

# A new symbol-and-GIS based detailed geomorphological mapping system: Renewal of a scientific discipline for understanding landscape development

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## Abstract

This paper presents a comprehensive and flexible new geomorphological combination legend that expands the possibilities of current geomorphological mapping concepts. The new legend is presented here at scale of 1:10,000 and it combines symbols for hydrography, morphometry/morphography, lithology and structure with colour variations for process/genesis and geologic age. The piece-by-piece legend forms a “geomorphological alphabet” that offers a high diversity of geomorphological information and a possibility for numerous combinations of information. This results in a scientific map that is rich in data and which is more informative than most previous maps but is based on a simple legend. The system is developed to also be used as a basis for applications in GIS. The symbol-based information in the geomorphological maps can be digitally stored as a powerful database with thematic layers and attribute tables. By combining and further developing aspects of different classical mapping systems and techniques into expanded data combinations, new possibilities of presentation and storage are developed and thus a strong scientific tool is provided for landscape configuration and the reconstruction of its development; in turn the combination paves the way for specific thematic applications. The new system is illustrated for two contrasting landscape types: the first is located on the border of Vorarlberg, western Austria, and Liechtenstein in a glacially influenced, high altitude alpine setting that is strongly modified by various degradation processes; the second area represents a formerly glaciated region in Dalarna, central Sweden near Mora, an area that is characterized by a variety of aeolian, fluvial, glaciofluvial and lacustrine depositional and erosional landforms and also reflects isostatic uplift. The new method functions well for both areas and results in detailed scientific outlines of both landscape types.

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## 1. Introduction

Activities focusing on geomorphological mapping as a scientific discipline in its own right have been relatively modest over the last 20 years. There may be two main reasons for this: (1) detailed geomorphological mapping is a time-consuming and costly activity; and (2)

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the present focus is on themes and applications rather than the holistic scientific maps. As a consequence, instead of a general understanding of an area with its mutual spatial, chronological and genetic relations between land elements (*sensu* Lawrance, 1972, cited in Cooke and Doornkamp, 1990, p. 21, Fig. 2.1; see also Speight, 1974), the discipline has come to be seen as fossil and not real science and now stands in the shadow of thematic and applied maps and technical developments focusing on specific problems. This is somewhat surprising especially because the decline in geomorphological mapping coincides with a strong development in GIS; yet the new possibilities that can spring from a combination of a GIS database and traditional field-based geomorphological maps and legends have been somewhat neglected.

A large-scale geomorphological map (scale between 1:10,000 and 1:50,000, occasionally up to 1:100,000 (Demek et al., 1972) or scale between 1:5000 and 1:10,000 according to UNESCO (1976) and Hansen (1984) as presented in Cooke and Doornkamp (1990) forms the strongest scientific source of information and the best explanatory presentation of landforms and landscape development. Such maps can serve as a basis for various applications, such as hazard maps (e.g. Kienholz, 1978; Seijmonsbergen et al., 1988, 1992; van Westen et al., 1999), use with planning and nature conservation (Ten Cate, 1983; Bocco et al., 2001) as well as engineering purposes (Cooke and Doornkamp, 1990, pp. 19–20). Such applications usually require generalisations of the geomorphological map as well as added information on a specific parameter, for example vegetation.

A large-scale geomorphological map should present a full picture of the landscape. According to Klimaszewski (1982, p. 267), “the map should inform about the distribution and correlations of forms of a certain appearance, size, origin, and age; it must include morphographic, morphometric, morphogenetic and morphochronologic data”. Many scientists also include lithology (e.g. Tricart, 1965; Cooke and Doornkamp, 1990). This means that the geomorphological map must present a systematic, concise inventory and scientific understanding of landscapes and their development (see also Verstappen and van Zuidam, 1968; St-Onge, 1981).

The combination of the scientific basis, i.e. the landscape analytical procedure and presentation, and the added spin-off derivative maps for practical applications made the production of geomorphological maps the target of several major efforts over the years up to the 1970s (see also the historic overview in Klimaszewski,

1990). For years these efforts included attempts towards increased uniformity of geomorphological legends, and involved numerous scientists in several countries especially in Europe (e.g. Maarleveld et al., 1977; Barsch and Liedtke, 1980; Barsch et al., 1987) and, most importantly, a major international co-operation by the International Geographical Union (IGU) commission on Applied Geomorphology-Subcommission on Geomorphological Mapping (Gilewska, 1966; Gilewska and Klimek, 1968; Demek et al., 1972).

Geological maps, which are generally more simple in their structure than geomorphological maps, have to some extent succeeded in keeping their legends uniform, but geomorphological maps have not: either local conditions emphasize presentation of specific features at the cost of others, or the legends are so exhaustive that they reduce readability. One of the obstacles that has hampered the development could be that many users believe a geomorphological map is easy to read, or they confuse such maps with more simple maps that only show selected aspects of geomorphology. But it needs to be stressed that in the same way a mathematical formula is a communication between mathematicians, the detailed geomorphological map is a research communication between geomorphologists. In this case it is about the landscape configuration and history and, as such, it is not directly readable for others who are not used to this kind of presentation.

Fieldwork remains the basis of detailed geomorphological mapping (Klimaszewski, 1982) but the increasing technical possibilities offered by digital remote sensing and the use of PCs and mobile GIS now offer added flexibility in data collection, data handling and presentation. For example, the much cheaper and diverse possibilities for use of colours in print and GIS software can be put to great advantage and today traditional maps have increasingly moved into the shadow of various GIS applications. Yet, care has to be taken with this step because GIS-based mapping systems tend to emphasize homogeneity, partly because of the limited memory capacity available and partly because of the costs and efforts of more accurate data collection (Longley et al., 2001).

Scientific geomorphological maps and legends need to be upgraded in parallel with new landscape planning needs and technical developments of presentation if a general perception of landscape configuration and development is to form a holistic platform for the understanding of our environment. Against the background of stagnation in the development and use of classical detailed geomorphological maps and mapping as a scientific discipline in its own right over recent

years, it seems timely to re-activate the discussion and try to develop this discipline further.

Therefore, we present a new, widely applicable, flexible symbol-based combination legend that increases the content and context of the geomorphological map for better analysis and understanding of landscape development. It was an aim of the work that the legend must be clearly structured and logical to facilitate the overview and that the number of symbols must be kept low for easy use. The outcome is a relatively simple piece-by-piece legend in which individual characteristics are kept separate so that the legend forms a geomorphological alphabet, which provides the possibility for numerous combinations of information. Consequently the new map contains more data than it has previously been possible to give in a single map without the use of an extensive legend. A number of previous geomorphological mapping systems are included as a basis for development and, as a consequence, the new system is rather widely applicable and of use in areas of different geomorphology. The resulting map is scientific and has its focus on geomorphological parameters and landscape understanding, but at the same time it provides a basis for thematic overviews. To add to the use of the map in computer-based applications, the map and the legend are developed to be used with a GIS-based version, which implies that the geomorphological map is easily transferred into a digital database.

## 2. The geomorphological map: review and new proposal

Ideally, a geomorphological map should contain information on morphometry, morphography, hydrography, lithology, structure, age, and process/genesis. This goal has proved hard to achieve and as a result geomorphological maps have become the result of a number of choices, related to extent and history of the area, the mapping scale and the geomorphological characteristics given highest priority, e.g. presented in colour in the map.

### 2.1. Background to the map and its presentation

To date, there have been many attempts in different countries to create maps that cover various aspects of geomorphology but, as mentioned above, in spite of efforts towards similarity between the maps the results have differed dependent on the landscapes and traditions they represent. Comparative studies (Gilewska, 1967; van Dorsser and Salomé, 1973, 1983; Salomé et al.,

1982) contributed much to clarify similarities and differences between selected mapping systems, but clearly many problems remain to be solved.

Any mapping system should be constructed to reduce subjective impressions as far as possible, thus allowing the map-reader to see the data upon which the conclusions are based so that the map is open to alternative interpretations and changes once new knowledge is available. Physical properties such as lithology and slope gradient can usually be presented fairly objectively, but problems arise in particular with genetic classification, i.e. the scientific interpretation, which inevitably becomes more subjective.

Easy readability of relevant information is a quality that any map should have. The building blocks that can be used to present data for geomorphological maps include colours (including hue and intensity), symbols, lineation, shading/hatching, letters, and numbers, alone or in combination. For easy orientation in the terrain, it is advantageous if the geomorphological map is based upon a geo-referenced topographic map or orthophotograph that shows selected infrastructure and also gives contour lines.

