The Cartographic Journal Vol. 51 No. 4 pp. 360–371 November 2014

OBSERVATIONS

Design Principles for Swiss-style Rock Drawing

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Swiss-style rock drawing uses shaded hachures to show the characteristic forms and the third dimension of rocks and cliffs. Rock faces, trenches, gullies, faults and other rock features relevant for orientation and navigation in mountainous areas are shown as seen from the ground instead of from an orthogonal perspective. The density and dimensions of hachures change with the exposure to a source of illumination to generate a shading effect that highlights the terrain's three-dimensionality. The generation of rock drawings in Swiss style is time-intensive and requires an eye for the artistic rendering of the terrain's third dimension as well as an understanding of different rock types and their morphology. Design principles have not yet been documented in a detailed and comprehensive manner and only rudimentary algorithms exist for the digital generation of simplified representations. This paper discusses the defining characteristics and specific design principles of Swiss-style rock drawing based on figures and unpublished documentation from the Swiss Federal Office of Topography swisstopo. We identify three main types of hachure-based rock drawing and discuss graphical elements for the most common type. We also discuss the combination of rock drawings with contour lines, their generalisation and the drawing process.

Keywords: rock drawing, Swiss maps, relief map, terrain map

INTRODUCTION

The cartographic representation of exposed rock – non-vegetated, bare outcrops of mineral material – is a demanding task that has challenged cartographers and topographers for centuries. The depiction of jagged cliffs, escarpments and rocky peaks of high-altitude mountainous regions provides important information to the map user. The steep and rugged terrain in these areas is a major obstacle and is often only traversable by trained alpinists using specialized climbing equipment. Cliffs and mountain faces are also salient geologic features important for localisation and navigation.

There are different techniques for rock representation used today. To illustrate the large variety of methods, one can compare the Swiss hachures method to a raster-based representation. The hachures method uses contour lines and skeletal outlines of geomorphological features to provide a general framework that is eventually filled in with hachures (Figure 1). All hachures are drawn in black, but width and density are carefully modulated to create a shading effect. The raster method, as seen in Figure 2, combines rock and relief shading. Unlike hachures, the terrain surface is shown with colour and the image may contain elements from orthoimagery. Digital raster filters applied to the shaded relief image can be used to generate the raster-based rock representation. It is to note that in addition to these two methods a variety of other rock representations exist, some combining hachures, contour lines and area tones.

The Swiss style of rock drawing, which uses shaded hachures, is considered exceptional by many (e.g. Hodgkiss, 1981; Keates, 1996) in the field of cartographic rock representation and is the focus of this paper. Figure 3 illustrates the effectiveness of this type of rock representation. In the orthophoto (Figure 3, top left), rock faces are disguised by shadows and are difficult or even impossible to discriminate from areas covered with scree, alpine meadows or shrub. Different types of land coverage become discernable with contour lines (top right), but the contour lines are unable to show the vertical cliff faces and rough terrain, which the aerial photograph shows dominating this landscape (bottom left). These contour lines are extremely dense in rocky areas, making the terrain's third dimension difficult to distinguish even for experienced map users. In contrast, the Swiss-style rock drawing in the bottom right of Figure 3 shows crisply depicted rock masses with distinct outlines and clear indication of crest and gully lines, and a

DOI: 10.1179/1743277413Y.0000000052

Figure 1. Swiss-style rock drawing with shaded hachures (swisstopo map 1193 Tödi, 1 : 25 000, 2009)

map reader can immediately grasp the third dimension of the terrain.

Swiss-style rock drawing with shaded hachures has an important artistic component that places challenging demands on cartographers. The time and effort required to generate a map is extensive and costly. When swisstopo generated the first edition of their current map series with manual scribing on coated glass plates, one square centimetre of rock drawing in the Swiss style required approximately one hour of work by a specialized cartographer. At that rate, an average mountain sheet required roughly 2000 hours of work (Hurni *et al.*, 2001). Fortunately, updates to current swisstopo maps are less time-consuming because graphics software accelerates the drawing process. Revising existing rock drawings is generally simpler and therefore also less time-consuming than drawing from scratch. In fact, only rather small areas of rock drawing require periodic revisions, typically areas affected by landslides or glacial recession (Gilgen, 2006). However, due to the prohibitive costs, elaborate rock drawing with shaded hachures is rarely used except in maps of the Alps. Well-known examples of other mountainous areas drawn in this style include a map of Mount McKinley in Alaska (Washburn, 1960), and a map of Mount Everest (Washburn *et al.*, 1988).

A digital, automated method for applying Swiss-style rock representations to more areas is highly desirable. Automated approaches have been developed for simplified graphical styles (Hurni *et al.*, 2001; Dahinden, 2008; Gondol *et al.*, 2008), but high-quality digital solutions for large areas are currently unavailable. Understanding the design principles and characteristics of Swiss-style rock drawing are essential to creating an automation of Swiss-style rock drawing. However, these principles have not yet been documented in a detailed and comprehensive manner. At the Swiss Federal Office of Topography swisstopo, the knowledge has passed down among generations of cartographers since the time of the first Dufour map published in 1845. Only superficial or vague descriptions of the design principles have been published to date (Blumer, 1927, 1932; Bühler, 1938; Kraiszl, 1930; Jeannet, 1938; Bertschmann, 1953, Imhof, 1965, 1982; Bolliger, 1967; Spiess, 1970; Gilgen, 1998, 2008; Hurni *et al.*, 2001; Spiess *et al.*, 2002). The lack of formal documentation is not due to sluggishness or secretiveness on the part of Swiss cartographers, but it is simply difficult to reduce rock drawing principles to a set of graphical rules of thumb. Eduard Imhof (1965 and 1982) provides arguably the best resource for Swiss-style design principles in his books. But even Imhof, famous for his relief shading work on maps and atlases, does not discuss such specific design techniques as dimensions or densities of strokes.

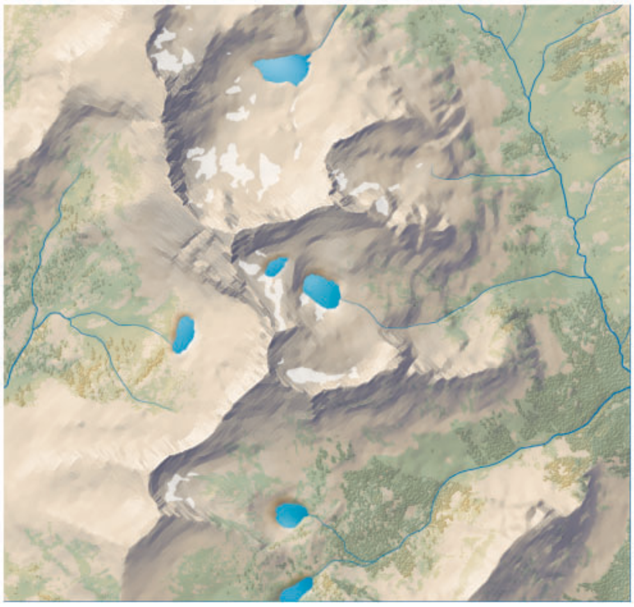

Figure 2. Raster-based rock representation combined with shaded relief (T. Patterson, 2002, Teton Range, Wyoming)

Drawing upon figures and principles provided by internal unpublished documentation from swisstopo (Maire, 1983; swisstopo, 2008; Gilgen, 2009), this paper discusses the defining characteristics of Swiss-style rock drawing in detail. The discussed design principles apply to rock drawings in the scale range between 1 : 25 000 and 1 : 500 000.

The following section identifies the main characteristics of the Swiss style and examines three different rock representations. The section on 'Graphical elements for craggy rock representation' analyses graphical elements for the most common rock types, including different stroke types, rock elements, arrangement, and dimensions. The last four sections discuss the combination of graphical elements with contour lines, their generalisation, the drawing process and conclusions.

