1
INTRODUCTION

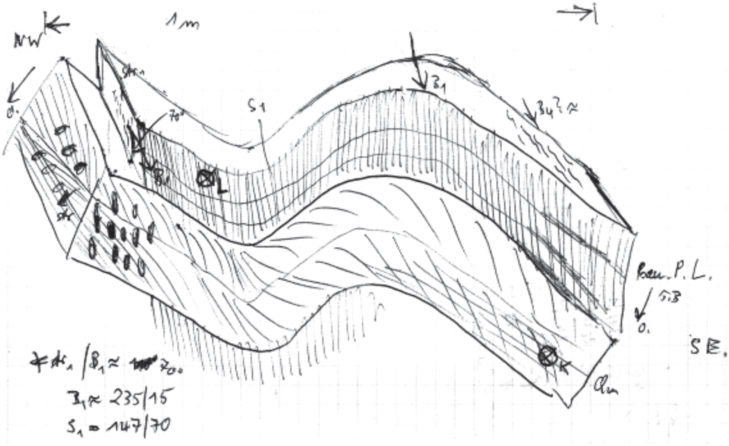
> *"Of course you should draw! You should draw everything that can be drawn . . . "*
>
> *"But, Professor, I have no artistic talent!"—"You do not need it! You aren't supposed to make art, but simply draw as well as you write. Firstly, so that you can learn to better see and observe, because the drawing pencil forces the eye to look closely and give a detailed account of the facts, for drawing is guided seeing; secondly, because drawing is often the shortest and best form of description. For this you need no talent, only diligence and a little guidance . . . "*
>
> (Hans Cloos, 1938)

Drawing is one of the elementary human abilities. It requires practice. But one must not draw with the skill of a Leonardo da Vinci or an Albrecht Dürer to be able to create drawings that are informative, aesthetic, and a joy to others. The drawing of geological objects is at a level that anyone can reach with a little practice and by following a few rules (Figure 1.1).

When we talk about drawing, we usually mean *artistic drawing*. In the case of Leonardo da Vinci—the brilliant painter, sculptor, architect, naturalist, and engineer of the Renaissance—this includes *technical* or *scientific drawing*. But in later times, the artists were rarely scientists and the scientists rarely artists. The tasks were distributed. Alexander von Humboldt "measured the world" and Aimé Bonpland drew it. Carl von Linné systematized species classification, while Maria Sibylla Merian painted insect and flower pictures, and John James Audubon left behind "The Birds of America." Only a few artists sketched geology (apart from the omnipresent Goethe), like Robert Bateman, for example: "I enjoyed painting the rock, a kind of granite called gneiss, using little trickles of turquoise and pink and yellow and gray. When I paint rocks I like to convey their characteristics and to make sure that they belong in the landscape and are recognizable geologically" (Terry, 1981); it is the geoscientists, rather, like Clarence E. Dutton (1882) or Albert Heim (1921), that have seen rocks and their structures with the eyes of artists (Figure 1.2).

Today, constructive drawing is what is meant by the term technical drawing, and that is done almost exclusively by computers. Academic (or scholarly), in particular scientific and specifically geological, drawing resists automation, because

Drawing Geological Structures, First Edition. Jörn H. Kruhl.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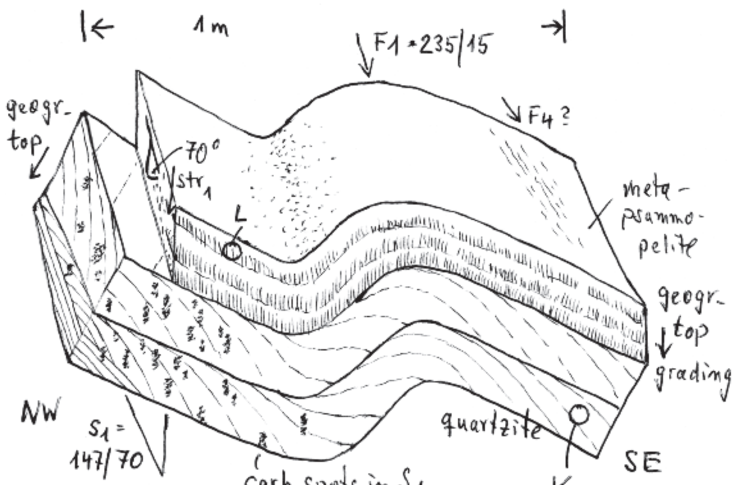
(a)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(b)

Figure 1.1 *One of the author's early, but failed, attempts to draw samples and outcrops in the field, and a better version of the same drawing.* ***(a)*** *Monoclinic fold in psammopelite and quartzite layers of the Moinian (Grampian Highlands at Loch Leven, Scotland); field drawing; outcrop KR513; field book 6 (Kruhl, 1973). The drawing contains numerous shortcomings; above all, imprecise layout of lines, a sloppy perspective, and an incorrect positioning of foliation planes in the metapsammopelitic layers.* ***(b)*** *The same drawing redrawn years later. Cross bedding and S1 foliation planes are more precisely placed; the perspective is correct and, consequently, the 3D appearance of the drawing is better; the carbonate spots are more realistically illustrated; and the labeling is more closely related to the structures. Circles L and K indicate positions of samples. Both drawings ca. A6; black ballpoint pen.*

Figure 1.2 *Drawing of part of the Grand Canyon, "Vishnu's Temple" (Dutton, 1882, plate XXXIV): a felicitous combination of artistic, geological, and geomorphological representation.*

nature knows no straight lines. Geological objects, like rock layers, folds, volcanic dykes, foliation planes, joints, and the outlines of crystals cannot be represented using the shapes of Euclidean geometry. This is not a question of precision, since the shapes of all these objects don't just vary by chance from the Euclidean form. We know today that many natural processes are not linear and produce shapes of non-Euclidean, fractal geometry (Mandelbrot, 1983). Many geological shapes appear complex and are usually described qualitatively (*sutured, rounded, amoeboid*) or are represented with the help of picture plates, like the degree of rounding of sand grains, for example. These images are usually paired with specific names (*angular, subangular, subrounded, rounded*) to ensure the transition to a written description. Complex structures can be captured truly precisely only when they are quantified using fractal geometry. Using these rules while sketching geological structures is well worthwhile. The gain in naturalness and closeness to reality is big.

While scientific drawing is based on a number of rules of artistic drawing, it has many of its own laws. Therefore, geological drawing requires different rules, in part, from artistic drawing. However, the principally irregular form of geological objects does not necessarily mean that it must always be drawn "irregularly" or "fractally." There are reasons for schematic, Euclidean drawing. This is why geological drawing must shuttle between lifelike and abstract representation. This is not easy, and the questions of when is it better to draw realistically, when is an abstract representation more effective, and how can a balance be established between the two, will be discussed in detail.

What is drawn must, however, already be technically understood and interpreted. This is the only way to select and distinguish between what is geologically important and unimportant. "It is the theory that determines what we can observe" (Einstein, 1955). Or, in other words: "You only see what you know" (Weizsäcker, 1955). When transferred to the drawing of geological structures, this means: We only see what we already have as a mental model. We only see the geological structures we expect and that already belong to our knowledge base. Although this may seem a little bit strict, it is true that we have difficulty perceiving and often dismiss structures that we do not know and that aren't part of our empirical knowledge.

Of course it is fundamentally possible to perceive even the unexpected or unusual, but it's hard, and we therefore do well to look at structures exactly before drawing them. If we interpret first, it will be easier to perceive the unexpected and unusual, and incorporate it into our knowledge and experience. This can be time consuming, and causes difficulties. Nevertheless, drawing itself, the physical process of seeing and sketching geological objects, is on a level of craftsmanship that anyone can achieve with a little practice, and, in any case, a "bad" drawing is still better than no drawing!

