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Digital geomorphological landslide hazard mapping of the Alpago area, Italy

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ABSTRACT

Large-scale geomorphological maps of mountainous areas are traditionally made using complex symbol-based legends. They can serve as excellent "geomorphological databases", from which an experienced geomorphologist can extract a large amount of information for hazard mapping. However, these maps are not designed to be used in combination with a GIS, due to their complex cartographic structure. In this paper, two methods are presented for digital geomorphological mapping at large scales using GIS and digital cartographic software. The methods are applied to an area with a complex geomorphological setting in the Borsoia catchment, located in the Alpago region, near Belluno in the Italian Alps. The GIS database set-up is presented with an overview of the data layers that have been generated and how they are interrelated. The GIS database was also converted into a paper map, using a digital cartographic package. The resulting large-scale geomorphological hazard map is attached. The resulting GIS database and cartographic product can be used to analyse the hazard type and hazard degree for each polygon, and to find the reasons for the hazard classification.

INTRODUCTION

Slope instability phenomena are related to a large variety of factors, involving both the physical environment as well as human intervention. Assessment of landslide hazard therefore requires knowledge about a large series of variables, ranging from geological structure to land use.

The most complex, and the most subjective, type of information for hazard assessment in mountainous areas is a geomorphological map. Geomorphological maps play an important role in many of the analytical landslide hazard techniques that can be applied, such as heuristic, statistical or deterministic methods [Soeters & Van Westen, 1996].

Many different geomorphological mapping systems have been proposed either for universal application or for specific areas, usually consisting of mountainous terrain. Overviews of conventional geomorphological mapping systems at medium and large scales are presented by Demek & Embleton [1978] and Van Zuidam [1986]. In common practice many different systems are being used. The conclusion can be drawn that there is no universally accepted system that is adequate for mapping in different environments.

Comparisons of different systems have been presented by Gilewska [1976], Klimazewski [1982], Van Dorsser & Salomé [1983], and Salomé & Van Dorsser [1982,1985]. In contrast to the systems applied on regional scales, which almost all involve outlining homogeneous units, the conventional geomorphological mapping systems for scales of 1:25,000 and larger are based on individual representation of features such as morphometry, morphography, drainage, genesis, chronology, materials, or processes with different symbols, lines, colors, and hatchings. The various mapping systems differ in the importance assigned to each feature and in the method of representation. A common element in all of them, however, is that different types of geomorphological data are combined on one map sheet.

Large scale geomorphological maps based on such detailed legends can serve as excellent "geomorphological databases", from which an experienced geomorphologist can extract a large amount of information for applied mapping, such as geotechnical maps or hazard maps [Seijmonsbergen, 1992]. However, such databases should be consulted only through the eyes and with the expert knowledge of the geomorphologist; they cannot be formalised in decision rules applicable in a GIS. Traditional symbol-based geomorphological mapping systems are unsuitable for use in a GIS for the following reasons:

1. A GIS requires information for each pixel in a raster structure, or for each polygon in a vector structure. Information for all parts of the terrain is required to avoid problems in analysis. Many of the conventional geomorphological systems do not display informa-

tion for the whole terrain, but only for geomorphologically "interesting" parts. Other systems apply full coverage, but are based on lines, and the area between the lines is not coded, but is instead interpreted by the geomorphologist based on the information from surrounding lines and symbols. Whenever coloring or hatching of areas is used, it applies only to one feature, such as morphometry (slope classes), morphogenesis or chronology. Thus, in conclusion: most maps are not uniform polygon maps.

2. Most conventional systems store different types of information on a single sheet, using different signatures such as symbols, lines, letters, numbers, colors, and hatching. In a GIS, each pixel or polygon in one data layer can contain only one type of information.

These problems should be avoided in a geomorphological mapping system developed for medium- or large-scale analysis with a GIS. Although it is possible to reinterpret these traditional maps, and convert them into separate polygon and line maps, this method is considered less effective. It is better to design a geomorphological mapping system for photo-interpretation and fieldwork, which is tailor-made for the use of GIS.

In this paper, two of such approaches are presented:

Unique condition polygon mapping, in which the area is divided into the smallest mappable units, represented as polygons. These are normally slope facets, or individual landforms. Slope facets are the smallest subdivision of the landscape, with homogeneous morphometric characteristics. They can be derived semi- or completely automatically from a Digital Elevation Model [Carrara *et al*, 1991]. Individual landforms, which are genetically homogeneous, can also be used as unique condition polygons. They are derived from image interpretation and fieldwork by a geomorphologist. For each of these polygons, a set of parameters is described using checklists during the photo-interpretation and the fieldwork. These parameters refer to genesis, chronology, morphometry, morphography, drainage, materials types, processes, and hazard classification. The result in GIS is a single polygon map, in which each polygon receives a unique identifier, and which is linked to an attribute database.

- Another approach is to generate separate maps for the individual parameters such as genesis, chronology, morphometry, morphography, drainage, materials types, processes, and hazard classification. These maps can be either point, line or polygon maps. The use of complex legend structures can be avoided by generating different layers, each with a rather simple legend that will provide the complete information when they are consulted simultaneously in a GIS.

STUDY AREA

The two methods for GIS-based geomorphological mapping have been tested in a small catchment in a mountainous area, located in the Alpago basin, situated to the East of the city of Belluno in north-eastern Italy (see Figure 1).