CHARACTERISTICS OF SWISS-STYLE ROCK REPRESENTATION

Rock faces, cliffs, and other terrain features are recreated in maps to help readers find their location and identify an accessible route through mountainous regions. In general, the map must show the third dimension of mountainous regions, the spatial extension of rock and scree areas, and the steepness of the terrain. At a more detailed level, the map must allow for the identification of elevation at every point and should show important edges, ridges, gullies and other small features critical to finding a climbing route. A

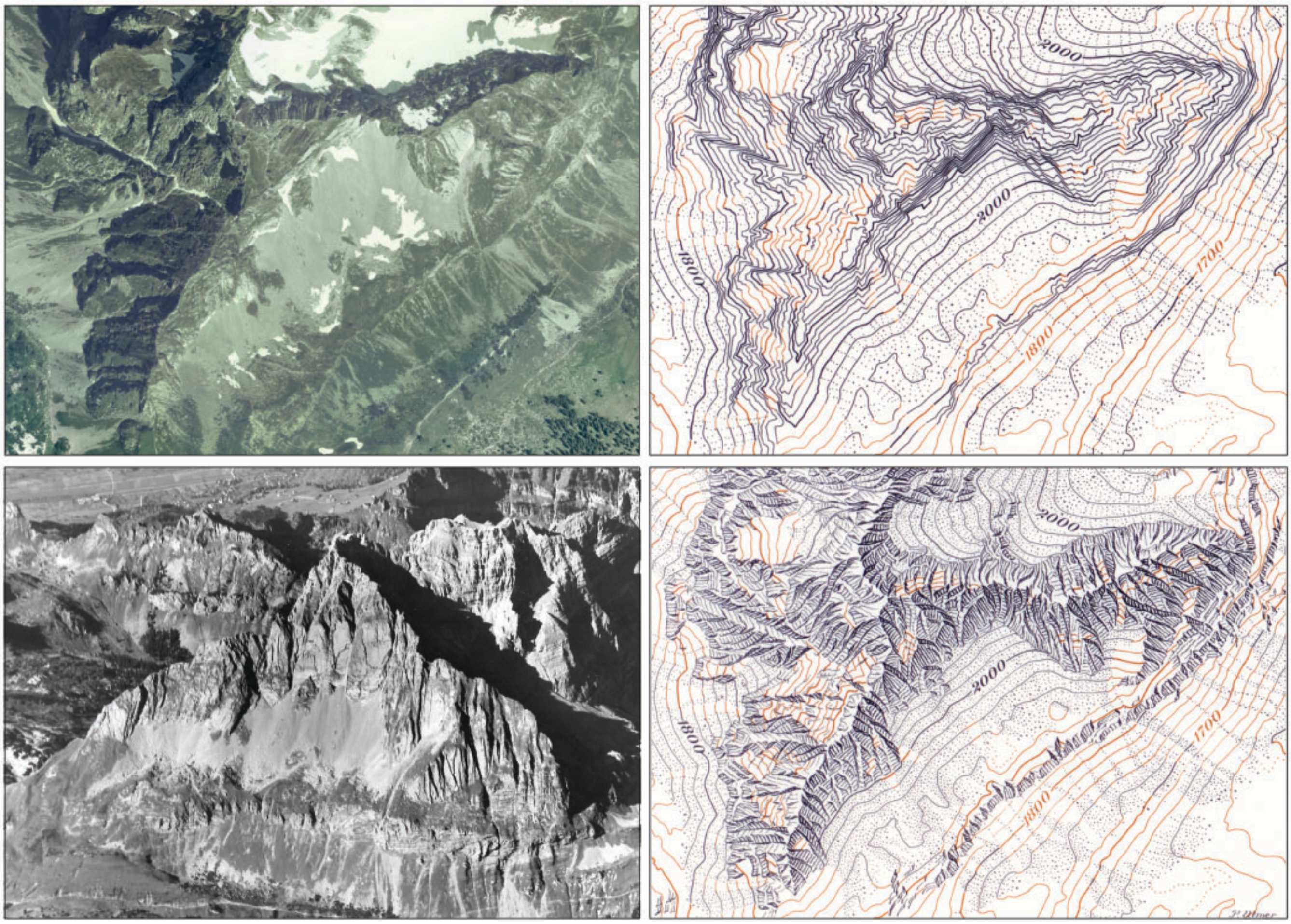

Figure 3. Orthophoto, contour lines only, aerial photography and Swiss-style rock drawing (from top left to bottom right). Rock drawing by Paul Ulmer, 1 : 25 000, Mürtschenstock, 47°4′10.4″N 9°8′41.3″E, photo from Imhof (1982)

successful rock representation should also illustrate the morphological rock type and its physical characteristics (Spiess, 1970; Dahinden, 2008). These requirements led to the development of the Swiss style, which is defined by three important characteristics: (1) a continuous three-dimensional illustration of the terrain surface; (2) ground-view perspective; and (3) characterisation of the rock area.

1. Continuous three-dimensional illustration of terrain: This is the most important of the three characteristics. An immediate three-dimensional impression of the terrain surface is created by combining shaded relief, a yellow light tone, rock drawing, and scree representation (Jenny *et al.*, 2010). The brightness of rock and scree representations varies with an illumination source to create a vivid three-dimensional impression of a continuously illuminated terrain surface.
2. Ground-view perspective: Rock faces are drawn as seen from the ground instead of from an orthogonal view directly above. This allows the map user to make the connection between the rock face on the terrain and the rock face on the map more easily since they tend to look similar.
3. Characterisation of the rock area: Rock areas are characterized by steepness, shape and rock type. The representation of the rock on the map should accurately illustrate the rock's type and appearance.

Continuous three-dimensional illustration of terrain surface

With Swiss-style maps, rock and scree representations receive a shading effect that is modulated with the terrain, complementing both the shaded relief and yellow light tone. The purpose of the shading effect is to clearly visualize the terrain in three dimensions across the entire map regardless of the type of land cover, i.e. rock, scree, meadows, forest, etc. The result is the impression of a three-dimensional surface that should be immediately perceivable by the map user.

To create the rock drawing, as well as the shaded relief and the scree representations, a virtual illumination from the northwest (top left) is applied. The direction of the illumination is adjusted locally to best accentuate the various mountain forms. If possible, only a single direction of illumination is used per mountain or mountain range. Occasionally, the direction of illumination has to be adjusted on a local level to better show the shape of the mountain.

Illumination divides the topography into light and shade faces. Cartographers divide each terrain formation into primary and secondary light faces and primary and

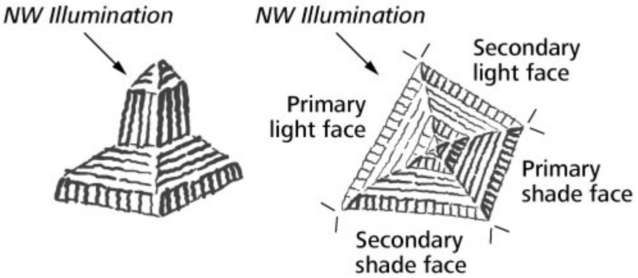

Figure 4. Shading model for rock drawing. The primary light face is the brightest, the primary shade face is the darkest, and the two secondary faces have an intermediate brightness and darkness (by J. Gilgen)

secondary shade faces. Secondary faces are only partially illuminated (Figure 4).

A hypsometric areal perspective is simulated, resulting in a stronger contrast between illuminated and shaded faces at mountain peaks and a weaker contrast in lower areas. Although all the strokes are printed in black, the contrast between neighbouring faces can be adjusted by varying stroke length, width and density. This adjustment can be applied to both light and shade faces so that shaded faces are darkened at the top while light faces are lightened.