Colour is the most eye-catching graphic variable and it is, therefore, normally used to indicate the geomorphological characteristic that is given the highest importance. Although the human eye can differentiate many colours it is of benefit to the readability of the map that the number of colours is kept as low as possible with as few degrees of intensity as possible. Colour can present information in two principal ways: (1) different colours are used to indicate variations within one legend unit set, which is the more common and is often used to indicate different genesis/processes in different colours; and (2) different unit sets are given in different colours, for example colours can be used for combinations of lithology and chronology. Few colour conventions are generally agreed upon, yet some prevail over others in relation to particular information: blue is normally used with hydrography, black with anthropogenic forms, and yellow with aeolian forms.

Most maps use colours that cover entire areas, sometimes combined with letters, hatching and other symbol presentation, but there are exceptions to the rule: for example the AGRG system (De Graaff et al., 1987) uses colour to give outlines only of genetic/morphological units. Some problems can arise because boundaries between forms are to be indicated in the maps, yet in nature boundaries between units or systems are not always sharp (e.g. Batten, 2001) and, therefore, representation of transitions would be advantageous as would portrayal of the polygenetic origin of some

landforms. However, such combined information is not often included even if it is sometimes possible to use combinations of colours and/or symbols to indicate transitions.

Shading/hatching/stipples are often used with description of lithology, gradient and age. For other geomorphological characteristics, symbols can denote type of process and/or direction of material movement, whereas lineation can be used to indicate structures or outline morphologic discontinuities.

Presentation of features too small to be included at scale, such as gullies, often poses a problem. In many maps such forms are nevertheless indicated. In the ITC system (Verstappen and van Zuidam, 1968), they are presented not as geomorphological form elements but as a process acting on part of the slope marked by symbols. In the AGRG system (De Graaff et al., 1987) and the GMK 25 (Barsch and Liedtke, 1980), selected small forms can be presented by symbols, which often have a genetic implication. This presentation has the disadvantage that size and spatial distribution of small forms are lost, but the advantage that the reader is aware of minor geomorphological changes and their causes.

To some extent the new system is based on a number of existing approaches, in order not to differ too much from “established systems” (e.g. Verstappen and van Zuidam, 1968; Barsch et al., 1987; De Graaff et al., 1987); at the same time, it is a priority that it can be used to solve specific problems, e.g. present sediments of mixed composition and give bedrock lithology and age directly in the map. It is also a priority that it must be easy to convert into a GIS. Solutions are sought to questions that have previously presented problems with the construction of geomorphological map systems, for example presentation of hard rock together with other information. In addition, it must be sufficiently flexible to indicate polygenetic landscapes and transitions between forms.

Scientific synthesis, i.e. the genesis of the landscape, is shown in colour. To allow for presentation of as much information as possible in the basic geomorphological map, coloured lines and symbols are used in accordance with the AGRG system (De Graaff et al., 1987), rather than using coloured areas of specific form elements or units. To use colour in this way gives space to present information on the map without overprinting.

The list of geomorphological parameters of morphometry, morphography, hydrography, lithology, structure, age and genesis/process on the one hand and the building blocks of colours, symbols, lineation, shading/hatching, letters and numbers as tools to present these on the other, give numerous possibilities of combination

























(Fig. 1). This means that each legend point can be rather simple, preferably expressed in one or very few words only, and it is the combinations of these that give the explanation. This gives a flexible and expandable legend and makes some combinations self-explanatory, e.g. yellow dots indicate aeolian sand. No legend distinction is made between accumulative and denudative forms, but in this respect the context will often provide information. Significant forms too small to be indicated at scale in the map are given by symbols (Fig. 1) coloured for their genetic classification, and added information is provided by their mutual random or aligned organisation.

In the new map, the graphic sign system is kept simple and the perception of the map is related to the differential variables and the principles outlined in Bertin (1974, p. 50f), Bertin (1981, p. 177, p. 230) and Cleveland (1994, pp. 223–240). At the same time, the signs and their uses are kept in line with previous geomorphological mapping systems outlined below in as far as possible. To complete the legend, some newly designed graphical symbols and colour letter codes are added. In the map the variation in graphical expression such as direction and weight of lines, and the size of objects help to give meaning to the map (compare with Kraak and Ormeling, 2003).

To illustrate the principles of and reasons for the graphical choices some examples of the symbolisation and graphics in the new legend are given: visual relation between symbol and object is expressed, for example, in the symbols for patterned ground and V-shaped grooves; layering or lack of such in clay/silt deposits is reflected in the orientation of symbols. Particle size for sand and coarser sediments is reflected in the size and, for the coarsest components, shape of individual symbols in the pattern, which is given in “dot-style” to allow for combinations of grain sizes and origins of materials with a minimum number of legend points. Lines for undulating terrain, modified area and slope lines are thinner than lines used for geomorphological forms and features to make the former less conspicuous; but to avoid further accentuation of some geomorphological forms as compared to others, further differentiation of lines thickness is omitted. Variations in line discontinuity are used to express less certain boundaries and non-permanent streams, thus adding a component of certainty and hierarchy to the information. Exposed consolidated rock is given in letter code and information on rock age is added and expressed by the colour of the letter code with the colours following the conventional code for geological period/epochs (see Section 2.4 below). Apart from this use of colours, they are given



A

Hydrography	Morphometry/Morphography	Specific features
(In blue)  	Forms mapped at scale (Colour according to process/genesis)  Slope with gradient of slope (in black) 	(form/process integrated) (In colour of process, incl. Endogenic)  
Stream, ephemeral (Dots in black if anthropogenic) 	Upper slope boundary a. height < 10 m b. height > 10 m 	Debris flow/ Other fast flow 
Stream, subsurface (Dots in black if anthropogenic) 	Escarpment a. height < 10 m, distinct b. height < 10 m, less distinct c. height > 10 m, distinct d. height > 10 m, less distinct 	Slide (symbol at scarp, arrow in direction of movement) 
Abandoned channel 	Slope discontinuity a. distinct b. less distinct 	Small slide/ Slumplike form 
Waterfall/Rapid/Dam 	Undulating terrain with slope angles 2–35° 	Known transport direction 
Spring/Sinkhole 	Modified area 	Pothole and similar features 
Waterlogged area, permanent 	Geomorphological boundary a. certain b. uncertain 	Glacial pressure imprint a. certain ice-direction b. uncertain ice-direction 
Waterlogged area, periodically including flooding 		Tensional fissure 
Lake, Sea with bathymetry 		

B

Lithology			Structure
Consolidated rock Metamorphic, igneous, Sedimentary and Evaporites (In colour of geological age) Examples Am Amphibolite An Andesite Ba Basalt Br Breccia Co Conglomerate Db Diabase Do Dolomite Ga Gabbro Gn Gneiss Gr Granite Gw Graywacke Gy Gypsum Li Limestone Ma Marl Mb Marble Pe Pegmatite Rh Rhyolite Sa Sandstone Sc Schist Sh Shale Sl Slate	Unconsolidated deposits and regolith, incl. volcanic Organic (In light brown) Peat/Organic Gytja Shell deposits Permafrost Glacier/ Perennial snow with contour lines Known stratigraphy P - peat. C - cohesive sediments. F - non-cohesive sediments. T - till. Underlining means that sequence reaches bedrock. Numbers specify thickness of sequence in meters. Unspecified number indicates thickness of unknown sequence • 3p 5C 1F 2I		Strike and dip (Angle in black) Horizontal Vertical Overtured Faults/Joints
	Clastic s.l. (In colour of process/genesis) Clay/Silt (< 0.06 mm) a. layered b. massive or distorted structure Sand (0.06 - 2 mm) Gravel (2 - 60 mm) Cobbles (60 - 600 mm) Boulders (0.6 - 1 m) Large boulders (> 1 m) Single block (> 150 m <sup>3</sup> ) including large erratics Erratics (> 1 m <sup>3</sup> )	(In red) 15° + ∅ ∅ ∅ ∅	



Fig. 1. The new legend. This system combines lines, hatching, symbols and letters/figures with colours. The flexible legend makes it possible to include a wider range of geomorphological parameters than previous mapping systems.

much importance in the presentation of the process/genesis of landforms and materials as mentioned above. To enhance readability and visual prominence of spatial relationships and patterns information on materials is presented with a colour intensity of only 50% of that used with information on morphography (Dent, 1999).

The legend is designed for maps at scale 1:10,000 where many small-scale landforms can still be included for explanation of the landscape, its constituents and their genesis. At a scale of 1:25,000, and in particular at 1:50,000, a number of the symbols, such as (arrows

with) gradients in degrees and most “specific features” will become difficult or impossible to use, i.e. the information will become less detailed with decreasing scale.

Below, individual parameters of the field-based geomorphological map are outlined for some traditional systems and the new one proposed here. The new legend is tested for two contrasting areas, one in the European Alps (Section 4.1) (see also Seijmonsbergen, 1992) the other in central Sweden (Section 4.2). For both areas, a geomorphological map in colour at scale 1:10,000 is

presented according to the new system, and in Sections 3 and 4.3 a general outline is given of the GIS-based version of the map.

