RELIEF

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Geomorphology is the discipline that explains relief evolution on the solid crust, i.e. of landforms on the Earth's surface. The subject of geomorphological research is the richness of topographic features and their dynamics. Part of a global system, landforms are incessantly changing manifestations of interacting processes. The tasks of geomorphology are to reveal laws in the evolution of surface relief, to identify types of landforms and to demonstrate the impact of geomorphic evolution on socioeconomic activities. Without knowledge on landform evolution, the laws governing the development of the geosphere would not be understood and no solution could be found for environmental problems.

In collecting, processing and systemizing geomorphological information, related disciplines also have an important part to play. Today diverse geomorphological research extends to the fields of geology, pedology, hydrology, geophysics and other sciences. Its methodology is partly empirical and partly involves the quantitative, mathematical description of the properties of landforms and their dynamics as components of the evolution of the Earth's surface.

Representation of relief on geomorphological maps

In Hungary the principles and detailed legend of geomorphological mapping were elaborated under the guidance of the directors of the Geographical Research Group, Hungarian Academy of Sciences (MTA), Béla Bulla and then Márton Pécsi. Mapping usually covers five main factors: surface rock (lithology), geomorphic processes, genetic landforms, the age of the surface and landforms and finally – to help orientation on the map – some topographical, relief and hydrographical elements. The *lithological base* shows young surface formations with *colours* indicating their origin (for instance, fluvial deposits are bluish green, mass movement features are brown and wind-blown sand is yellow). The *presently active geomorphic processes* are represented by the style of hachures (continuous, dashed, double), its thickness and colour, which also points to slope character. Landforms of larger dimension (e.g. piedmont surfaces) are shown proportional to their actual extension, while minor features (e.g. dolines) appear as map symbols. For the nature of processes and the origin of landforms the same conventional colours are used as for lithological formations. The *age of surfaces and landforms* is indicated by letters (e.g. T stands for Tertiary, P for Pliocene and Q for Quaternary forms).

With progress in the research on hills and medium-height mountain areas, which make up a considerable part of the territory of Hungary, the symbol system of geomorphological maps has been gradually enriching 1 2. Mapping in lowlands was a particular challenge since surface rocks there are rather uniform and slopes are of no significance. Instead, typical geomorphological surfaces (e.g. floodplain) and diverse, mostly fluvial and aeolian landforms (like point bars and swales or sand dunes) are to be represented, particularly on detailed geomorphological maps 3.

Relief visualization using digital terrain models

Beside classical methods of relief visualization techniques, 3D representation of topography is an everyday practice, today. It is based on digital terrain models (DTMs), which can be created either by the digitization of contour maps or by remote sensing technology. The maps of this atlas were created using the so-called SRTM digital elevation dataset.

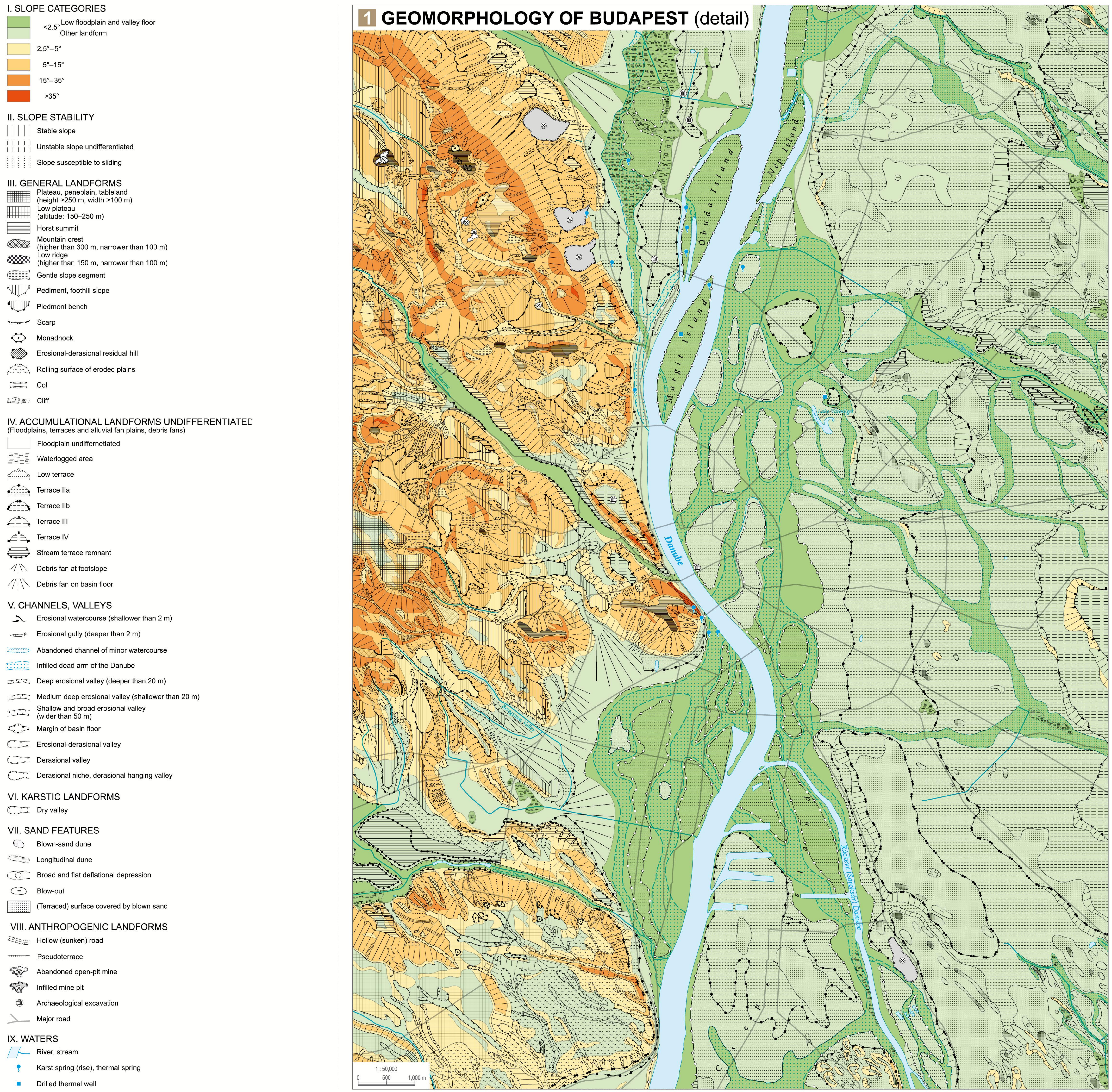
*The **digital terrain model** (DTM, or digital elevation model) is a dataset containing x, y and z spatial coordinates of topographic surface points. By default, point elevations represent the bare earth surface, i.e. the height of objects (e.g. vegetation, buildings) is not included in the elevation. However, depending on the data acquisition technology, the point elevations occasionally include the height of objects as well, in these cases, the correct name is 'digital surface model'. Geomorphometrical maps of this atlas were derived using the freely available SRTM (Shuttle Radar Topography Mission) dataset created by NASA (National Aeronautics and Space Administration) after the radar interferometric measurements of the Space Shuttle Endeavour in February, 2000. Radar interferometry is a more advanced radar technology used on satellites or space shuttles to produce relatively high-resolution elevation data about extended areas. As the radar signal is reflected from any solid object, this technology provides digital surface models.*

DTMs can be used to produce classical relief visualizations and 3D images as well. The advantage of the latter is that the relief is more appealing and more easily interpretable, but a drawback of this method is that the elevation cannot be precisely read from these images. 3D pictures can be combined with other relief mapping methods, notably with hill-shading, hypsometric tinting or contour lines. Further on, in the case of georeferenced coordinates, any kind of thematic maps can be draped over the 3D frame, thus the map content (e.g. lithology, land cover, roads, settlements) can be easily interpreted in terms of topographic settings.

Principally, 3D visualization is appropriate for small land areas, since in the case of extended areas, the image is more complicated, certain parts of the image may be hidden due to higher landforms in the foreground, and geometric distortions are more pronounced. Thus, in regional or continental scale maps, classical plan view and relief shading are more suitable visualization methods.