There are some aspects of geological drawing relating to geological maps and the construction of profiles that we will not touch upon, because they veer too much into the field of technical drawing. For this, there are a sufficient number of good books and, above all, websites where these techniques can be trained online. Furthermore, this book is not about drawing fossils. Although the drawing of fossils coincides in many ways with the drawing of geological structures, there are still some fundamental differences, like the object fidelity, which is essential to the drawing of fossils but more of a hindrance when drawing geological structures. The present book is mainly about:

- the way in which one must represent geological objects at different scales,
- how the purpose of the representation affects the nature of the representation,
- the way in which a balance between detailed and symbolic representation must be maintained in such drawings, and
- how one can practice all of this.

We will go from small to large, from thin section to outcrop, especially the ensemble of outcrops, and from the two-dimensional representation to the three-dimensional. This order has been chosen in part because two-dimensional representations are technically and in their principles easier, and because the two-dimensional surfaces of three-dimensional objects are seen first. Secondly, big geological objects are made up of many small pieces, and the bigger picture is best understood, if we understand the details.

This book is intended as an exercise book for the purpose of self-study. It should encourage the playful retention of structures, the anchoring of one's own geological data collection in the form of graphic representations, and the occasional replacement of the camera with paper and pen in the field. In addition, this book is meant to encourage the use of the benefits of exact drawings especially when it comes to precision and conciseness (e.g., in publications). Finally, I would like the representations in this book to show that geological structures have not only scientific value but also deserve our attention for their complexity and aesthetics.

1.1 Why Do We Need Drawings?

Anyone who has tried to describe a thin section, a rock sample, or an outcrop without the help of drawings (or photos), would probably not pose such a question. Compared to the expressiveness and the rich detail of graphic representations, the spoken or written word is an inadequate tool. Drawings and photos can document things that would otherwise take much more time to describe, in no time. And since graphics can be digitized, the electronic storage and processing of graphic information is not a problem.

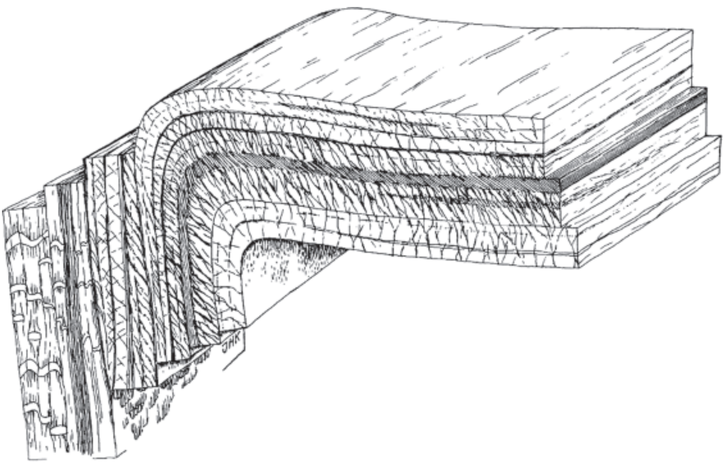
There is no strong conflict between drawing and photo. Photography is a quick and easy type of documentation. When taking pictures, one can be sure that all the details in the range of resolution are preserved. Even on a small scale, subtleties, which would not be accessible in a drawing or which would cost a lot of time to include, can be captured. Those who have participated in a field trip with an eager leader racing through a packed itinerary have learned to appreciate the camera. If 20 minutes are allotted to an outcrop with nice sedimentary structures or complex folds, one can leave the field book or the sketch pad in one's pocket, unless of course one belongs to the small, gifted group of precise fast-drawers.

On the other hand, the photograph reaches its limits when it comes to filtering out the essentials from a jumble of small details. Who hasn't photographed an outcrop that appeared clear and impressive to the eye, or even a rock thin section, that then, in black and white or in color, on paper or on the screen, appeared only as an indissoluble mixture of details distorting the essentials? In addition, the photo also captures the unimportant surrounding and provides information that we do not need and that we must carry with us as interfering ballast. Computer-aided photography provides opportunities to smooth surfaces and thus to convert photographs overloaded with details into sketch-like representations (Hayes, 2008). This development, however, is still in its early phases and it remains to be seen how useful it will be for geological objects with complex, detailed structures, and, especially, if the effort of editing the photographs exceeds that of sketching.

For three-dimensional objects, it may prove especially hindering that a photo only delivers a two-dimensional view of structures that in small form, even at the two-dimensional outcrop face, appear three-dimensionally and contain much more information in three dimensions than in two (Figure 1.3). We can

Figure 1.3 (a) *Photo of the "Spitznack" Fold (near the Loreley, Middle-Rhine region, Rhenish Massif, Germany). Centimeter- to decimeter-thick metapsammopelitic layers are bent to an open, monoclinic fold. The boundaries of bedding are represented by strong fractures in the horizontal fold limb and by weak fractures and differences in brightness in the vertical limb. In addition, a schistosity can be recognized. It is represented by narrow-spaced, nearly parallel fractures. The schistosity is pronounced and steep in the horizontal limb, fan-shaped in the fold crest, and is barely visible in the steep limb. Additional fabric details cannot be recognized. Hammer as scale.* ***(b)*** *Schematic drawing of the same fold. Based on the small protrusions and the fabrics that can be recognized on them, the planar, 2D view has been supplemented to form a 3D block. Highlighted are (i) the partitioning of the schistosity to two different sets of foliation planes in metapsammitic layers, (ii) the pile shape of the schistosity in metapelitic layers, (iii) the stretching lineation on an obviously bedding-parallel foliation plane, (iv) the compressed and sheared quartz veins in the steep limb, and (v) the slickensides on steep bedding-parallel shear planes. All these structures are not visible in the photo and are only revealed by close observation of the fold. Modified after Zurru and Kruhl (2000, Figure 33); size of original drawing ca. B4. A more comprehensive drawing is shown in Figure 4.27.*

(a)



(b)

(interpretatively!) capture three-dimensional structures more clearly and comprehensibly on two-dimensional paper when drawing perspectively. This also applies during microscopy: The brain can better distinguish between important and unimportant, and filter out the structures in question. How aesthetically and clearly identifiable the deformation and metamorphic fabrics could be, were it not for the retrograde influences that transform aesthetic plagioclase twins into an “ugly” mix of small mineral grains or that superimpose all the striking quartz deformation structures with an iron-plated net of micro fractures.

This means: Drawings are important when it comes down to emphasizing details or omitting the unessential, and when representing the three-dimensional three-dimensionally. This is a scientific decision! The strengths of the sketch are highlighting, omitting, and combining things that were not together in the original. One composes an image so that it meets the necessary requirements. This may seen “unscientific” at first glance. But fidelity is not most important; what is worth striving for is the scientific documentation and the interpretation of structures. Of course, structures that do not belong together should not be put together in such visual compositions, and no other, or even false, interpretations may emerge. But a drawing is not purely for documentation; it communicates beliefs and ideas. From this follows: Drawings must always contain an interpretation. Strictly speaking, one can hardly draw without interpreting, because even an omission is an interpretation. The geological stereogram (Chapter 5) is one of the most impressive forms of interpretation. In it, detailed pictures from individual outcrops are combined into one image that is neither to scale nor must show things next to one another as they occur in nature. The point of a stereogram is to represent the principle of the large-scale structure of geological area. The stereogram is therefore the model that a processor makes of a given area.

Drawings assist geologists in their everyday work. Sketches preserve the memory of details that would’ve been impossible or too complicated to photograph in the first place (poor lighting conditions, too many details, vegetative coverage, etc.). Drawings become indispensable when it comes to defending one’s hypotheses in discussions and when trying to directly convey impressions of outcrops to discussion partners who are unfamiliar with them. Even in a cartoon-like presentation of how structures develop, drawings are well suited. In any case, the apparatus of geological drawing must be mastered in order to draw accurately and powerfully.

