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GEOMORPHOLOGICAL MAPPING USING GIS FOR LARGE TABLELAND AREAS - AN EXAMPLE FOR FĂLCIU HILLS, IN EASTERN ROMANIA

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Abstract: This paper presents a complex and versatile geomorphological information combination that enhances current geomorphological mapping methodology by using digital GIS based layers. The map and legend presented here at scale of 1:50,000 combines symbols for hydrography, morphometry, morphography, present geomorphological processes, anthropic relief forms, etc. with symbol colour variations for erosional processes, river terraces, types of rivers and creeks, their relation with the geologic structure, etc. The 25 digital layers were created using different sources of information starting from topographical maps, recent LANDSAT and SPOT imagery, in the field GPS mapping and refined for certain categories of information by using latest orthorectified aerial imagery. This large number of layers can be combined in various maps as each layer consists of simple graphical information but connected with attribute database which can be used to display these graphic features regarding certain requests or specific processes attributes. The versatility of the combined layers is reflected in various scientific or engineering purposes it may be used. This results in a complex scientific map that is rich in data and which is more relevant than many traditional previous maps and uses a simple legend created by using GIS abilities to display patterns, colors or even more complex symbols by using programming scripts to generate them. This is illustrated on a relatively large area (2,200 km^2) Fălciu Hills, in the eastern part of Romania, which has a simple geology, with a monoclinal structure of the strata, consisted of soft rocks (silt, sand and clay) and largely used in agriculture.

Keywords: GIS, geomorphological mapping, digital layers, database, spatial analysis, morphometry, GPS, aerial and satellite images

1. INTRODUCTION

The studied area is a representative area within Bârlad Tableland, a regional component of the Moldavian Tableland, in the eastern part of Romania (Fig. 1). Geologically, consists of soft sediments (mostly silt, clay and sand) deposited in the former Sarmatian Sea with a monocline structure oriented NW-SE. On these deposits was incised present river network that shaped today topography, and the temperate continental climate with excessive trends left its imprint on today geomorphological processes. Aditionally, anthropic impact has its role in triggering today erosional and landslide processes. Moreover, some land reclamation works made in the '70s changed natural waterflows in the area, were created irrigation systems, mostly degraded today and which induced some floods from time to time and other degradation processes. Land use and parcel area has dramatically changed after the '90s, from large exploitations to very small ones, due to former owners retrocedation, with direct and negative impact on today geomorphological processess.

In this respect, a comprehensive digital geomorphological mapping may be a useful tool for land reclamation, planification, sustainable development of the area, risk and hazard assessment etc.

Regarding the topography, monoclinal structure, dominance of miocene-pliocene in the shallow Sarmatian Sea deposits generated a fast cut of the initial topography by river network and relief energies are relatively high, along the clay presence that triggered landslides. Some relatively hard volcanic ashy sands horizons and oolithic limestones modified transverse valley profiles and structural surfaces. Long interfluves are dominant especially in northern and central part of the area and mostly hilly in the southern part, in general relatively narrow, also, due to hydrography, were generated structural cuestas of I[st] and II[nd] order.