Relief visualization and geomorphometric maps

Beside the variegated cartographic methods of relief depiction, there has always been a need to present some measurable parameters of the relief in specific maps. In the broad sense, *morphometry* comes from a Greek word meaning 'measurement of form', and it



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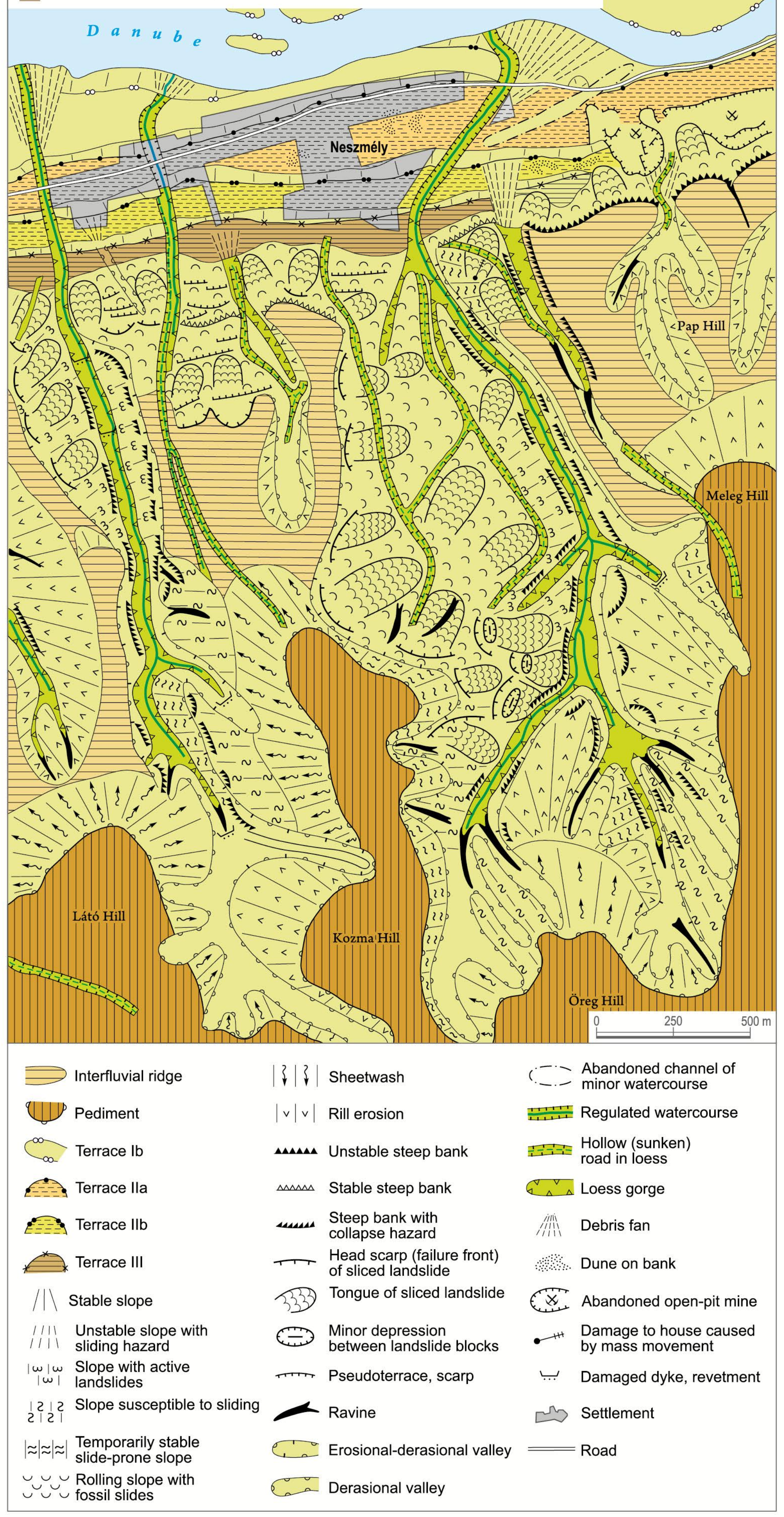
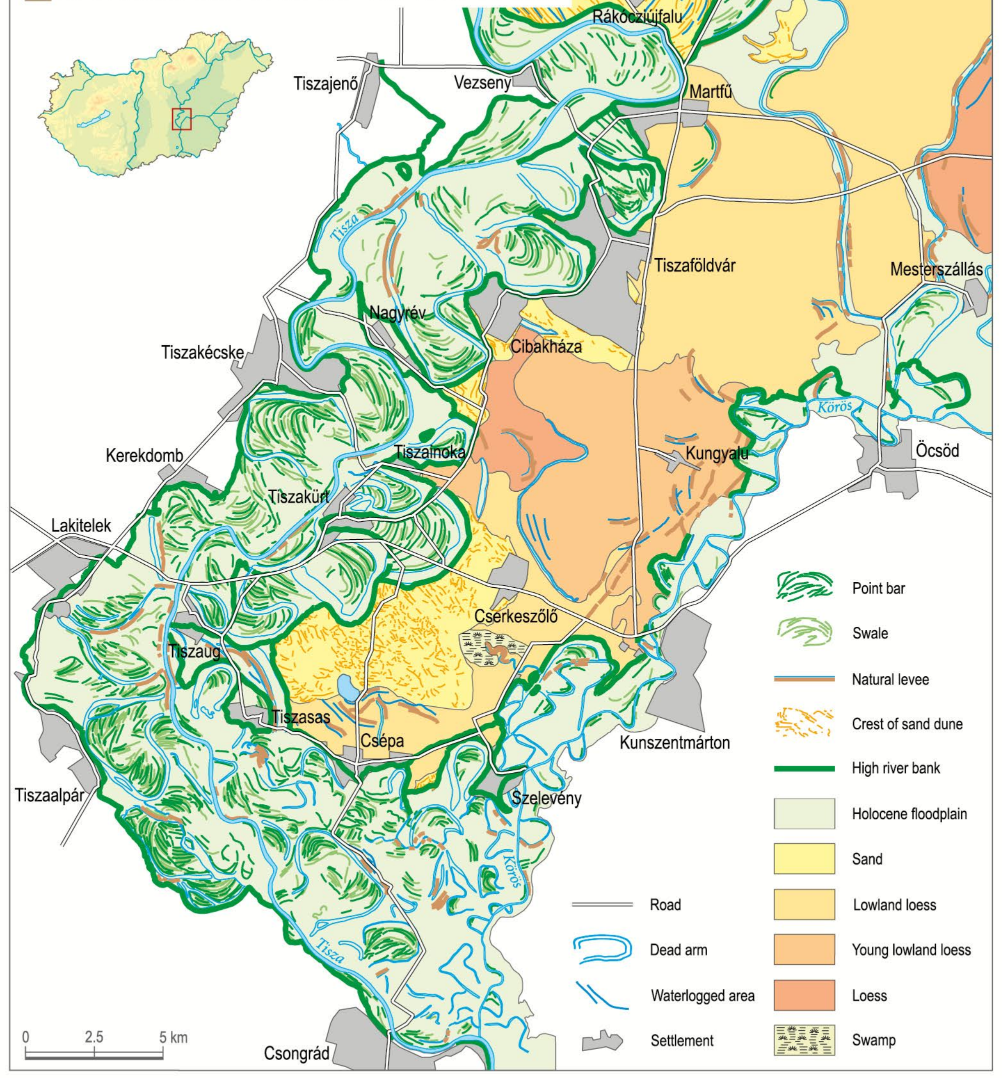
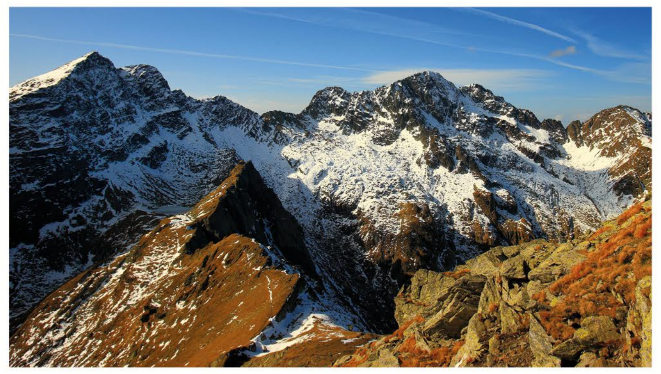


2 GEOMORPHOLOGY OF THE ENVIRONS OF NESZMÉLY



3 GEOMORPHOLOGY OF THE TISZAZUG

is an integral part of different disciplines. In general, morphometry can contribute to precisely describing and classifying different kinds of phenomenon, and to seeking quantitative relationships. There exist some generally used relief parameters, which can be derived from DTMs to produce geomorphometric maps. It is noted that morphometric maps in fact do not contain new information, instead, they 'unpack' the content, which is inherently included in the DTMs. The quantification of certain relief parameters can help to recognise landforms and surface patterns. The most frequently used and most easily comprehensible relief parameters are *slope* and *aspect*.