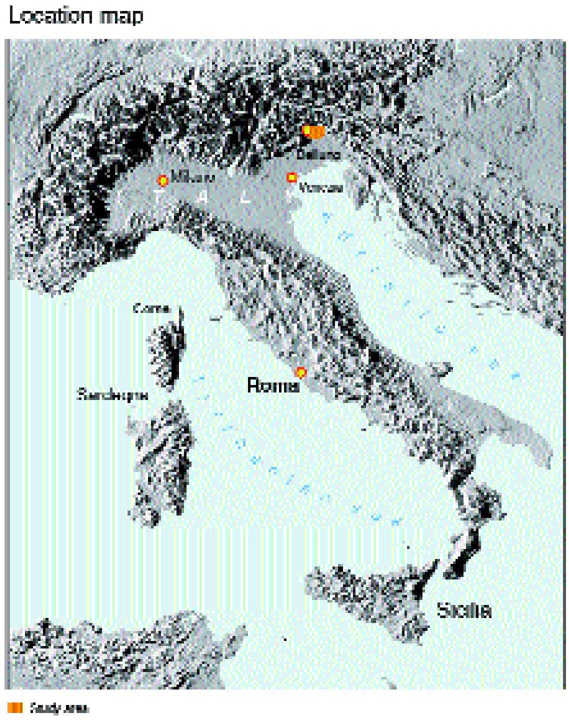

FIGURE 1 Location of the study area.

A general geomorphological map of the study area is shown in Figure 2. This small area of 20.8 km^2 is located East of Chies d'Alpago and consists of two catchments: the Borsoia catchment to the South with the villages Palughetto, Borsoi, Lavina, Tambre and Tambruz, and the Boccolana catchment in the north. The NE border of the area is formed by a steep mountain ridge that rises up to more than 2000 m, while the SE part of the area has a more gentle, undulating morphology. Gentler slopes characterize the central zone of this morphostructural basin, formed within a large syncline with a NW-SE trending axis.

The oldest rocks outcrop in the eastern part of the study area, above 1100 m. They belong to the Jurassic-Cretaceous calcareous Formation of *Monte Cavallo*, and consist of bioclastic limestones with stratification ranging from beds of 1-2 m in thickness to thinner beds containing marly levels up to 30-40 cm thick [Mantovani *et al*, 1976]. The stratigraphic sequence continues with marly and marly-limestone belonging to the Cretaceous-Paleocene Scaglia Formations (*Scaglia Grigia* Formation and *Scaglia Rossa* Formation). The Middle Eocene Flysch outcrops in most of the area at altitudes lower than 1100 m.