The brightness of each face is also adjusted along the direction of contour lines to increase the contrast towards its neighbouring faces. Secondary shade faces are made darker towards the edge touching the primary light face and secondary light faces are made lighter towards the edge touching the primary shade face (Figure 4).

Ground-view perspective

Rock faces are often the most prominent features of a landscape and play a pivotal role in determining orientation and navigating on the terrain. Because of their essential function in these tasks, it is important that the map user be able to easily correlate the physical landform with its representation on the map. Therefore, rock faces are drawn as seen from a ground view instead of an orthogonal view. Figure 5 illustrates this idea. The characteristic triangle-shaped faces (top left and top right) are only visible from a ground perspective, but entirely hidden in the orthogonal view (bottom left). The triangular faces, however, are represented in the rock drawing, imitating the terrestrial view (bottom right).

For exceptionally steep rock faces, as shown in Figure 5, the footprint of the formation is slightly increased to generate the required space to draw the detailed faces from ground perspective.

Characterisation of the rock area

There are three main types of rock representations identifiable on swisstopo maps. Each representation corresponds to one of three types of rock: (1) *craggy*, (2) *loose* or (3) *Karst* (Figure 6).

1. *Craggy*: This is the most common type of rock in the Alps and is therefore, the most frequently represented rock type on Swiss-style maps. *Craggy* representation is used for jagged, rough, and uneven rock. There is also a subvariety of *craggy* rock that is applied to formations polished by glaciers. These formations are drawn with rounder shapes. Hachures are less shaky and longer. Design principles for *craggy* rock types are discussed in further detail in the following section.
2. *Loose*: The *loose* rock representation is used for large heaps of rubble, slate, and soft sandstone. This type of rock is almost exclusively drawn with strokes placed along the direction of contour lines. For extremely *loose* rocks, strokes are intermingled with scree dots. Unlike *craggy* rock, all contour lines are drawn through for *loose* rock. On average, there are seven strokes drawn each 2 mm. To create a shading effect, four strokes are drawn on illuminated faces. Nine strokes are drawn on shade faces. Stroke width is also varied between light and shade faces. Since loose rock is found rarely and in limited extents, this type of rock drawing is seldom used.
3. *Karst: Karst* areas are typically located in regions of limestone, especially in areas of flat terrain. In the Alps, *Karst* is common where late snowmelt erodes the rock surface, creating sharp ridges and edges. *Karst* is extremely difficult to represent cartographically because the morphological connections and contour lines are difficult to extract from aerial imagery (Kraiszl, 1933). To preserve global shading by preventing the darkening of generally larger, flatter *Karst* areas, fewer strokes are used per area unit in *Karst* areas than in *loose* or *craggy* types. Strokes follow the structures on the terrain, symbolizing ditches, gullies, isolated dolines, cliff edges and ridgelines. As with loose rock, all contour lines are drawn through. Hachure strokes are usually placed in the direction of contour lines and accentuate the globally flat, but locally rough, surface.

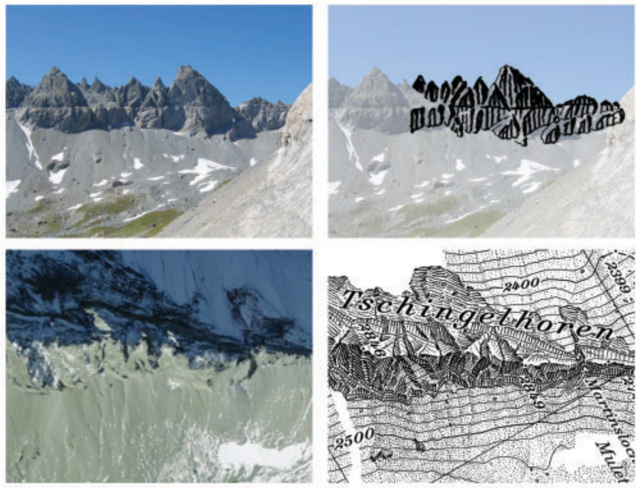

Figure 5. Terrestrial view, sketch of the main structures with triangular elements, orthoimage, and map (from top left to bottom right) (Tschingelhörner 46°53′53.8″N, 9°13′16.8″E; map 1174 Elm, 1 : 25 000, 1997, rotated 60° in clockwise direction; sketch by J. Gilgen)

Because *craggy* rock is the most common type of rock in the Alps and the most often represented rock in Swiss-style mapping, its representation would be the most interesting

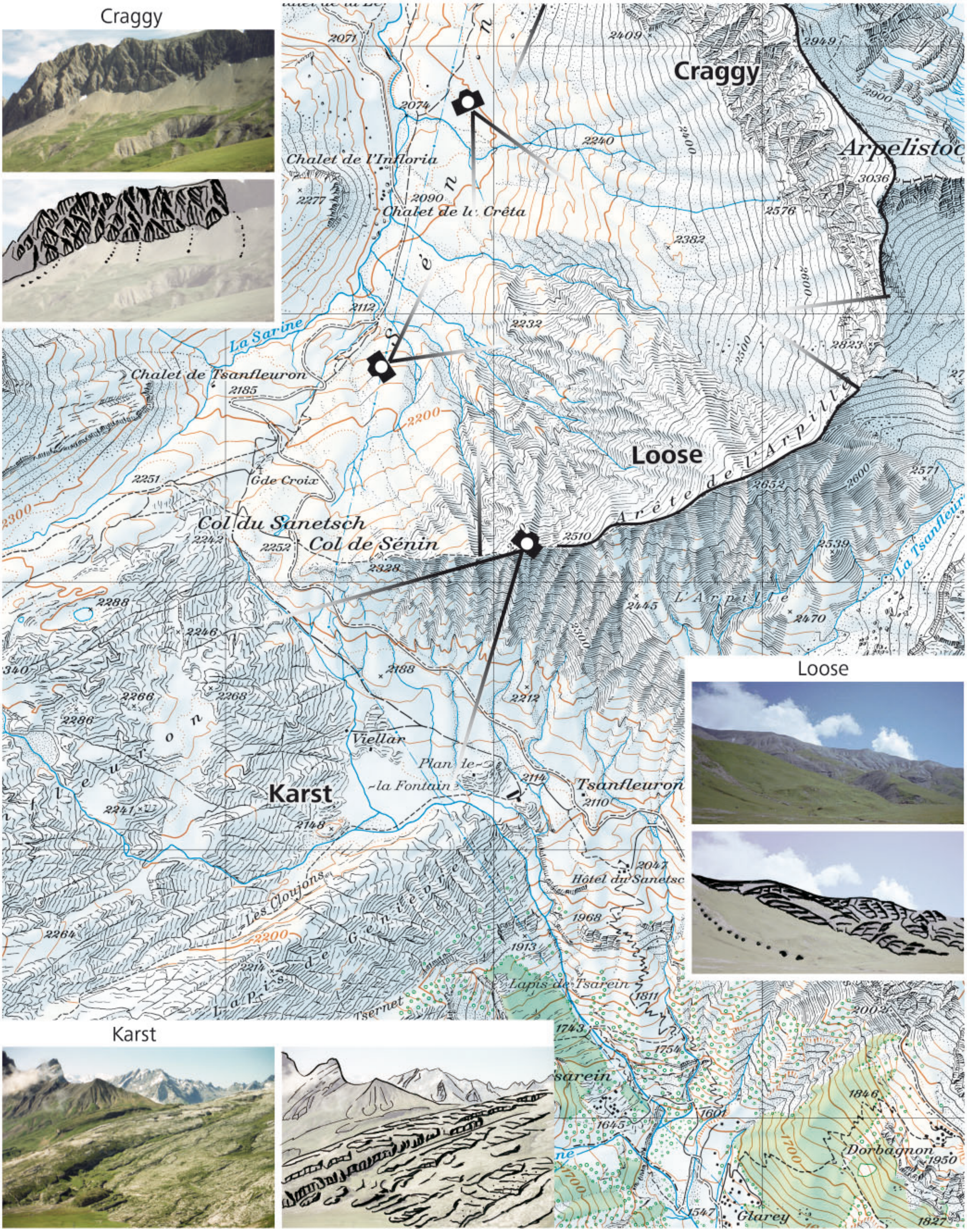

Figure 6. Karst, loose and craggy rock representation. Camera icons indicate the direction of view in the photos (map 1286 St. Léonard, 1 : 25 000 at 125%; sketches by J. Gilgen)