1 *Făgăraș Mountains*

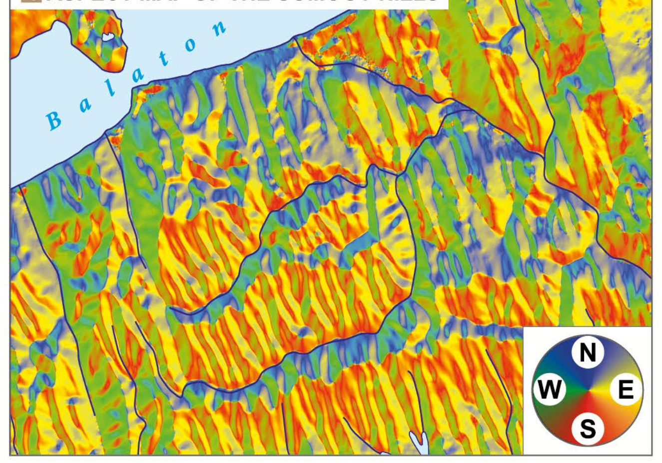
Slope

Slope is the measure of steepness relative to the horizontal plane, and it is typically expressed as angle or percentage. One of the visual advantages of slope maps is that smaller landforms have more enhanced contours. In addition, slope is an important parameter from a hydrologic point of view, because slope determines the velocity of runoff water. Further on, the surface slope reflects the compound effects of endogenic and exogenic forces, and at the same time, surface slope significantly influences the working of these processes, for instance, the triggering of landslides. Moreover, the slope is a basic factor from the viewpoint of natural vegetation and agriculture alike, and it must be taken into consideration during the planning of buildings and roads as well.

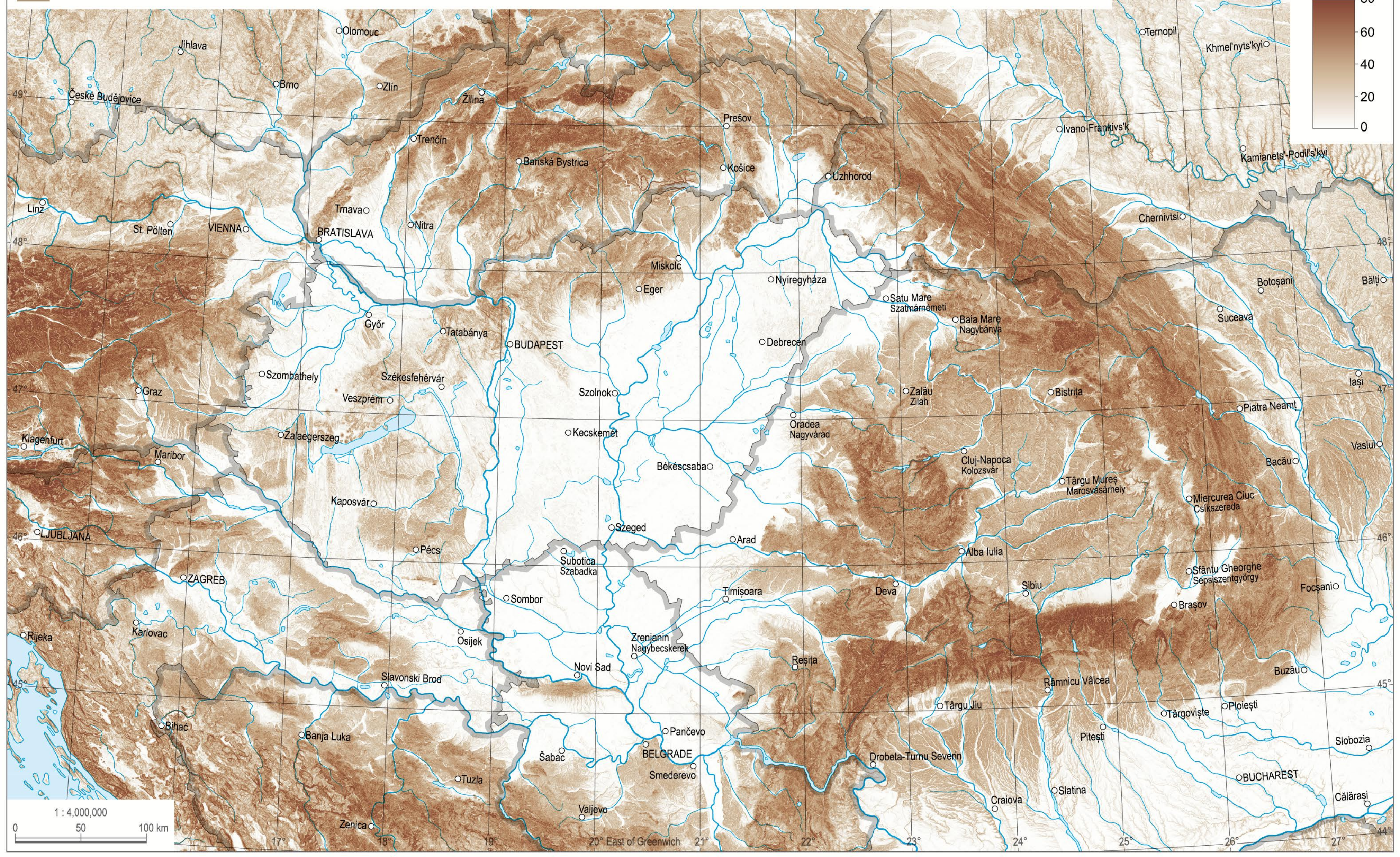
The slope class map of the Carpatho–Pannonian Area 5 is especially designed to demonstrate the variety of landforms. In general, it is observed that the higher ranges of the Carpathians have at the same time steeper slopes as well. At first, it seems obvious, but is not so simple, as a number of high elevation, but less dissected terrains (e.g. plateaus) exist on Earth. On slope class maps, valleys of different widths can be more clearly recognized than on simple topographic maps. The outer ranges of the Northeastern Carpathians built up of folded sandstones (more precisely of 'flysch rocks') can be easily observed. The slope makes a remarkable difference between the flat, undissected intermountain basins like Gheorgheni (Gyergyó), Ciuc (Csík) and Brașov (Brassó) Basins and the hilly Transylvanian Plateau, which is densely dissected by fluvial valleys. Smaller volcanic forms can be also identified in the Balaton Uplands or in the inner range of the Northeastern Carpathians as tiny circular patches with light centres and dark margins. Some lithology related topographic features can also be distinguished, for instance the karst plateaus. Their steep edges are enhanced with dark colours, whereas the plateaus themselves have lighter colours. Notable examples are the Bükk Mountains, the Slovak and Aggtelek Karsts and the Northern Eastern (Limestone) Alps. To the contrary, in the case of mountains built up of impermeable rocks, a more homogeneous brown colour is typical meaning a generally steep surface like in the case of the High Tatras or the Făgăraș Mts. 1, which are occasionally dissected by valleys marked by light colours. The characteristic radial valley system of Transdanubia is also spectacular, the Zala Hills are dissected by north to south valleys, the Sokoró Hills and the Mezőföld Plains by north-northwest to south-southeast valleys, whereas the Gödöllő Hills (already east of the Danube river) by northwest to southeast valleys.