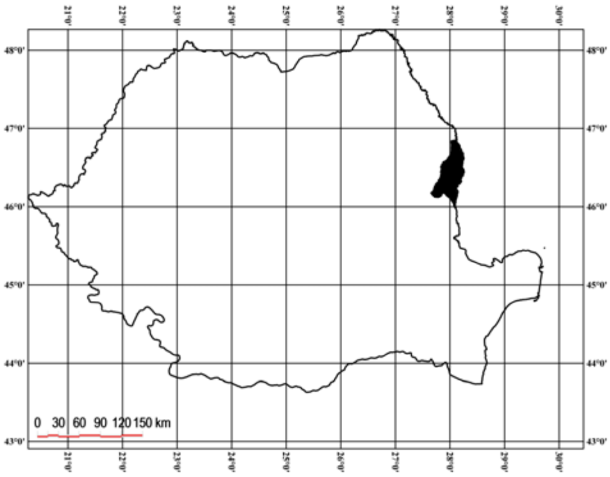

Figure 1. Study area location within Romania

2. WORKING METHODOLOGY

A first more simple version of this GIS based geomorphological map was finalised in 2004 (pH.D. thesis, Condorachi, 2006) using several GIS layers, mostly based on topographic maps, field mapping and observing mostly the Romanian scientific experience in classical geomorphological mapping that was the only one accessible at that time (Armas, 1999, 2001, Bălteanu, 1983, Donisă, 1968, Grecu, 2003, Grigore, 1979, Hârjoabă, 1968, Ichim, 1979, Ichim et al., 1989, Ioniță, 2000, Lupaşcu, 1996, Rădoane, 1996, 2002, 2004, 2007, Martiniuc, 1954, Ungureanu, 1978, etc) and some european scientists (Demek, 1972, Evans, 1990, Gilewska, 1967, 1968, Klimaszewski, 1965, 1982, 1983, 1990, Panizza, 1968, etc) that pointed out different methods of mapping, with stress either on genetic landforms, morphometry, morphography, lithology, geology etc., and making specific legends regarding the purpose of the geomorphological maps were created for.

During years, many geomorphologists tried, at a certain level, to implement GIS, GPS and remote sensing techniques into their maps, using a variety of GIS and map design software that enhance precision and readability but especially on extracting and/or analyzing DEMs created from various sources to obtain morphometric, morphographic maps and landform classification (Bolongaro-Crevenna, 2005, Dikau, 1990, 1991, Dymond, 1995, Genitzon, 2000, Giles, 1998, Guth, 2003, Iwahashi, 2007, Kertesz, 1992, MacMillan, 2000, Maksud, 2004, Minar, 2005, Miska, 2005, Pike, 2001, Prima, 2006, Reuter, 2006, Smith, 2006, Takagi, 2002, van Asselen, 2006, Wakamatsu, 2006, etc).

The geomorphological mapping issues and the GIS role in doing it was consistently reviewed and applied on a small mountain area in Sweden by Gustavsson et al. (2006, 2008, 2009), while in Romania, were some theoretical exploration of using GIS in geomorphological mapping (Haidu, 1998, Donisă, 1998, Mihai, 2005, Armaş, 2006 etc). The scientific and technical issues presented there we also confronted with when creating thematic layers and later, more detailed attribute database for them.

While Gustavsson used as a GIS platform ArcGIS from ESRI, we used TNTMips from Microimages Inc. (see reference for copyright).

2.1. Input Data and Data Processing

The main source for creating digital layers were the topographic maps at scale 1:50,000 and for certain areas at scale 1:25,000 that covered 2,200 km^2. Due to the fact that these were issued in the '70s extensive field mapping was done for updates and multispectral satellite imagery analysis (LANDSAT – at 30 m cell resolution and SPOT – at 10 m resolution, offered at that time by EURIMAGE, through CRUTA, Bucharest) for the years 1990 and 2000 was used. Updates were made in the last years by using a handheld Garmin GPS for surveying and, lately (2006-2009) orthorectified digital aerial imagery (at scale 1:5,000) at 0.5 m spatial resolution, to detail certain processes and phenomena, also to increase mapping relevance.

The foundation for the mapping is based on the DEM (Digital Elevation Model) generated from hipsometric curves extracted for the entire area from topographic maps at scale 1:50,000 that allowed us to generate quality DEM with a 20 m cell resolution.

Subsequent DEM processing allowed us to generate specific morphometric and morphographic maps like: illumination, slope, aspect and hipsometry which were classified using specific scripts (within a SML interface – Spatial Manipulation Language – which is basically a C++ programming interface).

As all of them are raster based representation and having in mind the idea to display from them relevant information and also to be easy to read and interpret they were converted in vector class areas of slope, aspect and altitude.

Different classes agglutination were tried in order to keep the most relevant ones and with importance in geomorphological processes and also to depict the most important features of the relief in the studied area.

