were carried out in the nineteenth century, these regions had to be mapped with an accuracy never needed before. Especially in the Alpine countries, techniques for clearly designed, but precise, terrain representation were developed. The most prominent examples are manual hill-shading and cliff- and scree-drawing. However, as is very often the case in cartography, graphic quality, clarity, and geometrical accuracy are not always fully compatible. Consequently, different cartographic demands and applications have led to a broad variety of representations.

In the case of cliff drawing, most methods derive from slope-shading hachures, a relief-presentation technique that was commonly used during the 1800s. In Switzerland, on the famous Dufour map (1838–1865) such hachures were overlaid by cliffs (Figure 1). As a conse-



Figure 1. Extract from the Dufour map, sheet 17 “Vevey–Sion,” 1844. Slope-shadow hachures combined with cliff hachures.

quence of the change to contour line maps after 1860, cliff drawing and topography had to be disentangled.

At the Swiss Federal Office of Topography at Wabern/Berne, the technique of shadow-cliff hachures was developed further, especially after 1935 when the production of the new National Map Series began (Kraiszl 1930). Cliff areas were divided into morphologically homogeneous units using structure lines. Within this framework, structure and shape lines, as well as vertical and horizontal filling hachures, were modulated according to an illumination model (Figure 2).

As an example of this technique, Figure 3 shows an extract of an expedition map covering the “Panta” area in the Peruvian Andes (Spiess 1960). The modulated shape lines and filling hachures were scribed on coated glass plates. The rough, natural appearance was created by the deft handling of the scribing tool by an experienced cliff artist. More details in the cliff representation techniques of the Swiss National Map Series can be found in Spiess (1970) and Gilgen (1998).

Other Styles of Cliff Representation

Besides the cliff-shadow hachures used by the Federal

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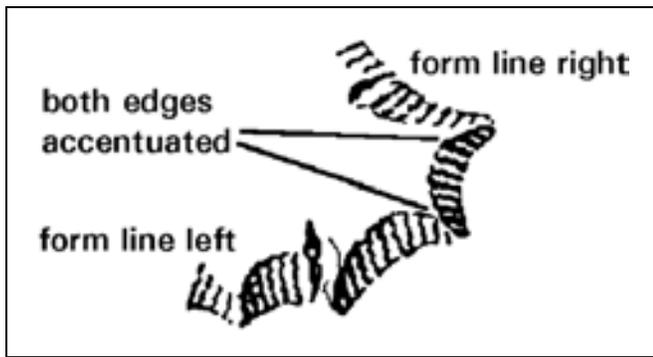


Figure 2. Modulation of shape lines (outlines) and filling hachures according to aspect. Source and ©: Internal guidelines of the Federal Office of Topography (Swisstopo 1996) (BA035538).



Figure 3. Extract from the black plate of the map "Panta 1:25,000" by E. Spiess with cliff representation. Scribing on coated glass plates.

Office of Topography, a broad variety of alternative techniques exists. In Switzerland, extensive discussions about a new kind of cliff representation took place mainly in the 1920s and 1930s (Blumer 1927). The proposal of Walter Blumer, a former engineer at the Federal Office of Topography, should be mentioned. His method, based on the literal interpretation of original photogrammetric compilations, did not allow for the geometrical exaggeration of cliffs. Vertical cliffs are replaced by short, barely modulated hachures perpendicular to the contour lines. They are interrupted only by numbered contour lines. In less steep areas, contour lines are generally uninterrupted, if at all possible. In some cases they are replaced by light, horizontal or vertical fill hachures.

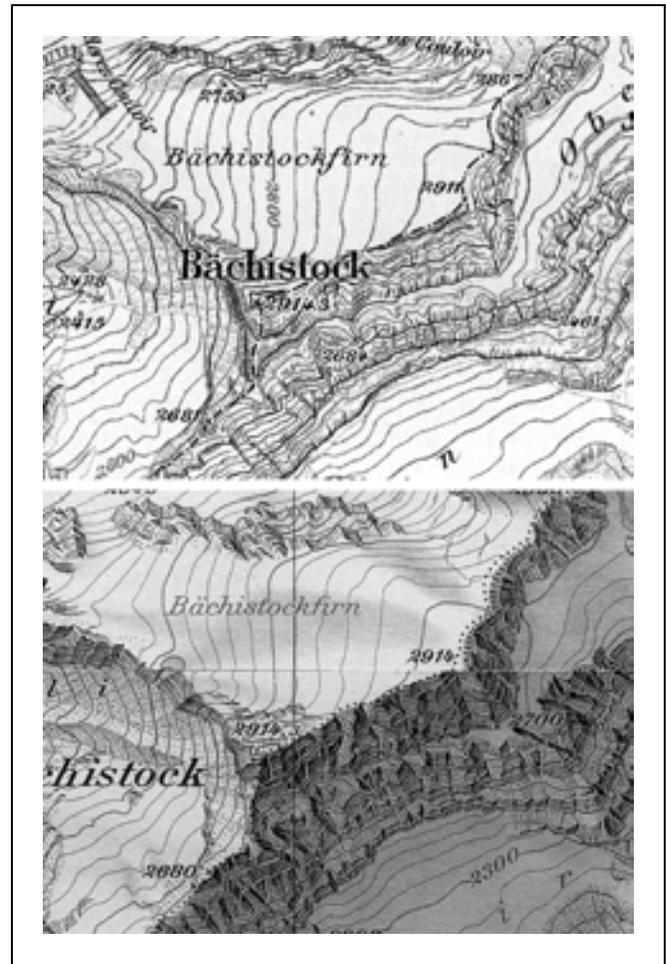


Figure 4. Comparison of extracts from Walter Blumer's map from 1937 (above) with the Swiss National Map Series 1:25,000, sheets 1153 and 1179 (below). © Swiss Federal Office of Topography (BA035538).

Figure 4 shows an extract of Blumer's map of the Glärnisch massif (Blumer 1937) compared with the Swiss National Map Series 1:25,000.