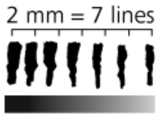

Figure 7. Modulated density and width of strokes creates a brightness gradient

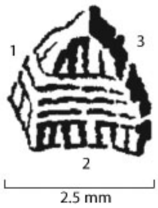

Figure 8. The basic rock element with a clear distinction between (1) light face, (2) intermediate main face, and (3) shaded face. The base line of this element measures approximately 2.5 mm

and advantageous to automate. *Loose* rock is considerably simpler to draw than *craggy* rock and its production could be more easily automated; however, it is only applied to small areas and is of minor importance. *Karst* rock is extremely demanding to create by manual production methods and encounters many problems when confronted with the possibility of automation such as limited high-resolution LIDAR data currently available for these areas.

GRAPHICAL ELEMENTS FOR *CRAGGY* ROCK REPRESENTATION

Strokes

The smallest graphical unit for Swiss-style rock drawing is the stroke. The average density of strokes is seven strokes per 2 mm on the map, making the mean distance between strokes less than 0.3 mm. To generate the shading effect, stroke widths and distances are varied according to their exposure to illumination (Figure 7). Light faces typically have four to five strokes per 2 mm. At the peak on shaded faces, there may be nine thick strokes per 2 mm. Table 1 shows the variation of stroke widths with illumination.

On light faces, strokes are generally thicker and denser at the foot of the slope face and thinner and less dense in the upper area of the slope face. This gradation enhances the black-white contrast, thereby accentuating the three-dimensionality of the shaded relief.

The degree of stroke 'jitteryness' changes according to rock type. Strokes usually have an edgy appearance to characterize the rough *craggy* rocks of the Alps. Strokes may be interrupted to highlight irregularities in landforms. Interruptions can be used to avoid creating too dark of a

Figure 9. Sketch of Eiger's north face in a terrestrial perspective (by J. Gilgen)

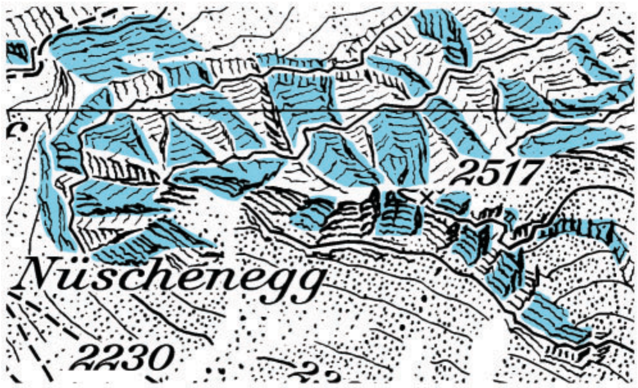

Figure 10. A patchwork of rock elements, every other rock element highlighted

representation for illuminated slopes, which could compromise the three-dimensional appearance of the shaded relief by reducing the contrast between light and shade faces.

As a basic principle, rock strokes should not cross over one another. Crossing strokes often produces a muddled drawing where individual forms and rock formations are nearly indistinguishable to the human eye. Because of resolution limitations on printing technology, crossed strokes can smear in the printing process and become black spots rather than distinct symbols. However, some salient geomorphological formations such as geological faults are actually represented more clearly by using one relatively long line to cross over other hachures if the map scale allows for sufficient space to draw such details.

Rock elements

When multiple strokes are combined, they form small rock elements that become the building blocks for rock drawing. Rock elements are often triangular shaped, a few millimetres large, and frequently have a light face, intermediate

Table 1. Width of strokes for rock drawing

Mean line width	*ca* 0.12 mm
On shaded slopes	0.22 mm (beginning of strokes at lower end of slopes) to 0.26 mm (end of lines at upper end of slopes)
On illuminated slopes	0.1–0.06 mm (possibly with interruptions)

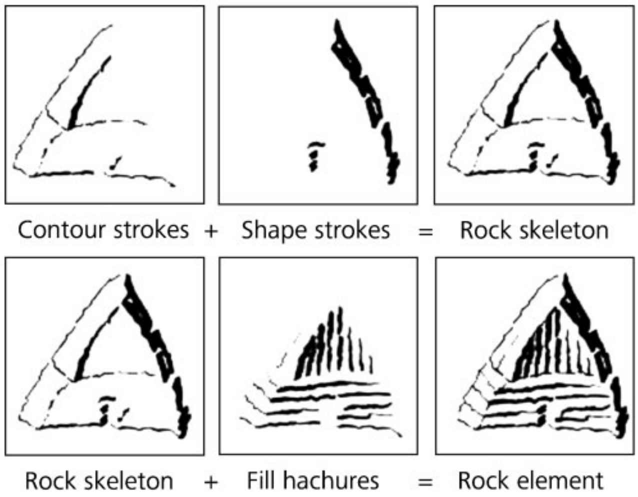

Figure 11. Contour strokes, shape strokes and fill hachures for constructing a rock element (by J. Gilgen)

Figure 13. Rock skeleton formed by contour and shape strokes, combined with shaded relief (from Imhof, 1968, 1 : 25 000)

main faces and a shade face (Figure 8). Multiple rock elements are drawn closely together to fill a larger section of rock outcrop or mountain face. The structuring in multiple smaller elements is an obvious design principle for sketching rock faces from a ground view in perspective drawing. For example, Figure 9 shows Eiger's north face from a terrestrial perspective made up of numerous, mostly triangular-shaped, individual rock elements. Because one of the main characteristics of Swiss-style rock drawing is the representation of rock faces as seen from a ground view instead of an orthogonal view, it is logical to apply this design principle from perspective drawing to otherwise orthogonal maps.

Figure 10 illustrates the 'patchwork' design principle by highlighting every other rock element. Figure 10 also shows that the upper and lower limits of a rock element often align with contour lines.

For *craggy* rock representation, cartographers use three different stroke types: contour strokes, shape strokes, and fill hachures. Contour strokes define sharp-edged rock formations and are typically used to indicate the edges of an illuminated face of a rock element. Shape strokes, on the other hand, are used on shaded faces and are considerably thicker to show important incised features like gullies (Figure 11). Fill hachures are used to fill the outlines of a rock element, which are known as the rock skeleton. The orientation of the hachures indicates the steepness of the slope.

Similarly to how the global brightness of a rock face is adjusted to highlight the third dimension with the shading effect, strokes within each rock element are also adjusted according to the source of illumination (Figure 12). To create the shading effect in individual rock elements, the width of contour strokes, shape strokes and fill hachures vary in order to emphasize the local shading effect applied to small rock elements. An illumination direction strictly from northwest would cast the same amount of light on faces parallel to the direction of illumination. The northwest illumination is therefore adjusted locally to clearly discriminate the faces of both large formations and small rock elements. Most often a secondary light direction from a west-northwest direction is applied. In exceptional cases the illumination direction can also be changed to north-northwest if the legibility of the terrain forms is improved.

