Map reproduction

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Content

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High-quantity and high-quality reproduction

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Additional Reading

The printing of a map or the electronic duplication of a map in a digital format. Presently, cartographers have a number of reproduction technologies from which to choose, including offset printing (lithography), plotters, large-format printers, desktop printers and electronic media. Process selection depends on the intended use of the map, quality and quantity desired and cost. For a large quantity or for high-quality printing, offset printing is typically required. For a small number of copies, personal printers or large-format inkjet printers suffice. Additionally, an increasing number of maps are being reproduced and disseminated on electronic media and via the Internet. See also: Cartography

INTRODUCTION

Map design is the creative act of visual communication, with the

composition of the map, choice of symbols and colours and the compila-

tion of map content requiring thoughtful consideration to transfer the

message of the map. Geomorphological maps are highly complex thematic

maps depicting the composition of the Earth’s surface and the processes

working there. To deliver this complex information, geomorphological

maps commonly make full use of the various elements of cartographic

design. Different kinds of symbols and colours need to be arranged and

composed carefully in order to generate a readable map that clearly

expresses the map content and message.

Before starting the process of map design, it is necessary to review the

following questions:

• What is the purpose, message and central aspect of the map?

• Who is the map aimed at?

• Who will be using the map?

• How will the reader use the map (i.e. office, field)?

Applications of geomorphological maps range from simple descrip-

tions of a field site, for example accompanying a journal publication or

construction site report, to specialised land system analyses, for example

for land management or natural hazard assessment. It is equally important

to consider the production process and dissemination of the final product.

Is it a paper map? Is the map produced in colour or black and white? Is

the map accompanying a journal publication? Will it be published online?

These issues strongly influence how you compile and arrange your data,

which symbols are used, how the various map items are composed and

whether colours can be used or not.

Prior to data collection, for example going into the field or digitising

from aerial photographs, fundamental decisions need to be made in rela-

tion to the mapping area, scale (field scale and output scale) and in the

choice of the symbols to be used. These settings influence the design,

shape and final appearance of the map. When all data are collected, speci-

fications for map composition and production need to be considered:

What map sheet format shall be used? Can colour be used? What will be

the size of symbols and text? Which coordinate system will be used?

How will topography be represented on the map?

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Besides accuracy and quality of the data, good design creates a good

map. In this chapter, we will briefly review principles and elements of

cartographic design and communication through maps, before we intro-

duce common legend systems available for geomorphological mapping.

Practical issues of map and symbol creation using graphic and geographi-

cal information system (GIS) software are provided, and some basic mate-

rial concerning final map production are introduced. Map dissemination

through the Internet is increasingly important for geomorphologists

(Hake et al., 2001), and therefore, technical issues on web mapping are

presented towards the end of this chapter.

2. ELEMENTS OF CARTOGRAPHIC MAP DESIGN

Geomorphological legends commonly use complex, sometimes pic-

torial symbols to represent landforms or landform characteristics, surface

materials and processes. What differentiates geomorphological maps from

other thematic maps is that qualitative information prevails over quantita-

tive or classified data. Quantitative information in geomorphological

maps is delivered by displaying proportional landform sizes (large-scale

maps) or, for example, by providing data on depth, age or grain-size com-

position of deposits. In order to understand the differences between dif-

ferent symbol types and their role in map design, we will now look at the

basic elements of cartographic design.

The basic representations of objects in maps are the symbol primitives

of point, line and area (Figure 9.1). These are also referred to as dot, dash

and patch, or termed marker, line and polygon (area) symbols in many

GIS applications (Robinson et al., 1995). Whether a linear feature in

nature is represented by a line symbol on the map is mainly a question of

scale. For example, a river could be depicted by a blue line. On larger

maps (with increasing size of the map items), the river would be depicted

using an area symbol. The map scale also determines if a landform is

depicted by a point symbol or if it is split up into its morphological com-

ponents. Rock glaciers, for example, could be represented by a single

point symbol on small-scale maps or by the assemblage of line and area

symbols that differentiate the step height of the rock glacier front, furrows

and ridges and the accumulation of boulders and blocks on top of the

rock glacier, if the map scale increases.

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A differentiation of these basic representations, to express relationships

among or differences between the data, can be achieved by variations of

the basic visual variables: shape, size, orientation, texture or colour

(Robinson et al., 1995; Kraak and Ormeling, 2002). Shape refers to dif-

ferent forms of the graphic symbol for points (marker) and lines

(Figure 9.1). Shape variation demonstrates qualitative differences and is

the most commonly applied visual variable in geomorphological maps

because of the great number of different symbols for different landforms.

Difference in symbol size will be apparent by changing geometric dimen-

sions, such as area, length or width of the symbol. Size variations are typi-

cally used to represent nominal differences, for example to underline

variations of importance, size or activity of a landform or process.

Differences in shape and size always refer to the variations of the symbol

itself and not to changes of the object shape. When using area symbols,

pattern orientation can be altered to depict qualitative or quantitative infor-

mation differences. Texture variations represent changes that result when

the shape, orientation or the spacing of components that generates a pat-

tern is modified. Furthermore, the spatial arrangement of the pattern, for

example systematically ordered or randomly distributed, is a way to illus-

trate symbol differences. Patterns or hatched symbols are used in geomor-

phological maps, for example, to depict lithology or slope gradient.

Colour is an important visual variable, mainly used to depict qualitative

differences. However, geomorphological maps are commonly produced

in black and white, especially when they are part of a journal publication

to keep production costs low. If colour is used, variation of colour

y

g

y

g

g

y

r

r

r

Size Shape Texture Hue Value

PointLineArea

Figure 9.1 Primitives of map symbols and visual variables (y 5yellow, r 5red, g 5green).