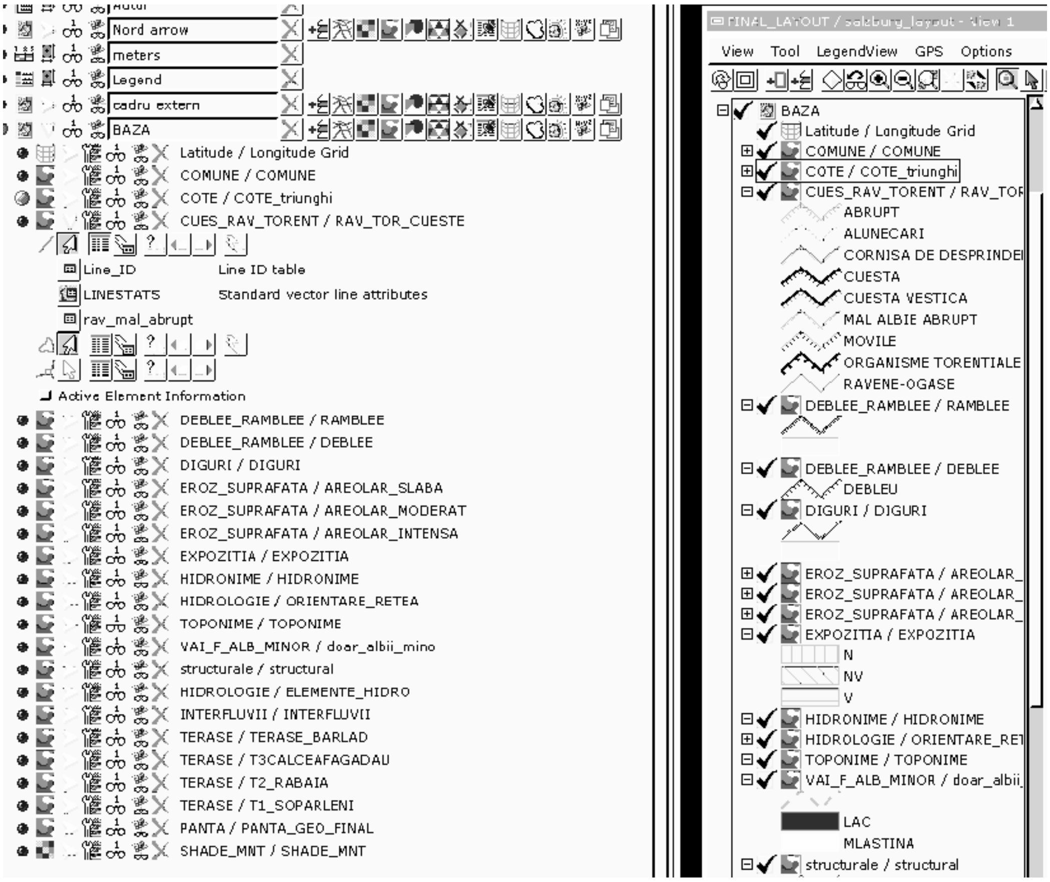

Figure 2. The complete set of layers in a final printable layout (screenshot detail from TNTMips software)