## 2.2. Morphometry/morphography

The morphometry gives a quantitative description of the shapes of the landforms (Tricart et al., 1963; Tricart, 1965, pp. 187–188) while the morphography is the qualitative description or the configuration of the landforms (Tricart, 1965, pp. 187–188). The two parameters thus cover the measurable properties of an area and the geometric shapes of landforms. Together with lithology and genesis/process, these often outline a geomorphological element, a generalised area with homogenous shape, material and genesis.

### 2.2.1. Review

Many geomorphological maps use topographic maps and the contour lines given in those to indicate slope characteristics and altitudes as the primary information layer. However, in some maps additional information on slopes is extensive. For example, the 1:50,000 geomorphological mapping system of the Netherlands (Maarleveld et al., 1974, 1977; Ten Cate, 1983) classifies landscape elements according to the combined slope angle and length into eight relief classes given in different colour intensities. In turn, the landforms are classed into 15 form groups as defined by a qualitative definition (plateaus, fan-shaped forms, etc.). Also, for example, the Polish legend gives much emphasis to the relief and shape of landforms (Gilewska, 1967) as does the German GMK system (Barsch and Liedtke, 1980). The latter gives slope classes in a grey shading system in the GMK 25 and with blue contour lines added to shaded slope classes in the GMK 100 map (Barsch and Liedtke, 1980). In a Belgian system developed by Robert and Beckers (1970, in Salomé et al., 1982), the morphography is even given in colours upon a map with contour lines. The Unified key (the result of the IGU Sub-commission on geomorphological mapping (1968; Gellert, 1972, p. 13)) is designed to be used at several scales and uses a slope classification divided into six gradient categories at 2°, 5°, 15°, 35° and 55° expressed by different intensity in addition to contour lines (Scholz, 1972; Demek and Embleton, 1978). The landforms are further classified into 16 form groups based on shape and genesis combined (Demek et al., 1972) and in some applications (e.g. Bocco et al., 2001) a classification into form groups has proved useful. Other geomorphological mapping systems, such as the ITC system (Verstappen and van Zuidam, 1968) present

some information on slope and shape but use a separate morpho-conservation map to divide the landforms into gradient classes rather similar to those of the IGU key. The Alpine Geomorphology Research Group (AGRGR) (De Graaff et al., 1987) uses a simple slope classification system based on slope height (<10 m or >10 m) in combination with contour lines in grey, arrows and numerical values in black, and symbols, in colour of process, for breaks of slopes. Information on changes or breaks of slope angle is also commonly used in British morphologic maps, which follow a tradition based on a subdivision into concave or convex breaks or inflections (Evans, 1990). In Sweden, an experiment was done to express topography by means of combinations of contour lines, hatching, shading and symbols (Elvhage, 1980). In spite of the fact that slope gradients are important in slope stability assessment, only a few geomorphological maps produced during the last decades include direct information on slope gradients other than contour lines.

According to Speight (1974), there are two principal approaches to the description of landforms: the *Landform Element Model* which separates the landscape into geometric elements (e.g. slopes and plains), and the *Landform Pattern Model* which presents repeated and definable forms (e.g. ridges and mounds) within a landscape pattern. The AGRGR system (De Graaff et al., 1987) uses the first of these models where the landforms can be presented at scale. This system has the advantage that fewer generalisations have to be made and fewer symbols are needed in the legend. Table 1 summarises the general presentation principles in a number of selected mapping systems.

### 2.2.2. New system

The topographic map is used as a base map and contour lines are given in grey. The possibility of copying to different scales makes the choice of scale flexible, and experiments have been done with 1:5000, 1:10,000 and 1:50,000. In addition to the contour lines, information on slope angle is given by a combination of black arrows pointing downslope and a figure of slope angle in ° next to it also in black (Fig. 1). Slope breaks/discontinuities are indicated by symbols in the colour of the form-giving process(es) and shoulders by lines, also in colour of process, with slope height in line symbols similar to the landform element model used by the AGRGR system (De Graaff et al., 1987). In addition, small-scale undulations of an area, such as the gently undulating topography of many glacial landscapes, are given by a symbol in the colour of process (Fig. 1). For two reasons, neither shading nor colour is used for slope



Table 1

Overview of how the main geomorphological parameters are presented in selected European mapping systems as compared to the new system

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, <a href="#">Verstappen and van Zuidam, 1968</a>	Contour lines, symbols and lines	Hatching, lines and symbols in blue	Patterns, lines and symbols	Not indicated	Colours and symbols	Colours in separate map
Netherlands, <a href="#">Maarleveld et al., 1977</a>	Contour lines, colour intensity and code	Lines, areas and symbols in blue	Not indicated	Partly in legend	Code, legend	Code/legend
GMK 25, <a href="#">Barsch et al., 1987</a>	Contour lines, grey shading symbols and lines	Blue lines and symbols	Red pattern and separate map	Not indicated	Colours, red and black symbols	Colour
AGR, <a href="#">De Graaff et al., 1987</a>	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 process
Western Alps, <a href="#">Nicod, 1988</a>	Black contour lines	Blue lines and symbols	Yellow shading for consolidated rock	Black lines, yellow lines and symbols	Coloured lines and symbols	Partly included with rock lithology
Italy, <a href="#">Bartolini et al., 1986</a>	Grey contour lines, hachure. Line symbols for erosional scarps	Lines, areas, symbols and patterns in blue (and black)	Colour, shading. Text to profiles	Brown lines and symbols	Coloured shading and symbols	Intensity of shading and symbols. Separate map
New system, this paper	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 code for consolidated materials	Red lines and symbols	Coloured symbols, colours	Coloured letter code for consolidated rock

For further information, see the text.

classes or morphographic subdivision. First, shading or colour “fill” the map too much, and second, they only indicate a generalised interval of slope angle or slope form within an area rather than changes over the unit. It is consequently less descriptive on slope angle and changes of slope forms than the system proposed here.

### 2.3. Hydrography

#### 2.3.1. Review

Water is an important agent in landscape development and most geomorphological mapping systems include information on the hydrography. An early effort even focuses on this parameter ([Klimaszewski, 1956](#)). Some systems, e.g. the IGU Unified key ([Demek et al., 1972](#); [Demek and Embleton, 1978](#)) and the ITC system ([Verstappen and van Zuidam, 1968](#)) integrate detailed hydrographic information with related processes and deposits, while others, such as the AGRG system ([De Graaff et al., 1987](#)) include hydrographic parameters upon the topographic map as the second information layer. The German GMK 25 is rather detailed in these respects ([Barsch and Liedtke, 1980](#)) as are some applied

maps (e.g. [Kienholz, 1978](#)), while other systems, e.g. the Soviet ([Bashenina et al., 1960](#), in [Gilewska, 1967](#)) and Polish maps ([Klimaszewski, 1963](#), given in [Gilewska, 1967](#)) give very little direct information on hydrography.

#### 2.3.2. New system

Running water courses and their morphological traces and standing water bodies are indicated in blue in accordance with many other maps. [Fig. 1](#) gives types and characteristics of lines, symbols and areas used with the hydrography. The legend also contains symbols for features such as springs, permanently and intermittently wet areas and areas inundated by floods, the latter according to the ITC legend ([Verstappen and van Zuidam, 1968](#)). Dependent on the hydrographic characteristics of the area additions can be made, preferably according to the ITC legend.

### 2.4. Lithology

The materials of a landform are intimately linked to its development and contribute to landform (in)stability

in relation to different processes and consequently to its sensitivity to change. Earth surface materials are diverse and can be subdivided into various groups. A common way of doing this is to distinguish hard and soft rocks. Hard rocks primarily include rocks of endogenic origin like metamorphic and igneous rocks and some eruptives. A second rock group includes lithified/consolidated sedimentary rocks and evaporites. Since the different rock types have different qualities in relation to landscape development their individual portrayal is useful in the geomorphological map. Regoliths (in situ and transported loose particles) dominate the surface materials in many parts of the world and there are local occurrences of organic sediments.

#### 2.4.1. Review

Presentation of rock types, especially hard rock, in geomorphological maps has often presented problems and in some cases a separate, small overview map gives the geologic characteristics of the region (e.g. the GMK 25 system, Barsch and Liedtke, 1980; Barsch et al., 1987). The IGU system to a large extent links rock type with its origin (Gilewska and Klimek, 1968) while rock characteristics are included as part of a separate transparent geotechnical overlay map in the AGRG system (Seijmonsbergen, 1992). In the French system different rock types are indicated by hatchings (Tricart, 1965), and a system that presents part of the western Alps (Nicod, 1988) gives them in yellow shading while the ITC system denotes them in a combination of shading and letter code, the latter indicating specifics on the rock type within the group (Verstappen and van Zuidam, 1968). Unconsolidated sediments are presented in most maps, usually by means of shading or stipples, which indicate a generalisation of the grain size composition; sometimes these legend points have a colour of their own (red in the GMK 25); in other cases the genesis/processes and/or age determine the colour of the symbol (e.g. the AGRG system). In some maps (again the AGRG system), materials are partly classified according to their genesis indirectly implying that deposits of similar genesis have similar properties; yet diamict, for example, can have a wide variety of grain sizes and much difference in dominant particle size between adjacent areas and thus have different qualities regarding hydraulic characteristics and resistance to erosion and mass wasting.