In microscopy, drawings serve as a memory aid. They help record the otherwise fleeting impressions that arise during the examination of thin sections. Here, in contrast to laborious photography, drawing is an effective form of documentation. It does, however, require its own style that is different from the style of outcrop, sample, or exact thin section drawing.

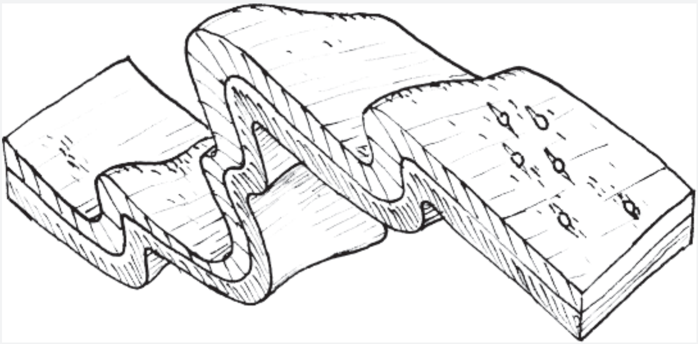
Even the processing of data is facilitated by drawing. If one wants to evaluate, on the basis of one's field book, how often and where certain geological structures (e.g., foliations or shear zones) occur in a given area, even just rapidly flipping through the drawings in a field book can give a rough idea. Searching for this information in texts can be extremely time-consuming. Additionally, the close connection between drawing and text (labeling) increases the informational content. It is even possible to obtain certain information (e.g., spatial relationships of lineations to foliation planes, the orientation of joints to layering) from careful drawings that one did not pay attention to or write down in the field.

Perhaps the most outstanding feature of drawings is that they are an important tool for thinking (Larkin & Simon, 1987). Experiments provide evidence of the "analog," that is: the visual processing of information in the brain (Brooks, 1968, Shepard & Metzler, 1971—cited in Metzig & Schuster, 1993). "One technique for avoiding the rigidity of words is to think in terms of visual images and not use words at all. It is perfectly possible to think coherently in this way ... The visual language of thought makes use of lines, diagrams, colors, graphs and many other devices to illustrate relationships that would be very cumbersome to describe in ordinary language" (De Bono, 1990, p. 73).

Drawing, like writing, is suitable—in many cases even more so!—for sorting and bundling thoughts. While drawing, the unimportant can be separated from the important, new ideas can form, and old ideas can be specified. It can also be resolved whether ideas are even usable and can be translated into logical and consistent models. Therefore, we should draw as often as possible while discussing, explaining, or even while thinking; what we are talking or thinking about should always be conceptualized with simple sketches or accompanied by schematic drawings. Such drawings can stretch our imagination (and that of others) and help to find the mental entry into a topic.

Finally, the circumstantial information can be more effectively saved with the help of drawings. "Pictorially presented material or visual representations [can] be stored particularly easily and permanently," and "descriptions of many creative thinkers specifically [reference] the course of pictorial ideas and the resulting creative act (like Poincaree, Kekule, Heisenberg, and others)" (Metzig & Schuster, 1993). The advantage of the schematic sketch versus an artistic, detailed, and extensive drawing has also been highlighted in investigations. "And so the development of details compared to outlined images leads not to an improvement of memory (e.g., Angin & Levie 1985). In fact, insignificant image details are forgotten shortly after being presented" (Rock *et al.*, 1972—cited in Metzer & Schuster, 1993). Although the brain is well suited for processing visual information, a photographic reproduction of individual details is not saved, "but rather, stored visual prototypes are resorted to for a mental image ... " (Metzig & Schuster, 1993).

Exercise 1.1:



Exercise 1.1* *(a) *Describe the fold structure in all of its geologically relevant details.* ***(b)*** *Give your description of the folds to a fellow student or colleague and have them draw the fold. Compare this drawing to the supplied sketch of the fold.*

Notes on Exercise 1.1:

What is geologically relevant? Certainly the monoclinic form of the fold. It refers to a movement of the "top" to the left (in the sketch). Furthermore, parts of the sketch and their geometries can be linked with geological structures and processes as follows:

- The angle of ~50-70° between the fold limbs with a "moderate" shortening,
- the "light" layering with its fan-shaped, wide-spaced foliation planes with a more quartz-rich, mica-poor composition,
- the "dark" layering with its slightly pile-shaped, narrow-spaced foliation planes with mica-rich composition,
- the foliation-free upper margin of the lower layer with a grading (mica-free versus mica-rich) and the resulting "stratigraphic up" that points, geographically, down,
- the slightly thinned fold limbs and thickened fold crests, also in the quartz-rich layer, with crystal-plastic deformation of the quartz and, consequently, with deformation temperatures of >300°C,
- the slightly curved shape of the fold axes with clearly crystal-plastic behavior of the rock layers.

- Additionally, the lineation on the layering (mica and feldspar- and garnet-blasts with preferred orientations) attests to the fact that (i) the foliation of the first deformation event (D1) already lies parallel to it, and, with that, the fold already represents a second fold and the sketched foliation a second foliation, and (ii) the extension of the first deformation event (D1) lies approximately perpendicular to the D2-fold axes, and that, therefore, the kinematic system during D1 and D2 was probably oriented the same way.

Probably, you will notice a difference between the present fold drawing and the fold drawing based on the description.

1.2 The Tools

When drawing in the field, the only drawing materials we need are a pen and paper. It is important that the pen leaves clean lines. The paper should be smooth (but not too smooth) and blank. Smooth paper has poor moisture retention, which gives a clean line. If the paper is too smooth, however, the pen will slip easily. Lined or graph paper interferes with drawing and scanning. Of all utensils used for artistic drawing, the ones that are most practical for geological drawing in the field are pencils, felt-tip pens, and ballpoint pens. The pencil is often recommended for drawing in the field. I, however, find it not particularly useful in most cases. If one doesn't want to keep sharpening it to avoid thick, inaccurate strokes, one must work with a hard pencil. This, however, generates pale, low-contrast drawings that require great effort by the brain to grasp and decrypt. Even when rapidly flipping through a field book, the higher-contrast drawings can be identified and compared more quickly.

A black ballpoint pen or a waterproof felt-tipped pen with a thin line offers better services compared to a pencil. Ballpoint pens also have the advantage that, depending on the pressure, lines of different weights can be generated without having to continuously sharpen the pen. The lines of waterproof felt-tipped pens can bleed on rough or wet paper. Waterproof paper is expensive or only available in field books ("rite-in-the-rain") whose layouts aren't always favorable for drawing. Damp paper, however, can be avoided with a large umbrella (the most important piece of equipment for any field geologist), for example. But if it's pouring, field work beyond just mapping is not useful, because fine structures are poorly visible in wet rocks. It is better to stay at the inn, prepare for the next field day, evaluate the drawings from the previous days, or enjoy some of the local culinary specialties. Not being able to simply erase strokes also breeds precision and thinking ahead. The pencil tempts especially beginners to draw blurredly to conceal an inaccurate observation with hatchings and the like, or to indulge their own artistic talent. Even the knowledge that "wrong" lines can be deleted leads to unconcentrated work.

Although it rarely rains during microscopy, the above applies to fast, documentary thin section sketches as well. Thin and high-contrast ballpoint or felt-tipped pen lines increase readability. One is forced to observe closely and concentrate while drawing, while abstaining from making the drawing "artistically" diffuse.

However, drawings that are meant to appear in a paper or publication and need to be precise are better executed—best with a field or thin section sketch as reference—on a new sheet of paper and in pencil first. Here, it makes sense to keep all correction possibilities open. Such drawings should be copied neatly with an ink pen that guarantees a defined and constant line weight. To get a clean and detailed drawing, it is still best to work with ink on large tracing paper. Tracing paper that is not too thin, allows for precise lines that can be corrected cleanly. Any remaining inaccuracies will disappear during digital downsizing.