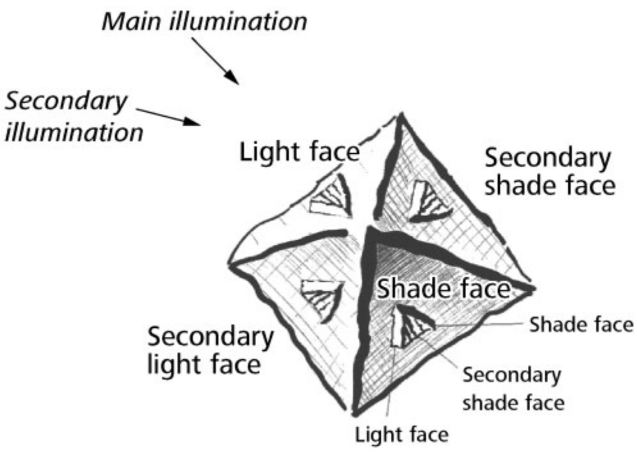

Figure 12. The main illumination is adjusted if rock faces are oriented in northwest direction. The main illumination would render the shade face and the light face of the bottom-right rock element with the same brightness. The secondary illumination discriminates the two faces (by J. Gilgen)

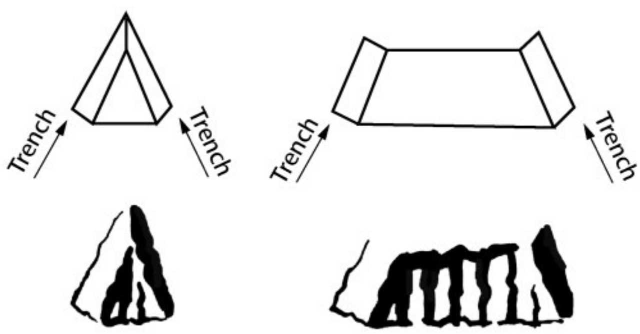

Figure 14. Elementary forms for rock drawing. Left: the smallest possible rock element delimited by two trenches. Right: a larger element, using the same graphical principles. An extra-wide shape stroke on the right side symbolizes the shaded face of the element (by J. Gilgen)

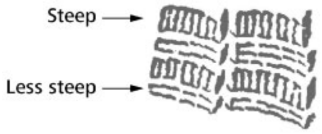

Figure 15. The orientation of fill hachures indicates steepness

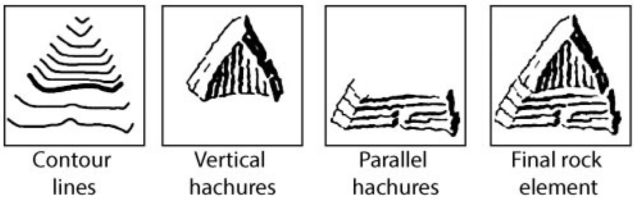

Figure 16. The orientation indicates steepness (by J. Gilgen)

Contour strokes and shape strokes

Contour strokes (not to be confused with contour lines) and shape strokes show a generalisation of morphological structures in a variety of forms and shapes (Figure 11). Both stroke types outline rock elements, thus creating a skeletal framework along gullies, edges, ridges, erosion lines and other visible structures. The skeleton by itself can efficiently portray rock areas, as illustrated by Figure 13 (compare with Figure 1). However, in rock drawing as applied by swisstopo, cartographers fill in the skeletons with hachures.

Although most rock elements are triangular-shaped, basic rock elements along band-shaped cliffs may be quadrangular-shaped. The edges of triangles and quadrangles are important for properly identifying the shape, so special attention is paid to their appearance. Contour strokes showing the borders of rock elements are sometimes interrupted to show a blurred border or to brighten up a light face.

When contour strokes would be placed too close to each other to maintain visual clarity or fill hachures would be too short, shape strokes are used. Shape strokes, typically used to depict gullies and trenches, emphasize shaded slopes and are considerably thicker than contour strokes or fill hachures. An extra-wide shape stroke may be used if the shaded face of a rock element is narrow and delimited by a trench. Shape strokes are essential for making basic rock elements appear three-dimensional (Figure 14).

Fill hachures

Rock skeletons are filled with hachures, which intensify the shading effect by locally adjusting the mean brightness. Fill hachures are also significant because they indicate steepness by their orientation. Fill hachures drawn vertically relative to contour lines represent steep areas whereas in flatter areas, fill hachures are drawn parallel to contour lines (Figures 15 and 16). Hachure lines are generally shorter, heavier and closer together for shaded faces and longer, lighter and more widely spaced for illuminated faces. Steep slopes on illuminated faces may occasionally become too dark when hachures are placed vertically to contour lines. To avoid this darkening and maintain pronounced black–white contrast between light and shade faces, hachures are occasionally drawn parallel to contour lines on light faces close to mountain peaks, ideally only showing the skeleton of the small rock element.

Table 2. Length of fill hachures

Fill hachure vertical to contour line	0.25–2.5 mm
Straight fill hachure parallel to contour line	0.25–1.8 mm
Curved fill hachure parallel to contour line	0.25–4 mm

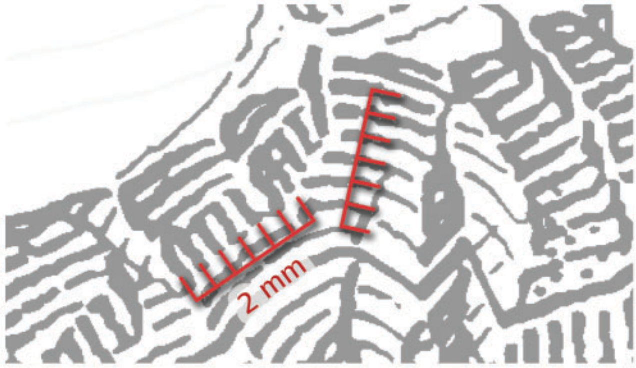

Figure 17. The mean density of fill hachures is 7 per 2 mm

There is no clearly defined slope threshold for determining hachure orientation. Generally, vertical hachures are applied when snow or vegetation cover is not securely held on a landform's surface, when there is danger of rock fall, or where only experienced climbers with specialized equipment can traverse. Parallel hachures are drawn in less dangerous areas that can generally be traversed by hikers.

Hachures parallel to contour lines follow the curvature of the contour lines and can achieve a maximum length of 4 mm. Vertical hachures follow the direction of the steepest slope and are usually straight. If the space inside a rock skeleton does not allow for a minimum hachure length of 0.25 mm, no fill hachures are drawn. The range of lengths for vertical and parallel hachures is listed in Table 2. Fill hachures that are vertical to the contour lines may also vary in width, becoming thinner on the upper area of light faces and thicker on shade faces. In some cases, hachures on light faces are incomplete or interrupted to brighten up the overall image.

Fill hachures are regularly distributed and form a sort of standard pattern. On average, the mean density is seven hachures for each 2 mm on the map, resulting in 0.28 mm mean distance between any two hachures (Figure 17). If the hachure would be placed too close to the border of a rock element or if the regular pattern cannot be achieved, the size of the element can be adjusted. The necessary enlarging or shrinking of the element should be within a general 0.3 mm displacement tolerance.

Figure 18. Connecting hachures and shape lines (from Swisstopo 2008, by H. Walker)

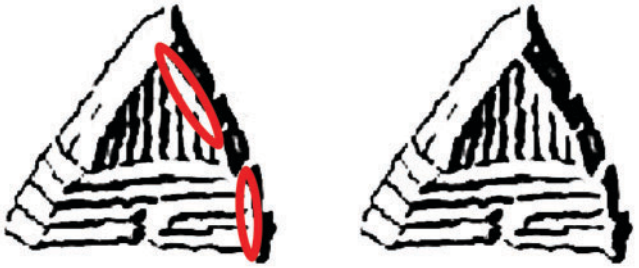

Figure 19. White space (highlighted in red on the left) between hachures toward fill hachures (by J. Gilgen)

Vertically oriented hachures on shaded faces are tightly connected with the upper and lower restricting contour lines. On light faces, hachures are only loosely connected with the upper contour line. The ridgeline – the borderline between light and shade faces – is created by the contour stroke on the shaded side of the ridge. Hachures on the light face narrow towards the ridge and are not connected to the contour stroke (Figure 18). Fill hachures are shortened along the border with the shaded face in order to accentuate this edge (the red-marked area in Figure 19).