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characteristics, that is hue, value (lightness) and chroma (saturation) are

the most powerful tools to emphasise certain aspects of the map

(Table 9.1). As the human visual perception is adapted to colours, we

strongly react to differences in colour. We can use colour variations to

draw the reader’s attention to specific features, or to convey information,

sometimes in a subjective way (e.g. the colour red has a connotation with

danger). The use of colour also demands great care because the percep-

tion of colours has physical and psychological aspects. These include the

ability to differentiate contrasts between different colours, or to perceive

colours in very small areas. Certain colours have conscious or unconscious

connotations, for example the so-called warm (red, yellow) and cold

(blue) colours. Most connotations are the result of the different wave-

lengths that lead to different moments when the colour reaches the eye.

Long wavelengths (e.g. red) are seen ‘earlier’ and appear to be ‘nearer’,

while short wavelengths (blue or green) are seen later and appear ‘further

away’ (Rouleau, 1993). Wrong usage and composition of colours can

destroy the readability of the map or lead to misunderstanding. Within

cartography, some colour conventions exist that should be acknowledged

to avoid confusion. For example, on topographic maps blue is used for

objects related to water, for example rivers, springs or lakes; green gener-

ally represents areas covered by vegetation. A valuable assistance for colour

selection is provided by the online tool ‘Colorbrewer’ (Brewer, 2009).

The tool assists in choosing the right composition of colours by displaying

different colour schemes. Colour combinations can be tested on a com-

plex map sample that enables the user to experience the differentiation

and perception of the colours used. Geomorphological maps use blue col-

ours generally to represent features related to the hydrological processes

Table 9.1 Definitions of Hue, Value and Chroma

Hue Refers to the colour we perceive. It describes the dominant

wavelength of light (e.g. red, blue and yellow)

Value Refers to the relative lightness or darkness of a hue. Light

variations of a hue are referred to as high value, and dark

changes have a low value

Chroma Describes the colour saturation. It represents the ‘colourfulness’ of

a hue, which can be reduced adding white or black. Chroma

can range from a greyish hue with no apparent colour pigment

(or proportion of light of the specific wavelength reflected) to a

pure, intense hue.

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and black for anthropogenic features. In many geomorphological legend

systems, colours are applied to represent variations in landform genesis,

process domains or lithology (see Section 3). These are either expressed

by coloured area symbols (Sta

¨blein, 1980) or by using coloured line or

point symbols (Gustavsson et al., 2006).

2.1 Graphic Communication and Design Principles

Communication with maps differs significantly from other types of

human communication. Maps are visual media and evoke visual stimuli

that cause different reactions in people in comparison to books or conver-

sations. In books or spoken conversation, information is delivered in a

sequence, one sentence following another. In contrast, graphic communi-

cation, like maps, delivers all information at once. This means informa-

tion is not perceived sequentially, but instantaneously with respect to the

location and relative position on the map sheet or screen. Thus, the

appearance and composition of graphical elements should be considered

thoughtfully. On a map, all information is spatially related and needs to

be considered holistically. The composition of map items decides if and

how the reader understands the message, with perception and under-

standing occurring subconsciously. To allow map users to understand the

meaning of the map, a visual sense to the symbols and their attributes that

correspond to the intention of the cartographer needs to be assigned

(Robinson et al., 1995). When looking at the graphic design of geomor-

phological maps, an inverse relationship commonly occurs between the

ability to read the map and the amount of information expressed in col-

ours and symbols. Thus, geomorphological maps tend to be ‘overloaded’

with information.

The principles of graphic design of maps include legibility,visual con-

trast,figure-ground perception and hierarchical composition (Robinson et al.,

1995). Legibility is probably the most important principle and provides a

challenge especially for geomorphological maps. A large number of differ-

ent symbols generally are using graphic variables that bear the potential to

render the map unreadable and hence not understandable (Figure 9.2).

Ready-made legend systems are commonly used; however, each symbol

needs to be clearly distinguishable. Legibility mainly depends upon sym-

bol size and density, which results from the size of the map. Map space is

characteristically restricted or determined by the extent and/or scale of

the final map. The map maker’s task is to find the right balance between

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the number and size of symbols used, which includes the process of gener-

alisation. Generalisation is the abstraction of map objects aiming at a sim-

plification of the map content in order to fit the scale or purpose of the

map without significantly changing the map’s message (Slocum et al.,

2005). In geomorphological maps, generalisation could mean that com-

plex surface morphology is not represented by different line symbols that

follow breaks in surface, but by single illustrative point symbol that

depicts the landform type (Speight, 1974; see later).

Contrast is the basis of vision. Visibility of the map depends to a large

extent on the right contrast between the graphic elements. Variation of

contrast can be achieved by changing shape, size or colour of a symbol,

or all of them. Figure-ground perception describes a person’s ability to dis-

tinguish between an object and its surrounding. The figure, that is the

Figure 9.2 Section of the geomorphological map 1:25,000, sheet 8114 Feldberg,

from the GMK 25 mapping programme in Germany. Colour intensity and the density

of symbols render this map hard to read. Extracted from Geilhausen, Otto and Dikau

(2007).

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object, should be clearly separated from the less distinct (back)ground.

This happens automatically as a natural and fundamental characteristic of

human visual perception. In relation to maps, a common example is the

discrimination of land and water on a simple map of continents. The

figure-ground differentiation is generated choosing different hues (brown

and blue) or values (light and dark) to generate a contrast from which

the continents clearly emerge from the surrounding seas (Figure 9.3).

Figure-ground perception is supported when the figure is familiar.

Unfamiliar objects need special effort to allow figure recognition.

Geomorphological maps require a good differentiation of map

element structuring. Hierarchical organisation and visual layering enable sep-

aration of meaningful characteristics in order to depict differences, inter-

relationships or hierarchies. Different line symbols of roads on a road

map, for example, are used to differentiate between different levels of

(a) (b)

(c)

Figure 9.3 Illustrating the figure-ground relationship: (a) A simple black line on white

does not help to differentiate between different levels of information. (b) The grey

colour now separates the different features on the same map, but the outcome is

still ambiguous. (c) By adding lines representing rivers, the separation of land and

ocean becomes more obvious. Inspired by Robinson et al. (1995).