Executing drawings using drawing programs is particularly popular. What remains if we disregard that fact that such programs are a wonderful toy for people who have too much time? With the software and hardware available to the average person today, large-scale and detailed drawing is not satisfactory or can only be done with great effort—also because only few people actually know how to professionally use drawing programs. Generally, the expended effort is much higher, for the first draft as well as the corrections, than with manual drawing. Drawing on the computer forces schematization more strongly and excessively strengthens the "symbolic" side of drawing (Chapter 1.3). With that, digital drawing is not useful for all the types of drawings that are discussed in this book, namely thin section, sample, and outcrop drawings, as well as geological stereograms.

However, these programs can still be used wherever schematic information is important, like in bar graphs or maps that can be kept relatively schematic, or for drawings that are to be used repeatedly as templates, for example. These programs are also well-suited for the schematic development of manually done drawings (Chapter 2.7). It is useful to scan drawings done by hand and outfit them, with the help of appropriate imaging software, with everything that can better be created schematically (labels, north arrows, scales bars, etc.). The correction possibilities of such programs should also be used. Even other functions, like contrast enhancement, line broadening or line thinning, and sharpening of lines should certainly be put to good use.

1.3 Sizes of Drawings

The size of a geological drawing, be it a quickly drawn outcrop sketch, a thin section sketch, or a drawing meticulously created for a publication, is limited both by its top and bottom borders. The simpler a drawing and the fewer details it contains, the smaller it can be. The sketch of a gneiss, which contains, aside from some foliation, a few more feldspar blasts, doesn't need to be larger than about

6 × 4 cm. Sketches of rocks that contain significantly more structures or composite block images and complexly structured thin section drawings require an area of at least 15 × 20 cm (i.e., A5)—in some cases even more.

A line cannot be arbitrarily thin and the drawing paper not arbitrarily large. Regardless of whether an ink pen, a ballpoint pen, or a pencil, 0.1 mm represents the lower limit of generatable line weights. Since the line weights in a drawing should vary to increase the readability and interpretability of a drawing (Chapters 2.4 and 3.3), the line weights are usually significantly higher than 0.1mm. However, details in a small drawing cannot be brought out by thick lines. Therefore, line weights limit the size of the drawing.

Of course, lower line weights can be achieved in print (on paper or digital). In the literature, great examples of complex stereograms can be found that have been downsized from square-meter-sized templates to areas of A3 or even A4 formats (Chapter 5). They contain lines well below the 0.1 mm line weight. But these are exceptions that are not of importance for everyday drawing in the field or at the microscope.

For thin section drawings, areas of about 15 × 20 cm (A5) to about 20 × 30 cm (A4) are useful and practical formats. The same applies to the "final draft" of sample or outcrop drawings and, in my experience, for drawings done in the field. There, the drawings often develop gradually. Progressive observations are "built on" and added to the initial drawing but the add-on direction cannot always be selected (Chapter 4). This means: The field book should be about 15 × 20 cm (A5) big (or slightly smaller). This allows for "standard drawings" up to A5-size and offers the possibility or extending the drawing to A4 if need be.

Larger field books are impractical, because they usually can't be stowed in jacket pockets or belt bags. I consider A6-sized field books, which only offer a double-sided drawing area of about A5, but are distributed in this size as "official" geology field books, to be too small. In combination with a thick pencil, detailed and precise drawing is no longer possible.

1.4 Geological Versus Artistic Drawing

There are similarities and differences between the two types of drawing. Neither artistic nor geological drawing is concerned with reproducing objects exactly. However, both require the ability (i) to observe, (ii) to keep what is being observed in focus while constantly switching between object and drawing, and (iii) to interpret what is being observed. Drawing has nothing to do with photographic reproduction, otherwise it wouldn't have survived the invention of photography and its development to the present state of digital processing. This, of course, does not affect that fact that every photograph is an interpretation.

Still, the differences between artistic and geological drawing are significant. Geological drawing might be easier for someone who is good at artistic drawing, although it could certainly be hampered by this ability as well. Betty Edwards (1979) explains why this is so. She elaborates on the problematic process of learning to draw and offers many useful exercises and instructions for self-study.

Up until the age of 10 to 12 years, children draw stick figures, houses made of lines, and the sun as a circle with a wreath of lines. When drawing, they use symbols for every object they are trying to represent. When they get older, are talented, or enroll in good art classes, they start to represent things more accurately. This is what is meant by "artistic drawing." Outlines of objects are no longer represented through lines or transformed into symbols; instead, a "photographic" picture is drawn that emerges through light and shadow. But most people remain at the stick figure-level for their entire life—not because they are lacking talent, but because no one ever showed them a different way of drawing.

Through language, we are trained to classify things and impose names. Similarly, we have saved a symbol for every object or class of objects. If we draw a table or a human nose, we draw the corresponding symbol. We have to classify our environment in this way, so that our thinking can work quickly and effectively. But if we want to portray things exactly, we must proceed differently. We must try to observe as accurately as possible. This is hard, requires time, and has to be learned. But there are many good books on this subject (Edwards, 1979, Sale & Betty, 2007, Jenny, 2012, et al.) and many websites with online courses.

Artistic, representational drawing works with gradations of light and shade. A constant exchange of glances between the object and the drawing is how our sketch grows. Guiding the drawing hand is as important as the concentration and rhythm that develops and contributes to silencing our logically thinking left brain hemisphere, which is always looking to impose a range of symbols on us.

Even when we draw geologically, we observe closely and try to represent an object or an image accurately on paper. But, at the same time, we must filter the geologically relevant and omit the unimportant information. This means, when we are drawing a geological structure, we are already interpreting it. We need to interpret. First, there is never enough time to represent everything in every detail. Secondly, essential elements must not drown in the ocean of trivialities. Thirdly, drawings are meant to document. This only works when schemata are used while drawing and structures across many drawings can be compared with one another. Geological drawing must therefore meet the demand of representing structures as precisely, but also as schematically, as possible, highlighting essential information, omitting the unimportant, and doing this all in the shortest time possible. This means: To make our sketch geologically understandable, we must also use symbols. We do not draw the soft, monoclinic folded rock layer the way we see it; instead, we draw the symbol of a soft, monoclinic fold in its place. The symbol must be such that it contains all the important information.

What is the important information? This is decided before we start drawing. First, we must carefully look at the geological structure and separate the geologically important from the unimportant, which means interpreting the structure. We must first understand what happened geologically, and then we draw. This, of course, means that we only recognize and draw what we can interpret. Fortunately, the situation is not quite as bad. Experience shows that one can definitely draw things without understanding them, that one can interpret while drawing, and that one instinctively retains supposedly unessential information in a drawing that later turns out to be important. Normally, however, we (first) only interpret: "Here is a foliation, and, between the planes, the folds of a former foliation can be seen," and then turn this observation into a mixture of lifelike and symbolic drawings. On the one hand, we use symbols while drawing for everything that we have geologically understood; on the other hand, we must portray some things as realistically as possible, since geological structures are often too complex and diverse for there to be a different symbol for each one. We are constantly balancing on the border between realistic and symbolic representation. This makes geological drawing quite challenging in certain respects.

1.5 Drawing With Symbols

Symbolic drawing is widespread in geology—just glance at a textbook. When we draw symbols, we represent a certain structure in a reduced schema that is immediately clear and comprehensible for everyone. This means: Symbols can only be used for well-known structures, objects, or simple processes and should only be composed of a few prominent lines. Our everyday life is interspersed with symbols. *Pictograms* are their best-known form and *droodles* perhaps the more obscure one. Even ancient pictographic scripts, like hieroglyphs, for example, relay information in the form of symbols that sometimes closely model the objects they represent and sometimes abstract significantly from them.