Aspect

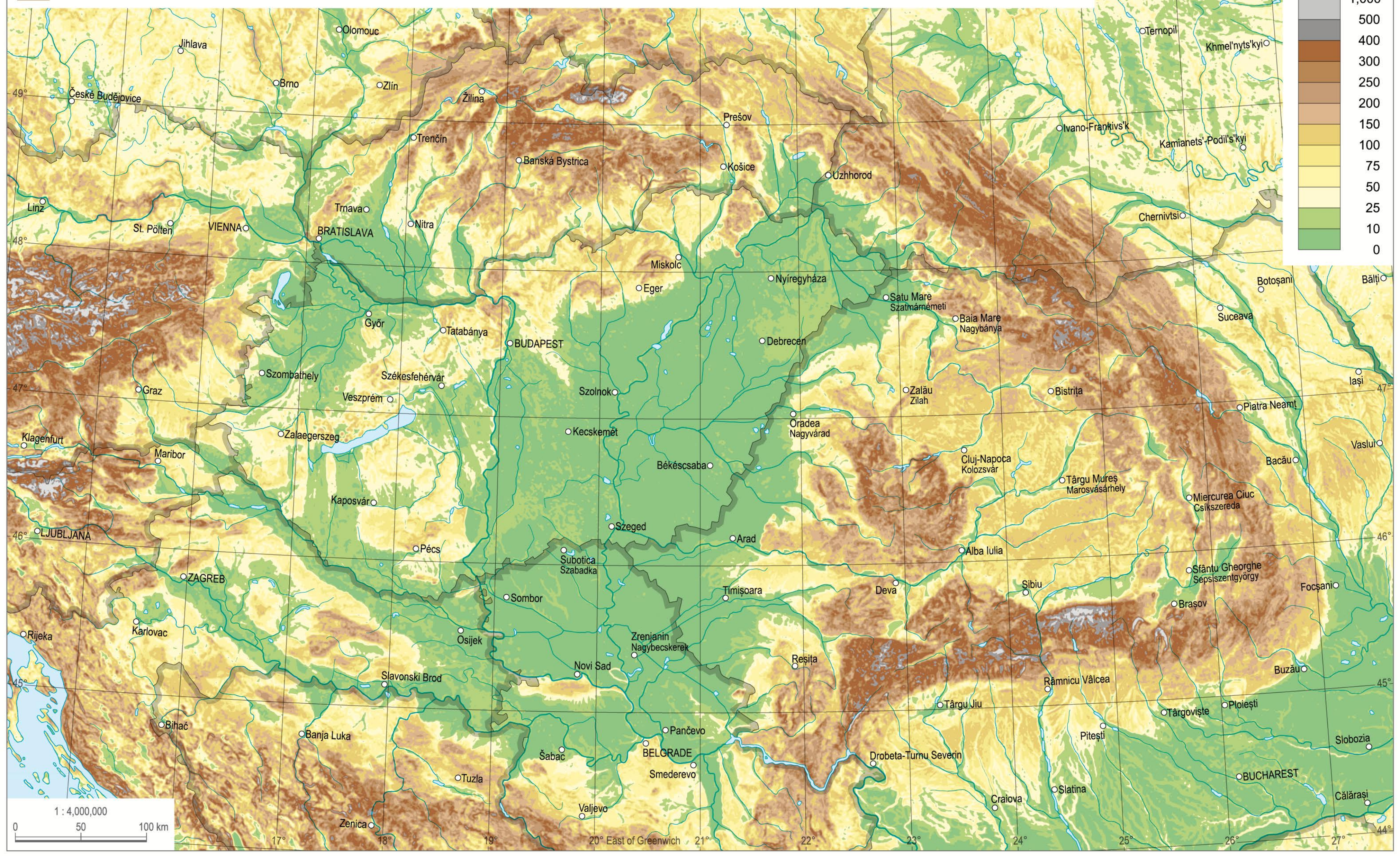
The *aspect* (or exposition) is the direction of the steepest ascent. In contour line maps, aspect is everywhere perpendicular to the contour line. In geography, aspect is usually given as the clockwise angle relative to the north direction. An aspect map in itself is not easy to comprehend, so it is often combined with other maps, but it may help to identify certain tectonic features. Moreover, aspect in combination with slope highly influences the insolation of a given area, therefore, it has an effect on most climatic parameters, which in turn determine natural or cultivated vegetation. Besides, the aspect is significant from the viewpoint of landform processes as well, since the rate of weathering or the likelihood of landslides are highly sensitive to the water content of the regolith, which is dependent on aspect. Thus, it is not incidental that in the Northern Hemisphere, for instance in the Carpathians, the northerly exposed mountain slopes are generally, but far from always, steeper than their southerly exposed counterparts.