Later, Blumer's method was taken up again and modified by Leonhard Brandstätter. He also strived for an orthogonal and geometrically precise representation and for a combination of cliff drawing and contour lines. The impression of plasticity caused by the contour-line image, especially in steep areas (Brandstätter calls this effect *Scharungsplastik*), combined with a ridge- and edge-line drawing, served to emphasize the morphological and geological structures. Moreover, cliff representation is supported by a locally matched hill-shading. Figure 5 shows such a cliff representation (Brandstätter 1996). That publication also gives an overview of the different cliff representation techniques used in the German and Austrian Alpine Club Maps.

Another method is ridge-line representation (Imhof 1965). Only dominant edges and structure lines are represented and modulated, and fill hachures are omitted

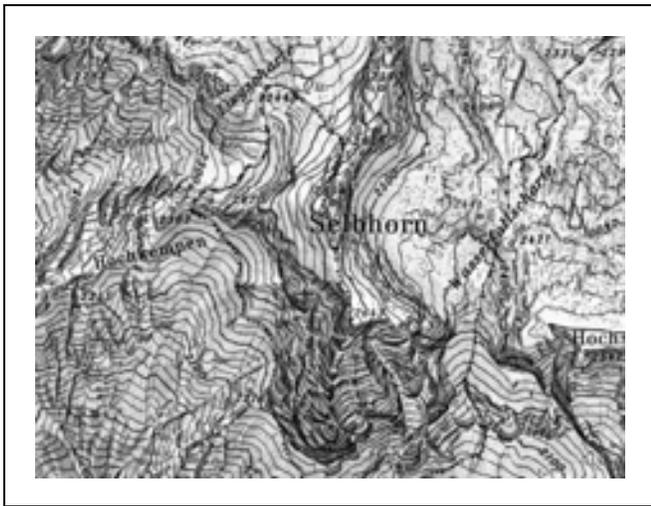


Figure 5. Extract from the Alpine Club map Steinernes Meer, by Leonhard Brandstätter.

entirely. In 1933, the Federal Office of Topography compared the ridge-line representation, the “classical” method with fill hachures, and a contour-line representation with a light hill-shading, in a series of map prototypes (Figure 6).

In recent years, tests that combine elements from orthophotos and conventional maps were undertaken. Aschenbrenner’s experiments (Aschenbrenner 1993) with aerial images and overlaid ridge-line drawings are worthy of mention. Figure 7 shows the major problems encountered when using orthophotos in a high-mountain environment. Steep, shadowed areas lose their information content (centre bottom), and uninterrupted contour lines disturb the perception of the map image (upper left). On the original map, however, some line elements are depicted in colour.

A Digital Approach to Cliff Drawing

The manual cliff-drawing and scribing techniques discussed previously are very time-consuming and costly to produce. For instance, the cliff drawing of an average mountain sheet of the Swiss National Map Series requires approximately 2000 working hours, and total costs run about 250,000 Swiss francs per sheet. Considering the exorbitant expense, it should come as no surprise that nowadays new designs of cliff plates are possible only in special cases, such as the National Geographic map of Mt. Everest or the map of the Columbia Icefield in the Canadian Rocky Mountains. Nevertheless, when initiating new cartographic projects, the question of how to represent rocky areas in ways that are geometrically correct, well designed, inexpensive, and computer-compatible is still a relevant issue.

RIDGE-LINE REPRESENTATION

In a mapping project carried out at the Institute of Cartographica, VOLUME 38, # 1&2, SPRING/SUMMER 2001

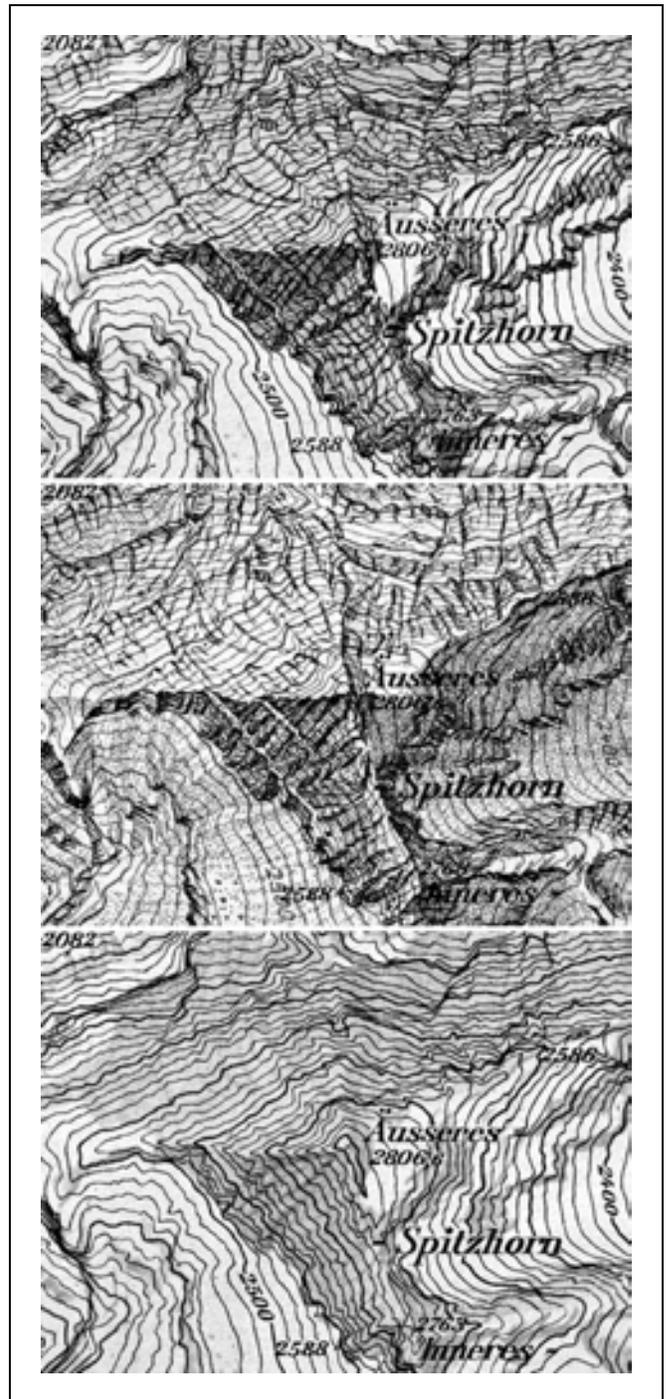


Figure 6: Prototype map series Spitzhorn produced by the Swiss Federal Office of Topography in 1933. From top to bottom: Ridge-line representation, “classical” method with fill hachures, and contour-line representation with a light hill-shading. © Swiss Federal Office of Topography (BA035538).