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road types like highways, major roads and local roads. Typical rules of car-

tographic language only apply marginally for geomorphologic maps.

These rules are related to the appropriate use of the visual variables in

order to represent the level of relationship among the data types. For

example, quantity relationships are depicted by varying symbol size, order

relationships can be expressed using different tonal values or changing

symbol size (Bertin, 1982; Rouleau, 1993). On geomorphological maps,

relationships between map elements are usually expressed by the composi-

tion of the legend (see Section 3) that may put a visual focus on one set

of information (e.g. morphogenesis) by altering the visual variables. The

various layers of information, such as morphostructure, processes or sub-

surface material, can be arranged specifically to highlight one layer

according to the purpose of the map (Figure 9.4). A geomorphological

map created for the purpose of hazard assessment, for example, will prob-

ably highlight the active, hazardous processes. This is performed using the

graphic principles mentioned above.

Figure 9.4 Section of the geomorphological map 1:25,000 Turtmanntal, Switzerland

(Otto and Dikau, 2004). This map contains several hierarchical levels of information:

coloured area symbols represent the process domains, light grey (orange in the coloured

image) symbol fills show surface material information, black point and line symbols indi-

cate landforms and processes, and point symbols in light grey depict active processes.

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2.2 Map Layout and Graphic Organisation

Geomorphological maps characteristically include a great number of sym-

bols, organised in thematic categories. This requires a large portion of the

map sheet to be reserved for the legend. However, the final map is not

only composed of the mapped data, its symbols and its legend, but typi-

cally includes other map components such as a title, scale bar, border and

additional information (GITTA, 2006). These components set the

mapped data into a spatial and topical context and help to identify

the place, symbolisation and orientation of the map. Map components

have to be systematically arranged to generate visual harmony and balance

and to deliver the message of the map. Just like preparing a presentation

or a publication, it can be useful to produce a basic outline of the map

beforehand in the form of a sketch. This helps to get an idea where to

place the title, legend, main map and other information on the

map sheet. Experimenting with different layouts during the process of

map making helps to find the right visual composition, which makes the

map reader focus on the content and not on the layout.

Map layout consists of the arrangement of the map components into a

functional composition and a meaningful and aesthetically pleasing design

to facilitate the visual communication (GITTA, 2006). Geomorphological

maps characteristically include the following map elements surrounding

the main map (Figure 9.5): title, legend, scale, directional indicator (north

Figure 9.5 Typical items of a geomorphological map.

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arrow), coordinate grid or border, information on coordinate system and

map projection, and author credits. Commonly, inset maps are included

to show the location of the mapped area (essential for large-scale maps),

an overview of the geological situation or other additional information

on the study area (e.g. a slope map). These items need to be arranged

carefully to guide the viewer’s eyes towards the focus of the map. Just like

a book, a map also has a reading direction, which is usually from top-left

to bottom-right. The visual centre of the map is located slightly above

the actual centre (Krygier and Wood, 2005). The map reader tends to

focus on the visual centre, implying that the most important information

should be positioned here. This is of course not always possible on geo-

morphological maps, because there is probably more than just one impor-

tant feature. However, the arrangement of the map elements should

account for this phenomenon of human perception. Geomorphological

maps generally require a coordinate grid to allow special referencing.

Borders around other map elements, such as the legend or scale, should

be avoided as borders separate objects and interrupt the flow of visual

perception.

Between the different map components, a visual balance should be

achieved to generate focus and keep the reader’s attention on the map.

Balance refers to the variable weight and direction of the map items.

Lighter features are small, dully coloured or irregularly shaped, while

heavier items are larger, brightly coloured and more compact in shape.

Balance may be symmetrical or asymmetrical that is achieved using a cen-

tral axis (vertical or horizontal). Due to the reading direction of the map,

components placed in the upper part of the map and at the right side are

heavier compared to objects located towards the bottom or left border of

the sheet. With increasing distance to the visual centre of the map, a

component’s weight increases proportionally (GITTA, 2006). Using an

imaginary grid may help to structure the positioning of map components.

The grid subdivides the map sheet into horizontal and vertical spaces and

generates sight-lines that create stability of the layout. Map items should

be aligned along the grid to generate order and visual harmony between

them (Krygier and Wood, 2005).

Colours draw the viewer’s attention strongly to certain areas. The

strongest colours should be used for the most important information. On

many topographical maps, for example, rivers and lakes are characteristi-

cally the first features one perceives, because the dark rich blue colour

contrasts strongly with more gentle colours such as green, brown and

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grey used for other information on the map. To verify the visual focus of

the map, look at it from a distance and see what dominates the layout.

3. GEOMORPHOLOGICAL LEGEND SYSTEMS

AND MAP SYMBOLS

Finding new ways to describe and visualise the landscape surround-

ing us has a long tradition. Even though early maps were not aimed at

scientific purposes, but rather for easier orientation, military or economi-

cal uses, they did describe the landscape using simplifying symbols (later

using colour) (Klimaszewski, 1982). Since the early twentieth century, the

requirement for a more detailed scientific description of the landscape has

been linked to a need for new symbols and cartographic designs for land-

scape description in geomorphological maps. Whether the symbol sets or

mapping systems are used to construct thematic or comprehensive

geomorphological maps, they are important both for the readability and

the scientific content of the maps.

No matter what scale is chosen, depicting the physical landscape in an

exact manner would be an impossible task, and thus the purpose of geo-

morphological mapping systems is to show an interpreted, generalised

and understandable picture of the area/feature mapped. The tools avail-

able for this are the symbols and colours summarised in the legend.

When constructing a geomorphological legend, an important task is

to enable the separation of descriptive and interpretative information.

This is important since it opens the possibility for other map readers to

draw their own conclusions or at least clarify what underlies the map

maker’s interpretation of the area. This also enables both the description

of individual landforms, for example morphogenesis, and their relation to

other forms and processes in their surroundings (St-Onge, 1981).