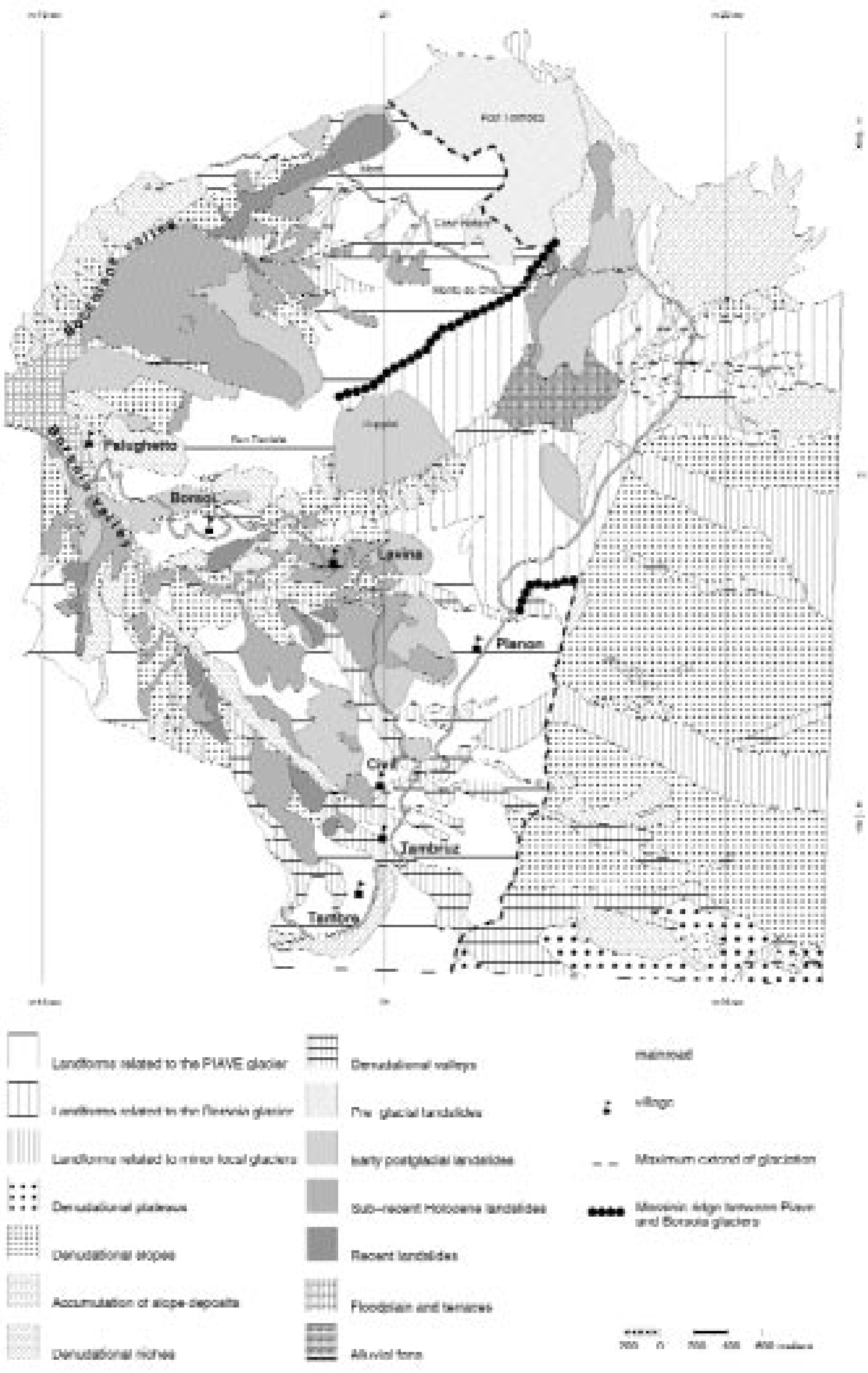

FIGURE 2 Overview of the geomorphology of the study area.

Slope deposits, derived from old landslides and scree material, are found extensively as well. In the NE part of the study area, the scree material, derived from limestone, is partly cemented.

GEOMORPHOLOGICAL EVOLUTION OF THE STUDY AREA

PRE-GLACIAL LANDFORMS

Some pre-glacial landforms can still be found in the study area, all above 1100 m. In the area surrounding Pian Formosa (see Figure 2), the terrain consists of a number of flat areas, separated by steeper slopes composed of cemented scree material. This area was interpreted as a large landslide that occurred on a former scree slope, which was partially cemented. The toe of the landslide is included in the lateral morainic ridges of the main Piave glacier. Based on this evidence, it was concluded that the landslide is of pre-glacial age.

Two other areas, near Case Rofare and Monte de Chies, have geomorphological evidence that they were created by landslides before the last glaciation. They both have a niche-like form, representing the erosional part of a landslide, but lack the depositional part. In both areas, glacial and fluvioglacial landforms (morainic ridges and fluvioglacial fans) are found within the niches. This leads to the conclusion that these landforms represent pre-glacial landslide areas that were modified during the last glaciation.

The Quaternary cover is very extensive and locally very thick, and it covers about 75 percent of the area. Ablation moraine deposits of the Würm and Early Holocene age, which are partly of local provenance and partly derived from outside the basin, are found at an altitude around 1100 m, representing the maximum extent of the main Piave valley glacier, which came from the North during the last glaciation. Large areas below 1100 m are covered by subglacial till deposits, and fluvioglacial deposits. The areas above 1100 m were largely unglaciated, or occupied by small local glaciers.

LANDFORMS THAT ORIGINATED DURING THE MAXIMUM GLACIATION PHASE

During the maximum extension of the last ice age, the main Piave glacier covered nearly the entire study area up to an elevation of approximately 1100 m, as evidenced by a series of ice-marginal complexes (see Figure 3A). The morainic materials show ice-pushed structures, as well as collapse structures. The smaller and local Borsoia glacier did not have the opportunity to advance very far against the large Piave glacier. A contact zone of the two glaciers is found in the area NE of Pianon (see Figures 2 and

3B). Some other, even smaller, local glaciers also existed. A large area between Tambre and Pianon was mapped as a series of levels with a thick deposit of subglacial till.

LANDFORMS THAT ORIGINATED DURING THE EARLY DEGLACIATION PHASE

After the maximum glaciation phase the regional Piave glacier, with its source area located further to the north, began to retreat. This allowed the local Borsoia glacier, with its source area directly East of the study area, to advance (see Figure 3B). A large medial moraine was formed in the area between Duppiai and Monte de Chies. Some fluvioglacial fans were also formed during that period, partly covering the sub-glacial till material. Due to the geotechnical characteristics of the sub-glacial till, this material is very vulnerable to landslides. Large retrogressive landslides initiated in the sub-glacial till level. Some of these landslides are located East of Pianon, near Lavina and near Civit (see Figure 2).

LANDFORMS THAT ORIGINATED DURING THE LATE DEGLACIATION PHASE

At the end of the last glaciation, the main Piave glacier retreated from the area, leaving a series of ice-marginal levels in the area surrounding San Daniele (see Figure 2). The Borsoia glacier still remained (see Figure 3C), building up a series of morainic ridges in the area East of Duppiai. Large landslides occurred, due to glacial oversteepening, especially in the area NW of San Daniele, where a large dipslope failure occurred, and in the Duppiai area, where a large rotational failure took place, with only small overall displacement. The morainic ridges from the eastern side of the landslide can still be traced on the landslide itself, although at a lower elevation. In the vicinity of Tambre and East of Monte de Chies a series of flowslides in the sub-glacial till level took place.

LANDFORMS THAT ORIGINATED IN THE LATE HOLOCENE

During the Holocene, mass movement activity remained high in the area. Older landslides were reactivated and many new ones occurred, due to the following unfavorable conditions: stream undercutting, dipslopes in Flysch rocks, loading of rockfall on top of fine-grained materials, and contact between permeable and impermeable materials. Deforestation is also assumed to have contributed substantially to the occurrence of landslides in historic times. During the last decades, many of the agricultural areas have been abandoned, and there has been a shift from agriculture to tourism, leading to a renewed increase of vegetation in the area. A large erosion control program was also executed in the last decades, during which many check-dams were built in the main streams. In several places these check-dams have now already been destroyed by landslides, which tend to close the valleys, and by stream undercutting.