tography at ETH Zurich, about 1,100 cliff objects on the volcanic Methana Peninsula in Greece had to be mapped quickly (Hurni 1995). To accomplish this challenging task, a pilot project utilizing semi-automated cliff drawing was developed. In order to avoid the place-

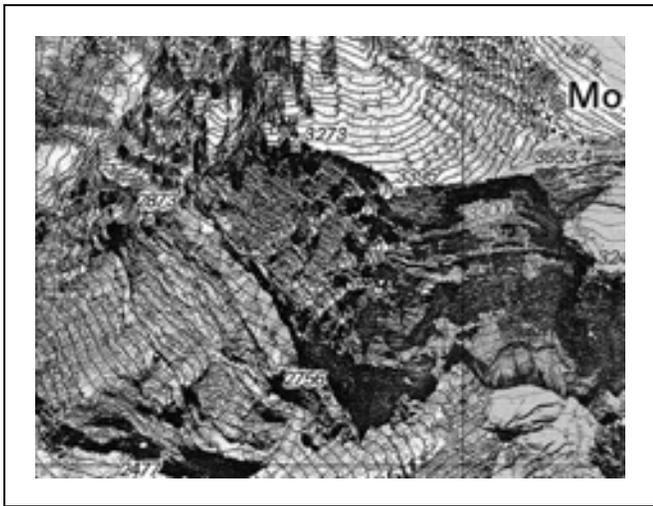


Figure 7. Combination of an orthophoto with conventional map elements (original in colours); after (Hurni 1989). Aerial image: © Swiss Federal Office of Topography (BA035538).

ment of complex hachures, the chosen ridge-line representation method depicted only major contours, ridge crests, and drainages. The upper and lower edges of a cliff were digitized manually from field sketches. An illustrated catalogue containing the following design rules can be found in Swisstopo (1996):

- The representation is reduced to vertical ridges and drain lines (“form” lines) and upper and lower edge lines. There are no fill hachures.
- The hachures have a rough appearance.
- Aggregation of objects and highlight/shadow contrasts are necessary.
- Light and shadow sides should be easily distinguishable by their overall brightness (line weights).
- On the shadow side, upper (higher elevation) edges are thicker than lower edges (cuneiform).
- On the light side, upper edges are thinner than lower edges.
- On the shadow side, vertical form lines are thicker on the upper side; on the light side they are thicker on the lower side.
- The direction of illumination is assumed to be from the northwest; slope angle is also considered.
- On the shadow side and with southwest to southeast aspects, edge lines are thicker on the left side; with northeast to southeast aspects, they are thicker on the right side. With pure southeast aspects, the lines are thicker on both sides and thinner in the centre.
- On the light side and with northwest to southwest aspects, edge lines are thicker on the left side; with southwest to northeast aspects, they are thicker on the right side. With pure northwest aspects, the lines are thinner on both sides and thicker in the centre.
- As a result of erosive effects, very often concave and convex shapes of the cliffs can be found.

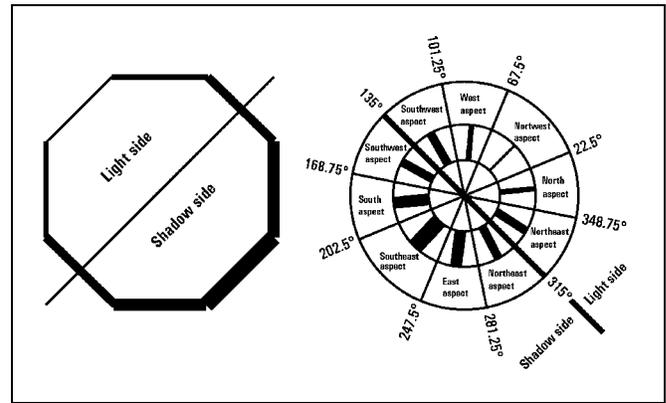


Figure 8. Line weights for light and shadow side. Average line weights (left). Tolerance sectors (right). The azimuth of aspect is perpendicular to the axis between two digitized vertices of the upper and the lower edge of the cliff area.

An attempt was made to simplify and formalize these rules in order to implement them in a computer program. The problem can be divided into five separate processes (illumination model, edge lines, form lines, roughness, concavity/convexity) as described in the following sections.

ILLUMINATION MODEL

In order to show direction changes in cliff bands with variable contrast, a simplified illumination model assuming a light source at northwest was chosen. This was further subdivided into three sectors of shadowing (three average line weights) for the light side, and three corresponding sectors for the shadow side. Figure 8 shows this line-weight model with the azimuths of the sector edges. The left illustration shows line weights for the light and the shadow sides presented on an octagon. The right illustration shows the tolerance sectors for the various azimuths.

EDGE LINES AND FORM LINES

Digitized upper and lower edges of the cliff objects with an identical number of vertices (very important) serve as input data. This leads to a box-shaped ridge-line image containing those edges and the vertical form lines. This method yields better results with long cliff bands. The average line weight for the upper and the lower edge is different:

Light side	Lighter on the upper edge, heavier on the lower edge
Shadow side	Heavier on the upper edge, lighter on the lower edge

Additionally, the line weight is modulated continuously between the vertices by aspect, giving them a hachure-like, cuneiform (tapered) appearance:

Shadow side	Southwest to southeast aspects	Thickening towards left side
	Northeast to southwest aspects	Thickening towards right side
	Southeast aspects	Thickening on the left and on the right side
		Thinning in the centre
Light side	Northwest to southwest aspects	Thickening towards left side
	Northeast to northwest aspects	Thickening towards right side
	Northwest aspects	Thinning on the left and on the right side
		Thickening in the centre

The line weight of the form lines is also changed continuously between the upper and the lower edge:

Light side	Thinning towards upper part, thickening towards lower part
Shadow side	Thickening towards upper part, thinning towards lower part

These rules are visualized in Figure 9. Both figures must be regarded separately. Depending on whether a cliff primarily faces the light or shadow side, other hachure directions will result in southwest and northeast sidelight aspects.