Regarding descriptive and interpretative information, there are two com-

monly used models in use. The first is the Landform Pattern Model, which

is a more interpretative model, and here the landforms are presented as

repeatable, easily definable forms or patterns (e.g. hills, ridges and chan-

nels) usually not drawn at scale. The second model is the Landform

Element Model where the landforms are described as combination of geo-

metric elements (e.g. slope, crest and plain) and thus presents a more

descriptive picture of the morphology (Speight, 1974). Depending on

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scale, however, the latter model often has to be complemented with the

first model in various degrees. It is also an advantage if the mapping sys-

tem is flexible, allowing the user to adopt the symbols most appropriate

for the mapped landscape and if the mapping system is to be used at

different scales (Verstappen, 1970).

3.1 Presentation of Different Legend Systems

This section outlines some of the more commonly used or recently

developed detailed geomorphological mapping systems, that is mapping

systems designed at scales 1:100,000 or larger (Demek et al., 1972). In

addition to these there are also numerous other mapping systems or sepa-

rate map sheets not connected to any mapping system published. The

descriptions below outline the general characteristics of the mapping sys-

tems regarding both their scientific content and their graphical layout.

More detailed descriptions of these mapping systems and their legends

can be found in the references cited in each section.

The basis for most geomorphological maps is generally a base map

(commonly atopographic map with reduced contrast) presenting contour

lines (sometimes together with hypsometric shading) and the general lay-

out of the hydrography. Some infrastructure may also be shown. National

or global grids generally are included or indicated with ‘ticks’ in the mar-

gins. Also commonly found is the use of line and pattern symbols, or

shadings, for illustrating information on gradient (or morphography).

Many, but not all, geomorphological mapping systems also follow the

guidance established by the International Geographical Union (IGU)

Subcommission of Geomorphological Survey and Mapping (Gilewska,

1968)by, for example, putting the emphasis on morphogenesis and

expressing this information in colour.

Even though most mapping systems share this common base for map

construction, the appearance of geomorphological maps and their content

varies (Table 9.2). Many of the differences in the construction of geomor-

phological mapping systems can be explained by the fact that the appear-

ance of geomorphological maps is very much a result of the scientific

tradition of the mapping geomorphologist and the purpose of the map

and thus on what geomorphological information the emphasis is placed.

These differences are reflected in the legends and consequently also in the

appearance of the map sheets. Maps covering the same area but mapped

by different geomorphologists using different mapping systems can

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Table 9.2 Representation of Different Geomorphological Parameters in the Legend Systems Introduced

Mapping System Morphometry/

Morphography

Hydrography Lithology Structure Process/

Genesis

Age

IGU, Unified Key

(1968)

Contour lines and

symbols

Lines and symbols

in blue

Not indicated Not indicated Colours, patterns,

lines and

symbols

Letter code

ITC, Verstappen

and van Zuidam

(1968)

Contour lines,

symbols and lines

Hatching, lines and

symbols in blue

Patterns, lines and

symbols

Not indicated Colours and

symbols

Colours in

separate map

The Netherlands,

Maarleveld et al.

(1977)

Contour lines,

colour intensity

and code contour

lines

Lines, areas and

symbols in blue

Not indicated Partly in legend Code, legend Code/legend

GMK 25, Barsch

et al. (1987)

Contour lines, grey

shading symbols

and lines

Lines, areas,

symbols and

patterns in blue

Red pattern and

separate map

Not indicated Colours, red and

black symbols

Colour

AGRG, De Graaff

et al. (1987)

Grey contour lines,

symbols for

breaks, etc.,

arrows and

figures for slopes

Lines, areas,

symbols and

patterns in blue

Separate transparent

maps, based on

existing

geological maps

Not indicated Colours, symbols Relative age

according to

youngest

progress

Gustavsson et al.

(2006)

Grey contour lines,

symbols for

breaks, etc.,

arrows and

figures for slopes

Lines, areas,

symbols and

patterns in blue

(and black)

Symbols for

unconsolidated/

letter

Red lines and

symbols

Coloured

symbols,

colours

Separate map

Coloured

letter code for

consolidated

rock

Source: Modified from Gustavsson et al. (2006).

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therefore give completely different impressions, depending upon whether

the emphasis is on morphometry/morphography, chronology, lithology

or genesis/processes.

In order to illustrate differences between the legend systems intro-

duced, Figure 9.6 illustrates how a moraine ridge and a fluvial terrace are

represented by map symbols.

3.1.1 The IGU Unified Key

The IGU Unified Key mapping system was the result of the IGU

Subcommission of Geomorphological Survey and Mapping (Gilewska,

1968)presented by Demek et al. (1972) in the Manual of Detailed

Geomorphological Mapping. Another version of the mapping system

designed for mapping at smaller scales was also published as the Guide to

Medium-Scale Geomorphological Mapping (Demek and Embleton, 1978).

The legend of the Unified Key is comprehensive, presenting informa-

tion about genesis, lithology, morphometry/morphography and age.

However, since the legend is used for many different scales, the detail of

this information varies. Although there is an attempt to make a compre-

hensive geomorphological mapping system for the whole world with an

extensive legend, Demek et al. (1972) claims that it is not a ready unified

legend covering all forms and processes and that the legend sometimes

needs to be extended or modified to fit local or regional conditions

(Demek et al., 1972; Barsch et al., 1987).