Figure 20. The arrangement of strokes parallel to contour lines compensates for omitted intermediate contour lines at 1 : 25 000

COMBINATION OF ROCK DRAWING WITH CONTOUR LINES

When redesigning the swisstopo map series in the first half of the twentieth century, there was passionate debate among German speaking cartographers as to whether contour lines should be included in rock areas or replace previously used rock drawings altogether (Blumer, 1927, 1932; Lehmann, 1931; Schneider, 1934; Brandstätter, 1941/1942, 1960, 1983; Imhof, 1982). Several test areas were mapped in different styles by various authors. As a result of these tests, swisstopo decided to only include index contour lines at the 1 : 25 000 scale. Intermediate contours – contour lines spaced at the regular contour interval – are omitted at this scale because they blend together in steep areas and are extremely difficult to read in irregular, rocky topography (Imhof, 1965, p. 279; Spiess, 1970). At scales smaller than or equal to 1 : 50 000, no index contour lines are mapped for the same reasons that intermediate contours are omitted on 1 : 25 000 scale maps. Representations of *Karst* and *loose* rocks are an exception to these rules. Because area of *Karst* and *loose* rocks are relatively flat or gently sloping, index and intermediate contour lines are show at all scales in these areas.

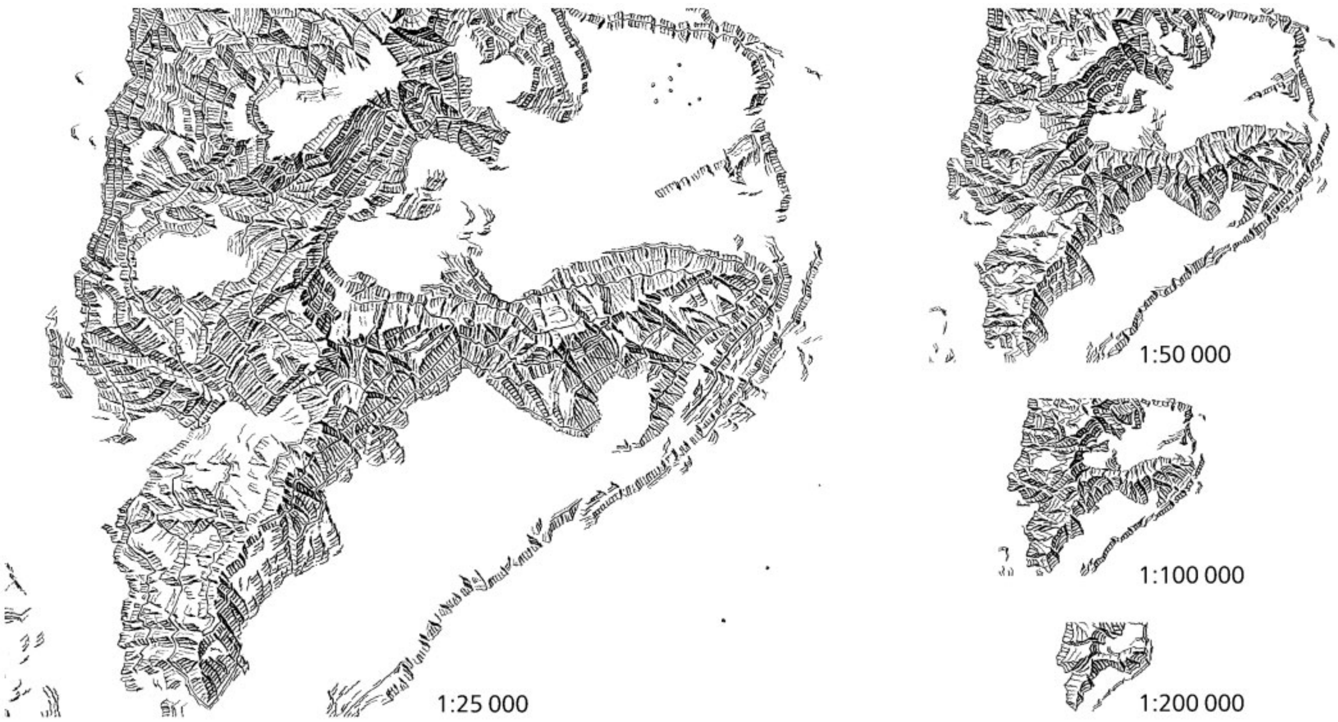

Figure 21. The same design principles applied to a scale range between 1 : 25 000 and 1 : 200 000. Maps enlarged by 150% (drawn by Paul Ulmer, Mürtschenstock 47°4′10.4″N, 9°8′41.3″E, from Spiess *et al.*, 2002)

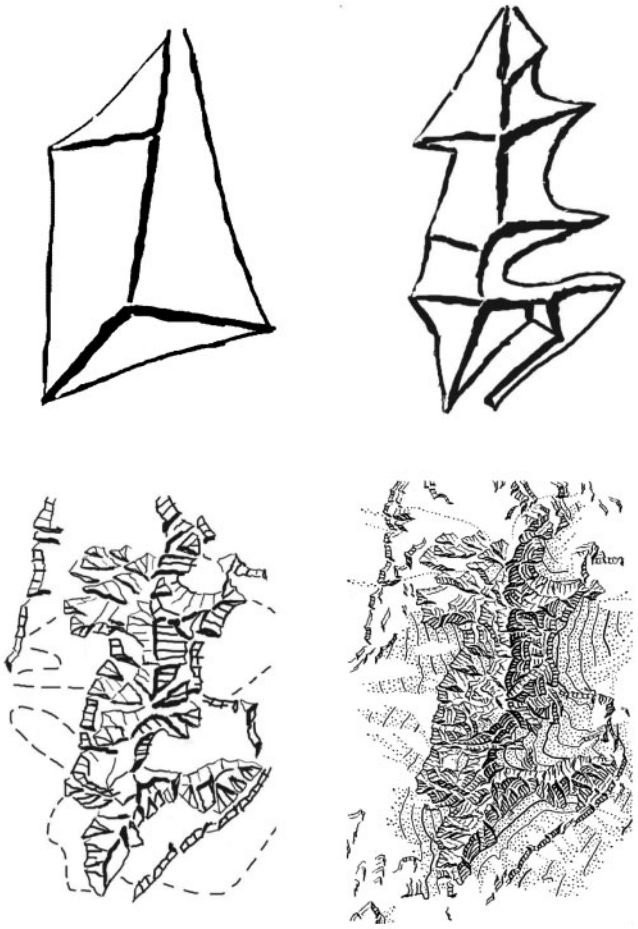

Figure 22. Gradually refining a sketch structuring the main landform into illuminated and shaded sides (top row) to a rock drawing based on skeleton lines (bottom left) and the final rock drawing (bottom right) (sketches by J. Gilgen; lower right drawing by P. Ulmer from: Swiss Society of Cartography, 1977)

The arrangement of hachures can partly compensate for the omitted contour lines in two ways. First, the base line of many rock elements is parallel to the direction of imaginary contour lines and second, fill hachures in less steep rock formations are placed parallel to contour lines. When these elements are combined, they create a 'curve effect' and guide the eye along the direction of the omitted contour lines (Figure 20).

The combination of contour lines with hachures at 1 : 25 000 exemplifies the best both elements have to offer – the vivid three-dimensional impression created by the shaded rock drawing and the metric reference provided by contours (Blumer, 1932; Imhof, 1965 pp. 266–281). It is noteworthy that swisstopo varies the thickness of contour lines with their exposure to illumination. Contour lines in light faces are thinner than those on shaded faces to accentuate the shading effect of the terrain.