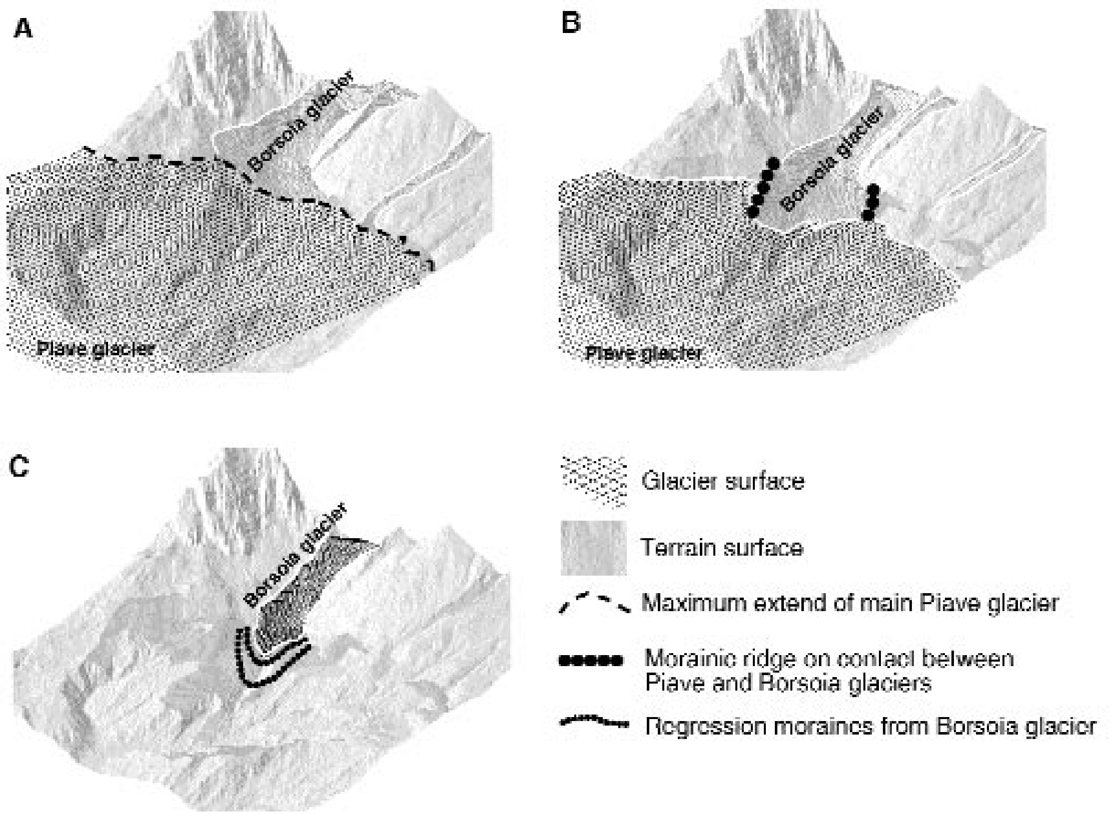

FIGURE 3 Three-dimensional views illustrating the deglaciation history of the study area. A: Situation during the peak of the last glaciation; B. Situation during early deglaciation; C: Situation during late deglaciation.

GEOMORPHOLOGICAL MAPPING

The area was mapped according to three different geomorphological mapping methods;

- traditional symbol-based geomorphological mapping;
- unique condition polygon mapping;
- geomorphological layer mapping.

First a detailed airphoto-interpretation was performed using four sets of airphotos from 1954 to 1980, with scales ranging from 1:10,000 to 1:30,000. A detailed field check was made and the resulting geomorphological units were drawn on 1:5,000 scale topographical maps.

TRADITIONAL SYMBOL-BASED GEOMORPHOLOGICAL MAPPING

In order to demonstrate the difficulties involved in converting traditional large-scale geomorphological maps to GIS, the area was also mapped in the traditional way, according to the legend system developed by the Alpine Geomorphology Research Group of the University of Amsterdam [De Graaff *et al*, 1987; Seijmonsbergen & Van Westen, 1988; Seijmonsbergen, 1992]. The mapping system was designed for mountainous areas and has successfully been applied in a number of environmental and engineering projects with local authorities in Austria, Switzerland and Liechtenstein. Mapping was done at a scale of 1:5,000 using a traditional symbol- and line-based legend. This manually constructed geomorphological map provides information on the geometry, morphography, hydrography, materials, direction of transport, processes, and genesis of the landforms by using lines, symbols, hatchings, and colors. A fragment of the geomorphological map is shown in Figure 4.

The map shown in Figure 4 contains a high degree of detail, and it could be called a "geomorphological database on paper". The map is intended to be a base map for the geomorphologist, from which he/she can generate derivative maps intended for planners and decision makers, such as a hazard map or a geotechnical map. Although the map itself looks quite complicated, the advantage of this method is that the legend is rather simple. It basically uses different line symbols to demarcate landforms, colors to indicate the genesis of the landform and symbols to indicate small geomorphological features, processes, and materials. By using combinations of these basic elements, complex descriptions of the geomorphological situation can be made. The legend contains four types of information:

- Drainage (in blue)
- Morphography/morphometry: The morphographical and morphometrical lines and symbols are combined to constitute the framework of form and relief.
- Non-lithified material is shown in colored hatching and symbols, with an indication of the direction of deposition (the colors depend on the geomorphological environment in which the materials were deposited)
- Processes/genesis; a distinction is made by means of colors:
- blue is used for hydrography and karst related forms; orange is used to indicate subglacial, ice-marginal erosive and accumulative forms and related materials; brown colors indicate fluvial erosive forms, slope processes and related materials; olive-green is used to indicate ice-marginal fluvial and glacio-fluvial landforms and related materials; black is used to indicate all numerical values as well as man-made features.