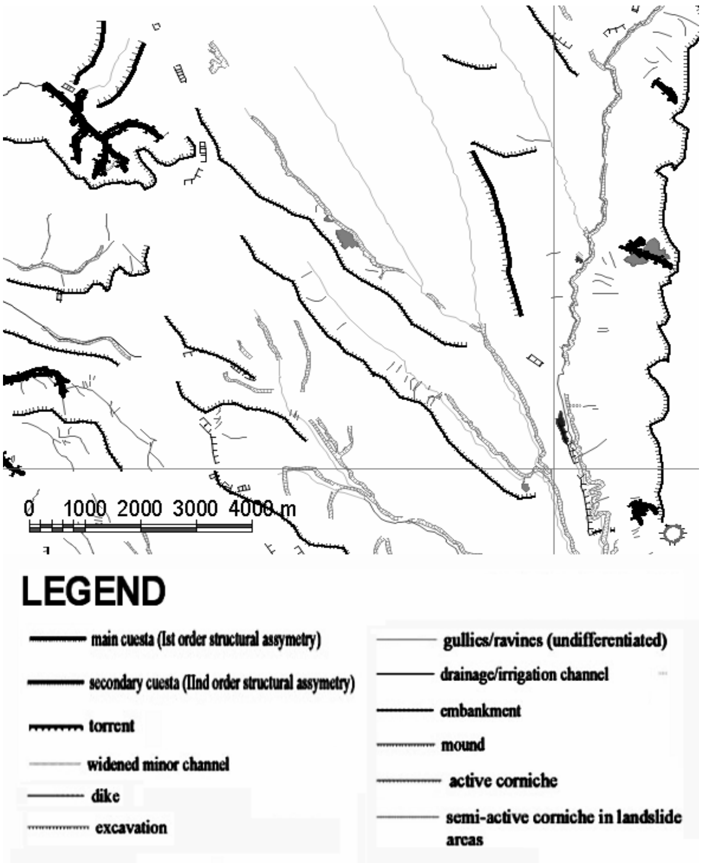

Figure 3. Combination of cuestas (Ist and IInd order), gullies, deepened creeks, active landslides, mounds, drainage channels (Elan River mid course)

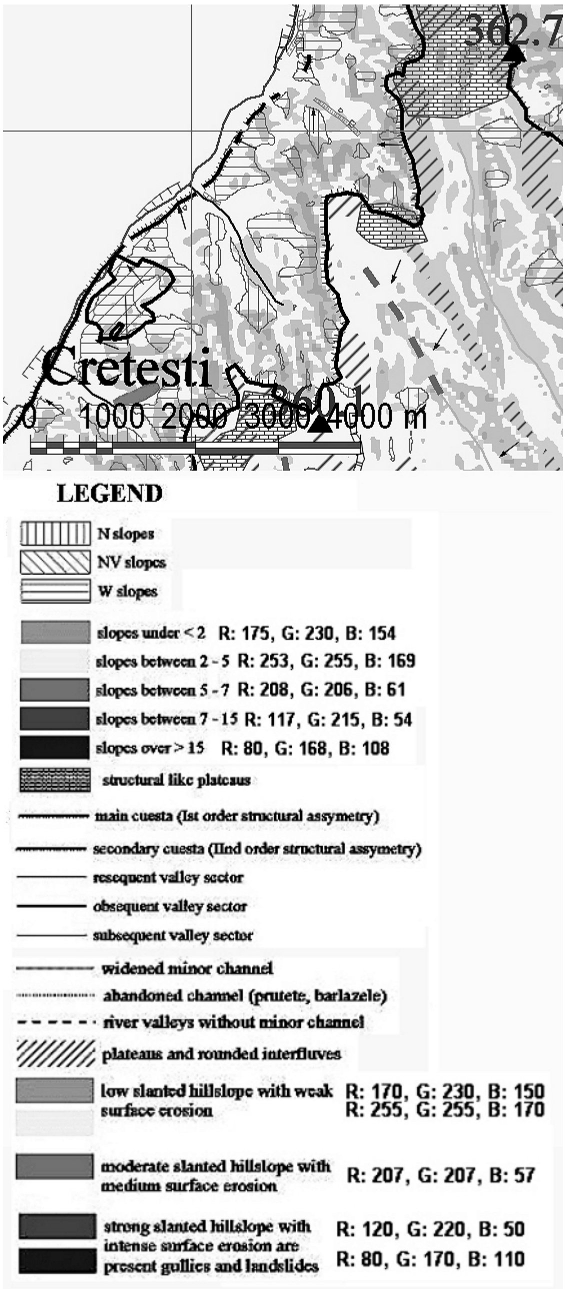

Figure 4. Example of complete combination of the thematic layers to create general geomorphological map

As the known international system of processes and relief forms representation did not consider at that time digital possibilities to create classical signs and symbols we had to adapt them observing the GIS software possibilities at this time, to generate a complex general geomorphological map. In this respect we used different styles, patterns and colour transparencies assigned for different layers. For certain signs were created different scripts and other script-generated signs from GIS library were adapted to comply as much as possible our needs.