Strictly speaking, droodles are inverted pictograms. The search engine, Google, yields about 52,900 results (as of 08/17/2016) when the keyword "droodle" is searched. Wikipedia defines the term as, "... a picture puzzle, in which what is represented must be deciphered; the view is often an unusual or extreme perspective or an extreme outcrop." This means, droodles should represent complex things using simple shapes but should do so in a disguised, rather than in an obvious, way. They are puzzle games that feed on our addiction to and enjoyment of abstractions. A few well-known droodles are depicted in Figure 1.4 including some gems I experienced in my youth. There are usually several different solutions to each droodle. A part of their charm comes from the fact that of all the existing solutions, one can usually still come up with one's own personal favorite. However, it should not be forgotten that some people (unlike the author) simply find droodles silly.

Even writing has evolved from symbolic sketches. Especially in Egyptian hieroglyphics, the two opposed types of symbols can be found—those that stay very close to the object they are symbolizing, and those that are abstract and strongly

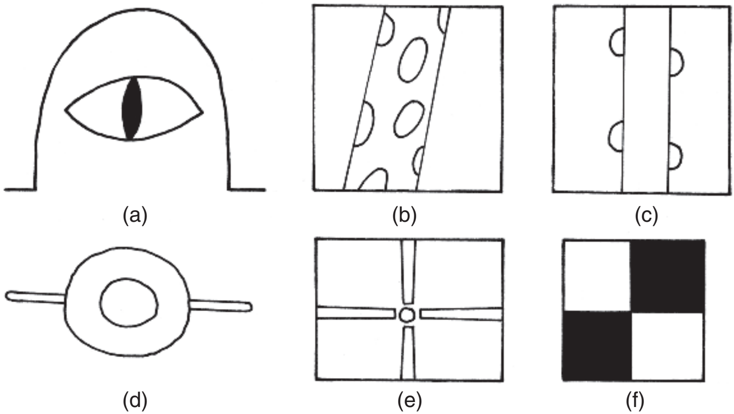


Figure 1.4 *Six well-known droodles. Together with other ones, they can be easily found in the internet.* ***(a)*** *Cat that peers into a mousehole;* ***(b)*** *giraffe standing in front of a window;* ***(c)*** *bear climbing a tree;* ***(d)*** *person with a large sun hat on a bicycle;* ***(e)*** *four elephants nosing at a ping-pong ball;* ***(f)*** *chessboard for beginners.*

deviate. Moreover, each hieroglyph also represents a letter or a number, which means that the step towards complete abstraction was already completed in this millennia old font.

Let's start strengthening our ability to understand and draw symbols. What better way to begin than with pictograms? This term originates from the Latin *pingere/pictum* (= to paint) and refers to a "single symbol or icon that conveys information through a simplified graphical representation." As symbolic terms, pictograms guide us through many situations in our everyday life—whether as go/no-go symbols in the public sphere, street signs, flight arrows, male and female stick figures, the dot in the circle that leads us to the city center, the beer mug on the hiking map that shows us the way to the nearest beer garden, the smarticon bar on our computer screen, and emoticons. These are all taken up directly by our brain, often without further thought, and processed like oral or written notifications. Pictograms are constructed with as few lines as possible, rarely contain irregularly curved lines, and are therefore well suited for computer presentations. In geology, pictograms are mostly used to portray structures and shapes, but rarely geological processes. Geological pictograms are usually not quite as simple as the pictograms in everyday life. They are only used for

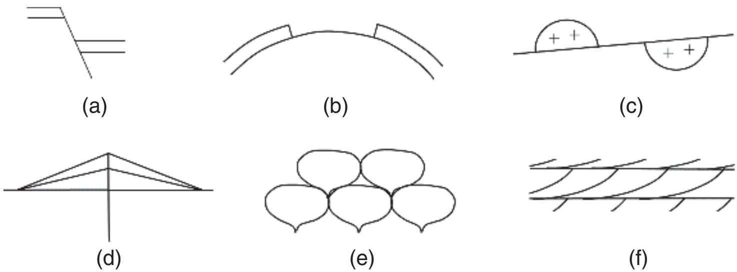


Figure 1.5 *Geological 2D pictograms ranging from kilometer to decimeter scale, reduced to the essentials.* ***(a)*** *Detachment;* ***(b)*** *metamorphic core complex;* ***(c)*** *strike-slip fault that displaces two halves of a granite pluton;* ***(d)*** *stratovolcano;* ***(d)*** *pillow lava;* ***(f)*** *cross-bedding.*

well-defined geological structures or bodies (Figure 1.5). As with the symbols in everyday life, geological symbols with no direct relation to the displayed object have established themselves. They are derived only from indirect references or have been defined on the basis of general agreement, like the symbols ⊙ and ⊗, which represent movements that are directed either towards or away from the viewer. Significant geological processes can sometimes also be represented by a series of pictograms or, in some cases, even a single pictogram (Figure 1.6).

Many structures are too complicated for pictograms. Their simplicity does not suffice to represent even just the most important components of the structure. In this case, a schematic drawing is necessary. The transition from a geological pictogram to a schematic drawing can be very smooth. These schematic representations, however, are generally structured very differently and are generated in other ways. The fact that many geological forms are scale-independent is problematic for pictograms. In contrast to the drawing of a house for example, the size of fold cannot be discerned from a drawing. Moreover, a "fold-pictogram" can only represent the type of fold but cannot differentiate between a micro fold in thin section and a kilometer large fold. Such a distinction is no problem in a photograph of the terrain, in which one can place a coin or a hammer on the rocks, or kindly ask a friendly fellow to stand against the outcrop face as a benchmark. "Fold-pictograms" and all other pictograms of geological structures must contain an additional scale to allow for discrimination based on size. This contradicts the intention of a "minimalistic" pictogram. In contrast, in geological maps, existing structures can be represented with pictograms because the scale of the structures does not matter if it's only about the fundamental representation.

Figure 1.6 *Pictogram of a meteorite impact; redrawn symbol from a sign-board of the geopark "Nördlinger Ries" (Germany).*

Figure 1.7 *Schematic representation of rock fabrics.* ***(a)*** *Granitic (top) and volcanic vein (bottom) in a layered gneiss. Crosses represent feldspar cleavage planes in granite. "v" stands for volcanic rock. The homogeneous distribution of symbols represents the homogeneity of the rock fabric.* ***(b)*** *Orthogneiss layer in schist. The "wave" ~ symbolizes the wavy structure of the gneiss, which originates from the lenticular shapes of deformed feldspars and the distribution of the surrounding biotite flakes. The schematized fabric includes the information that the gneiss was deformed at temperatures high enough for crystal-plastic deformation of feldspar. The parallel lines represent the foliation in the schist. In addition, they contribute to the light-dark contrast that typically exists between orthogneiss and schist.* ***(c)*** *Bedded limestone. The cross-strokes symbolize fractures that form perpendicular to bedding during diagenesis and compaction and are rarely present in other rocks in such formation.* ***(d)*** *Folded limestone layer with schematized fabric adapted to the form. The cross-fractures were formed prior to folding and, consequently, remain perpendicular to the layering after folding. Watch out! This is an interpretation that needs to be supported by observation. Fractures generated during or subsequently to folding can be oriented differently.* ***(e)*** *Folded limestone layer with*