#### 2.4.2. New system

Lithology is subdivided into hard rock and unconsolidated material. The former includes bedrock types as well as lithified/consolidated materials in the widest

sense including duricrust and evaporites. The rock types are denoted by a letter code giving two letters for each rock type, e.g. Gn (gneiss), Co (conglomerate), Gr (granite), Gy (gypsum), Li (limestone), Rh (rhyolite), etc., and the list is expandable (Fig. 1). The letters are given on the rock outcrop in colour according to age of the rock (see below on chronology). Areas with exposed rock surfaces are left white in the map except for this added denotation, and, if necessary also structural symbols and symbols for “specific features” such as for example “glacial pressure imprints” (see Fig. 1).

Shading and symbols are used to indicate surficial regolith or detritus (where known, down to a depth of 0.5 m) and also unconsolidated volcanic ash. This part of the legend is inspired by Verstappen and van Zuidam (1968), Barsch and Liedtke (1980), De Graaff et al. (1987), Karlsson and Hansbo (1992) and the SGU A-series on Quaternary deposits (Persson and Svantesson, 1994). The subdivision of materials into the grain size classes of clay/silt, sand, gravel, cobbles, boulders and blocks is based on the SGF 81 grain size classification (Karlsson and Hansbo, 1992). Combinations of the symbols give information on the grain size composition of the material and all within-shading combinations are possible in as far as space allows. A diamict can, thus, be presented as a mixture of various grain size symbols which is of advantage in some areas in for example Sweden, which has a high diversity of bouldery diamictos with a wide variety of grain sizes and major differences in dominant particle size between adjacent areas. Single blocks  $>150\text{ m}^3$  and erratics larger than  $1\text{ m}^3$  are also indicated. In relation to unconsolidated clastic materials (*sensu lato*), the colours of the symbols indicate genesis/processes. For easier reading of the map the materials are printed with weaker intensity than used with, for example, morphography. Unconsolidated organic sediments such as peat, gyttja and shell accumulations are given by symbols. Further, a symbol is added for areas with permafrost, and glaciers or perennial snow are marked by a light blue colour with contour lines in blue.

The distinction proposed here gives direct information on whether the lithology consists of hard rock (*sensu lato*) or if it is of unconsolidated material. It might be argued that the system is inconsistent by denoting one type of lithology in coloured letters according to age and another set by coloured symbols according to genesis. But apart from giving direct information on lithology it has the advantage that it solves the problem of presenting the age with regard to the former and also gives information even if a consolidated rock is very young (gypsum duricrust for example), as Holocene

rocks too have letter codes in colour. For hard rocks the system thus gives information on rock composition and, implicitly, to some extent also on rock quality directly in the map.

## 2.5. Structure

In hard rock areas rock structure contributes to landscape development in various ways, and geologic structure is, therefore, included in many but not all geomorphological maps.

### 2.5.1. Review

Some mapping systems present structure only where it affects land surface stability (De Graaff et al., 1987) while others present more complete information (Gilewska, 1967). Almost invariably structure is given by lineation (joints and fault lines, anticlines, etc.) or symbols (dip and strike) often in black (French system: Tricart, 1965; ITC system: Verstappen and van Zuidam, 1968). The Hungarian system (given in Gilewska, 1967) follows the red colour of its endogenic origin. A system for the western Alps distinguishes between Tectonic and Structural forms with the former in black and the latter in yellow (Nicod, 1988).

### 2.5.2. New system

The open construction of the new map legend leaves space to include some information on tectonics and rock structure where it is needed, and in this way some information on rock quality is indirectly added. Lines in the red colour of endogenic process give anticlines, fault lines, etc., while symbols are used for dip and strike (Fig. 1). Also slopes and escarpments caused by tectonic forces can be denoted, for example a 5-m tectonic fault can be indicated by a red <10 m distinct-escarpment symbol.

## 2.6. Age

The chronology of landscape elements, units or systems are important in reconstruction of the landscape history and, thus, landscape dynamics. This goes for both stable landscapes with slow rates of development and for landscapes with high geomorphological activity, the difference between them being mainly the timescale and the activity of the prevailing processes, which in turn are dependent on climate regime and geological activity.

### 2.6.1. Review

Presentation of age has been done in different ways. The French system gives it the highest priority with a

covering colour (Tricart et al., 1963) and the history of the landscape can thus be read through the different colours in relation to landscape development in line with the geologic map systems that also give age in colour. Also the Polish system ranks age highly although to some extent in combination with the aggradational and degradational status of landforms (Gilewska, 1967); and an Italian system gives a simplified outline of age by giving colour (including recent in red) to some of the symbols and shading denoting other characteristics of the map (Panizza, 1968). The ITC system (Verstappen and van Zuidam, 1968) presents ages with black letter codes, but there are also systems that merely present the relative age of selected landforms, sometimes even implicitly: for example the AGRG system (De Graaff et al., 1987) give different varieties of green colour to fluvial and glaciofluvial terrace deposits.

### 2.6.2. New system

As mentioned above, letter codes in colour give age to consolidated rocks in the new system. The colours follow those of the Elsevier Geological Time Table (Haq and van Eysinga, 1987). Presentation of age in this way adds an absolute time dimension directly to a map that is already rich in information without making the map unreadable, and an added geologic map is, thus, not needed. On the other hand, the system proposed here is not sufficiently detailed to give specific information on the chronologic succession of rocks dating from within a certain period or epoch such as can be the case in geologically active areas, for example regions of continued and regular volcanic activity. It is maybe more problematic that the legend does not directly give the age of landforms built up of non-lithified sediments. As a consequence, it is not possible to indicate if an unconsolidated landform element dates from the Quaternary or some earlier period. In areas that have been strongly influenced by climate change such as the glacial and periglacial parts of northern Europe, Asia and America, the combination of genesis and sediments together with morphometry and morphography can sometimes give indirect information on age to readers familiar with this kind of area. In such areas, a map of the age affiliation of Quaternary deposits can be constructed from the geomorphological map, often relatively easily, once selected deposits are dated.

## 2.7. Genesis/processes

Information combined from the previous geomorphological map parameters, together with additional background information and field observation of

ongoing processes, makes it possible to reconstruct the processes that have formed the present land surface elements and their mutual configuration within an area. It, thus, becomes possible to propose a genetic classification of landforms and the relationship between them.

### 2.7.1. Review

The scientific synthesis presented by processes and genesis is given the highest priority in many maps, but the number of processes included varies according to the geomorphology of the area and to some extent also on the tradition of the mapping system.

The full scale of processes is long and includes the main groups of endogenic (mainly constructional) and exogenic (mainly denudational) forces. The form groups proposed by the ITC classification (Verstappen and van Zuidam, 1968) distinguish structural and volcanic forces for the former group, while it includes forms of denudational, fluvial, marine, glacial and periglacial, aeolian, and solution (karst) origin in the latter. This is a slightly simplified list of the form groups in the Unified key system (Gilewska and Klimek, 1968). The Polish and a few other legends subdivide genesis into constructional and denudational processes. This goes for landforms of endogenic as well as exogenic origin, for example fluvial landforms are subdivided according to these two categories in the Polish system (Salomé et al., 1982). Also an Italian legend (Bartolini et al., 1986) distinguishes between erosional and constructional forms, in this case in a system that focuses on glacial and periglacial landforms in a high mountain area.

In some systems (e.g. the AGRG system, De Graaff et al., 1987), the focus is on the last, or occasionally earlier, process that acted upon the land surface. In many cases, it can be argued that the characteristic landform was created earlier, for example a moraine ridge can be overprinted by surficial mass movement that has not substantially altered the original form. Such polygenetic landforms are reflected in some maps, e.g. the German GMK 25 system (Barsch and Liedtke, 1980; Barsch et al., 1987), which makes a distinction between “areas of process and structure” and “actual process” in order to stress present-day activity. The polygenetic origin of landforms is more fully reflected in the Dutch legend and indicated by a combination of code and covering colour (Maarleveld et al., 1977).

The scientific interest in genesis of landforms by geomorphologists has also resulted in a more thematic–genetic type of mapping. For example, a series of maps for the Swedish mountains has been produced by the Department of Physical Geography in Stockholm (e.g.