The IGU Unified Key includes 353 symbols representing different

landforms, which enables a detailed inventory of the landscape. The main

information in the legend is on morphogenesis, and thus this is expressed

in 10 colours in combination with texture, line- and point symbols. The

genesis is further divided into 3 form groups representing endogenic pro-

cesses and 13 form groups representing exogenic processes. The red col-

our is reserved for endogenous landforms, black for biogenic/

anthropogenic forms or data, grey for contour lines and slope classes and

blue for water surfaces and hydrography. The rest of the colours describe

different erosional and depositional exogenous forms. To describe land-

forms with complex genesis, two colours can be used where the first, used

as a base colour, shows the original genesis, and symbols in the second col-

our shows the modifications of the landform. According to the IGU

Commission on Geomorphological Survey and Mapping, the altitude in a

detailed geomorphological mapping system should be described with con-

tour lines while surface inclination should be described by the shade of the

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Genesis

Form/genesis

Genesis/

surface material

Morphogenesis

/landforms

Process/landform

Landform

Legend system

IGU Unified Key

(Demek et al., 1972)

Moraine ridge Fluvial terrace

Process/genesis

Morphogenesis

Morphogenesis

Emphasis

Figure 9.6 Comparing the symbols for moraine ridge and fluvial terrace of the different legend systems presented in this chapter.

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genesis colour, and thus the mapping system developed uses both these

ways to express information on slope. The slopes are classified into six cat-

egories according to their gradient (0 2!, 2 5!, 5 15!, 15 35!, 35 55!

and .55!). The IGU Commission on Geomorphological Survey and

Mapping also suggests that, in some areas, a classification based on other

critical slope values may be used. Information on geological age is

expressed with a letter code in black. When possible the landforms are

represented by figures at scale and in other cases they are shown by symbols

(Demek et al., 1972; Klimaszewski, 1982).

3.1.2 The ITC Geomorphological System (Enschede, The Netherlands)

In 1968 the Dutch International Institute for Aerial Survey and Earth

Sciences (ITC) published a comprehensive geomorphological mapping

system for all scales. The ITC maps are, however, divided into two

groups: (1) large- and medium-scale maps and (2) small-scale maps.

Depending on their content, reliability and degree of generalisation, the

two map groups can also be further subdivided into several classes

(Verstappen and Zuidam, 1968). The ITC geomorphological mapping

system presents information about morphometry/morphography, pro-

cesses/genesis, age and lithology (with particular attention to rock-type

properties). Stress is placed on geomorphological processes, which deter-

mines the landscape units shown on the map.

In the ITC system, colours are used in two ways. First, shading is used

to define larger landscape units based on the dominant process, which

gives a good overview with pronounced geomorphological units. Second,

10 colours are used for line symbols describing processes and genesis of

smaller landscape elements. The symbols in the ITC system are subdi-

vided into 14 groups based on process/genesis, morphometry, lithology,

chronology and topography. In addition to this there are also two special-

purpose map legends. The use of these almost 500 unique line symbols

makes the production of maps printed in greyscale possible. If presented

in greyscale, the symbols describing geomorphological processes are

printed in black while topography and lithology are printed in grey.

There are also additional symbols available for some specialised maps con-

nected to the system (e.g. the morpho-conservation map and the hydro-

morphological map). A disadvantage of this legend size is that it gets

complex and hard to use for geomorphologists not familiar with the

system. The age of the landforms is indicated by a letter code in black

(Verstappen and Zuidam, 1968; Salome

´et al., 1982).

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3.1.3 The German GMK Mapping Systems

Geomorphological mapping has a long tradition in Germany with early

work (Passarge, 1912) generally related to concepts of landform analysis

(Kugler, 1964). In 1976 a research programme on geomorphological

mapping was initiated, managed by D. Barsch; for 9 years B40 groups

from German universities mapped different landscape types typical of the

Central European landscape. The research programme resulted in 27 geo-

morphological maps at 1:25,000 scale (GMK 25) and eight geomorpho-

logical maps at 1:100,000 scale (GMK 100). All available maps of the

research programme are available online at the homepage of the German

Working Group on Geomorphology (www.ak-geomorphologie.de).

InCentral Europe, the GMK (GMK = Geomorphologische Karte)

maps have been created with two main practical applications in mind: (1) to

create a planned cultural landscape and (2) to reduce the destruction of the

natural environment, in order to keep the ecology in as natural a state as pos-

sible. The GMK 25 legend system allows for the production of derivative

and interpretation maps, such as the GO

¨K (Geoo

¨kologische Karte) 25, a

geo-ecological map (Barsch and Liedtke, 1980b; Barsch et al., 1985). The

development of the GMK has resulted in three versions of the legend: the

red legend (1972), the green legend (1975) and the white legend (1990).

The earliest legends had problems with the delineation of slope angles; this

was solved by the use of mean slope angles. In 1998 a complement to the

legend for mapping in alpine environments was published in the GMK

Hochgebirge. This complement provided additional symbols for permafrost

phenomena, slope forms and mass movement (Kneisel et al., 1998). Symbols

of the GMK Hochgebirge are available for ArcGIS software and can be

downloaded at http://www.geomorphology.at/ (Otto, 2008).

The information in the GMK mapping system is presented in a legend

consisting of eight layers of information presenting: (1) areas of process

and structure (in colours), (2) hydrography (blue), (3) actual processes

(black+red), (4) subsurface material/surface rock (reddish brown), (5) cur-

vatures (black screen), (6) steps/minor forms/valleys/roughness (black),

(7) slope angles (grey raster) and (8) situation/topography (grey) (Barsch

and Liedtke, 1980a,b). Bright red is used in the maps to highlight recent

geomorphological processes or to give attention to active morphody-

namics and areas of potential danger. Since the legend is constructed like

a construction kit, individual layers can be easily modified extending the

use of the mapping system to areas outside Europe where, for example,

other surface forms occur.

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In the GMK 25, areas larger than 50 m 3100 m are represented at

accurate scale while the smallest landform presented at accurate scale in

the GMK 100 is 200 m 3400 m (Barsch and Liedtke, 1980b; Barsch

et al., 1987; Klimaszewski, 1990; Kuhle, 1990).

Each map sheet displays a relevant part of the complete GMK legend

printed in the margin. A separate geological reconnaissance map at

1:300,000 scale printed in the margin of the GMK maps presents a good

overview of the main geological conditions of the mapped area. On the

main map, detailed information on lithology is presented as grain-size

compositions of substrate material. When the substrate material is com-

posed of easily weathered bedrock such as limestone, the weak resistance

to weathering is also presented. In coastal areas, some submarine features

are also included.