4 ASPECT MAP OF THE SOMOGY HILLS

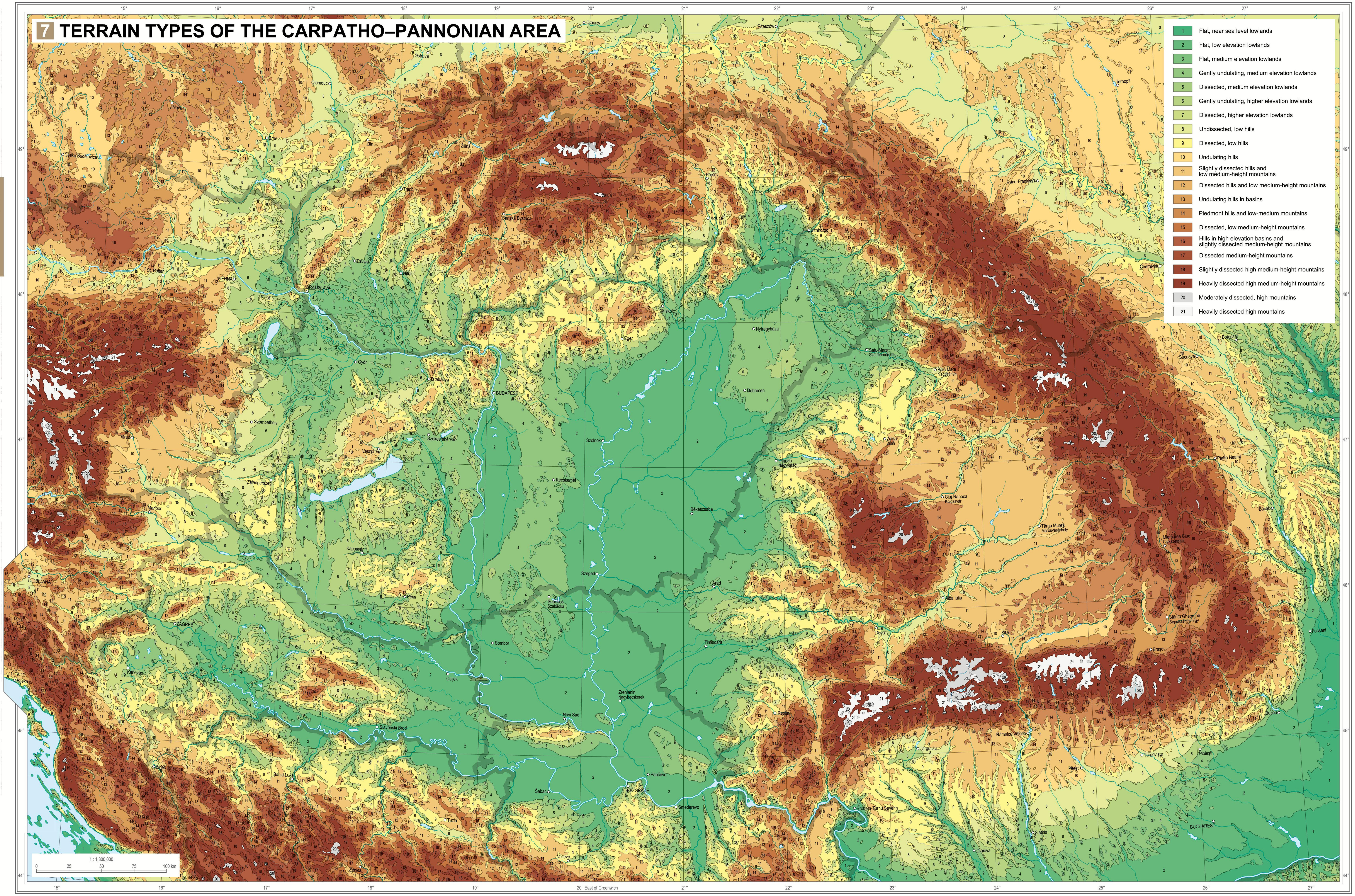


5 SLOPE CATEGORY MAP OF THE CARPATHO–PANNONIAN AREA



6 RELATIVE RELIEF MAP OF THE CARPATHO–PANNONIAN AREA

7 TERRAIN TYPES OF THE CARPATHO–PANNONIAN AREA



2 *Southerly exposed slope in the Outer Somogy Hills near Karád village*

Aspect maps are usually highly mosaic-like, thus they are rather used to depict smaller areas. In this atlas, the aspect map of a part of Somogy Hills is presented as an example 4. The cold bluish colours mark the northerly exposed, cool and wet hillsides, whereas warm, reddish colours are assigned to the southern slopes getting more insolation 2.

Relative relief

Beside the above mentioned classical morphometric parameters (slope and aspect), geoinformatic programs provide quick and easy tools to precisely calculate several other topographic parameters. One of these parameters is the so-called *relativ relief* (named also as relief energy), which quantifies the vertical differences of a terrain. Relative relief is defined as the elevation difference between the highest and lowest points within an arbitrary circular environment of a given point. In the case of small circle radius, the relative relief is closely related to slope, but as radius is increased, larger area and compound terrain types can be more easily characterized by this parameter.

The relative relief map of the Carpatho–Pannonian Area 6 was created from the DTM by using 1 km² area circular environments around each point. Thus, it presents vertical differences in metres within 1 km² circles. This map discriminates flat plains and hilly or mountainous areas dissected by fluvial erosion at various degrees independently of absolute elevation. Within plains, completely flat areas traditionally called 'as flat as a table' can be clearly distinguished from gently undulating areas like Nyírség or Mezőföld. The green colour of the less dissected terrains appears even at high altitude, but flat intermountain basins (e.g. Gheorgheni/Gyergyó, Ciuc/Csík and Braşov/Brassó Basins in the Eastern Carpathians, and the Orava, Nowy Targ and Spiš Basins in the Northwestern Carpathians). As for the hilly areas, terrains with smaller vertical differences, such as the Transdanubian Hills and regions with higher degree of dissection, such as the Transylvanian Plateau or the Outer Carpathian hills can be discriminated. Majority of the Transdanubian Range look like a hilly region, except certain parts of the Dunazug Mountains, whereas higher sections of the North Hungarian Range have typically larger vertical differences (250–300 m/km²). It is worth observing in the map the volcanic ranges of the Inner Northwestern and Northeastern Carpathians, which consist of ring-like, separated structures. In the case of lower high mountains (e.g. Low Tatras, Apuşeni Mountains, a large part of the Eastern Carpathians) the typical relative relief values are between 300 and 400 m/km², occasionally exceeding that limit. Finally, the most dissected terrains, the real high mountains often with values between 500 and 1,000 m/km² can be clearly recognised in the relative relief map.

Terrain types

In the characterization of large-scale topographic units, the elevation above sea level and the degree of relief dissection are the most important factors. Obviously, other parameters can be also incorporated into morphometry based terrain classification, but the above two factors constitute the minimum set necessary to discriminate plateaus and lowlands as well as rugged and undissected high elevation topographies. In order to elaborate the morphometry based terrain types of the Carpatho–Pannonian Area 7, eleven elevation categories were created first, from the 'near sea level' category to the 'high mountains' category with upwards increasing elevation intervals. Secondly, terrain dissection was characterized by relative relief values distributed into categories from 'flat' to 'deeply dissected'. Thereafter, geoinformatic operations were used to create compound classes. Naturally, there are compound classes, which are not present in the real world, or whose spatial extensions are limited. Classes with similar parameters and containing few elements were merged, so finally, twenty-one generalized terrain types occurring in the Carpatho–Pannonian Area were produced 8.

3 *Göcsej Hills near Kustánszeg*

The resulted map 7 apparently discriminates different type surfaces. It is easy to distinguish the large area, low elevation flatlands of the Alföld (Great Hungarian Plain, 2) and the slightly higher and gently undulating sandy areas (4, 6; e.g. in Danube–Tisza Midland or in Nyírség region). The medium elevation, flat and gently undulating lowlands filled by the alluvial fans of rivers flowing from the Carpathian ranges to the inner plains can be also observed (3, 4). Where lowlands are dissected (5, 7), they are perceived as hilly areas, even if their elevations are lower than 200 m, and in fact, the map justifies that these terrains are found in areas, which are traditionally called hills (e.g. most part of the Transdanubian Hills 3, Gödöllő Hills) or foothills (e.g. Mátraalja, Bükkalja regions). Low hills, either undissected or dissected (8, 9) and undulating hills (10) are highly remarkable features, however, they are less typical within the Carpathian Basin, where the only notable example is the Alpokalja (Eastern Alpine Foreland). On the other hand, they are widely distributed north and northeast of the Carpathians, in the so-called flysch zone and even over there (e.g. in the Podillian Upland). As a result of the generally low topographic settings of Hungary the geographic traditions consider some parts of the more or less dissected hills as low-medium mountains. Consequently, this compound category (11) is very significant in Hungary, it links the elements of the Transdanubian Range to form a unified landscape, and the same is true for the North Hungarian Range and for the Mecsek Mountains as well. The most extended area of less dissected hills is found in the Transylvanian Basin 4, whereas dissected hills (12) practically surround every higher terrain, but they are generally arranged into narrow bands. In some places, there are undulating terrains in the same elevation range as low-medium mountains (13); these landscapes are only slightly dissected in spite of being at high altitude, because they are found in closed mountain basins, where the incision capacity of rivers is limited. The piedmont hills (or foothills) are clearly distinguished from the previous category because of their higher relative relief and their positions at mountain margins (14; e.g. hilly areas around the Târnava (Küküllő) rivers, the northern margins of the Apuşeni Mountains including Pădurea Craiului Mountains 5, and a significant part of the Northwestern Carpathians).

4 *Undulating landscape in the Transylvanian Basin*

8 CATEGORIES OF THE TERRAIN TYPES MAP

Type	Name	Typical elevation range above sea level (m)	Typical relative relief (m/km²)	Areal proportion within the whole map (%)	Areal proportion within Hungary (%)
1	Flat, near sea level lowlands	0–50	0–50	2.1	———
2	Flat, low elevation lowlands	50–100	0–50	12.7	34.2
3	Flat, medium elevation lowlands	100–150	0–50	2.1	4.0
4	Gently undulating, medium elevation lowlands	100–150	5–50	7.6	26.4
5	Dissected, medium elevation lowlands	100–150	25–100	2.6	3.3
6	Gently undulating, higher elevation lowlands	150–200	5–25	3.4	6.0
7	Dissected, higher elevation lowlands	150–200	25–100	5.2	8.6
8	Undissected, low hills	200–300	5–50	9.3	3.9
9	Dissected, low hills	200–300	50–150	8.7	8.6
10	Undulating hills	300–500	5–50	6.0	0.4
11	Less dissected hills and low-medium mountains	300–500	50–150	12.2	2.9
12	Dissected hills and low-medium mountains	300–500	150–300	3.1	1.1
13	Undulating hills in basins	500–750	5–50	1.4	0.0
14	Piedmont hills and low-medium mountains	500–750	50–150	5.6	0.2
15	Dissected low-medium mountains	500–750	150–500	6.2	0.5
16	Hills in high elevation basins and less dissected, medium mountains	750–1,000	5–150	1.7	0.1
17	Dissected, medium mountains	750–1,000	150–500	5.3	0.1
18	Less dissected, high-medium mountains	1,000–1,500	50–150	0.6	———
19	Deeply dissected, high-medium mountains	1,000–1,500	150–1,000	5.3	———
20	Moderately dissected, high mountains	1,500–2,650	50–300	0.4	———
21	Deeply dissected high mountains	1,500–2,650	300–1,000	0.6	———