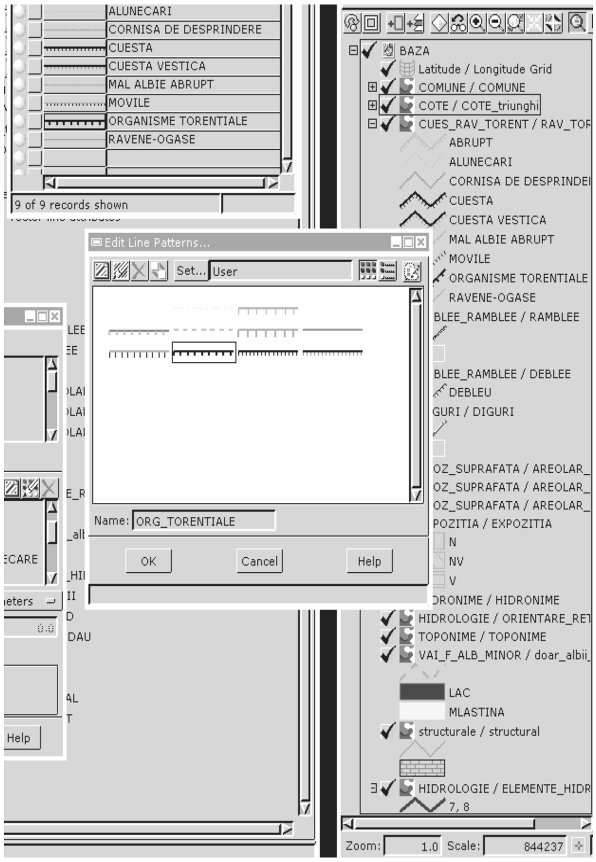

Figure 5. Example of styles used for gullies, ravines, torrents, channels and other forms with depth dimension (screenshot detail from TNTMips software)

Some hybrid conventional signs, as graphical aspect, were created separately and/or regrouped, due to the known GIS fundamental concept to work with clear defined objects, like raster, vector (polygons, lines, points), CAD, etc. Due to superior graphical quality and versatility, all the layers are in vector format, except the illumination raster used as background and also to give more plasticity and enhance the map reading.

For a better management of the graphical data separate thematic layers were created for each and every relief form or geomorphological process (25 layers) and as detailed as possible (further database extension is possible) attribute database linked with these layers and objects within them. Here are some of them: slope, aspect, structural areas, landslides (which were refined in details like active, semi-active, inactive, estimated age, having delimited the perimeter, cornice, height of the cornice, etc), torrents and gullies (active, inactive, their width and depth, etc.) alluvial fans, terraces (altitude, age, etc.), drainage network classified on different criteria, etc. (Fig.2).

Another issue was labelling relevant relief forms, rivers, etc. that have to be set observing the scale it is intended to be visualised, analysed, printed, etc. in order not to cover important information on the map or to be unreadable. Along labelling another major issue was to create the complex map by displaying different layers in a favourable order so as all the layers to be visible and readable. In this respect must be taken into account the area on which the phenomenon is present (larger areas on bottom), complexity of the symbols (towards the top), frequency of the phenomenon, etc.

Along the creation of the layers (features) an internal database is created and can be used for further statistical analysis, like computed indices for morphometry and morphography of relief, drainage basins, etc.

Attribute tables were kept simple (one to several attributes, depending of the feature complexity, with one-to-one or one to many assignment type) as the layers and are easy to update them as changes are recorded and can feed the GIS from different sources.

Due to specific software architecture, spatial entities linked with attribute tables are also linked with internal tables that contain precise dimensional parameters we are mapping and also they can be a mix of vector spatial features (points, lines and polygons) that can be contained within a single layer (not possible in ArcGIS platform).