The GMK system enables a detailed and informative presentation of

the geomorphology and also shows the degree of anthropogenic change

in the landscape. The amount of information presented in the maps how-

ever makes them hard to read at first. In the GMK system, the symbols

describing morphography and morphometry are genetically similar, and it

is therefore hard to separate similar landforms originating from different

genesis. Also the substrate pattern is presented in a highly differentiated

symbol key inherited from a standard of pedological mapping. When

this reddish pattern is printed on a similar colour describing ‘areas of pro-

cess and structure’, it is hard to read the content. There are many colours

used for describing ‘areas of process and structure’, and this sometimes

makes the differences between them too small to differentiate. On the

GMK 100, problems may arise with the placement of generalised sym-

bols, for example by using the same symbol for deep narrow valleys and

broader flatter ones (Barsch and Liedtke, 1980b; Barsch et al., 1987;

Kuhle, 1990). It is also hard to get a clear picture of the shape on valleys.

This is especially true for flat-floored valleys. The results of a survey in

alpine environment in Switzerland also show that the information in the

GMK 25 is too dense to be readable. To solve these problems, suggestions

were made by Kneisel and Tressel (2000) to change the colour intensity

of some features in the map legend.

3.1.4 British Geomorphological Maps

In Britain a geomorphological mapping system has been developed using

the Ordnance Survey 1:25,000 as a base map. Emphasis has mostly been

put on mapping form and genesis for particular groups of landforms. The

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tradition in Britain has been to construct geomorphological maps using

the Landform Element Model (Speight, 1974) and thus the emphasis has

been on morphology. Because slope gradient is an important variable for

many processes and applications, classification of relevant slope class limits

has been considered especially important. The maps have been shown to

be useful in developing an ‘eye for the landscape’, and practical applica-

tions have been made in landslide areas. Depending on the purposes of

the maps, materials are classed in different ways. Geomorphological maps

made for geological and soil surveys classify materials based on a combi-

nation of both genesis and characteristics (till, glacial sand, gravel and so

on), whereas maps constructed to describe current processes and hydrol-

ogy describe the materials based on their physical properties (grain-size

distribution). For the description of bedrock, special emphasis is placed

on the degree of jointing (Cooke and Doornkamp, 1990; Evans, 1990).

3.1.5 The AGRG Geomorphological Mapping System (Amsterdam,

The Netherlands)

The detailed geomorphological mapping system of the Alpine

Geomorphology Research Group (AGRG, Amsterdam, The Netherlands)

has been developed in the alpine surroundings of Vorarlberg, Austria.

Although developed in alpine areas, the legend has also successfully been

used in areas with less pronounced relief (with minor modifications). Due

to the complex geomorphology of alpine environments, the maps are

commonly made at 1:10,000 scale or larger.

The legend presents information about morphography/morphometry,

lithology, process/genesis and hydrography as four different layers on a

base map showing contour lines and other administrative information in

grey. Because the emphasis is on the process/genesis, this information is

expressed in six colours used to print the symbols. Unconsolidated mate-

rials are presented as pattern-like symbols that also can be used to indicate

the direction of transport of materials. The hydrography is indicated by

blue symbols with additional symbols in black for artificial drainage.

The geomorphological information is printed on a base map present-

ing infrastructure and contour lines in grey. Additional information about

the physical and chemical properties of the materials is printed on a sepa-

rate geotechnical overlay map. A natural hazard overlay map has also been

developed (De Graaff et al., 1987).

Because many periglacial and nival processes working in an alpine

environment are very similar to other degradational processes and thus

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difficult to objectively map in the field, these processes have been

grouped together. Also fluvial erosion and avalanches (as far as they are

geomorphologically active) are treated in the same way. Some special fea-

tures (protalus ramparts, rock glaciers and stone stripes) have been sepa-

rated in the legend. The AGRG mapping system does not make a

distinction between active and relict processes but presents indirect infor-

mation about relative age for a few features (De Graaff et al., 1987).

The materials are subdivided into four classes based on process/gene-

sis: sediments formed in or by water, glaciogenic or related sediments,

slope deposits and organic deposits. A further division of materials is

made on the basis of depositional environment and/or texture (De Graaff

et al., 1987).

The original legend is focused on materials (based on genesis) and

processes occurring in the Alps and lacks many symbols useful else-

where. The construction of the legend is similar to the construction of

the legend of the GMK with several layers overlapping each other. The

AGRG mapping system however uses an open framework, supported by

contour lines, to indicate the morphography by use of the Landform

Element Model (Speight, 1974). This framework and the absence of

covering colours make the maps difficult to read for geomorphologists

not accustomed to the system but gives the advantage of possibilities

of many combinations of forms and processes. Another advantage is

that the colours do not obscure other information (De Graaff et al.,

1987).

3.1.6 The IGUL Mapping System (Lausanne, Switzerland)

A simple mapping system for high and middle mountain areas was devel-

oped at the Institute de Ge

´ographie de l’Universite

´de Lausanne (IGUL),

Switzerland, in the late 1980s (Schoeneich, 1993). The system has a strong

morphogenetic and morphodynamic focus and only depicts landforms. It

combines several principles of previously published Swiss, French and

German mapping systems. According to the German system GMK 25 (see

Section 3.1.3), colours are applied to express processes. However, colours

are used to differentiate between the line and area systems, following the

French system of Tricart (1965), to present genetic information for the

landforms mapped. A differentiation of erosional and depositional dynam-

ics is provided using white and coloured surfaces, respectively (Schoeneich

et al., 1998). Morphographic information and lithology is not provided.

The legend system is mainly used for educational purposes but has been

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applied to landform inventories and the analysis of sediment dynamics

(Theler and Reynard, 2008; IGUL, 2010).