The map shown in Figure 4 is not suitable to be entered in a GIS. It would require a complete re-interpretation, which could only be done by the geomorphologist that prepared the original map. Since it is not very effective to do this double interpretation, it would be better to initially design a method for geomorphological field-mapping that would allow one to conserve the same kind of detail as depicted in the map of Figure 4.

UNIQUE CONDITION POLYGON MAPPING

Instead of using complicated line/symbol maps the geomorphological details on a map can also be mapped in a

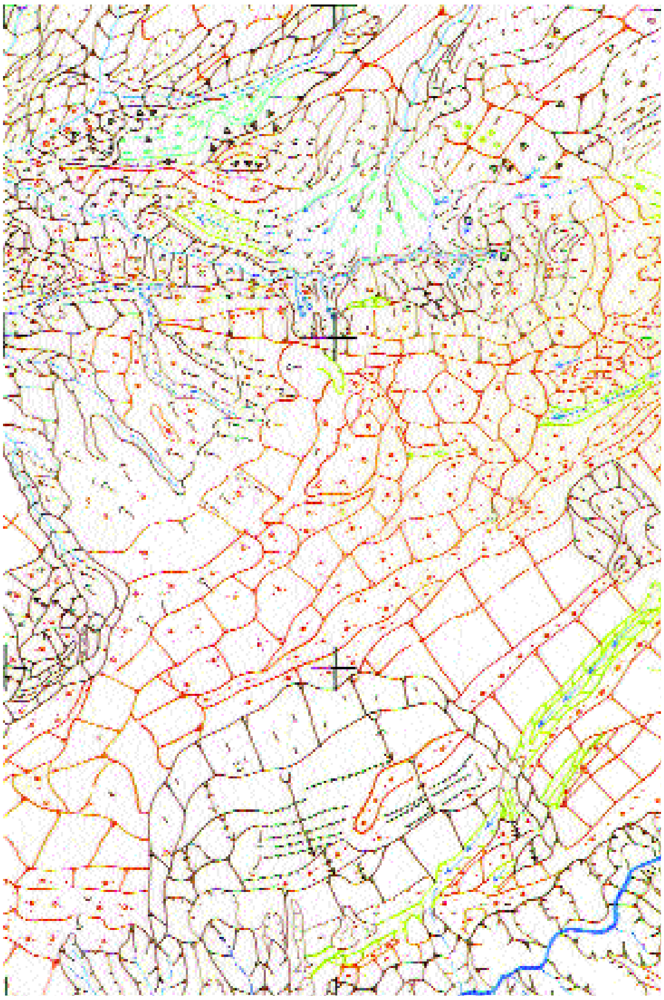

FIGURE 4 Fragment of the geomorphological map of the study area prepared according to a traditional symbol-based legend.

form that is designed to be implemented within a GIS, using unique condition polygons. In this method, the terrain is subdivided on the basis of image interpretation and fieldwork, into a large number of small polygons, which can be considered as homogeneous units in the sense of materials, geology, geomorphology and process type. The size of these units depends on the mapping scale, since homogenous units at a scale of 1:25,000 can often be subdivided into smaller units at a larger scale.

For the Alpago test area, this procedure resulted in 1842 individual polygons. During the mapping phase, each polygon received a unique identifier, and its information was described in a checklist. This checklist contained information on:
- the genesis of the landforms;
- the chronological order of the landforms;
- landform characteristics;
- morphography;
- quaternary materials;
- activity, type and main causes of denudational processes;
- hazard type and degree.

The polygon map was digitized, and the data from the checklist was entered into a database, which was linked to the map. A fragment of the resulting GIS map, for the same area as shown in Figure 4, together with a sample of the database, is shown in Figure 5. The headings in the textbox in Figure 5 are the items described in the database for the Alpago area, and are not exactly the same as the items shown above.