Melander, 1976; Borgström, 1989). These maps indicate selected landforms by genetic symbols on a topographical map at 1:250,000 with contour lines at 100-m intervals as the background. Other maps are also oriented towards processes, for example some Italian geomorphological maps emphasize slope stability aspects. This is reflected in detailed legends with the main focus on various mass movement processes and patterns (e.g. Panizza et al., 1996). In a map with the focus on fluvial, gravitational, glacial and periglacial landforms in the Italian Alps, a distinction is made between active and non-active landforms (Bartolini et al., 1986).

Most of the geomorphological systems that give priority to genesis at the highest level usually present each genetic form class by a specific colour that covers the whole area representing the form. As mentioned earlier, the AGRG system is an exception to the use of covering colours. Instead, colour is used for the outline, hatching or symbol for forms and features (De Graaff et al., 1987). This reduces the total number of legend points in the map and substantially increases the number of optional combinations between form, material and process.

### 2.7.2. New system

The proposed mapping system is constructed to have its emphasis on genesis, which is therefore expressed in colour (Fig. 1). The classification includes endogenic, encompassing tectonic and volcanic origin in one group, which is given in red; mass movement imprints (including mass movement following fluvial erosion), both aggradational and denudational, are in brown; landscapes modified by weathering (including karst) in orange; fluvial in green and glaciofluvial in olive green. Marine and lacustrine (including shore processes) are given in turquoise; glacial in violet and periglacial in pink; aeolian is yellow; biogenic origin is light brown; and, finally anthropogenic origin of landforms is given in black.

The colours for various processes are chosen from several different legend systems. Some colours, such as for mass movement, fluvial, aeolian and anthropogenic, are found in several other systems, others are less commonly used; for example red for endogenic, which follows the Hungarian legend (Gilewska, 1967) and pink for periglacial that follows the legend by Nicod (1988). Owing to the fact that “weathering” in the new legend encompasses weathering in general (including saprolite), orange is chosen for this to avoid confusion with traditional colours for karst phenomena in calcareous rock. The turquoise colour for marine and lacustrine is also an addition to the new system.



The colours are chosen so that they are easy to distinguish from each other and therefore colour combinations can be recognised in the map. For example, a combination of peat and clay symbols can be used to indicate a thin cover of peat (<0.5 m) over clay. A special case is the situation where diamicts with wave-washed surfaces in areas of isostatic uplift can be presented by a combination of violet and turquoise for the different residual grain sizes to indicate both the glacial origin of the sediments and the reworking and washing-out by wave activity.

In most cases, aggradational and degradational forms created by the same process are given in the same colour. There are exceptions to this: for example, it can be difficult to decide if a slope is the result of fluvial erosion or mass movement, and if space is too limited to indicate a combination of the two, the result is given as mass movement.

In nature the outlines of some landforms are diffuse and whether to make gradual transitions without delimitation of landforms on the map was considered. This presented problems in relation to GIS applications and in most cases it is, therefore, preferred to indicate outlines, which also improves the general overview; yet, a gradual change can still be expressed by gradations in the hatching of sediment grain size and by gradual colour transitions.

### 3. The GIS version

Maps produced according to this new system can easily be digitized, analyzed and reproduced in GIS. [Batten \(2001\)](#) emphasizes the importance of limiting the subjectivity of digital transformation by keeping the raw data intact and, thus, providing an opportunity for re-interpretation and exploration of many facets of the landscape. According to [Vožnilek \(2000\)](#), the GIS database should contain four types of geographical data: (1) vector data for representing features; (2) raster data for images; (3) triangulated irregular networks (TINs) for surfaces and (4) addresses and locators for defining geographical positions.

In a GIS database, there are two ways in which the data can be structured: as layers or as objects. The layered approach is the most common and has a long history which is inherited from thematic maps that show different features for an area. In this structure, the data are separated into thematic layers, each presenting one characteristic of the same area. The object approach, which is relatively new, structures the data as objects and groups of objects. Here the data is not separated into layers but grouped into classes and hierarchies of

objects. The advantage of this approach is that it more accurately reflects the real world but it has the disadvantage that there are problems constructing a workable GIS ([Heywood et al., 2002](#)). Depending on the purpose, selected information in the GIS map can be picked out and processed for colour presentations in thematic maps, which cover specific types of data, e.g. morphogenetic or natural hazard maps. However, when it comes to reproduction of readable geomorphological maps that cover the whole scientific aspect of geomorphology, the GIS software of today has limitations in the graphics layout. The reason is that the graphics is mainly based on use of covering colours, even though a variety of lines and symbols also can be used. Software, such as ESRI Maplex ([www.esri.com](http://www.esri.com)), offers the possibility to design personal covering patterns but further developments are needed before it becomes easy to present combinations of data sets such as, for example, genesis and lithology combined into one coloured pattern.

The GIS version presented in this paper is developed in an ESRI ArcGIS environment ([www.esri.com](http://www.esri.com)) because this system is widely used and allows advanced data handling. The vector data in the GIS map are in accordance with the polygons representing the landform elements used in the field-based geomorphological map, however, some adaptations are needed. The symbols or lines that represent geomorphological processes in the map have to be converted to areas. Areas then contain the process information and relate to some landforms and processes which are presented by symbols in the original map, e.g. small gullies might be transferred to become polygon-data. Other symbols might be digitized as point data or can be excluded. Hydrographical and infrastructural information is also digitized as vectors that form polygons, lines and points. Another adaptation is that distinct boundaries between the landform elements are always drawn. Each polygon, line or point is then linked to data tables that present additional data on the specific phenomena.

Since the original map in the new mapping system separates information on morphometry and morphography, lithology, genesis and processes and hydrography the conversion into the GIS database is easily made and in the GIS map the data is grouped into separate data themes for morphology, lithified and non-lithified rock, genesis and processes and hydrography. The transformation into the GIS thus involves a minimum of change as compared to the field-based mapping system. In addition to the themes inherited from the field-based map extra themes are added for bedrock/structure, infrastructure and a Digital Elevation Model (DEM),

which is included as digitized contour lines or as detailed raster data. The DEM enables easy Triangular Irregular Network (TIN) constructions, which present a good overview of the land surface; yet for detailed representation and analysis of the topography they often provide too generalised approximations and other surface interpolations such as spline or kriging will be used. In this context, it is important to keep in mind that different types of landscape require different interpolations (Lipcsey, 2000).

In addition to the information outlined above the GIS database stores information on sub-surface properties such as stratigraphical sequences and lithological columns. This added information in the database is linked to the geographical sampling positions and appears as sets of tables or pop-up figures on the digital map. To give the user a full overview of landscape data, the original geomorphological map is included as a raster image, and additional raster images

such as orthographic aerial photographs can also be included for analysis, correlations and orientation purposes.

#### 4. Examples

The new legend is tested in two areas with very different relief and genesis. One, the Upper Gamperdona valley, is in the European Alps and has a high altitude, high relief, alpine setting and was repeatedly glaciated during the Pleistocene. Since the last deglaciation it has been strongly modified by a variety of degradational processes, mainly mass-related slope processes, and it is therefore representative of large parts of the European Alps. The other, the Bonäs area, is a formerly glaciated region of moderate altitude and relief in boreal central Sweden, northwest of Mora (Fig. 2C). This area is chosen because of its landform diversity that includes aeolian, fluvial, glaciofluvial and lacustrine landforms

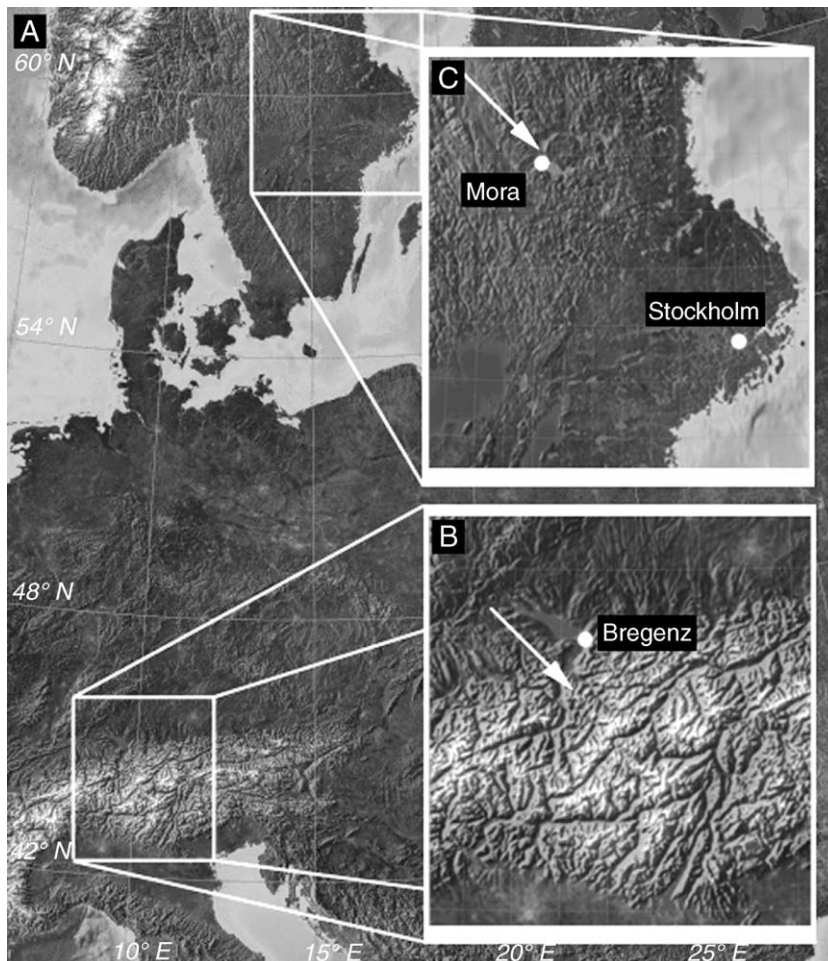


Fig. 2. Location of the Gamperdona (B) and Bonäs (C) field areas.



and also because it includes areas originally formed below the water level but which were later influenced by isostatic uplift.