ROUGHNESS OF LINES

In order to provide a natural, rough appearance of cartographic cliff representation, line widths are altered randomly and the line track is digitally modified to appear as if it were drawn by a slightly trembling hand (Figure 10). Tests have shown that five different line weights are sufficient to generate the cuneiform appearance of one hachure. Therefore, each hachure consists of five small line elements with increasing or decreasing width, which are modulated as a group according to the illumination model. In addition, to give hachures a more natural appearance, the line weight of each single line element is slightly altered by a random function. The line widths are defined as ordinal integer numbers, which are directly changed by the random generator (Formula 1). The effective metric line width can be assigned in a later phase, for example, during rasterization or in a vector-based desktop publishing program. The software allows users to fine-tune the integer line widths according to their position and aspect with about 250 parameters. This allows a very high flexibility of the cliff representations; however, in practice this time-consuming process has been carried out only once at the beginning of the pilot map project. The complete fine-tuning (including slope convexity and concavity, see below) took about 20 hours and was accomplished interactively by visually inspecting the actual results.

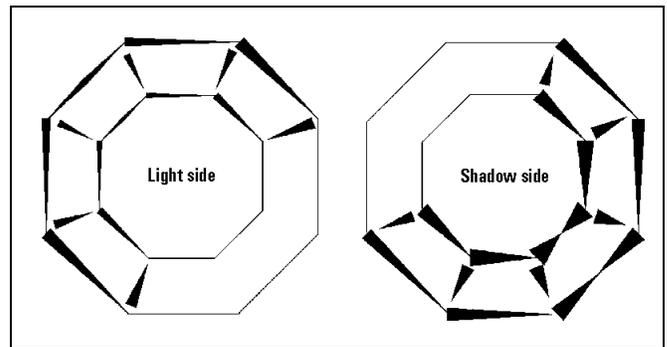


Figure 9. Illumination model: Continuous change of the line widths of edge and form lines, separately for light and shadow side. Cuneiform shape of hachures according to design rules.

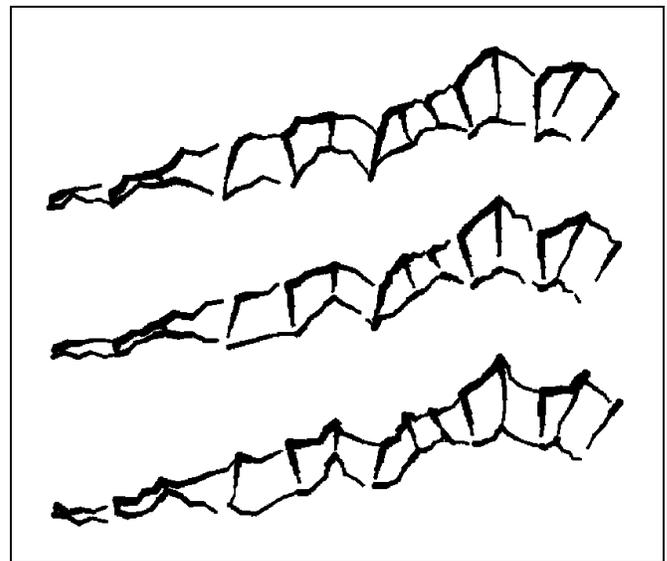


Figure 10. Three examples (from top to bottom) with concavity, without concavity, and with convexity. All examples have the rough appearance.

$$st_{out} = st_{in} + (rand \bmod a) - \frac{a}{2}$$

st_{out} Output line weight (ordinal integer value)

st_{in} Input line weight (ordinal integer value)

$rand$ Random value from the generator

a Line weight can be altered maximally by $6\frac{a}{2}$

Formula 1. Random variation of line weight (ordinal integer values). The modulo function is used to limit the range of the output values of the random generator.

The trembling line effect is also achieved by a slight variation of the position of the vertices by a random function (Formula 2). Only the azimuth between the vertices is changed; the length of the line elements is kept constant and the group of line elements is fitted between the digitized “box” vertices. The maximum deviation of the azimuth is limited to nine degrees, a threshold determined by tests made during the pilot project.

$$azi_r = azi_{ab} + ((rand \bmod 18) - 9) * \left(\frac{\pi}{180}\right)$$

azi_r Output azimuth altered by random function

azi_{ab} Input azimuth

$rand$ Random value from the generator

Formula 2: Random variation of azimuth. The modulo function is used to limit the range of the output values of the random generator. Transformation of result to radian.

CONCAVITY AND CONVEXITY

Erosion and other landscape morphological influences upon cliff areas very often have a concave or convex shape between two ridges. Slope concavity or convexity is usually portrayed in conventional cliff drawings. By attributing the cliff object, the radius (standard = distance between two vertices), concavity, or convexity can be chosen (Figure 10).

If concave and convex objects are connected, they must be digitized separately in order to apply their respective attributes. In the connecting parts, overlaps can occur, which are best removed manually using a raster editor after rasterization. This is also the case when two cliff walls form a ridge or a summit. From our experience, the amount of time to correct these cases interactively is rather limited. In the Methana Peninsula project involving 1,100 cliff objects, the manual retouching was done in less than an hour.

Figure 11 shows the general layout of the solution, whereas formula 3 explains the calculation of the intermediate vertices (between two digitized main vertices) lying on the “rounded” (concave or convex) polygon:

Step 1: Calculation of angle α between $\overline{P_1P_2}$ and central perpendicular line on $\overline{P_1P_2}$ (formula 3).