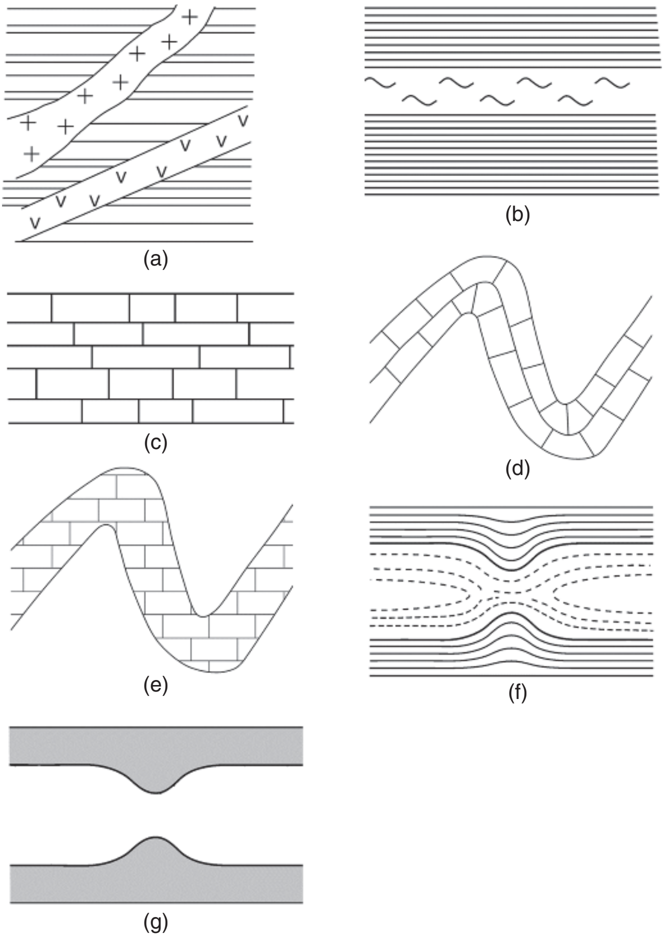


***Figure 1.7** (continued) schematized fabric not adapted to the form. Geometry of the fold and orientation of the schematized fabric communicate different messages. Their contrast may confuse viewers. **(f)** Boudinaged layer. Solid and broken lines represent foliation planes, which are curved as a result of boudinage. The light-dark contrast emphasizes layers of different composition. In general, the impression is generated that a strong gneiss layer is boudinaged in a mantle of weak schist. **(g)** The computer-generated gray-white gradation preserves the "correct" light-dark contrast; however, the foliation geometry cannot be represented.*

Exercise 1.2:

Draw pictograms of the following geological structures and processes: (a) graben, (b) unconformity, (c) subduction, (d) conglomerate, (e) porphyritic granite.

Notes on Exercise 1.2:

You will notice that pictograms (a) to (c) can be drawn more easily and clearly, but that pictograms (d) and (e) are less straightforward. The reason is that structures (a) to (c) have clear boundaries and are thus defined by lines, and (d) and (e) are not. The representation of a conglomerate requires a layer with boundaries as additional information, and even the pictogram of the porphyritic granite can only exist with boundaries. This is not specified for granite á priori and therefore meaningless. Furthermore, the sizes and orientations of the pebbles and feldspar crystals must be varied. Such additional information weakens the visual impact of the pictogram.

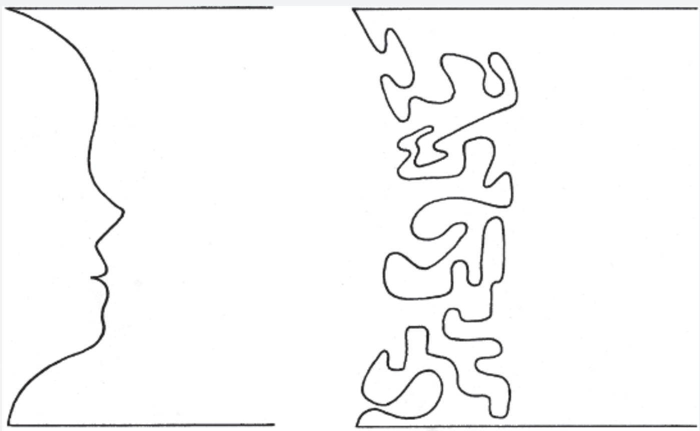
In the drawings of geological bodies, symbols, and specifically, rock symbols bridge the gap between the realistic and the schematic representation. They allow us to draw quickly and concisely under certain conditions. It is important that one does not, as is often the case with computer programs, schematically fill an area but, rather, adapts the schemas to geological formations (Figure 1.7). Geological forms are often anisotropic. This means, in different directions they show different lengths or are structured differently, for example. Symbols can also be anisotropic. This means, they too have different structure in different directions. It is bothersome when the anisotropy of the geological form differs from that of the symbol. This is mainly because the symbols are often modeled on the geological structures (Figures 1.7a-c), and deviations would contradict the "geological concept" and complicate recognition. Despite their schematization, symbols customized to the external form or the internal structure still appear natural and contain technical information (Figures 1.7d and f). Ill-adapted symbols, however, create a visual conflict and confuse the viewer (Figure 1.7e). Neutral, isotropic symbols (Figure 1.7g) are better, because they can easily be generated with a drawing program. However, geological information is lost, and they do not achieve nearly the same naturalness and inner tension as customized symbols.

Symbols are important, because they are needed for drawn rock sections regardless of their scale. Since we can never draw everything exactly as it is, we must schematize. A cleverly chosen and customized symbol allows us to bridge the gap to geological reality. Especially if we want to customize symbols, the computer won't be able to help us. Even the best drawing program is a cumbersome instrument compared to the loosely sketching hand. We will deal with choosing the appropriate symbols for different applications and how to implement them skillfully more extensively in later chapters. Although certain rocks (or geological structures) in the geological literature have their own standard symbols, some things are left up to one's own creativity.

1.6 Realistic Drawing

The bottom line when drawing is observation and not the movement of the hand. If drawing, like any other artistic task, is to succeed, we must be in a state of concentration and suspense. Let's observe this in the next few exercises that can be found in this or similar form in many other drawing books.

Exercise 1.3:



(a) (b)

***Exercise 1.3** Draw the "face" (**1.3a**) and then the abstract and more complex line (**1.3b**) mirrored between the two line ends.*

Notes on Exercise 1.3:

Draw the lines slowly, at a constant speed, and in one go. In order to do that, you must continually and quickly move your eyes back and forth between the existing and the emerging line. If you do this correctly, you will find yourself in a state of concentration and suspense, which leaves no room for rambling thoughts. The better you succeed in doing this, the better your lines will be.

We draw the first given line in its mirror image—slowly, millimeter by millimeter. When drawing, the eye is constantly jumping back and forth between the original and the new sketch. We constantly monitor the progress of the line, its shape, and its distance from the mirror image. We must get into a rhythm when we observe piecewise—execute, observe—execute. When we have drawn the first, simple line in its mirror image, we move on to the second, more complex line. Repeat this exercise until the lines you draw really represent mirror images of the originals. It is particularly important that the proportions are correct!

Exercise 1.4:

Drawing contours.

Notes on Exercise 1.4:

In this exercise, we place a hand on the table and draw its contour, or outline, on a piece of paper using the other hand, but without looking at the sketch! We transfer what we see into the movement of the hand without using the eye to control this movement. We are not allowed to give into the temptation of looking at the sketch while we are drawing. If we repeat this exercise often enough, we get a feel for the movement of the drawing hand and for how observation is translated into movement. This exercise must be carried out very slowly. If we need 3 to 4 minutes to contour the hand, we are not drawing too slowly, but rather too quickly.

Betty Edwards (1996) gives a detailed guide to this and other drawing exercises that strengthen the ability to observe and to graphically represent what is observed (and not the interpretation of it!). Overall, such exercises work to repress symbolic drawing and improve the ability to draw realistically. Such exercises also form the basis for geological drawing and the book by Betty Edwards, or any other drawing book, can be a good introduction into the subject.