3.1.7 Mapping System by Gustavsson et al. (2006)

Using parts of the basic concept of the AGRG mapping system

(De Graaff et al., 1987), the mapping system of Gustavsson et al. (2006) is

constructed through a thorough study of earlier developed geomorpho-

logical mapping systems. It has tried to solve specific problems often

occurring in the presentation of comprehensive geomorphological data,

for example presentation of sediment of mixed composition, diagenesis,

presentation of bedrock lithology and the separation between descriptive

and interpretative geomorphological data. An aim has also been to enable

a detailed presentation of varied and complex geomorphological environ-

ments without the use of complex legends (Demek et al., 1972). Since

the scale of a geomorphological map varies due to landscape complexity

and mapping purpose, the mapping system is designed to be used at dif-

ferent scales using the same legend (tested at 1:5000 to 1:50,000 scale)

(Gustavsson and Kolstrup, 2009).

The mapping system is not aimed at being as detailed and precise in

information as other more comprehensive mapping systems (Verstappen and

Zuidam, 1968; Demek et al., 1972), but uses a simple structure where infor-

mation is based on the combination of individual descriptive data. These

data are combined in an easy-to-use legend, which enables simple conver-

sion to a geomorphological GIS database constructed in parallel with the

mapping system (Gustavsson et al., 2006). The less-extensive legend also

allows for additions and improvement according to the needs of the user.

To reduce the subjectivity and to increase the possibilities for applica-

tion, the mapping system presents basic descriptive geomorphological data

as far as possible. Thus, the legend of the mapping system enables all geo-

morphological data presented to be read separately (e.g. material, process,

genesis or morphography), and it is the combination of these data that

enable the map reader to interpret the landscape (St-Onge, 1981). As in the

AGRG mapping system, the morphography is expressed at scale (where

permitted) by means of the Landform Element Model (Speight, 1974).

To enhance the readability, this mapping system avoids a saturated

combination of several layers of symbols in various colours. Like the

AGRG mapping system, this system instead uses an open framework that

enables additional point and line symbols together with a pattern describ-

ing the materials to be more clearly presented.

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As with the GMK and the AGRG systems, the system presents

detailed information on anthropogenic influence, and the system also

enables the description of biogenic genesis of forms and materials and

point descriptions of known stratigraphy. Whereas most mapping systems

include karst processes as genesis or as specific features, the legend incor-

porates weathering, which also includes weathering of non-calcareous

rocks as a morphogenesis or origin of materials. Unconsolidated litholo-

gies are expressed as grain-size distributions whereas bedrock types are

described in letter codes printed in colour of geological age according to

the Elsevier Geological time table (Haq and Eysinga, 1987).

Morphography and materials, both described by the use of symbols and

their genesis (11 different genesis types), are then expressed through the

use of colours. Diagenesis or, for example, surface-washed materials can

be expressed by combining colours. This use of coloured symbols enables

the original field observations of materials and forms to be seen in the

map, which allows the map reader to see what the interpreted genesis is

based upon. This separation also makes the conversion to a GIS database

easy. A disadvantage of this combination of data is, of course, that the

maps are harder to interpret by non-geomorphologists.

3.1.8 The Swiss BUWAL Mapping System

The BUWAL mapping system (BUWAL: former Bundesamt fu

¨r

Umwelt, Wald und Landschaft Swiss Federal Agency for Environment,

Forest and Landscape, today BAFU: Bundesamt fu

¨r Umwelt Swiss

Federal Agency for the Environment) for natural hazards has been developed

for applied mapping of potentially hazardous processes and landforms

(Kienholz, 1976, 1978; Kienholz and Krummenacher, 1995). Maps of

natural phenomena are regarded as a prerequisite for natural hazard assess-

ment and hazard management in Switzerland. Implemented within the

procedure of hazard management, the map is considered the first step in

the recognition and documentation of hazards. The final purpose of these

maps is to support the hazard assessment and decision process by increas-

ing transparency and traceability towards the engaged parties.

The legend system is compiled as a construction set to enable a greater

degree of freedom and flexibility for map creation and to accommodate

the purpose and requirements of the individual project. It follows three

formal principles:

1. Applicability for different map scales ranging from 1:1000 to 1:50,000.

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2. Applicability for specialised (restricted to one process) or general haz-

ard maps (several sources of hazard on one sheet),

3. Map compilation generated from a combination of simple and limited

basic elements (construction set).

The legend focuses on the mapping of processes and the related land-

forms of erosion and deposition. Three main differentiations of graphic

variables are provided regarding the topical map content: (1) difference in

colour (hue) depicts the various processes and (2) variations in colour

intensity (value) or (3) symbol size represent changes in process intensity,

activity, evidence, age or depth. Due to its origin, the symbol set concen-

trates on processes with hazardous potential in mountain areas and their

forelands. These processes include avalanches, debris flows, rock fall, land-

slides and hydrological hazards (flooding). Maps generated using this map-

ping system contain specialised symbols for areas of process origin,

transfer zones and depositional zones. What differentiates this legend from

others is its potential for predictive mapping of potentially hazardous loca-

tions, for example location within small creeks that indicate the potential

for blocking by woody debris during debris-flow events. Thus, these

maps not only document existing phenomena but also provide an inter-

pretation of the mapped objects with respect to hazard assessment.

4. MAP PRODUCTION AND DISSEMINATION

Traditionally, geomorphological features are mapped in the field, or

at the desk using tracing paper or drawing film draped over an aerial pho-

tograph or a topographical map sheet (Evans, 1990; Lee, 2001). These

field maps are then digitised or scanned to transfer the information into

the computer. Alternatively, geomorphologic features are digitised

directly on the screen (see Chapter 8 for further details) or by using a

portable mapping device in the field (see Chapter 6 for further details).

Combined with a GPS, a portable device delivers georeferenced informa-

tion in a GIS format e.g. (Dykes, 2008). The final production of the map

is generally performed using graphic or GIS software. Although graphic

software is used for on-screen visual design, GIS software focuses on spa-

tial data management, analysis and map creation. One advantage of map

creation using a GIS is the geographical referencing of the input data so

that it can be analysed and used for several applications. Although not

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comparable to graphic design software, the capabilities remain very good.