GENERALISATION

The level of generalisation must be adjusted for different scales, but regardless of scale, the design principles outlined in the previous sections still apply (Figure 21). When

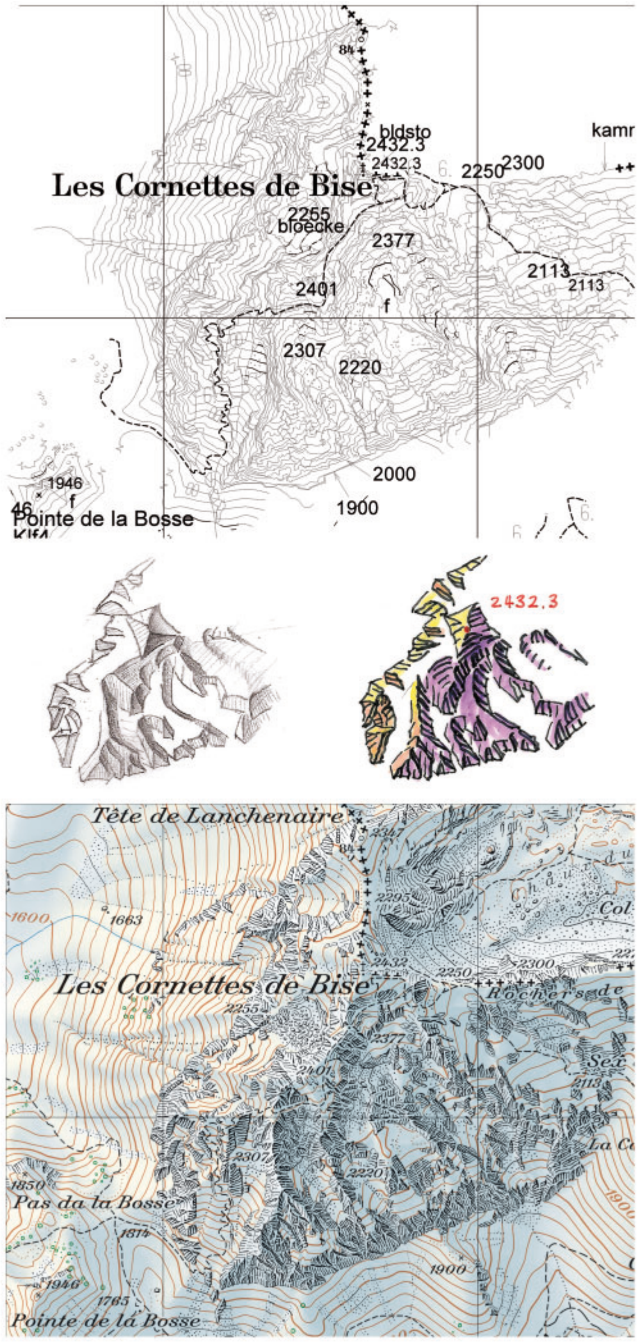

Figure 23. Contour lines and structural lines from a photogrammetric interpretation (top) and a segmentation of the main landforms into shaded and illuminated faces (centre row) are the base for a rock drawing (map 1284 Monthey, 1 : 25 000) (by J. Gilgen)

generalizing a rock drawing, important geological structures are emphasized to facilitate navigating and orienting on the terrain. Complicated details are simplified and irrelevant details are omitted. Figure 21 shows a map generalisation series with scale reduced from 1 : 25 000 to 1 : 200 000. The 1 : 25 000 map shows the most detailed representation of both major and minor forms as well as boulders. There are fewer details for major and minor forms and boulders on the 1 : 50 000 map. The 1 : 100 000 and 1 : 200 000 maps only show major rock formations and

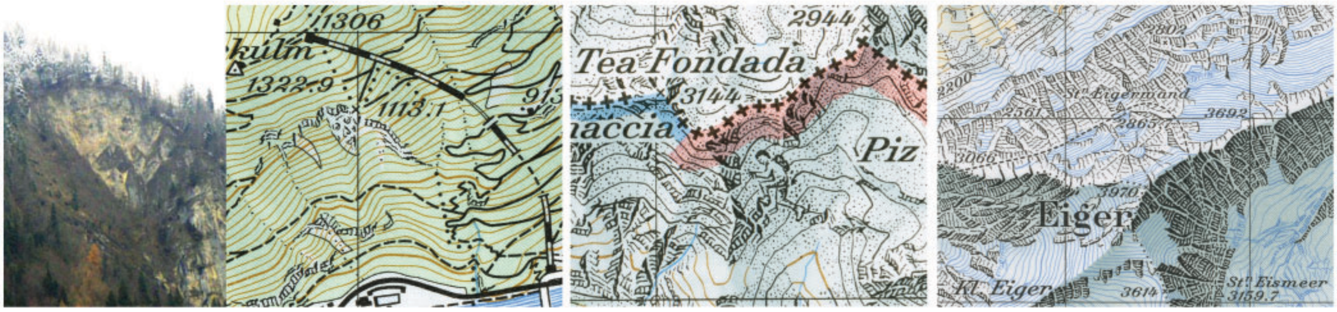

Figure 24. Hardermandli face, mountain climber, spider in the Eiger north face (maps: 254 Interlaken, 1 : 50 000, 2003, north of Interlaken; 39 Flüelapass, 1 : 100 000, 2006; 254 Interlaken, 1 : 50 000, 1980)

isolated boulders are omitted (Spiess *et al.*, 2002). At smaller scales, multiple rock elements are aggregated and smaller elements are removed.

DRAWING PROCESS: FROM BASIC INFORMATION TO THE FINAL DRAWING

During the analogue era of cartography, aerial stereo photography was the main source of information for rock drawing. To draw the first editions of the current map series, swisstopo cartographers used the outer edges of aerial photographs, where mountain faces were shown at a slightly oblique side view instead of from directly above as seen in the centre of the photograph, in order to best characterize the terrain. Another important source of information was a large collection of terrestrial stereo imagery that covered most of the Swiss Alps region. Nowadays, the main source is orthoimagery (Pillewizer, 1977). Occasionally terrestrial images showing side views of rock faces, as well as contour and structure lines derived from the photogrammetric interpretation of stereoscopic pairs of aerial images, are used.

Figure 22 demonstrates the steps in the drawing process starting from a coarse sketch and finishing with the rock drawing. First, the orientation of the main landforms is identified (Figure 22, top left). Second, landforms are subdivided into more detailed shaded and illuminated faces (Figure 22, top right). Third, a rock skeleton is drawn with contour strokes and shape strokes. Skeleton lines are placed along ridges, fissures, edges, and similar structures (bottom left). The skeleton serves as a base for the final version of the rock drawing that includes fill hachures (bottom right).

Figure 23 shows contour and structural lines derived from a detailed photogrammetric interpretation of aerial imagery (top). Main landforms then undergo a schematized segmentation into shaded and illuminated faces, which is important for drawing shaded rock hachures (centre). The map at the bottom shows the final rock drawing.

At swisstopo, rocks are drawn digitally. Adobe Photoshop and a graphics tablet are the preferred tools. Productivity is greatly increased compared to vector-based drawing controlled by a computer mouse or even the analogue scribing technique, mainly due to the ability of the graphics tablet to control the position and width of a stroke in an intuitive and natural way (Gilgen and Jenny, 2010). While the tools have changed, the design principles remain identical to those developed in the manual era.

CONCLUSION

Rock drawing representation is demanding and time-intensive. However, the final product can be exceptionally beautiful, and occasionally include amusing details. Figure 24 shows some of the more enjoyable aspects of rock drawing including the human face-like Hardermandli rock formation (left), a mountain climber (centre) and the spider on Eiger's north face, a rock formation well known to alpinists (right).