#### 4.1. Upper Gamperdona valley

The 1:10,000 geomorphological map in Fig. 3 represents an area of 1.6 by 2 km between approximately 1240 m and 2150 m asl across the border between the Principality of Liechtenstein and western Austria in the western Rätikon Mountains. The contour line interval on the map is 20 m. To facilitate the reading, the map is subdivided into squares A1–E4 with A1 in the SW and E4 in the NE corner. A small summer village, Nenzinger Himmel, in square E2/3 is located at approximately 47°05'N, 9°39'E. Gamperdona is a tributary valley of the river Ill, which drains into the Rhine near the city of Feldkirch.

In the investigated area the landforms reflect a complex geologic structure and diverse lithology (see Table 2), with imprints of former glacial processes as well as postglacial modifications particularly by different slope processes. For further details on the geological situation in Gamperdona valley is referred to Richter (1958), Reithofer et al. (1964), Heissel et al. (1965), Kobel (1969), Loacker (1971), Allemann (1953, 1985), Hüchel and Jacobshagen (1961), Helmcke (1974), Seijmonsbergen (1992) and Oberhauser (1998). In the following, a geomorphological explanation will be presented.

##### 4.1.1. Geomorphological explanation

The Gamperdona Valley was glaciated several times during the Pleistocene (Hantke, 1980; Keller, 1988; Seijmonsbergen, 1992; De Graaff and Seijmonsbergen, 1993). The Gamperdona glacier locally reached above

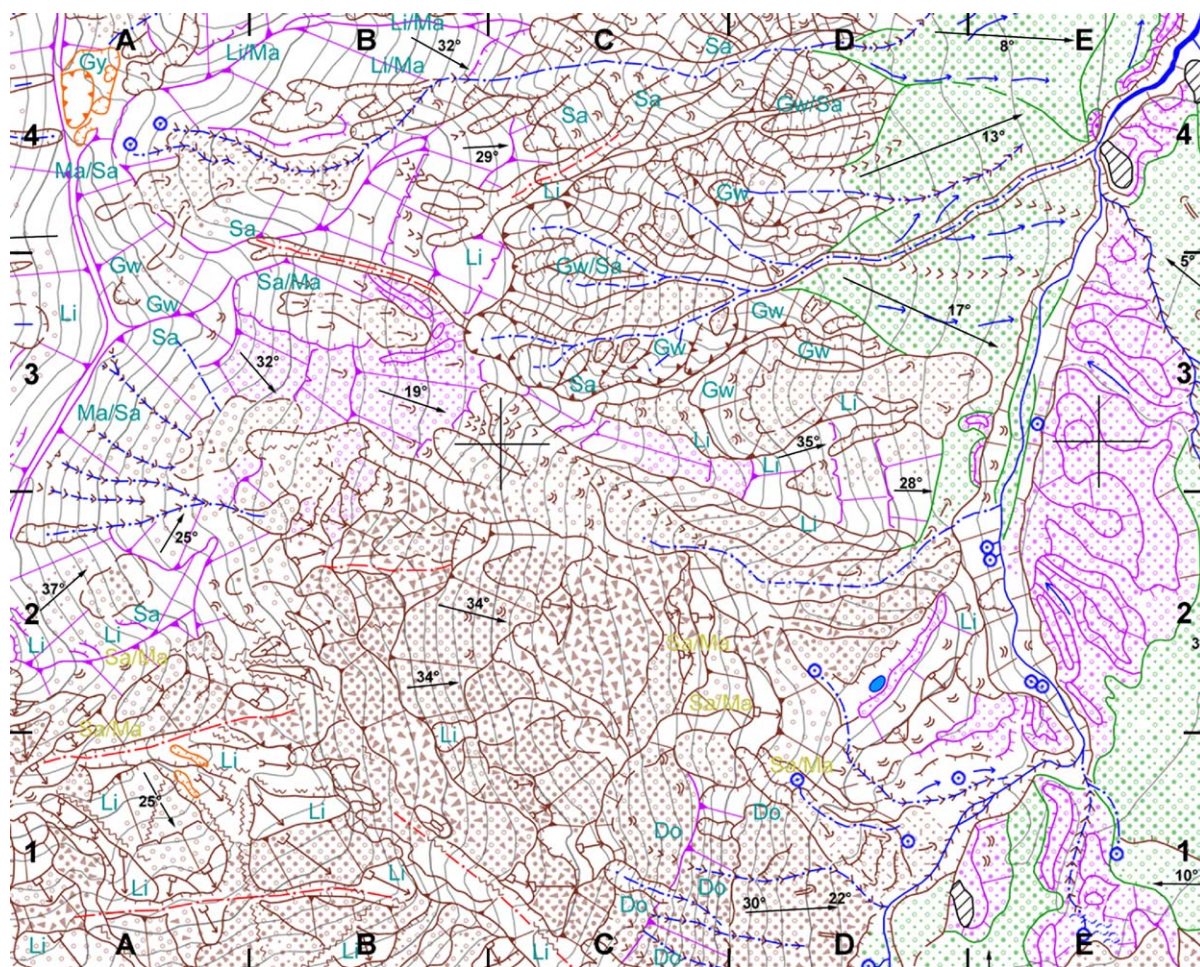


Fig. 3. The Alpine Gamperdona area with grid A1 (SW) to E4 (NE) for orientation. The map needs to be read with the aid of Fig. 1 and the text on this area. North is to the top. Each square in the map, e.g. A1, is 400 by 400 m.

Table 2

Summary of the chrono- and lithostratigraphic units in the Upper Gamperdona area after Oberhauser (1998) and Alleman (1985)

Period	Age	Nappe	Formation	Dominant lithology
Jurassic to Cretaceous	Dogger to Turonian	Arosa Nappe	Arosa Zone Formation	Marl (Ma) Sandstone (Sa) Silicate (Si)
Triassic	Norian Carnian	Lecthal Nappe	Hauptdolomite Formation	Dolomite (Do)
			Raibler Formation	Gypsum (Gy) Rauhwacke (Ra) Breccias (Br)
				Sandstone (Sa)
	Ladinian		Arlberg Schichten Formation	Limestone (Li)
	Anisian		Partnach Schichten Formation	Limestone (Li) Marl (Ma)
			Muschelkalk Formation	Limestone (Li)

1900 m during the Würm glaciation. A glacially modified water divide and adjacent slopes still stand out clearly in the western part of the area (A3/4). During deglaciation, the main glacier was fed by a series of smaller valley- and cirque glaciers, some of which developed from the areas represented in squares A/B3/4. In one area, a cirque moraine ridge has been preserved. During wasting of the valley glacier till became deposited in the central part of the valley where several Late-Glacial moraine ridges (purple in E1/2/3/4) are preserved. The sediments in the ridges are composed of angular, hand-sized fragments in a sandy matrix and the material resembles a typical ablation till.

The majority of the small landforms in the Upper Gamperdona Valley result from mass wasting processes. In particular, the slopes in A/B1 have undergone intense deep reaching slope failures. In a few cases, it was found that geological faults (indicated by red line symbols) act as detachment planes for these landsliding features (squares A/B1). Furthermore, the deep-seated slope deformation in this area is accentuated by surface rock disintegration with rock and block falls (e.g. C1/2).

In square A4, where the rock is of the Raibler Formation, gypsum karst has created sinkholes in the glacially modified water divide area and the adjacent eastern slope. Two associated karst springs occur slightly to the southeast. After the deglaciation, fluvial unconsolidated sediments (green) were deposited in part of the Upper Gamperdona valley (e.g. D/E3/4) and cover the glacial deposits in many parts. In addition, debris flows overprint a major part of these landforms and have produced a diverse sediment composition in many areas (Seijmonsbergen, 1992).