5 *Doline row in the dissected piedmont hills of Pădurea Craiului Mountains*

The majority of the Carpathians including the Apuşeni Mountains fall into the medium mountains categories (15, 16, 17, 18, 19). Due to their relatively high elevation, they are generally heavily eroded and most of them are dissected or deeply dissected. Within Hungary, only the highest parts of the North Hungarian Range belong to this class, whereas in Transdanubia these categories appear only in a few patches. Less dissected terrains (16) are found even at relatively high altitudes (between 750 and 1,000 m a.s.l.); some of them are hilly areas within high elevation basins (e.g. Liptov Basin), others are medium mountains with plateau surfaces formed by karst processes (e.g. in the Bükk Mountains or in the Dinarides), or they are uplifted planation surfaces, or terrains covered by volcanic rocks (e.g. both sides of Harghita/Hargita Mountains).

6 *The Borescu planation surface in the Retezat Mountains*

Finally, the two classes of high mountains (20, 21) are also in agreement with field experiences. The first is represented by uplifted planation surfaces (Godeanu, Retezat 6, Cindrel, Gilău Mountains) and Dinaric and Alpine high plateaus, which are less dissected, whereas the second class includes the jagged, deeply dissected high mountains like the High Tatras or the Făgăraş Mountains.

Geomorphological districts

The territory of Hungary lies in a basin encircled by the Alps, Carpathians and Dinarides. Therefore, its relief is basically characterised by low elevation and low vertical dissection. Accordingly, 82.4% of the area is lowland below 200 m above sea level. Although terrains above 500 m only constitute 0.6%, but by convention some of the landscapes between 300 and 500 m are regarded medium-height mountains (e.g. parts of the Transdanubian and North Hungarian Ranges and Mecsek). Thus, the ratio of medium-height mountains rises to 2.1%, while hills and foothills make up 15.5% 7. The lowest point (78 m) of the country is found at Gyálarét, near Szeged, and the highest (Mt. Kékes, 1014 m) is in the Mátra Mountains.

The surface of Hungary is mostly composed of marine, fluvial and aeolian sediments of various ages, while in smaller areas volcanic rocks are exposed covering the formations of older geological periods. Over more than two thirds of the area we find loess and loess-like deposits, related to Pleistocene climate change, intercalated with fossil soils, alluvial and debris fans as well as thick fluvial sand sequences. Similarly, the majority of karst landforms of limestone regions are of Pleistocene age, such as the caves of the Bükk Mountains, the Aggtelek Karst and the Dunazug Mountains. Also in the Pleistocene (more precisely in the Early Palaeolithic), about 350,000–400,000 years ago the first groups of hominids appeared in the area, as attested by the finds at Vértesszőlős and the Castle Hill of Buda. Human action led to the anthropogenic transformation of the landscape, a process which has become ever more intense and rapid particularly over the last few hundred years.

On the present territory of Hungary six major geomorphological districts are customarily identified: the Alföld, the Kisalföld (Little Hungarian Plain), the Alpokalja, the Transdanubian Hills, the Transdanubian Range and the North Hungarian Range, which is part of the Northwestern Carpathians 9.

The *Alföld* covers almost half of the country and in the east and south extends much beyond the actual Hungarian national border. (Out of the 100,000 km² total area 45% belongs to Hungary.) Compared to all other districts, evolution history and surface character are both most uniform: it is a flat lowland of Quaternary fluvial and aeolian deposits overlying Late Tertiary marine and lacustrine strata. The sediments and relief of the Alföld are the result of cyclical uplift of the mountain frame and the parallel subsidence of the enclosed basin as well as of the drainage network adjusted to rhythmical climate change with aeolian transport and accumulation added. Characteristic landscape types of the lowland are floodplains and alluvial fan plains, somewhat higher than floodplains, covered with fluvial deposits. The latter occur in several varieties: loess- or sand-covered and basin-marginal (terraced) alluvial fan plains.

In the heart of the Alföld, the *Danube–Tisza Midland* is the slightly rolling surface of the former alluvial fan of the Danube, which lies on average 20–30 m above both rivers. Mostly covered with sand sheets and dunes and, to a smaller extent, with loess, the midland typically shows sand dune ridges of northwest to southeast alignment, often bound with vegetation 7, alternating with saline flats and waterlogged meadows. The ridges of sand dunes and sheets were built by northwesterly winds from the deposits of the Danube during the Late Pleistocene. In the last 4,000 years sand movements were only generated by the activities of human society. Evidence shows that sand was in motion during the Bronze Age, the Sarmatian and Avar times and even after the Hungarian Conquest, when Hungarians turned from pastoral life to crop cultivation. Sand movements took place for the last time in the 18th century. Since then blown sand was bound by afforestation (with black locust trees) and the plantation of vineyards and orchards. Only minor patches of blown sand still in motion survived (e.g. west of Kecskemét, at Ágasegyháza, and in the southern part of the Midland). In addition to blown sand, between Nagykőrös and Kecskemét and in the south, in the Bácska region, loess mantles the surface in northwest to southeast directed stripes.

7 *Typical sandy area in the Kiskunság*

8 *Dráva Plain at Szaporca, southern Baranya County*

Along the Danube stretches the *Danubian Plain* from Budapest to the national border in about 200 km length and in a 20–30 km wide zone. Geomorphologically distinct from the neighbouring regions, this area had been largely a swamp before the water regulations of the mid-19th century. The most common landforms are former river meanders, now cut off, and groups of natural levees. Between the river bends, forming an irregular network, saline flats of variable size are enclosed. The *Pest Flat* is a microregion composed of the northern tip of the Danubian Plain, narrowing down to the north, and lower river terraces as well as gravel-mantled terrains of the older Danubian alluvial fan terrace continuing towards the Danube–Tisza Midland. The Danube, leaving the Visegrád Gorge, deposited its gravel bedload and periodically incised into it and, thus, created a terraced alluvial fan in the Tertiary and Quaternary periods 10. The river occupied its valley section south of Budapest by the latest Pleistocene. Downcutting was probably induced by the recent and intensive subsidence of the Paks, Kalocsa and Bácska depressions.

The relatively broad floodplain of the *Lower Dráva Plain* is connected to the Danubian Plain beyond the national border 8. This flat plain lies at 96–110 m elevation and, thus, total relative relief does not exceed 14 m. The left-bank valley floor with a sharp, terrace-like, northern boundary belongs to Hungary. Surface and subsurface deposits are invariably of Holocene fluvial origin, mostly silt. Abandoned meanders are the most typical landforms. The Dráva primarily transports gravels and had an extreme water regime and channel dynamics before the construction of barrages on the Croatian section.

The *Mezőföld* consists of a series of low alluvial fan zones of Pleistocene sand, arranged in northwest to southeast direction, covered with thick loess and blown sand. Its boundary towards the Danube is a steep undercut bluff, often affected by landslides and collapses (see the chapter on *Natural Hazards* 5 and 8). The broad floodplain of the Danube marks a distinct boundary between the Southern Mezőföld and Northern Bácska Loess Ridge, which originally was the continuation of the former.