The design principles are more guidelines than rules and can be overridden if they are unsuitable for a particular area. Some attempts at automating rock drawing have been made (Hurni *et al.*, 2001; Dahinden, 2008; Gondol *et al.*, 2008), but fully automating Swiss-style rock drawing has yet to be done. The highly subjective and artistic component of rock drawing complicates the automated production. Also an issue is the availability of detailed terrain information necessary to create algorithms to show local and small characteristic landforms. The authors hope that the discussion of Swiss-style rock drawing in this article will contribute to the automation of rock drawing.

BIOGRAPHICAL NOTES

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REFERENCES

Bertschmann, S. (1953). 'Felsdarstellung und Äquidistanz in den Gebirgsblättern der Landeskarte 1:25 000', **Die Alpen**, 29, pp. 219–221.

Brandstätter, L. (1941/1942). 'Das Geländeproblem in der Hochgebirgskarte 1:25.000', **Jahrbuch der Kartographie**, pp. 5–23 (1941) and pp. 18–66 (1942).

Brandstätter, L. (1960). 'Schichtlinien und Kanten-Zeichnung: Neue Methode der Geländedarstellung auf der Topographisch-morphologischen Kartenprobe 1:25 000 "Alpiner Karst am Hohen Ifen"', **Erdkunde**, 14, pp. 171–180.

Brandstätter, L. (1983). **Gebirgskartographie**, Franz Deuttike, Wien.

Blumer, W. (1927). 'Die Felsdarstellung: ein Beitrag zur neuen Landeskarte', **Die Alpen – Les Alpes – Le Alpi: Revue du Club Alpin Suisse**, 3, pp. 450–453.

Blumer, W. (1932). 'Zur Frage der Felsdarstellung', **Schweizerische Zeitschrift für Vermessungswesen und Kulturtechnik**, 30, pp. 82–84.

Bolliger, J. (1967). 'Die Felszeichnung auf amtlichen Karten und Plänen der Schweiz', **Zeitschrift für Vermessungswesen**, 11, pp. 435–442.

Bühler, P. (1938). 'Die Darstellung der Felsen', **100 Jahre Eidgenössische Landestopographie 1838–1938: Fachtechnische Abhandlungen**, 6, pp. 1–4.

Dahinden, T. (2008). Methoden und Beurteilungskriterien für die analytische Felsdarstellung in topografischen Karten. PhD dissertation. ETH Zurich. Zurich, Switzerland.

Gilgen, J. (1998). 'Felsdarstellung in den Landeskarten der Schweiz', in **Hochgebirgskartographie: Silvretta 1998**, Workshop der Kommission Hochgebirgskartographie der Dt. Gesellschaft für Kartographie, Wiener Schriften zur Geographie und Kartographie, 11, ed. by Kriz, K., pp. 11–21, Inst. für Geographie, Ordinariat für Geographie und Kartographie, Wien.

Gilgen, J. (2006). 'Revision of Rock, Scree and Glacier in a Databased Cartographic System', in **5th ICA Mountain Cartography Workshop**: **Mountain Mapping and Visualization**, Bohinj, Mar 29–Apr 1, pp. 83–88.

Gilgen, J. (2008). 'Aerial Photos + Photogrammetric Plot = swisstopo's Rock Representation: Caricatured Mountains?', in **6th ICA Mountain Cartography Workshop: Mountain Mapping and Visualization**. Lenk, Feb 11–15, pp. 63–69.

Gilgen, J. (2009) **Felsdarstellung in den Landeskarten der Schweiz: Dokumentation – Fels, Geröll und Gletscher (unpublished)**, p. 18. Federal Office of Topography swisstopo, Wabern.

Gilgen, J. and Jenny, B. (2010). 'Digital rock and scree drawing in vector and raster mode', **Geographia Technica**, special issue, pp. 24–31.

Gondol, L., Le Bris, A. and Lecordix, F. (2008) 'A new approach for mountain areas cartography', in **Headway in Spatial Data Handling**, pp. 315–333, Springer-Verlag Berlin and Heidelberg & Co., Berlin.

Hodgkiss, A. G. (1981). **Understanding Maps: A Systematic History of Their Use and Development**, Wm Dawson & Son, Folkstone.

Hurni, L., Dahinden, T. and Hutzler, E. (2001). 'Digital cliff drawing for topographic maps: traditional representations by means of new technologies', **Cartographica**, 38, pp. 55–65.

Imhof, E. (1965). **Kartographische Geländedarstellung**, Walter de Gruyter & Co., Berlin.

Imhof, E. (1968). **Gelände und Karte**, Eugen Rentsch Verlag, Zurich.

Imhof, E. (1982). **Cartographic Relief Presentation**, Walter de Gruyter & Co., Berlin.

Jeannet, A. (1938). 'La gravure cartographique des rochers', **100 Jahre Eidgenössische Landestopographie 1838–1938: Fachtechnische Abhandlungen**, 15, p. 7.

Jenny, B., Hutzler, E. and Hurni, L. (2010). 'Scree representation on topographic maps', **The Cartographic Journal**, 47(2), pp. 141–149.

Keates, J. S. (1996). **Understanding Maps**, 2nd ed., Longman, Harow.

Kraiszl, W. (1930). 'Topographisches Felszeichen nach der Schraffenmethode', **Der Schweizer Geograph**, extra issue 1, pp. 39.

Kraiszl, W. (1933). Das Karrenfeld als Formtyp in der Gebirgskartographie. **Schweizerische Zeitschrift für Vermessungswesen und Kulturtechnik**, 31, pp. 5–15.

Lehmann, O. (1931). 'Die Gründe gegen die Beibehaltung einer Felszeichnung auf der künftigen topographischen Karte der Schweiz', **Petermanns Geographische Mitteilungen**, 9/10, pp. 233–236.

Maire, K. (1983). **Felsdarstellung** (handwritten unpublished manuscript, transcribed by Feldmann, H.-U., Murten), Federal Office of Topography swisstopo, Wabern.

Patterson, T. (2002). 'Getting real: reflecting on the new look of national park service maps', **Cartographic Perspectives**, 43, pp. 43–56.

Pillewizer, W. (1977). 'Hochgebirgskartographie und Orthophototechnik', in **Beiträge zur Theoretischen Kartographie: Festschrift für Erik Arnberger**, ed. by Kretschmer, I., pp. 107–124, Franz Deuticke, Vienna.

Schneider, K. (1934). 'Fels-Isohypsen auf neuen Landeskarten der Schweiz', **Schweizerische Zeitschrift für Vermessungswesen und Kulturtechnik**, 32, pp. 207–219.

Spiess, E. (1970). 'Zur Felsdarstellung in unseren Gebirgsblättern', **Der Uto**, 10, pp. 138–144.

Spiess, E., Baumgartner, U., Arn, S. and Vez, C. (2002). **Topographic Maps – Map Graphics and Generalization**, Publication series no. 17, Swiss Society of Cartography, Bern, Switzerland.

Swiss Society of Cartography. (1977). **Cartographic Generalization – Topographic Maps**, Publication series no. 2, Swiss Society of Cartography, Bern, Switzerland. Translation of: Kartographische Generalisierung – Topographische Karten (1975), Publication series no. 1.

Swisstopo. (2008). **Richtlinien – 6.7 Darstellung Gelände** (unpublished), Federal Office of Topography swisstopo, Wabern.

Washburn, B. (1960). **Mount McKinley, Alaska (Map), 1:50 000, 71 × 71 cm**, Mass. Museum of Science, Boston, CA.

Washburn, B., Bishop, B. C., Garver, J. B., Altherr, W. and Jeanrichard, F. (1988). **Mount Everest (Map), 1:50 000, 52 × 73 cm**, National Geographic Society, Washington, DC (2nd edition, 1991).