#### 4.1.2. Discussion

One of the difficulties with the portrayal of this area is that both the Arosa Zone Formation and the Raibler Formations have quickly alternating rock compositions

so that even at this scale individual rock types cannot be indicated in the map. In such cases the dominant type was chosen or, alternatively, two letter codes separated by a slash are used. In some cases, it has also been difficult to find space for the codes within the area that represents the exposed rock type and, in such cases, the code needs to extend into a neighbouring regolith. Finally, a formation can span different geologic ages; in cases where the represented time spans are of almost equal duration the age–colour of the younger period is chosen.

#### 4.2. The Bonäs area

Fig. 4 shows a section of a 1:10,000 scale geomorphological map covering 1.6 by 2 km of a well-drained sandy area a few kilometres northwest of Mora (61°00'N, 14°32'E) in central Sweden (Fig. 2C). The area is situated between approximately 160 m and 190 m asl and contour lines in the map are at 5 m intervals.

##### 4.2.1. Geomorphological explanation

As other parts of Sweden, the Bonäs area was covered by the Fennoscandian ice sheet during the Weichselian. When the area became ice-free it was situated just beneath the highest shoreline of the Baltic sea, today situated at about 220 m asl due to the effect of isostatic rebound. As the retreating ice front became stagnant in the area, a glaciofluvial stream entering the sea just southwest of Bonäs caused the formation of a ca. 10 km × 20 km large glaciofluvial delta that covered the previously deposited sandy tills. The deltaic sediments in the area are graded from silty fine sand in the east (where Bonäs is situated) towards sand, gravel and cobbles in the westernmost parts. When the ice disappeared from the depression of Orsasjön (the lake in the NE part of Fig. 4) some dead ice bodies left



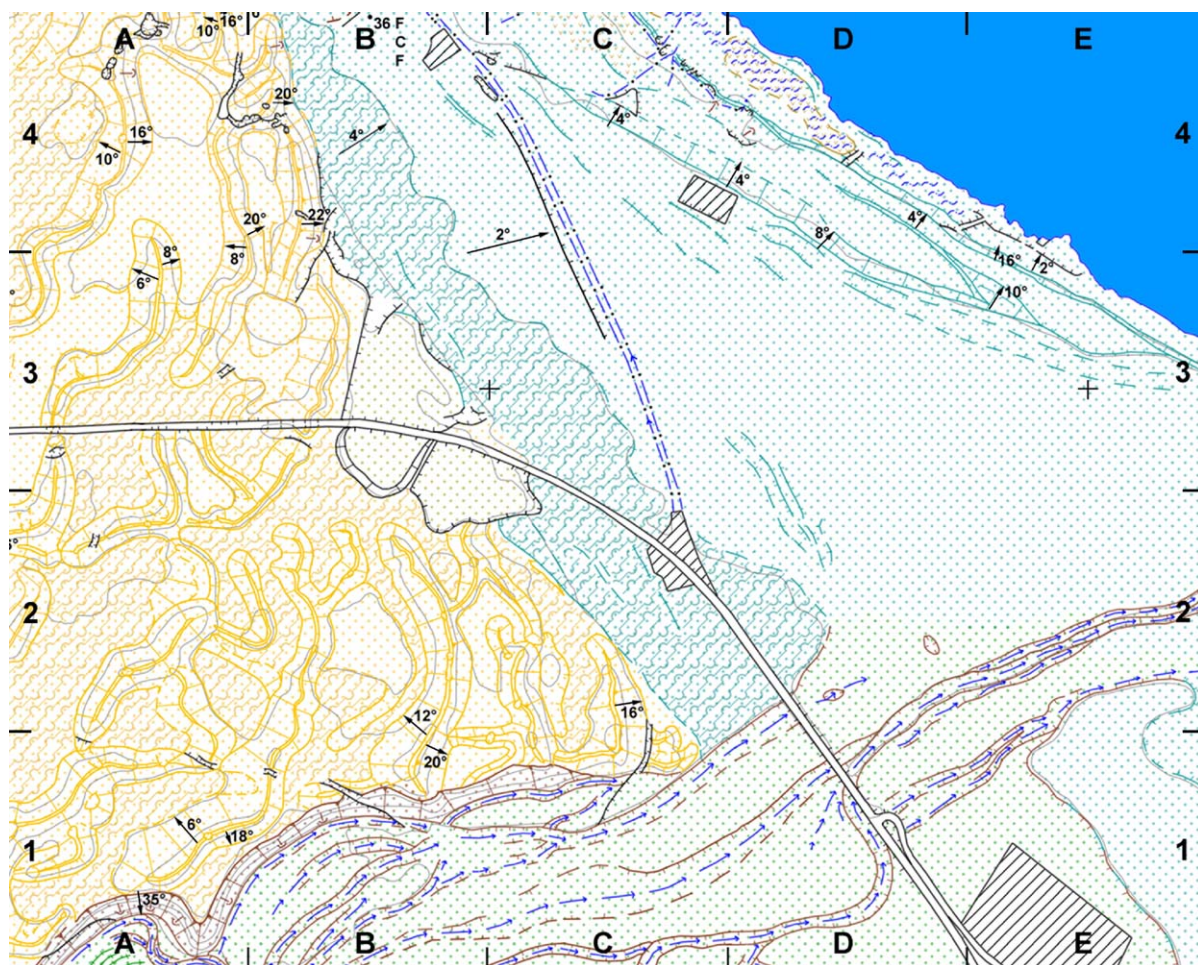


Fig. 4. The mid-Swedish Bonäs area with grid A1 (SW) to E4 (NE) for orientation. The map needs to be read with the aid of Fig. 1 and the text on this area.. North is to the top. Each square in the map, e.g. A1, is 400 by 400 m. Part of the Lake Orsasjön is visible in the NE corner of the map and old meanders of the Österdalälven can be seen in its lower part.

depressions in the glaciofluvial sediments (Lundqvist, 1951).

As the relative water level lowered further due to isostatic uplift, the exposed sandy delta surface experienced a period of aeolian activity causing dunes to be formed. A temporary threshold to the east caused a period of shoreline erosion at ca. 180 m asl preventing further dune movement towards the east and soon after presence of vegetation prevented further large-scale aeolian activity. When the threshold was eroded, the water level of lake Orsasjön gradually fell to the present level at ca 162 m asl (Nordell, 1984). During this time, the river Österdalälven incised itself into the deltaic glaciofluvial sediments and created floodplains, meanders and pointbar systems at different levels.

The western part shown in the map in Fig. 4 is dominated by an aeolian landscape with transverse dunes formed on the surface of the glaciofluvial delta.

The intricate morphological dune pattern is expressed by using simple combinations of crests, slopes and depressions in the colour of the aeolian genesis (yellow) (cf. A/B1/2/3/4 in the map). The areas between most dunes in this section are covered with aeolian sand and form undulating surfaces as expressed by the “wavy” hatching in yellow. In places the anthropogenic influence includes small pits and road cuttings. The three sand pits in B3 have been dug down into the underlying glaciofluvial material (indicated by using a black colour for describing the genesis of the forms (anthropogenic) and using dots in olive green to describe the glaciofluvial sands). To the east, the dune area is bordered by a sharp transition into an area with sandy lake sediments represented in turquoise. Just adjacent to the dune field the undulating lake sediment area stretches from C/D2 to B4. On its east side, this area is bordered by a weakly defined erosive shoreline along

the transition into a flat, sandy lake sediment surface that slopes gently towards the east. At places (for example at D2) some irregularities such as beach bars and depressions are visible. At E4, close to the present lake Orsašjön, is a periodically wet area behind the present berm crest. As indicated by the light brown V-symbols, a peat layer has developed in parts of this area and peat can also be found at C4. The mixing of peat and lake sediment symbols in these areas indicates presence of a thin peat cover (<0.5 m) over the sandy sediments below.

The southern part of the map section (from A1 towards E2) is dominated by fluvial incisions. Towards the dune area in the northwest (A/B/C1) traces of former meander bends can be seen as curved erosional slopes 15 to 20 m high that have been affected by younger soil creep as indicated by the symbols for slow mass movement. Beneath the slopes there is a level surface dominated by sandy fluvial sediment with a series of incised fossil channels. In A1 in the westernmost part of this area, a point-bar system is indicated as a series of small curved ridges indicated in green.

In B4 in the northern part of the map, a drilled core gives information about the stratigraphy. The letter code 36 F C F indicates a 36-m-thick sequence described in the geotechnical drilling report ([Geological Survey of Sweden. Hydrogeological database, Id 144200060, well no. 1](#)) as friction (interpreted as sand in the map), cohesion (silt and clay) and friction (sandy/gravelly till) materials. The depths of the transitions between these fractions are not known and since the section has not reached the bedrock the letters are not underlined.

Except for the abandoned channels in the southern part of the map section the only stream courses are the parallel, intermittent streams situated in C3/4. As indicated by the combination of black dots and blue lines, these water courses are man-made.