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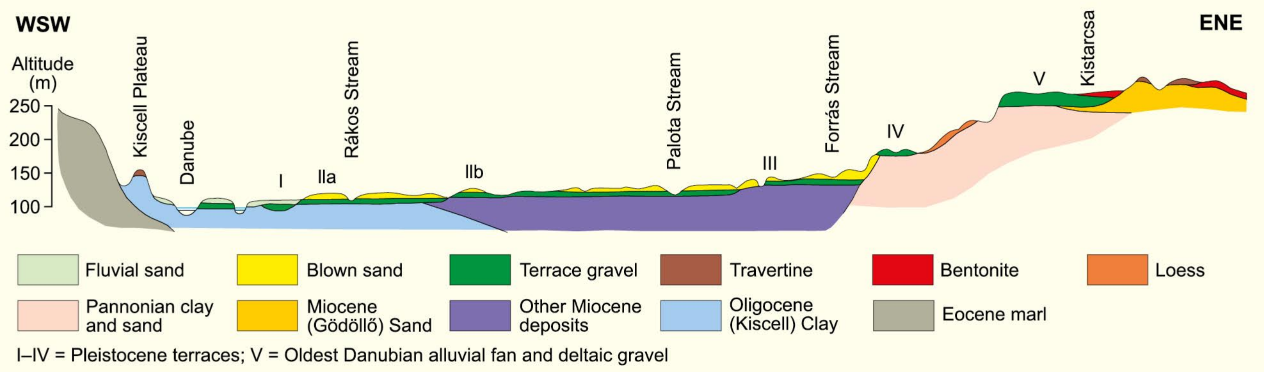
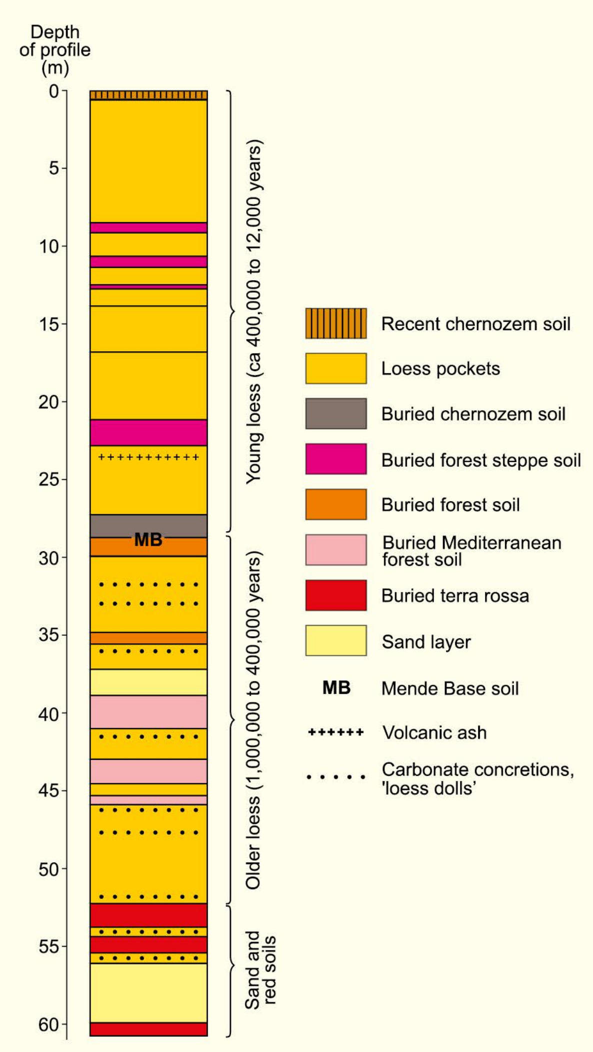
10 TERRACES IN THE PEST PLAIN



The *North Alföld Periphery* is constituted of the Quaternary alluvial fans of minor watercourses (Tápió, Galga, Zagyva, Gyöngyös, Tarna, Laskó, Eger) and of the Sajó and Hernád Rivers. Although only sporadic traces of the Zagyva and Tarna alluvial fans have remained on the edge of the Lower Zagyva Flat and north of Heves, the shifts of river channels can be clearly detected. The Sajó–Hernád alluvial fan is less dissected and its gravelly-sandy surface rises several metres above the Tisza floodplain.

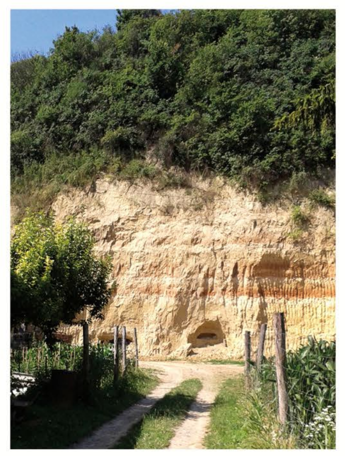
*The **high bluffs** exposed the loess sequence of the upland, where numerous loess pockets, buried palaeosols and sand layers alternate with one another* 10*. At the bottom of the sequence red soils and red clays overlie Pannonian clay and sand formations. The series of the Paks brickyard* 11*, known world-wide among Quaternary researchers for long, mentioned in many papers home and abroad, is regarded most suitable for the explanation of the nature and time sequence of climate changes in Central Europe. In the exposure the loess-palaeosol sequence indicates cyclical changes of cold and warm climates back to about one Mya. Loess layers mark cold periods, while a dozen of palaeosols were formed during the spells of warm temperate climate. The different palaeosols, like chernozem and forest steppe soils intercalated into young loess, the chestnut brown soils of Mediterranean type in old loess and the terra rossa of warm temperate–subtropical character are all products of different climates and environments.*

11 LOESS PROFILE OF THE PAKS BRICKYARD



The sediments of the *Nyírség* were predominantly accumulated by the rivers of the Bodrog river system, but in the south the Palaeo-Tisza and Szamos (Someş) also contributed to the process. From the thick fluvial sediment sequence the pervailing northerly winds built blown-sand landforms 9. Other typical geological formations are loess, clay and peat. Blown sand is thicker in the larger eastern part of the alluvial fan and the highest point of the region and of the entire Alföld (Hoportyó, 183 m) is found. In the central part the blown-sand surface is lower and the parallel north-to-south rows of dunes are separated by shallow valleys with valley watersheds. In the western portion of the Nyírség sand dunes are mantled by thin loess, which is getting thicker towards the west and transitional towards the uniform loess cover of the *Hajdúság* region.

The *Hajdúság* is a transitional region between the Nyírség and the Hortobágy (Central Tisza Plain). Pannonian strata here are covered with Pleistocene formations which are very thin in comparison to other parts of the Alföld. The surface is getting higher towards the south and the loess layers of different character are thickening (to 3–4 m).



10 *Loess wall with intercalated palaeosols at Báta*

The *Tisza Plain,* not so distinct from its environs as the Danubian Plain, is divided into three units. The Upper Tisza Plain, down to the Tokaj Gap, is an extensive lowland of high flood hazard, with shallow depressions accommodating peat bogs. The Central Tisza Plain broadens on the right bank to form the flats in the Heves, Borsod and the Jászság regions, while on the left bank, south of the low-lying Hortobágy 11, a connection towards the Berettyó–Körösök Plain, it is bordered with a high escarpment from the Nagykunság region. This section of the Tisza is of Holocene age and it separates the southern zone of the North Alföld Periphery from the mostly flood-free Nagykunság sand region. The Lower Tisza Plain is a broad lowland, a surface reflection of the deep structure of the Tisza Graben.

9 *Typical Nyírség landscape, Debrecen-Ligetalja*

In the *Nagykunság* region, in a relatively remote location from the mountain frame, only the finest deposits could accumulate. The sand found in a large area could be derived from a major river which had run here before the Tisza (Palaeo-Sajó? or Palaeo-Bodrog?). The sand is locally covered by thin (1 m on average) very young loess.

The meandering Tisza has changed its course on several occasions. In the Late Pleistocene it still flowed south of the Nyírség, across Érmellék (Ier Flat) and along the present Berettyó (Barcău) River towards the Körös (Criş) Basin and the Szeged Graben. About 14,000 years ago it shifted onto the northern boundary of the Nyírség. Leaving Bodrogköz at the Tokaj Gap 12, during the Holocene the river was wandering across Hortobágy puszta or Nagykunság to find a course in the direction of the Körös (Criş) Rivers and gradually occupied its present-day channel.