Building up concentration and suspense during geological drawing is not always easy; on the one hand, because the circumstances sometimes preclude those necessary for concentration, and on the other, because we must always also draw symbolically. The time constraints that sometimes plague us when drawing outdoors are no friend of concentration either. And when the wind tatters the field book and the cold causes the hands to cramp, it is hard to achieve and maintain an “artistic” suspense. Even the need to draw symbolically, can be a hindrance. If we always have to decide where and how to use symbols, what we want to omit and include from our observations, and in what form we should depict everything, these “rational” decisions continuously rip us out of the state of pure observation and destroy precisely the type of suspense that is important for geological drawing.

Exercise 1.5:

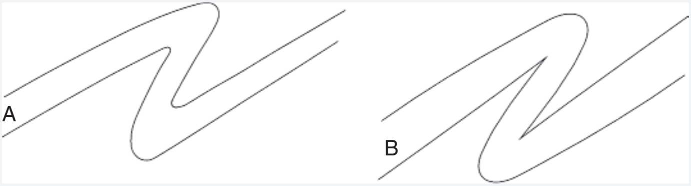
Exercise 1.5 *Upside-down-drawing: Children based on a line drawing by Heinrich Zille (1922). Draw the sketch first "right side up" and then upside down. Draw quickly and concentrated but without honing the details.*

Notes on Exercise 1.5:

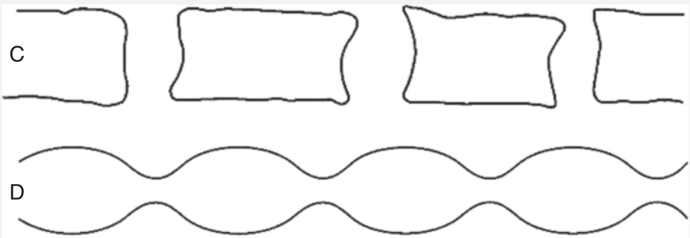
If you perform this exercise as described and compare the two sketches, you should notice that the upside down drawing comes closer to the original. This is because the "right side up" drawing is recognized by our brains as people.

This causes us to move more easily toward interpretive, symbolic drawing and deviate more strongly from the template. "Upside down drawing," however, makes it easier to find a rhythm and concentration, because we are not distracted from the reality of the drawing.

Exercise 1.6:



(a)



(b)

Exercise 1.6 (a) *The shape under the fold pictured in A mirrors a certain average intensity of deformation and a low strength difference between the folded layer and the surrounding rock. In comparison, the folded layer displayed under B is significantly stronger than the surrounding rock. The crests of this fold typically have a round exterior with a large radius of curvature, while the internal layer is compressed at an acute angle. When transferring natural shapes to paper, it does not usually come down to the details. The number of folds or the lengths of the limbs (although the long to short-limb ratio is usually important!), for example, must not be the exact same. Now draw, compared to (A) and (B), a folded layer with lower strength than the surrounding rock.* ***(b)*** *A boudinaged layer that is significantly harder than its surrounding is pictured under C, while the strength difference in D is less. Draw a boudinaged layer with only a slight contrast in strength to the surrounding rock.*

When we draw things that our mind has assigned symbols, we often unconsciously draw these symbols and not what we really see. It is easier to draw things that make no sense and are not composed of symbols. We draw Zille's children first "right side up" and then upside down. How are our two sketches different?

The ability to draw in a life-like manner is the basis of geological drawing. It prevents slipping into complete schematization. Nevertheless, geological drawing is influenced by schematizing—and by interpretation. What we see must be interpreted geologically. When we draw, the resemblance between the original and the drawing is less important. The determining factor is that our drawing allows for an accurate geological assertion by representing the essential elements. What is essential? Let's start with a simple exercise.

Everything that provides information about the properties of rocks and about the processes by which they were formed and changed is essential. The properties primarily include the composition of the rock and the rock fabric. Both determine not only the rock type but also influence numerous other, especially physical, properties: density, porosity, permeability, compression and shear strength, elasticity, heat capacity and heat conductivity, reactivity. In addition, a rock's history usually influences its mineralogical composition and always its fabric.

Conversely, layers in sedimentary rocks, for example, reflect different geometries and chronologies of deposition history. This is why the type of layering is an important feature of a sedimentary rock drawing. Even processes of diagenesis change the composition and fabric of a rock. Both are mainly visible in the micrometer to millimeter-scale and can be represented in thin section drawings.

Different magmatic rocks can often be differentiated from one another due to their different coarse or fine-grained groundmass. However, the graphic representation of the often diffuse magmatic structures can be very time-consuming. In some cases, however, the fabric is typical of a specific rock, like the columnar joint system of basalt, for example, and can easily be used for rock characterization.

Distinctive and clearly representable fabrics are mainly found in metamorphic rocks. Foliation planes, lineations, and folds are typical components of sample and outcrop drawings. Their chronology offers valuable information about the rock's history. Furthermore, grain fabric can be used to identify many rocks and represent them in a simple way. The microfabric, with its grain shapes and textures, offers many ways of characterizing both the rock and its history.

In the following chapters, numerous semi-schematic drawings of typical rock fabrics in the micrometer to 100-meter scale are presented and examples of how such drawings represent the history of deposition, crystallization, deformation, and metamorphism are shown.

1.7 The Fractal Geometry of Geological Fabrics

In nature, many structures are complex (fractal). They cannot, or only with great difficulty, be measured by means of Euclidean geometry but can be recorded and quantified by methods of fractal geometry (Mandelbrot, 1983). Geological structures, in particular, provide striking examples of complexity or "fractality" (Kaye, 1989), like Fe-Mn-dendrites, fracture patterns, or sutured grain boundaries, for example (Figures 1.8b-d). An essential characteristic of fractal structures is their self-similarity. Unlike mathematical fractals, that are exactly the same across an infinite number of orders of magnitude, the self-similarity of natural (including geological) fractal structures usually spans only one or two orders of magnitude (Kruhl, 2013). Moreover, this self-similarity is only of statistical nature. In addition to the fractality of structures (patterns), there is also the fractality of datasets. Grain sizes of phenocrysts in magmatic rocks or the thickness of sedimentary layers, for example, behave fractally (Figure 1.8a), meaning the size or thickness distribution follows a power law.

Both types of fractality are important for geological drawing. The statistical self-similarity of patterns means that they look almost the same in different scales and that their size cannot be deduced from their shape. This is why drawings and photographs of geological structures must always include a scale. However, this only partially applies to the schematized geological drawing of structures in specimen and outcrop scales. Since these do not create a copy of nature, but rather translate geological structures into a language of symbols, scale preservation must often be forgone in order to satisfy the symbolism. A meter thick orthogneiss in a 20 x 5 m large outcrop wall, for example, cannot be characterized through schematized feldspar lenses if these lenses are to be in the correct size ratio relative to the layer thickness (see Chapter 3.3).

If we do not copy "one-to-one," but rather, represent structures schematically and add to them, we must still observe properties that arise from the structure's fractality. If we do not, our sketches look unnatural. Above all, two properties need to be considered: (i) The self-similarity causes similar structural elements to appear in different sizes and makes the overall fabric appear "tighter" in some parts and "wider" in others. The structural elements are concentrated locally. (ii) The size distribution of structural elements according to the power law means that there are relatively few large structural parts but relatively many small ones. In a fractal size distribution of crystals in magmatic rocks, pebbles in conglomerates, or fragments in breccia, the appropriate number of small crystals, pebbles, or fragments occur and few large ones. The same goes for the distances between fractures or foliation and layer planes that are gathered closely in large numbers but are rarely further apart.