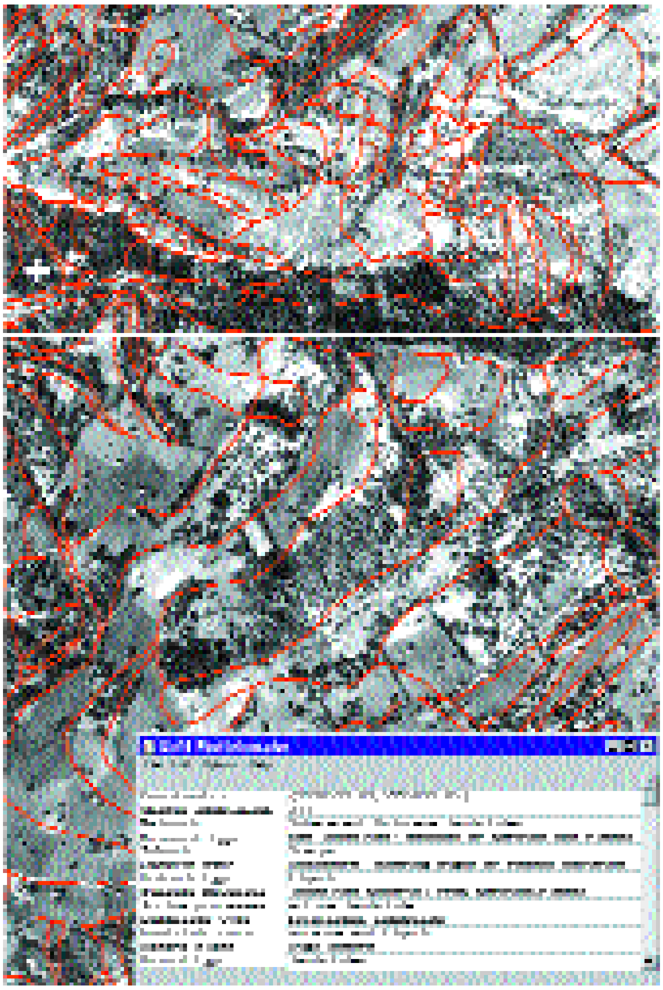

FIGURE 5 Fragment of the unique condition polygon map, displayed on top of an orthophoto. Attribute data is displayed referring to the white cross on the map.

With respect to the definition of the classes for the hazard map, it was decided that the hazard map would be aimed for use in municipal planning. This means that the only hazards evaluated were those that are relevant for the construction of small engineering works such as local roads, houses, and other buildings, which require relatively small excavations. The same map cannot be used for evaluating the hazards related to large engineering works, such as highways, railroads, tunnels, etc. In such a case the hazard would depend a lot upon the specific design criteria (cut slopes, fills, etc.), and a large amount of additional information would be required (geotechnical properties of the materials, hydrological information, etc.).

The legend was kept simple, using only three classes (high, moderate, and low). Other information regarding the type of landslides, and whether landslides are confirmed, inferred or suspected were written in the list of criteria. The following definitions of the hazard classes were used:
- *Low hazard*. In these areas no destructive phenomena (landslides, rockfall, inundation, etc.) are expected to occur within the coming years, assuming that the land use situation remains the same. Inadequate construction of infrastructure or buildings may lead to problems, however.
- *Moderate hazard*. In these areas there is a moderate probability that destructive phenomena will occur within the coming years that may damage infrastructure or buildings. However, the damage is expected to be localized and can be prevented or evaded by relatively simple and inexpensive stabilization measures.
- *High hazard*. In these areas there is a high probability that destructive phenomena will occur within the coming years. These are expected to damage infrastructure or buildings considerably. Construction of new infrastructure or buildings should be avoided in these areas, or at least should occur only after detailed study.

The hazard was assessed using the so-called geomorphological method [Van Westen, 1993]. This means that the hazard type and degree of each individual unique condition polygon was evaluated on the basis of geomorphological criteria, such as:

- presence of evidence of mass movement activity, such as scarps, cracks, moved blocks, etc.;
- freshness and relative age of these features;
- proximity to other unique condition polygons that might cause danger, *eg,* location below a scarp, or above a retrogressive landslide ;
- presence of other factors that might cause slope instability, such as slope deposits, sub-glacial tills, steep slopes, water stagnation, etc.

GEOMORPHOLOGICAL LAYER MAPPING

The unique condition polygon method has the disadvantage that all relevant parameters must be described and entered in the database for each individual unique polygon, which is rather time-consuming. Although the resulting database is simple in form, consisting basically of one single large table, there is a lot of redundancy in the database. To avoid this, the construction of separate maps for different geomorphological features is recommended. The following five layers of geomorphological information were prepared for the Alpago area:

1. Main geomorphological unit map, consisting of 425 different polygons in 52 legend classes, which show information on the genesis and material types, and the chronological information.
2. Geomorphological sub-unit map, consisting of 1774 different polygons in 81 legend classes, which contain detailed descriptions on each slope segment. Geomorphological sub-units are the smallest sections of the terrain that can be presented on a large-scale map. A geomorphological sub-unit consists of one landform, for which the genesis, together with morphographical characteristics is given.
3. Process map, in which all units with mass movement processes are stored. This map consists of 409 polygons with unique identifiers. The map is linked to an attribute table, which contains information on the mass movement type, the dimensions of the mass movement phenomena, and the main cause for the occurrence.
4. Surface material map, consisting of 185 polygons with 21 legend units. There may be some overlap with layer 1, wherever the material type forms one of the criteria for defining main units. However, the polygons in this layer contain a full coverage of material types.
5. Hazard map, in which all information is stored on the classification related to mass movement hazards. This map contains 241 polygons with unique identifiers. For each hazard polygon the deciding factors for the hazard classification were recorded in a database. For about 90 percent of the hazard polygons, the geomorphological information contained in the main- and sub-unit layers were sufficient for providing these decision criteria. In addition to the hazard class, the type of hazard was also entered (small rockfall, large rockfall, landslides, flowslides, flows, erosion, flooding and snow avalanches).

When the individual maps are digitized, it should be taken into account that several maps may share the same boundaries. It is therefore recommended to digitize the geomorphological main units first, and then to use this digital file later as the basis for the other maps.

Other information, which is not directly geomorphological in nature, and which is normally presented on a geomorphological map, as shown in Figure 4, is stored in other data layers. Two examples are:

- Morphometry. Morphometric information in a GIS is provided by a Digital Elevation Model, which displays the elevation at the center of each pixel. From this DEM, morphometric maps can be made displaying slope angle, slope aspect, slope length and slope concavity/convexity.
- Drainage, which can be digitized separately in the form of line symbols.

Land use might also be considered as one of the input maps for the database, as well as man-made constructions such as roads, buildings, check-dams, etc. This data can also be used for the inventory of elements at risk, and for risk mapping.