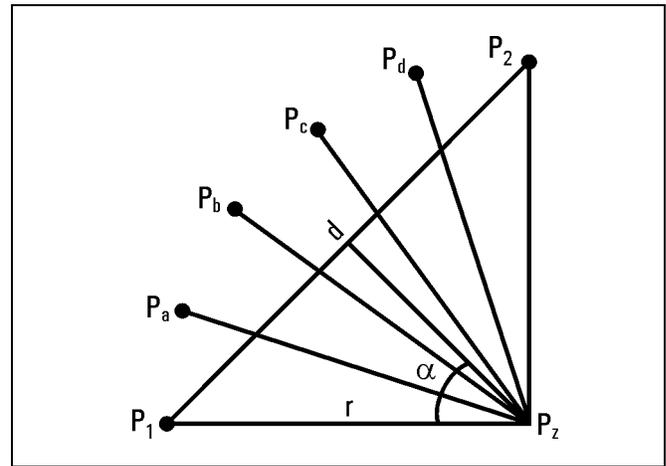


Figure 11. Calculation of concavity/convexity polygons (explanation of Formulas 3 and 4).

$$\alpha = \arcsin\left(\frac{\frac{d}{2}}{r}\right)$$

formula 3

Step 2: Calculation of co-ordinates of P_z with $(r, 90 - \alpha)$ starting from

Step 3: Calculation of azimuth azi from P_z to P_1 .

Step 4: Calculation of azimuth from P_z to P_a , P_z to P_b , etc. (formula 4).

$$azi_{za} = azi + \left(\frac{2\alpha}{5}\right)$$

$$azi_{zb} = azi_{za} + \left(\frac{2\alpha}{5}\right)$$

etc.

formula 4

Step 5: Starting from P_z : Calculation of co-ordinates of P_a , P_b , etc. using $(r, azi_{za}, \text{etc.})$.

Applications of Digital Cliff Drawing

The first test of the computer program was to simulate a cliff representation drawn by Eduard Imhof (1965). Figure 12 shows the digitization of the upper and the lower edge, the raw output of the program, the manual retouching in a raster editor, and the comparison to Imhof's drawing. Up to now, the program was used in four mapping projects.

In the Methana Peninsula pilot project (Hurni 1995), the terrain consists mainly of rather small cliff walls or bands. There are only a few big cliff walls with a changing morphology. For those cases, the computer program allows users to choose between three classes (sizes) of cliff objects with varying average line weights (Figure 13). These prerequisites make this case ideal for treatment using automated cliff-drawing methods. The digiti-

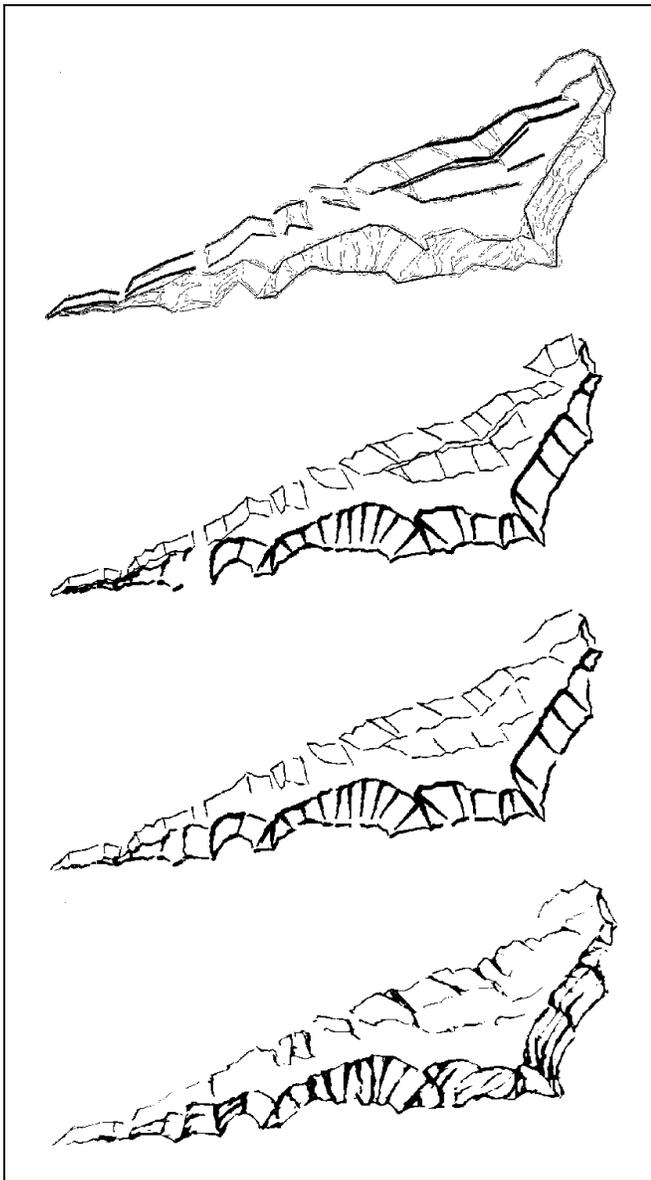


Figure 12. Production steps for digital cliff drawing. From top to bottom: Digitization of upper and lower edges, raw output of program, manual retouching, and comparison with manual drawing afterward (Imhof 1965).

zation is based on sketches drawn in the field on top of a detailed contour line map (Figure 14). The digitization of the 1100 cliff objects at the scale of 1:25,000 and the design of area-based scree representation were carried out in about 40 working hours (Figure 15).

In a large mapping project on the Arabian Peninsula, potentially dangerous canyon cliffs have been designed at the scale of 1:50,000 and inserted in orthophoto maps. In a test map 1:25,000 of the Silvretta massif in the Austrian Alps (Figure 16) (Hurni and Neumann 1998), the method was successfully used to visualize large cliff walls for the first time, together with a line-based scree generator (Hurni and others 1999). Another example is the map of Mt. Rainier containing a rather synoptic cliff

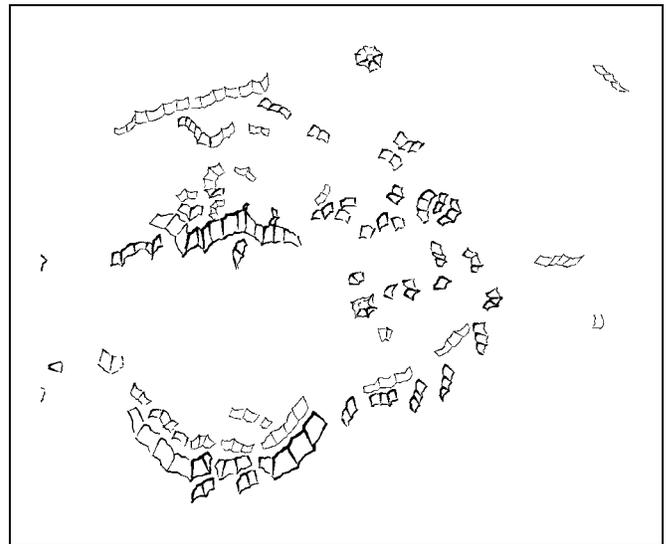


Figure 13. Small, medium, and large cliff objects.