#### 4.2.2. Discussion

A problem with the mapping of this area is to present the importance of the glaciofluvial delta in relation to the present landforms. Yet, indications of glaciofluvial materials are shown in the colour of the sand in the quarries and by the “known stratigraphy”, which can be interpreted as sandy lake sediments on top followed by a section of distal deltaic sediments before sandy/gravelly till is reached in the bottom of the cored sequence.

#### 4.3. The Bonäs GIS version

As indicated earlier, the GIS version illustrated in [Fig. 5](#) is based on the field-based geomorphological map

and most parameters were transferred into the GIS. To fully preserve the landform elements and the scientific information of this map in the GIS environment specific data tables as well as additional information such as drill hole data and information from the geological map was included.

In the GIS version, the analogue geomorphological map is presented as a background image. In [Fig. 5\(a\)](#), this image can be seen combined with a simple TIN-based surface model that was constructed from digitized 5-m contour lines which form the basis for the DEM in this map. This digital data layer contains most direct and indirect information on morphology.

Even though the bedrock is not always exposed at the surface it can still affect the surface geomorphology, for example as a source for surface deposits or it can be reflected in the landforms. Therefore, the GIS version of the new geomorphological system includes spatial data on the underlying rock type and its structure including dip and dip direction ([Kresten et al., 1991](#)) ([Fig. 5\(b\)](#)). Similarly, data on unconsolidated materials is presented in the “lithology” data table linked to the theme “Units”.

The layer “Units” ([Fig. 5\(c\)](#)) represents the key data theme in the GIS version of the map. This data theme is constructed of polygons that correlate to the landscape elements used in the field based geomorphological map. Each polygon is linked to tabular data that describes the coded feature characteristics of morphology, lithology, genesis and processes. An example of such an attribute table can also be seen in [Fig. 5](#). The “Morphography” data describe the form of the landscape elements. Here the information is classified into different form classes (slope, even surface, depression, etc.) each represented by a code. Surface geometry can be analyzed from the DEM. Information about surface materials is stored in a “Lithology” part of the data table and includes information on the surface (<0.5 m) lithology as based on grain size distributions transferred to a system of codes based on SGF 81 ([Karlsson and Hansbo, 1992](#)) with some additional codes for hard rock, organic materials and tills. The coded system allows unique combinations of grain sizes in the same way as the analogue map. The “Genesis” data table describes the main process that has formed the landscape element and uses a simple numerical code representing the same genesis used in the field based geomorphological map. The “Process” data table describes processes that caused surficial modification of landform elements. If several processes act on the same polygon the GIS database can contain several



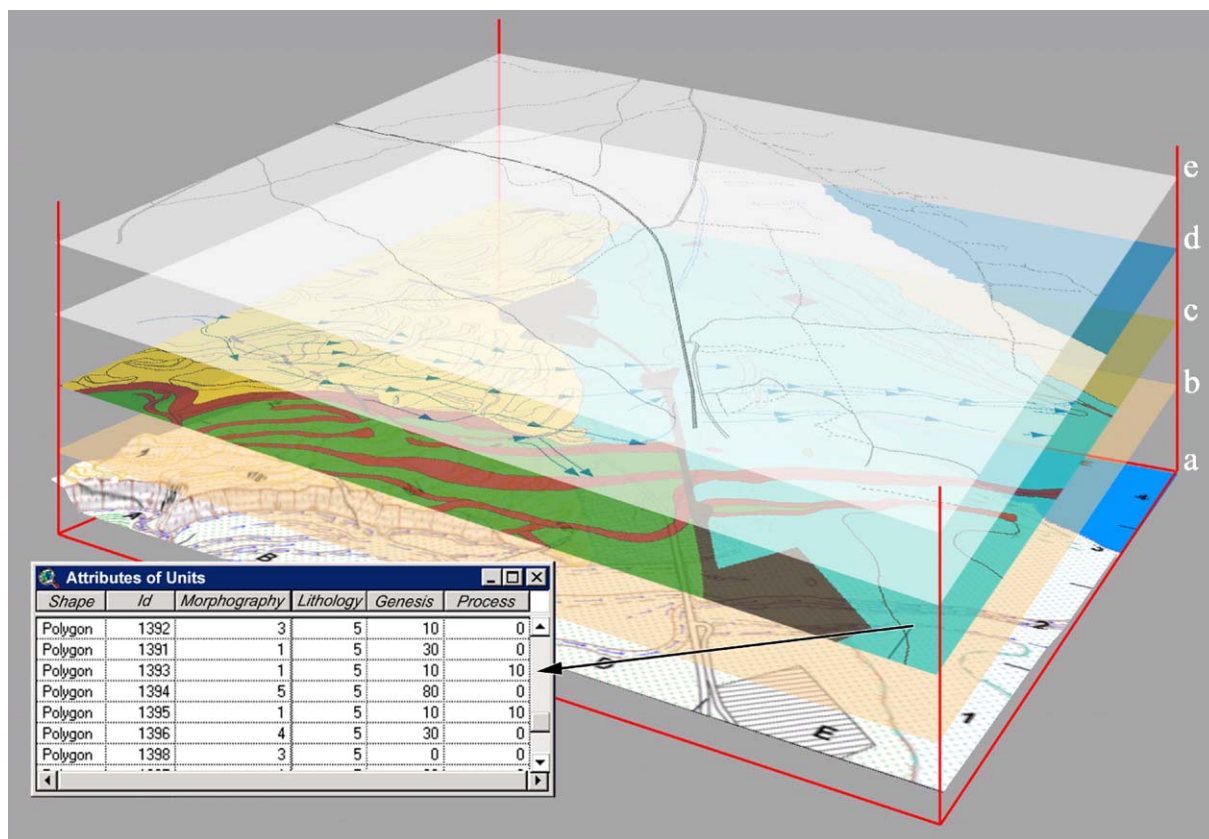


Fig. 5. GIS version of the Bonäs map. For further information, see the text on the GIS version of this area.

tables describing the different processes acting on the landscape element (in Fig. 5 there is however only one).

The hydrography (Fig. 5(d)) is represented by polygon-, line- and point-data. These data describe different types of water surfaces, stream types and other hydrological features such as springs and sinkholes. It also includes anthropogenic features such as dams.

Infrastructure is shown as a separate layer of information and describes routes for transportation including railways as well as tourist tracks.

In the GIS, stratigraphical columns are included as additional information on drillings and sampling sites. In the field-based geomorphological map these data are presented as “known stratigraphy” but in the GIS more detailed descriptions of the local lithology and stratigraphy can be linked to the map as “pop-up profiles” and/or data tables connected to points marking the sample locations.

#### 4.3.1. Discussion

The GIS version of the map offers numerous possibilities of presentation and combination of data

but there are still limitations in the graphic layout, which needs to be developed further. At present, the graphics work well for covering colours but there are limitations with regard to presentation of the lines and symbols that are needed with this new geomorphological mapping system. As a consequence, it is not yet possible to produce GIS maps that cover the whole scientific aspect of the geomorphology in an easily readable way; however, thematic maps which present a specific selection or theme of data can easily be made.

## 5. Conclusions

The symbol-based geomorphological map legend proposed in this paper contains more scientific information than has previously been possible to include with a single large-scale geomorphological map. This is because the geomorphological information is presented in more basic units than previously and because the combination of letters, symbols and colours is used more fully than hitherto. With this legend it has become possible to include morphology/morphometry, hydrography, lithology, structure, age

and process/genesis as mutually independent factors and, as a consequence, all the parameters that make up a complete large-scale (scale 1:10,000) geomorphological map are included in the same map for the first time. At the same time, the map has kept its readability. It follows that with the use of this legend the choice is not to decide which of the above characteristics and features are to be included, but to decide which of them has the highest priority. We have chosen to give the priority (and thus the colours in the map) to genesis/processes because this part is the explanatory and interpretative content of the map which requires a trained geomorphologist, and it makes up the scientific essence of the work and adds the scientific conclusion and perspective that is based upon and added to the descriptive parameters. In relation to this, it is also a strength of the legend that it is open to combinations of symbols and colours, so that, for example, combinations of grain sizes are expressed directly in the map and, most importantly, the polygenetic origins of specific landforms can be indicated by combinations of colours.

The new system is successfully applied in two highly contrasting areas, one in a glaciofluvial delta that was later modified by wind and water in central Sweden and the other in a high Alpine setting on the border between Austria and Liechtenstein.

As demonstrated, the system can also be digitized, labelled with attributes and visualised within a GIS environment and no doubt this version will improve with future graphical and technical developments. One of the most urgent needs at this stage is to develop the GIS software layout so that it presents data combinations as in the new field-based map of this paper. It is likely that future developments of GIS techniques will open up even more promising possibilities for analysis of the original field-based scientific information that was traditionally presented in geomorphological maps.

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