Thematic layers presented here were selected as being relevant for creating a general geomorphological map. Further layers can be added, according to specific scientific and technical requests. Along the paper (figs. 3-7) we present some map crops and screenshots details, simple combinations of several layers and complete set of layers for selected areas, styles, attribute table links and the legend used for the geomorphological map.

Regarding the feature mapping, and keeping in mind that nature‘s complexity is far from being described, yet, correctly by algorithms, regardless their complexity, some layers were produced automatically (like slope classes, aspect, rounded and flat interfluves, classified drainage network, etc) but others were created semi-automatically or manually using expert's experience in mapping various features that cannot be depicted on medium resolution DEMs, other digital resources or those that does not comply to natural relief evolution (dams, embankments, mounds, drainage channels, etc) or have very small spatial extent but important for local geomorphology dynamics (excavation, dykes, etc).

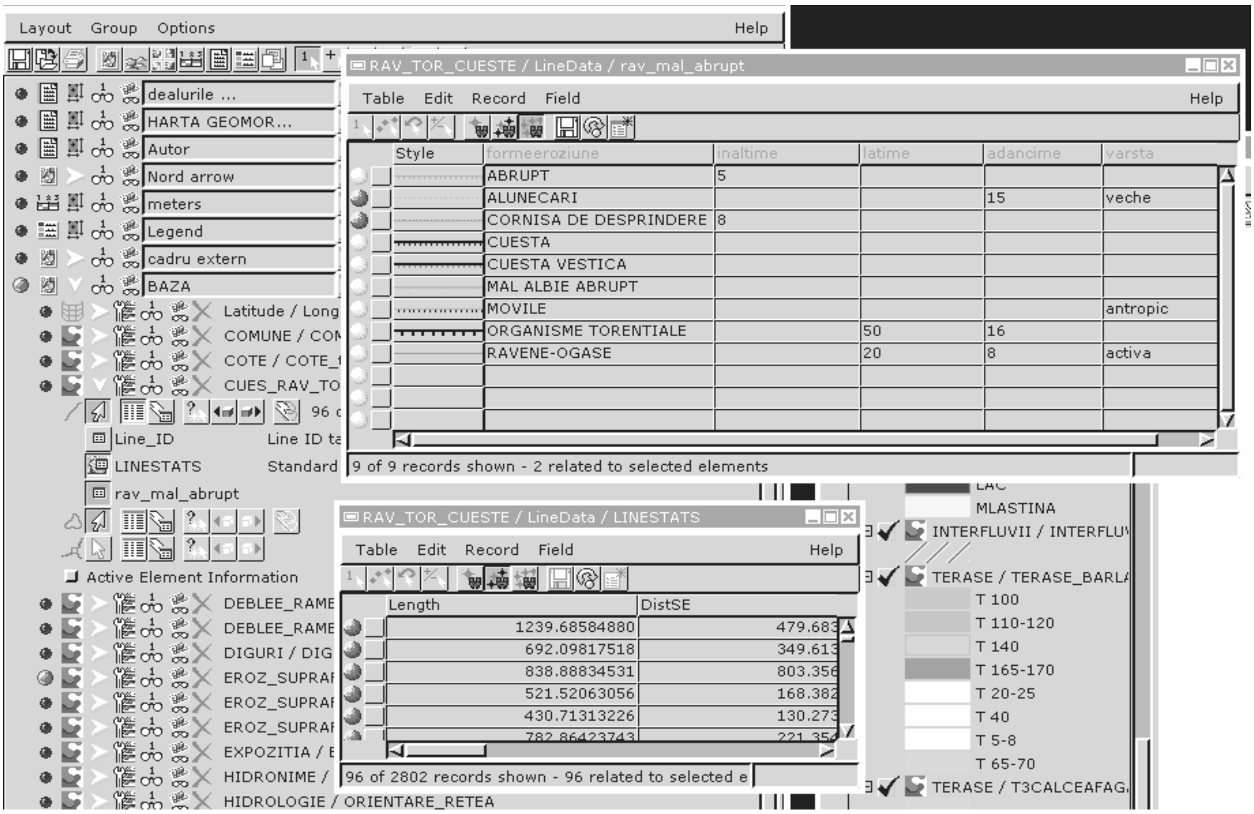

Figure 6. Example of attribute database (screenshot from TNTMips software)