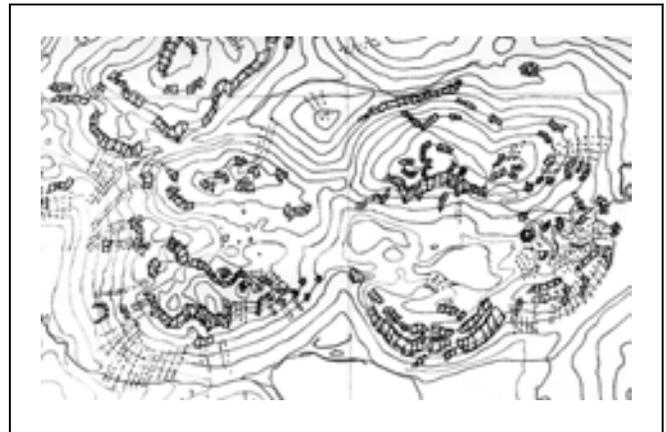


Figure 14. Manual field sketch of cliff objects for the Methana map.

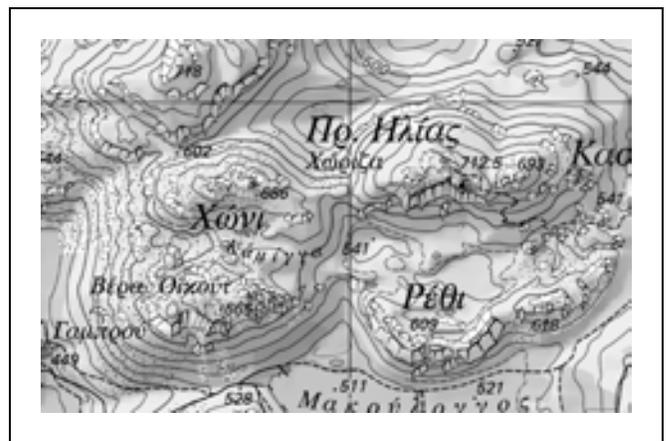


Figure 15. Extract from the topographic map 1:25,000 of Methana Peninsula in Greece with digital cliff drawing and scree representation according to the area-based approach. Compare to the right part of Figure 14.

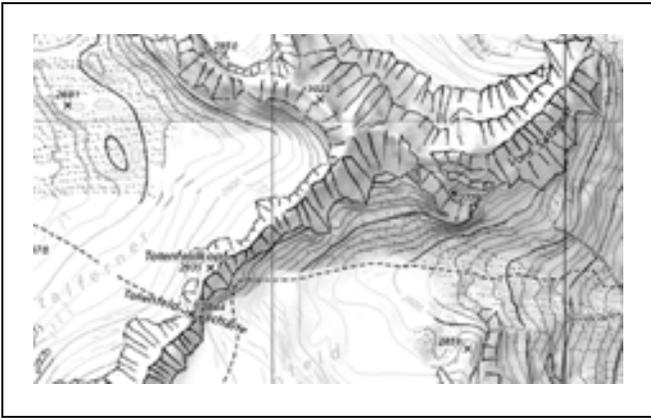


Figure 16. Extract from a test map 1:25,000 of the Silvretta massif with digital drawings, large cliff walls, and a line-based scree representation.

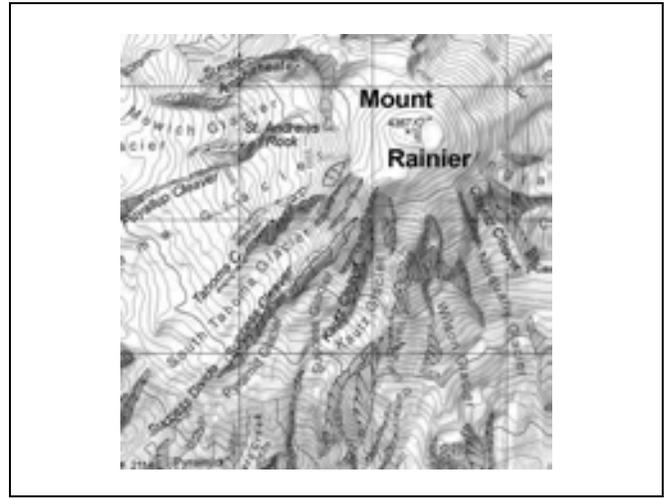


Figure 17. Extract of a map of Mt. Rainier, USA, using the ridge-line representation.

representation of the most prominent ridges around the central crater (Figure 17) (Hurni and others 2001).