The geomorphological layer mapping method only provides useful information to a user when all individual layers are consulted simultaneously in a GIS (see Figure 6). Only then is it possible to obtain the full description of the geomorphological situation, and to find out the reasons for the hazard classification.

DIGITAL CARTOGRAPHY

The geomorphological layer method is specifically designed for use with a GIS, so that the full overview of the geomorphology can be obtained by simultaneously reading the information from several data layers. It is more complicated, however, to represent the different types of information on a single map sheet. An attempt was made to combine the various layers of information into a single map, while still keeping the map readable.

A paper version of the geomorphological hazard map was made with the help of a digital cartographic package (PCI-ACE). The resulting color map is attached in this issue of *JAG*. The various data layers were combined in the following way:

- The main geomorphological units are displayed in colors. The first impression of the map by the reader is therefore directed towards the general geomorphological zonation of the area.
- The polygons of the geomorphological sub-units are

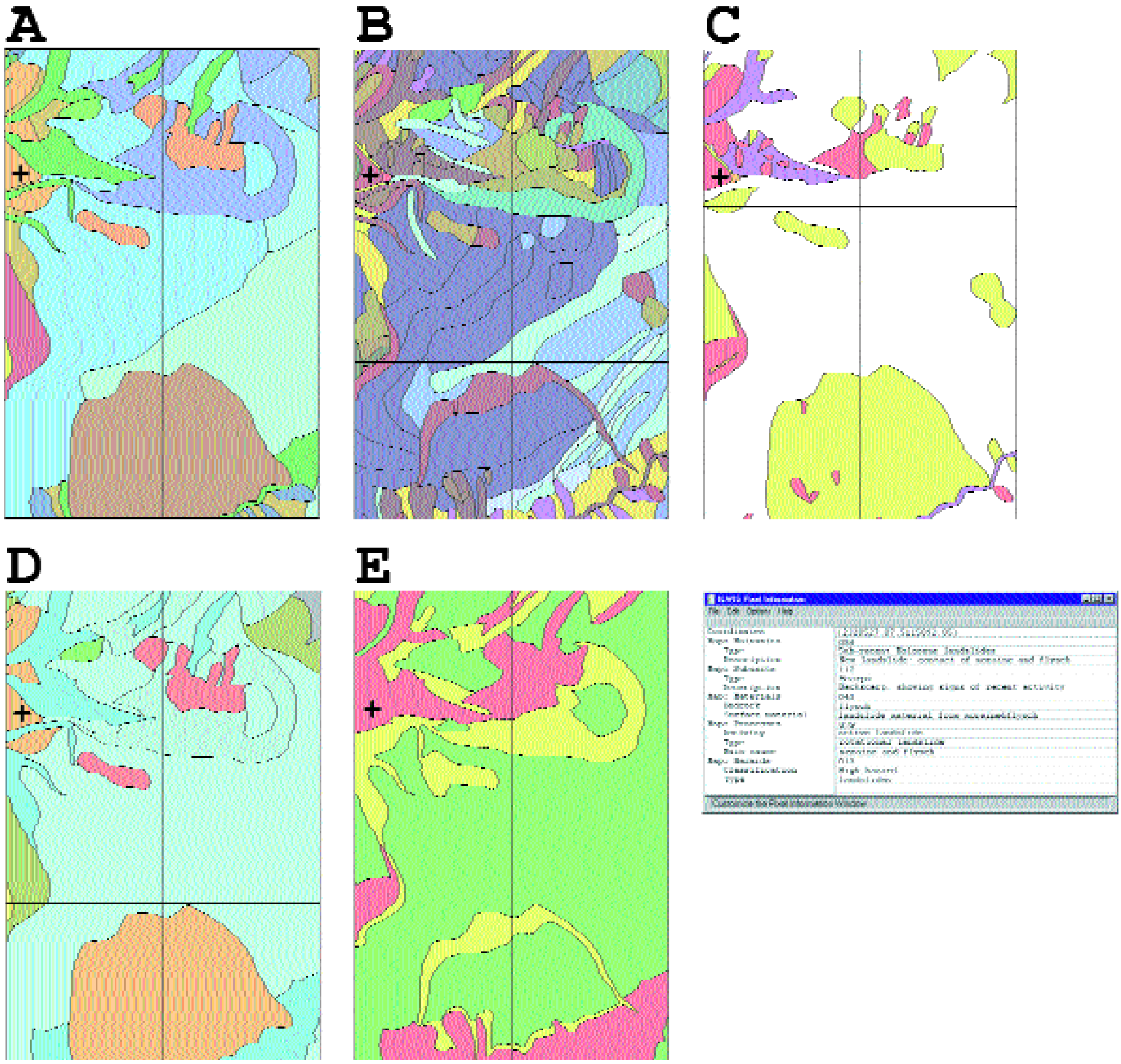

FIGURE 6 Fragments of the maps, made according to the geomorphological layer method for the same area as Figures 4 and 5. A: Main geomorphological units; B: Geomorphological sub-units; C: Process map; D: Surface material map; E: Hazard map. Attribute data is displayed referring to the black crosses on the maps.

represented only by their boundaries and by codes. It was decided not to use colors or hatching for them, since this would make the map too complex.

- The hazard classification is displayed with a small hatching of colored point symbols. Only the classes high and moderate hazard have been used. The areas without the hatching are the low hazard areas. It was not possible to also display the type of hazard in the map.