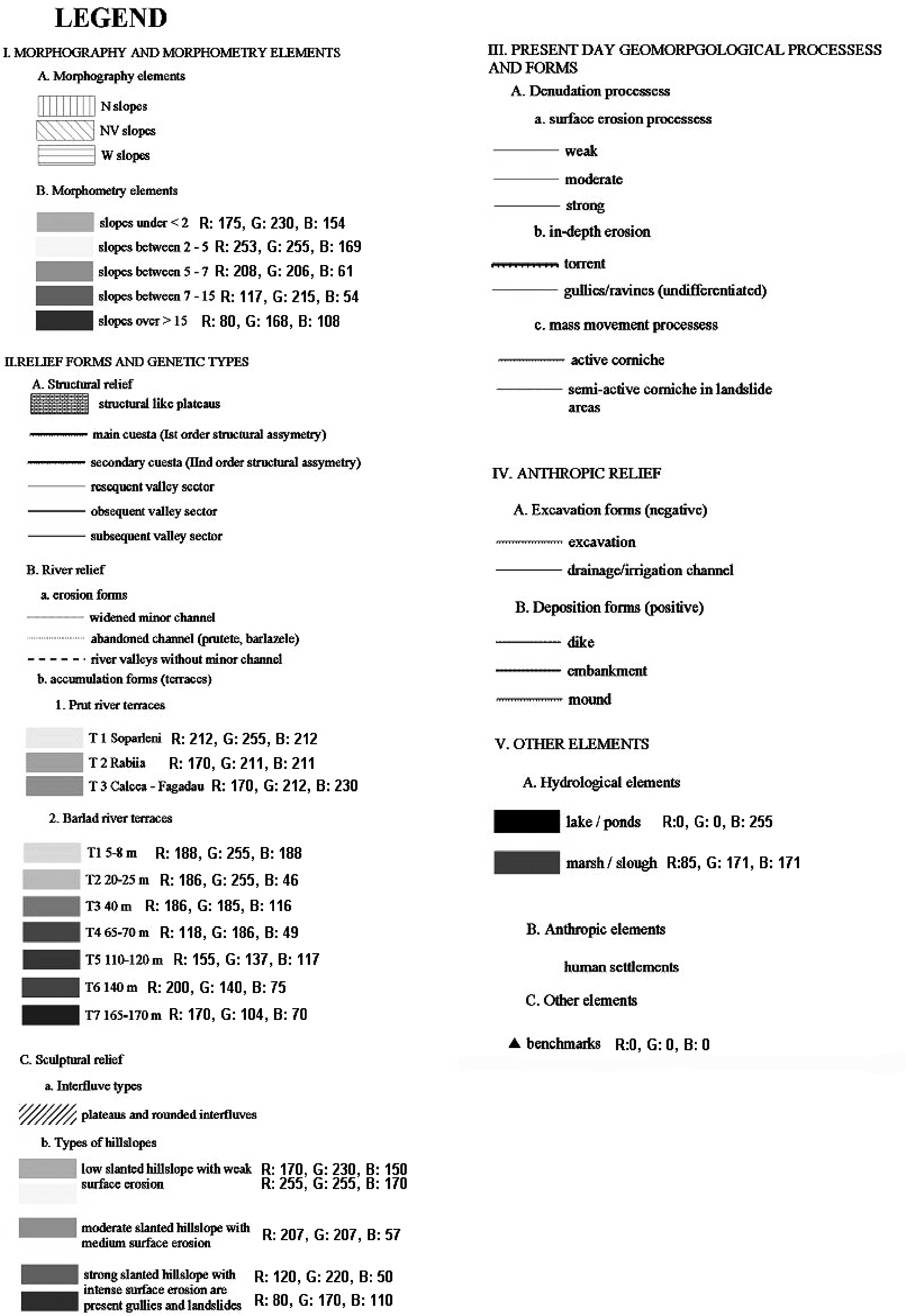

Figure 7. Geomorphological map legend

However, high resolution mapping sources were used to update, manually, gullies extent, landslides spatial evolution, river channel lateral dynamics or slopes affected by extreme surface erosion that can be used by technicians to take appropriate land reclamation measures, locally or regionally, by proper policies for sustainable development.

By using mapping sources from different times it can be evidenced those negative geomorphological processess with fast evolution that require immediate intervention or to be kept for monitoring.

Aditionally, in the field mapping is required for special data collection (channel depth, sediment deposition thickness, granulometry analysis, etc. that can affect river dynamics, landslide dynamics monitoring, 3D laser scanning, etc) which may feed, extend and update GIS thematic layers, that cannot be obtained from other sources.

3. RESULTS AND CONCLUSIONS

A geomorphological database (spatial and attributes) was created to store the representation of surface data in a relational database. All spatial feature classes in the database share a common co-ordinate system. The database contains landscape features and the relationships among them. An important aspect of a geomorphological database is that one can optionally create custom features. Features in a geomorphological database are implemented as a set of relational tables.

According to Voženílek (2000), there are some advantages of a geomorphological database:

- it can represent spatial data in four manifestations: discrete objects as vector features, continuous phenomena as rasters, surfaces as TINs or DEMs and references to places as locators and addresses

- it stores spatial data and GIS provides functions for performing spatial operations such as finding objects that are nearby, touching or intersecting; a geomorphological database has a framework for defining and managing the geographical co-ordinate system for set of data,

- it can model topologically integrated sets of features

- it can define general and arbitrary relationships between objects and features

- it can enforce the integrity of attributes through domains and validation rules

- it can bind the natural behavior of features to the tables that store features

- it can present multiple versions so that many users can edit the same data.

It is necessary to meet as close as possible integrity of purpose of mapping, method of operation, type of receiver and database structure.