The original version of the cliff program works only in batch mode on an Intergraph UNIX system. Thus, the cliff objects must be digitized in groups before the program can be executed. Since then, an interactive version has

been developed to run as an extension (X-tra plug-in) in Macromedia Freehand. It allows fully interactive design and control of all cliff objects. Figure 18 shows the interface of the Freehand plug-in, which allows the user to set parameters such as light/shadow side, size of objects, concavity or convexity, overall line weights, and weights of the

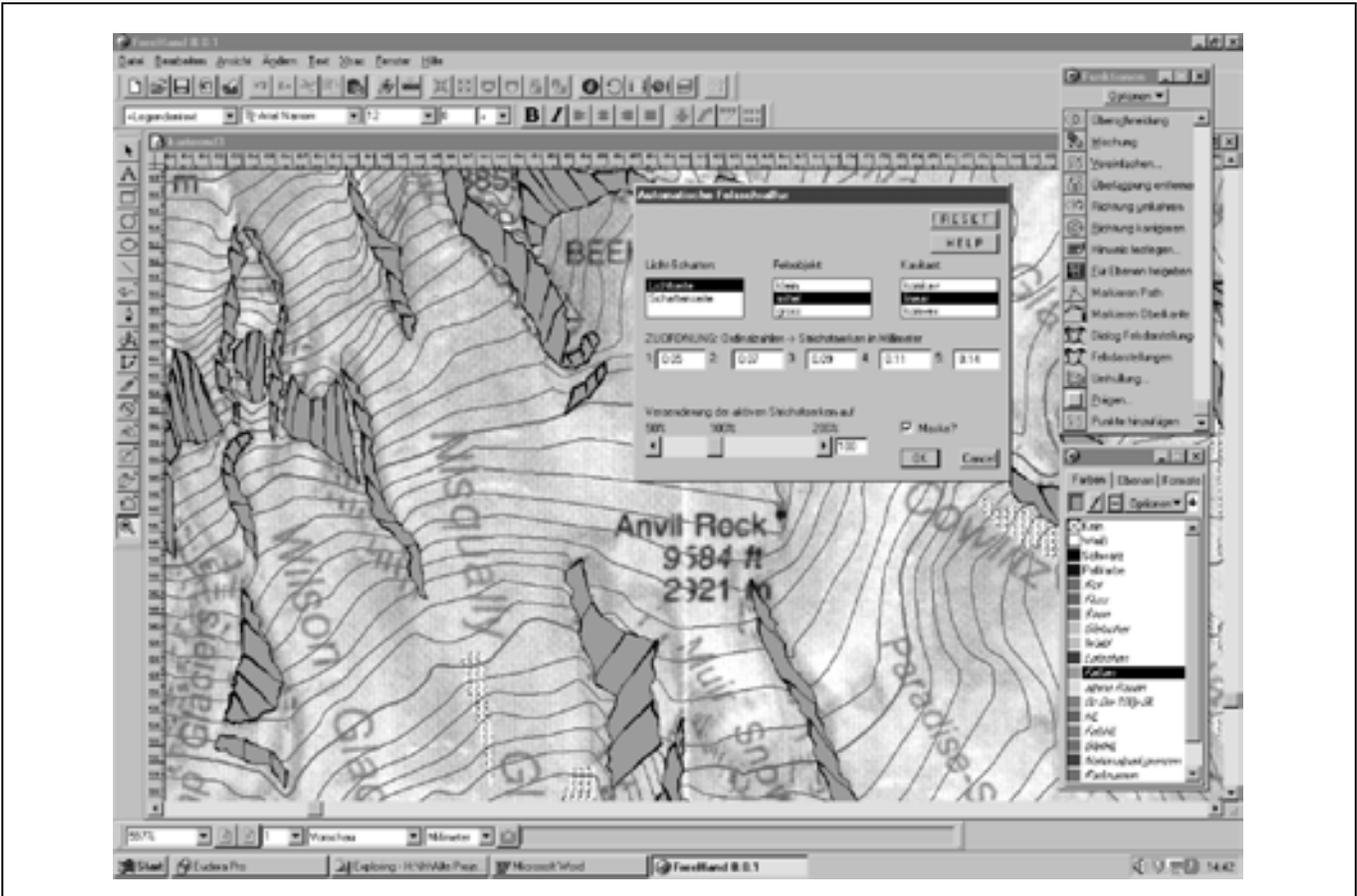


Figure 18. Interface of the Freehand plug-in of the digital cliff program.

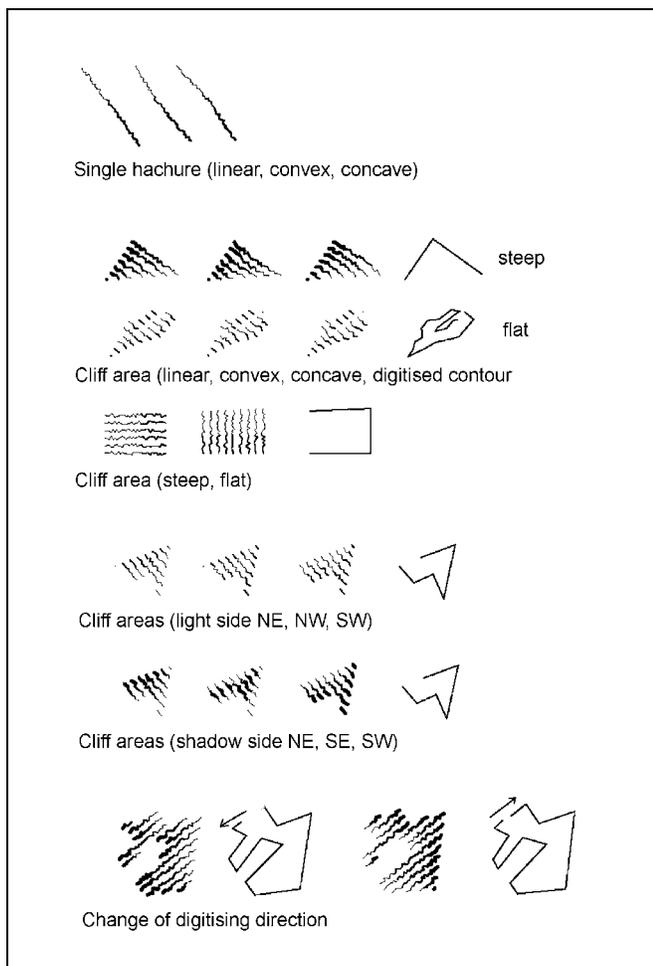


Figure 19. Change of parameters for cliff area fill.

five line sections that make up a hachure. For further information about the freeware Freehand plug-in (Windows version), please contact the authors of this paper.

Implementation of Shadow (Fill) Hachures

The ridge-line method – which has been used extensively in Eduard Imhof's school atlases – has one major drawback: the depiction is rather difficult to draw because the modulation of the rock faces with their different aspects can be accomplished only by changing the line thickness of the edge and form lines. Only very talented cartographers are able to design readable and aesthetic rock depictions using this method. The digital method still requires a sound knowledge of relief interpretation in order to digitize the upper and lower edges correctly.