Since the map is intended to be used for municipal planning, detailed topographic information related to houses, roads, powerlines, etc is also indicated, as well as the engineering works (check-dams) that have been constructed in the area.

In the bottom-right part of the map, the geomorphological evolution of the area is illustrated using a number of three-dimensional views. These views were generated using a hillshading image, derived from the Digital Elevation Model, which was fused with the geomorphological map, containing only those landforms that were generated in a certain period. In order to illustrate the location of the glaciers in the area, additional Digital Elevation Models of the glacier surfaces were constructed, and they were visualized on top of the three-dimensional views as grids.

When the legends of the geomorphological units and the geomorphological sub-units are compared (see the attached color map), it can be seen that they are not hierarchical in nature, but should be seen as two individual layers. This was done to prevent the construction of a very complex legend system. Consider, for example, a geomorphological main unit with the code "*denudational slopes*". The sub-units, indicated by codes, that may occur within this main unit do not necessarily fall under the sub-unit group of "*denudational slopes*", but may also be small landslides, small denudational valleys, small denudational ridges, etc. If all these sub-units had to be made by subdividing the code of the geomorphological main units, practically every main unit would have to be combined with many different sub-units, leading to hundreds of legend units. Basically the problem is related to the "homogeneity" of terrain units. This homogeneity is related to the generalization that is applied. If larger units are defined, the generalization is larger, and the units are not as homogeneous as when smaller units are defined.

DISCUSSION

When the traditional symbol map (Figure 4) is compared with the information from the two GIS-based methods (Figures 5 and 6 and the attached color map), it can be concluded that the amount of detail in the traditional map is still higher. This is because the combination of lines and symbols makes it possible to incorporate very subtle features, such as small patches of different materials, directions of deposition, etc. that are very difficult to map as individual polygons. One could say that the GIS-based maps conserve about 90 percent of the detail that is present on the traditional map. It is stressed that the GIS-based geomorphological mapping methods have been designed for multipurpose functionality. In this applied case study the geomorphological hazards were highlighted. However, geomorphological mapping can also be used for other applications, such as the generation of geo-technical maps or ecological maps.

Detailed geomorphological mapping is a time-consuming operation, both in the traditional method, as well as in the GIS-based methods. In the traditional method, most time is spent on field mapping and drawing of the final output map. In the GIS-based methods, a lot of time is required for digitizing the complex polygon maps. In that respect, the unique polygon mapping method requires less time, since only one polygon map has to be digitized, but the accompanying database will be larger than for the geomorphological layer method. However, the GIS-based methods allow for a rapid updating of the geomorphological database, and fast production of an output map using digital cartography.

Whether GIS-based or traditional methods are used, a comprehensive understanding of the geomorphological evolution of an area, combined with thorough and detailed mapping by expert geomorphologists, is essential in order to generate a reliable hazard map [Van Westen *et al*, 1999].

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RÉSUMÉ

Des cartes géomorphologiques à grande échelle de zones montagneuses sont traditionnellement réalisées en utilisant une légende de symboles complexe. Elles peuvent servir d'excellentes "bases de données géomorphologiques", à partir desquelles un géomorphologist expérimenté peut extraire une grande quantité d'informations pour une cartographie de zones à risques. Cependant, ces cartes ne sont pas destinées à être utilisées en association avec un SIG, à cause de leur structure cartographique complexe. Dans cet article on présente deux méthodes pour une cartographie géomorphologique numérique à grande échelle en utilisant un SIG et un logiciel de cartographie numérique. Les méthodes sont appliquées dans une zone de géomorphologie complexe dans le bassin versant de Borsoia, situé dans la région Alpago, près de Belluno dans les Alpes italiennes. La création d'une base de données SIG est présentée avec un aperçu des couches de données qui ont été générées et leurs relations entre elles. La base de données SIG a également été convertie en carte, en utilisant un ensemble de logiciels de cartographie numérique. La carte géomorphologique résultante à grande échelle des zones à risques est jointe. La base de données SIG résultante et le produit cartographique peuvent être utilisés pour analyser le type de risque et le degré du risque pour chaque polygone et trouver les raisons pour la classification du risque.

RESUMEN

Los mapas geomorfológicos a gran escala de las zonas montañosas se hacen tradicionalmente empleando complicadas leyendas a base de símbolos. Pueden servir de excelentes "bases de datos geomorfológicas", de los que un geomorfólogo experto puede extraer mucha información para la cartografía de riesgos. Sin embargo, estos mapas no están diseñados para ser utilizados conjuntamente con un GIS, debido a su compleja estructura cartográfica. En este artículo se presentan dos métodos para la creación de mapas geomorfológicos digitales a gran escala utilizando GIS y un programa de cartografía digital. Los métodos se aplican a un área con un marco geomorfológico complejo en la zona de captación de Borsoia, localizada en la región de Alpago, cerca de Belluno en los Alpes italianos. La configuración de la base de datos del GIS se presenta con una visión general de las capas de datos que se han generado y cómo están interrelacionados. La base de datos GIS se convirtió además en un mapa sobre papel utilizando un paquete cartográfico digital. Se adjunta el mapa de riesgos geomorfológicos a gran escala que se ha obtenido. La base de datos GIS y el producto cartográfico obtenidos se pueden utilizar para analizar el tipo de riesgo y el grado de riesgo para cada polígono y encontrar las razones para la clasificación de los riesgos.

Attached color map.

SEE AUTHORS'S ORIGINAL MS FOR FIGURES