Since the breaking of rocks follows these rules, the fine structures on rock surfaces, like lineations on foliation planes, are also fractal (Figure 1.9). All of this

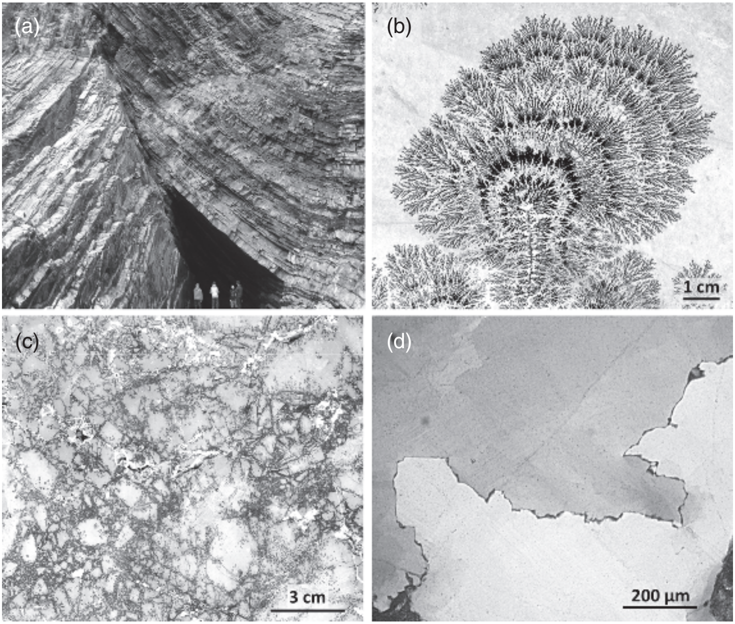
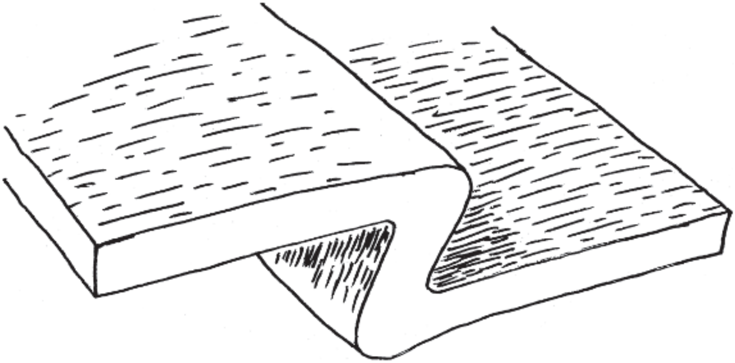
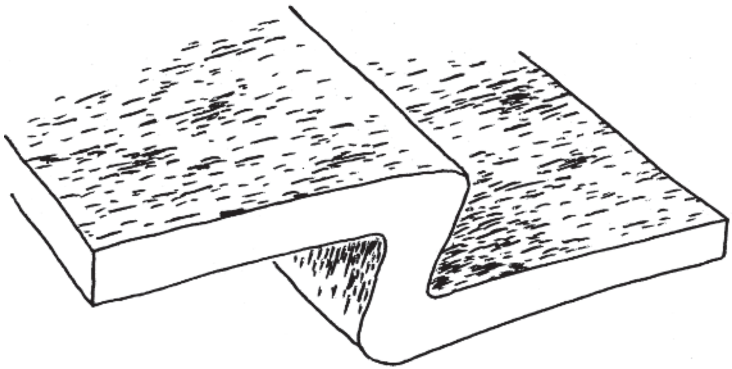


Figure 1.8 *Complex (fractal) geological structures.* ***(a)*** *Devonian metapsammopelite with bedding of variable thickness; Hartland Quay (Devon, England).* ***(b)*** *Fe-Mn dendrites on a bedding plane of "Plattenkalk" (Solnhofen, Germany). The dendritic pattern is similar on different scales.* ***(c)*** *Fracture pattern on a block cut of Malm limestone; sample KR5149B; Unterwilfingen Quarry (Nördlinger Ries, Germany). The fractures are clustered, that is, form few large and many small fragments. The size distribution of these fragments follows the power law.* ***(d)*** *Photomicrograph of a sutured quartz grain boundary; sample KR4846B; syntectonically crystallized tonalite (Abbartello, Golfo de Valinco, Corsica, France). The geometrical arrangement of the few large and many small sutures follows the power law.*

should be considered when drawing. Even distances between planes or linears or an even distribution of phenocrysts in rocks look unnatural compared to the distances that ensue from a fractal distribution. A sketch in which the individual structural elements are not only of the same size but spaced perfectly evenly, looks very artificial (Figure 1.10a). If the fabric is made irregular in one aspect, this only improves the overall feel slightly (Figure 1.10b). Only a variation of the fabric



(a)



(b)

Figure 1.9 *Sketch of a folded rock layer with two different types of schematized lineations:* ***(a)*** *variably long and evenly distributed strokes;* ***(b)*** *variably long and clustered strokes. Sketch (a) looks artificial, in contrast to sketch (b).*

according to size and spacing of the structural elements along with their local concentration will yield a natural impression (Figure 1.10c).

It is not necessary, however, to elaborately construct fractal patterns when drawing. It is sufficient enough to avoid uniformity and to be mindful of including significant variations in spacing and grouping at different scales. Amazingly so, a lot can be achieved simply by “leaving gaps.”

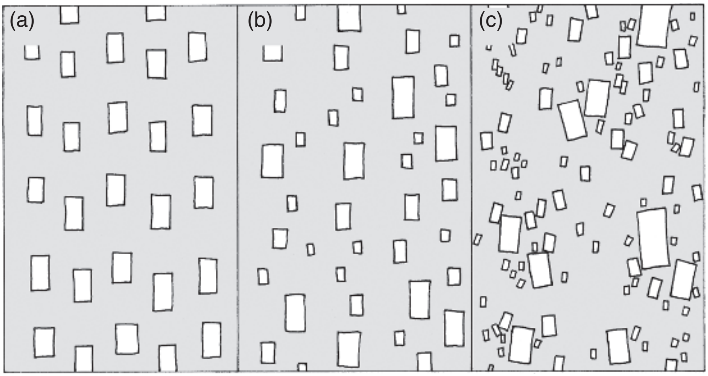


Figure 1.10 *Schematic distribution (flow) pattern of feldspar phenocrysts in a porphyritic granitoid. **(a)** Crystals of equal size with equal orientation and spacing. **(b)** Crystals of different size but with equal orientation and nearly equal spacing. **(c)** Crystals of different size (few large, many small crystals) with slightly different orientations and clearly different spacing (clustering).*

1.8 Basic Rules of Geological Drawing

A few basic rules for geological drawing can be derived from what has been written thus far. Although these rules will be discussed in detail in the following chapters, they should be presented in streamlined form at this point. Like all basic rules, they simply suggest the general course of direction one should follow but by no means constitute rigid commandments. One's behavior while drawing should be as variable as the types of drawings and their objectives. This is where artistic and geological drawing meet. Everyone should orient themselves according to requirements while still following their own intentions and developing their own style while sketching. Rules always include the freedom to variate or override them.

- Geological drawings should only consist of clean lines and dots. Contrasts can be reinforced and statements substantiated with different dot or line weights.
- Dots can have a geological significance but mostly serve to make surfaces different darknesses, highlight contrasts, or strengthen structures and use shadows to represent them three-dimensionally. When representing rock graininess, recrystallizations, and so on, at certain scales, dottings are especially important.

- Lines should always have a geological significance, provided they are not used to delineate artificial "blocks." Line-weight and length should be used to convey the geological message.
- Lines and dots can be used for shading as well as for geological evidence. Parallel lines cleverly distributed over curved surfaces can highlight lineations or curvatures of the surface, for example.
- Symbols may be neutral but should support, or strengthen, but never counteract, the geological information in the drawing.
- The geometry of geological structures is rarely Euclidean but usually fractal. Therefore, the naturalness of a drawing can be enhanced through grouping partial structures in different magnitudes of size and through different size distributions (according to the power law). It is usually sufficient to avoid "regularities" and leave gaps.
- A drawing should be large enough to represent all relevant structures, and details should be visible without using a magnifying glass.
- A "bad" drawing is always better than no drawing at all!

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