The main difference in map creation is that within the GIS, every drawn

point, line or area becomes an object in the database, whereas the graphic

software enables the manual combination of graphical strokes and points

to generate more complex objects and symbols.

The production of a geomorphological map requires the following

steps:

• Selection of the legend system,

• Mapping of the geomorphological objects (processes, landforms, mate-

rials) in the field, or from secondary data,

• Generation of a digital symbol set (optional),

• Transfer to the mapping software which may involve the following

steps:

•scanning of the field maps,

•georeferencing of the scanned image (only necessary for a GIS),

•digitising of features.

•Generalisation of map data including:

•simplification of complex objects to fit the map sheet,

•exaggeration of features that are too small to show at the scale of

the map.

• Printing or online publication of the map.

Geomorphological maps are composed of different layers of informa-

tion. The base layer is generally a topographical map or simple contour

lines as a reference source. As this information should not dominate or

influence the geomorphologic information on the map, the base layer

should be displayed using light colours (e.g. light grey). Thematic layers

differ between the mapping systems, depending on the focus of the map.

Typically, a geomorphological map includes layers on morphography

and/or landforms, process distribution, hydrology and subsurface material.

Changing the composition and the visual hierarchy of these layers allows

shifting the focus of the map. Such specialised geomorphological maps,

focused on, for example, process distribution or subsurface material, can

be of interest for application in natural hazard management or engineer-

ing projects.

4.1 Map Creation Using Graphic Software

Graphic software can be differentiated into programs focusing on the crea-

tion of vector graphics (e.g. Adobe Illustrator, Corel Draw and Inkscape)

or raster images (e.g. Adobe Photoshop, Corel Photo Paint and Gimp).

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Vector graphics are made up of points (nodes) and paths (edges), whereas

raster graphics are based on rectangular pixels organised on a grid. Raster

graphics are typically used to edit photographical images or create artistic

illustrations. Because vector graphics are not composed of a certain num-

ber of pixels, they can be scaled without losing image quality (Slocum

et al., 2005). Complex graphics and sketches produced for printing are

usually generated using vector graphics. The geometrical primitives,

points, lines and polygons that compose a geomorphological map are best

represented using vector graphics and produced with vector graphics

software.

The main advantage of graphical software with respect to the genera-

tion of geomorphological maps is the great number of tools for the crea-

tion and modification of graphic objects. Generally these can be adjusted

and customised to the user’s needs and exceed the possibilities provided

by GIS software. Common to all graphic software (as well as to GIS soft-

ware) is the ability to organise the objects in different layers. This feature

is particularly useful for map creation and should be utilised for the orga-

nisation and structure of items and different topical layers of the map.

Using layers enables certain objects to be fixed in order to prevent unin-

tentional modification, while working on neighbouring features. By

deactivating or masking a layer, the number of objects on the screen is

reduced during the process of mapping, allowing for a clear view of the

object in preparation.

The greatest challenge in the process of map production is the genera-

tion of reusable symbols (see Section 4.3). Graphic software allows the

definition of any drawing as symbol templates for points, lines or area fills

(e.g. in Adobe Illustrator: symbol, brushes and swatches). A large number

of ready-made symbols can be found on the Internet, very few however

are specially made, or useful for geomorphological maps. Although point

and area symbols are generally easier to apply, line symbols commonly

have problems in drawing symbols at corners and curves (see Section 4.3)

and thus require more effort to generate.

Due to the great number of graphic tools, graphic software offers

manyoptions for symbol creation and enables the creation of maps using

very complex symbols. Graphic software is designed to produce high-

quality print products and thus provide many tools for print optimisation.

However, this software is often very complex and requires some expertise

in order to fully handle the functionality and tools available.

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4.2 Map Creation Using GIS Software

The performance of GIS software goes beyond making maps. Data analysis

(queries, overlays and so on), data management and database storage are

central features of GIS software (Longley et al., 2005). Prior to transfer-

ring field data into a GIS, the structure and design of the database

should be considered. In the database, geomorphological information

should be stored in a logical manner and prepared for analysis and query.

Each object in the map is thereby linked to the database by its table of

attributes. The database provides additional information on the object

that is either gathered during the mapping campaign or generated after-

wards. Thus, GIS offers the ability to combine basic information on

landform/process/material type and geometry with secondary data on

feature characteristics (e.g. from sampling, dating, laboratory, geophysical

or GIS analyses). A simple structure for a database connected to a geomor-

phological map may include the following levels of information: (1) geo-

morphological features (landforms, processes), (2) geological/lithological

data, (3) hydrological information and (4) additional data used for map

construction, such as topographical maps, digital elevation models or aerial

photographs. An example of a geomorphological database structure using

Environmental Systems Research Institute, Inc. (ESRI) ArcGIS software is

given by Gustavsson et al. (2008).

GIS analysis commonly results in the compilation of a map and

consequently GIS software includes mapping facilities and graphic design

capabilities. Among these are automatic tools to generate the legend, scale

bar, north arrow and coordinate grid. These map elements are automati-

cally adapted to changes, for example the scale or symbol type. Often

special symbol editors are provided to compose and define the symbol set

for the map (see Section 4.3). As with graphic software, GIS software

offers tools to digitise vectors (points, line, polygons) with high accuracy

and the ability to modify single vector nodes. As the data structure in a

GIS is organised into different layers, these can be combined to form map

frames. By combining several map frames, inset maps can be created,

geographically referenced and created within the same GIS project.

One of the advantages of using a GIS is the geographical referencing

of the data. The geomorphological map can easily be rescaled, for exam-

ple, to enlarge certain areas or to fit a special sheet size. Further, the coor-

dinate grid and direction indicator (e.g. north arrow) are automatically

generated and adapted.

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