At the ETH Institute of Cartography in Zurich, the original cliff software has been developed further to automatically create cliff-shadow hachure fillings similar to those in the Swiss National Map Series (Dahinden 2000) (see also Figure 2). To the best of our knowledge, until now, there are at least three software solutions to create fill hachures. One is a commercial software product by



Figure 20. Extract of the Swiss National Map 1:25,000. © Swiss Federal Office of Topography (BA035538).

Hansa Luftbild, Münster, Germany, and the other is described by Yoëli (1985) and Regnauld and others (no date). Both solutions deal mainly with the problem of how to equally fill a given complex area with slope hachures. The individual modulation of the hachures is not discussed. In our solution, instead of relying on edge and ridge lines, continuous cliff faces with equal slope and aspect are covered with regularly placed hachures, either horizontally or vertically. In a manner similar to ridge-line representation, they must be modulated according to an illumination model. Areas of equal slope must be digitized by hand. It is possible to choose between single hachures or areas filled with hachures. The desired direction of hachures (horizontal or vertical) must also be determined by the cartographer. The program then fills the area with hachures according to defined spacing rules (three to four hachures/mm). Light modulation and random trembling of the lines are done automatically using the same functions as in the original software for ridge-line generation. The software also allows users to distinguish between small, medium, and large objects, between light and shadow sides, and between concave and convex cliff forms. Figure 19 shows results with varied parameters. The final implementation of the software was done in C++. As for the first software, the program is now integrated in a plug-in for the graphics software Freehand. A user-friendly interface allows easy handling of the software. Figures 20, 21, and 22 show preliminary results of digital fill hachures compared with an extract of the Swiss National Map series.

Conclusions and Further Developments

The successful application of the described procedures

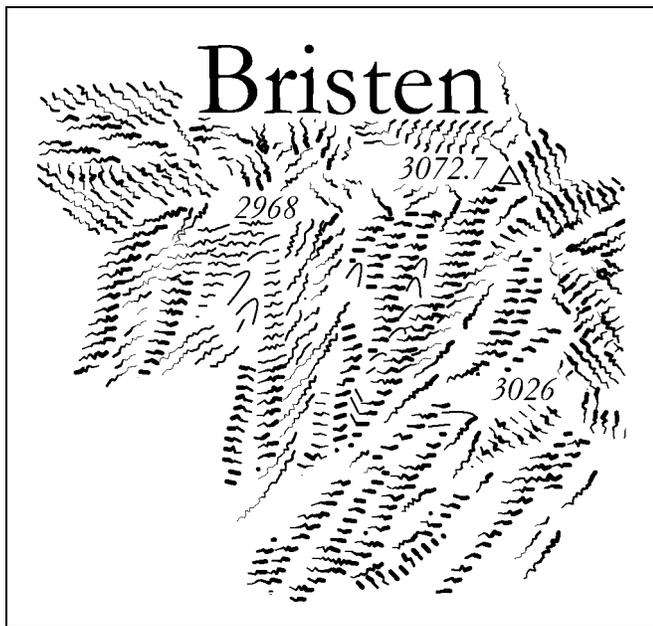


Figure 21. Cliff drawing using shadow fill hachures.

to actual map projects demonstrates that digital cliff representations can be produced quickly and easily. Using digital methods, the cartographer is now spared painful manual scribing tasks, such as the modulation of hachures. However, digital methods can be applied only in a limited spectrum of cases. Control of the full process by an experienced operator is still necessary and desirable. Further research should examine the implementation of basic morphological structures and modules that could be assembled in order to create complex cliff walls and representations. Moreover, future research must also aim at special, enhanced shaded-relief depictions of cliff areas (see Figure 6, bottom), a method that allows easier modulation of the terrain, provided that a detailed digital elevation model (DEM) is available. In the meantime, our work has proven the feasibility of using algorithms, controlled by an experienced cartographer, for the design of generalized cliff representations.

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Figure 22. Overlay of original map and new shadow fill hachures. © Swiss Federal Office of Topography (BA035538).

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Résumé Sur les cartes topographiques de montagne, les rochers figurent parmi les éléments les plus difficiles à reproduire, mais aussi parmi les représentations les plus spectaculaires. Cet article propose une vue d'ensemble de l'historique de la représentation de rochers et décrit les différents styles de dessins les plus couramment utilisés. De nouvelles méthodes numériques extrêmement efficaces, permettant la génération d'une représentation du genre squelette, y sont décrites de façon détaillée. L'article présente également différents exemples de cartes de montagne qui ont été produites en utilisant cette méthode semi-automatique, et suggère des travaux de recherche à suivre.

Zusammenfassung Felsdarstellungen gehören zu den am schwierigsten und aufwendigsten zu realisierenden Kartenelementen in topographischen Gebirgskarten. Sie gehören jedoch mit zu den spektakulärsten Darstellungen auf Karten. Dieser Artikel bietet einen historischen Überblick der Entwicklung der Felsdarstellung und beschreibt die gebräuchlichsten Felszeichnungsarten. Ein neues Verfahren wird vorgestellt, welches es erlaubt, vereinfachte Gerippelinien darstellungen mit Computerunterstützung rationell und vollständig digital herzustellen. Weiter werden Beispiele von Gebirgskarten vorgestellt, in welchen diese Programme zur Anwendung kamen. Der Beitrag schliesst mit Vorschlägen für weiterführende Arbeiten.

Resumen Los escarpados se encuentran entre los elementos más difíciles de representar en los mapas topográficos de montaña, pero figuran también entre los que poseen una simbolización más espectacular. El artículo presenta una breve visión histórica de la evolución en la representación de los escarpados y expone algunos de los estilos más comúnmente utilizados. Asimismo, se describen con detalle nuevas técnicas que permiten la generación, de una manera eficaz y totalmente digital, de las líneas simplificadas de crestas. Finalmente, se muestran algunos ejemplos de mapas de montaña elaborados utilizando este método semiautomático, y se sugieren también futuros trabajos de investigación.