The final product is a general geomorphological GIS based map that can be used as an analysis and inventory tool for scientists, land planners and other practitioners. In order to cover a large area a mid-scale topographic maps were used (1:50,000) and enhanced for certain processes especially gullies and landslides) by using satellite imagery and orthorectified digital aerial imagery.

Due to simple geological structure and lithology the importance of the morphometry, morphology and present geomorphological processes were evidenced.

Anthropic relief forms were also considered as they disturb, locally, normal evolution of the natural processes (dams, backfills, cuttings, channels, etc).

Attached attribute databases for each element (feature) allow criteria selection for display and analysis and may be enhanced according with future available data.

As previously stated, survey mapping is supposed and not excluded for a final GIS based geomorphological map.

Some advantages of digital mapping compared to classic geomorphological mapping are:

- digital storage of data
- ease of different data sources integration
- database updates are easy to make, for each feature class (layers)
- flexibility for features display, according with needed queries, end-user requirements, etc.
- quantitative (and precise) data for all the spatial features contained in the geomorphological database
- avoids in-field revisiting for updates, when using high-resolution satellite or aerial imagery
- customized thematic maps according to their destination
- possibility to display both generalized or very detailed features and attributes by using related tables, graphs, photos or other media
- spatial statistical modeling for features and attributes on different criteria, etc.
- provides metadata for all the layers and database

According to Rădoane (2007) this is the first consistent Romanian GIS-based geomorphological map.

Also this is the first GIS approach for the studied area and the geomorphological map evidenced with precise spatial and quantitative data that present geomorphological status, with clear scientific and practical application, which can be extended at regional or even national scale.

A unified geomorphological legend is required to be represented in a GIS environment. Further thematic layers can be developed and used for display, analysis and prognosis.

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