The *Berettyó-Körösök (Crişana) Plain* forms an extensive triangular plain in the interior of the Alföld. The surface is composed of alluvial silts and clays overlying fluvial sands. Peat bogs and swamps (Kis- and Nagy-Sárrét) are enclosed among the alluvial fans accumulated by wandering channels 13. Under natural conditions the meandering side-arms raised their banks with suspended load during floods, i.e. built natural levees, and accumulated arcuate point bars within the meanders, impounding numerous minor undrained bowl-shaped basins which were filled with water during floods and developed into saline ponds. River channels were regulated and excess water and swamps were drained by networks of canals. In addition to human-made tumuli, such microforms can be observed throughout the Tiszántúl Region.

The *Körös–Maros Midland* was built by the Maros (Mureş) River during the Quaternary. It is overwhelmingly composed of medium and coarse sands, gravelly sands and gravels, gradually refining towards the west, where more and more silt layers are intercalated in the sand series. In the north the sediment load of the Körös (Criş) Rivers is also present. The lowland surface is made more diverse by the remains of the meanders of ancient rivers. Along meanders and oxbows riverbank dunes and point bars occur in smaller patches.

The *Kisalföld* lies in the northwestern corner of the country, it extends downstream from the point where the Danube enters the Carpathian Basin. The axis of the plain is the Lower Rába, the largest right-bank tributary of the Danube in Hungary. Geomorphologists identify two generations of Danubian alluvial fans in the Kisalföld: the low-lying young alluvial fan plain in the basin centre and the dissected higher-lying old alluvial fan plain on the basin margin. The latter are transitional to the Transdanubian Range to the east and the foothills of the Alpokalja in the west.

11 *Typical Hortobágy landscape near Ágota-puszta*

12 *Point bars of the Tisza at Rakamaz*

14 *Hanság landscape at Földsziget (Csorna)*

15 *Somló, a lava-capped residual hill*

The younger fan at floodplain level, the accumulation of which continued in the Holocene, stretches in more than 100 km length and 60–80 km width from Bratislava to Komárom (Komárno). The Hungarian section comprises the *Fertő–Moson Plain,* the *Rábaköz* and the *Győr–Esztergom Plain.* Underground the about 200–250-m-thick gravel series of the Danube stores unexhaustable amounts of drinking water. The main channel of the Danube with many shoals follows the higher-lying axis of the alluvial fan. The Danube–Lajta/Leitha and Rába–Rábca alluvial fans of low elevation enclose the Fertő (Neusiedler See) basin with a shallow lake encircled by reed beds and the Hanság basin with peat bogs, ponds, patchy swamps and woodlands 14. The Rábaköz fan is elongated in southwestern direction. Under its fertile meadow and chernozem soils there is another thick gravel aquifer storing good-quality drinking water. The remnants of the older Danubian alluvial fan rise above the plain as terrace islands with deltaic gravelly sands and gravels from Győr to the east to Tata.

The alluvial fans of the Rába and Marcal (and tributaries) are adjusted in level to the lower alluvail fan of the Danube, while the Kemeneshát alluvial fan terrace lies at the level of the older Danubian fan. In addition to the Rába, its Alpine tributaries also shaped the double alluvial fan and created a higher and older (Pliocene) and a lower and younger surface, the *Vas–Sopron Plain.* The alluvial fan plain of the *Marcal Basin* turned from an infilling subsiding depression into an eroding half-basin, subsequently lined with gravelly deposits. The lava-capped residual *Somló Hill* (432 m) is a hallmark rising over the lowland 15.

On the western margin of the Kisalföld, the *Alpokalja* is a collective name for members of the central crystalline range of the Eastern Alps on Hungarian territory. In the *Sopron (Ödenburg) Mountains* and their environs Palaeozoic metamorphic rocks (mica schists and coarse gneiss) of the Lower Austroalpine Nappe are exposed. Mountain slopes are covered by a Tertiary gravel mantle, which had extended over the entire summit surface previously. The *Kőszeg (Güns) Mountains* and the *Vas Hill (Eisenberg)* to the south are tectonic windows of the Pennine Nappe built of the Palaeozoic schists and volcanites of the Western Alps. The deepwater sediments and volcanites were affected by strong metamorphism during the Alpine orogenies. The highest planation surface of Transdanubia is found on the contiguous block of summit position of the Kőszeg (Güns) Mountains (Írott-kő/ Geschriebenstein, 882 m).

To the south and west of Lake Balaton, down to the broad Central Dráva Plain, there are several independent hilly regions, collectively called *Transdanubian Hills.* In contrast to the basins of the Alföld and Kisalföld, this region has not been subsiding since the filling of Lake Pannon, but was uplifted. Consequently, the surface became more dissected and a hilly landscape resulted. In some parts of the Transdanubian Hills Pannonian deposits are overlain by thick river and shallow-lake sediments, chiefly sands with locally marked stratification. In the late Tertiary the gravel cover of the Kemeneshát and the gravels of the Zala Hills, which have only been retained in patches, deposited on these sands. The former flat foothill was the intial surface for the formation of ('meridional') valleys induced by subsequent uplift. In the Quaternary the hilly regions were dissected by valleys directed partly towards the Zala–Balaton catchment and partly towards the Dráva and the Danube floodplain, while the Miocene–Pliocene sands were locally strongly eroded. South of the western basin of Lake Balaton, in Inner Somogy river action became decisive during the Pleistocene. In this landscape, rather lowland than hills, in the late Pleistocene and the Holocene wind action, repeated in several stages, resulted in rows of blown-sand dunes.

The largest lake of Central Europe, *Balaton,* is a mountain foreland erosional basin formed along a main lineament, located between the Transdanubian Range and the Somogy Hills 12.

Although the lake region was repeatedly inundated by the Pannonian Sea and Pannonian Lake for a long period (10–5.6 Mya) and sediments in great thickness were deposited, the lake is not a direct remnant of the Pannonian Sea. Lake Balaton occupies a basin subsiding unevenly in space and time. Therefore, when explaining its development, the formation of the basin and the apppearance of intermittent and permanent water surfaces have to be distinguished in age. The basin took shape as early as the penultimate glacial, but recent research indicates that the contiguous water surface first appeared only in the late glacial (about 13,000 years ago), first in the west, in the Szigliget embayment. Then minor ponds emerged to the east and, finally, about 5,000 years ago were merged into a single water surface.

The *Zala Hills* are located among the Rába, Mura and Lower Zala valleys. The northern part follows the southwest-to-northeast strike of the Late Tertiary–Quaternary plateau-like, terraced alluvial fan, the Kemeneshát. To the south of the Kemeneshát and the Upper Zala valley, the valley network and the ranges of broad interfluvial ridges change to north-to-south direction. The 'meridional' valleys (of north-to-south direction) are particularly common in the eastern Zala Hills and the western Somogy Hills. The valleys dissect the Zala Hills into parallel flat ridges of roughly uniform elevation (200–300 m).

Morphologically, the *Somogy Hills* are composed of hill and plain landforms. Two main landscapes are distinguished. In the west, the Inner Somogy itself is double-faced. The long crest of the Marcal Ridge of loess-mantled Pannonian deposits (220–300 m) is separated from the Zala Hills by the basin of Kis-Balaton and a meridional valley which stretches down to the Dráva River. To the east the sand region has a much lower elevation. The Outer Somogy Hills is located south of the Lake Balaton shore between Fonyód and Siófok to the asymmetrical valley of the Kapos River 4 2. In the western part interfluvial ridges rise to 250–300 m elevation, while in the east transversal valleys disrupt the longitudinal ridges and create a chequerboard landscape. The slopes of the transversal valleys are stepped. Their northern slopes are steep and southern valley sides with slope loess are gentle and look upon broad and flat valley floors.

The *Tolna* and *Baranya Hills* are found south of the Kapos valley. The horst range of the *Mecsek Mountains* rises above the hills with a hardly observable transition in the north. The core of the mountains is built of Permian sandstones, Triassic limestones and Cretaceous volcanites. The foreland and environs were affected by repeated Miocene transgressions. The margins of the insular horst were covered by marine sediments. After the regression of the Pannonian Sea in the Mecsek foreland a long glacis was formed on unconsolidated deposits. The watercourses running down from the central block dissected the glacis, further uplifted during the Pleistocene into broad interfluvial ridges. The eastern and western foreland was also detached into independent hilly regions (Zselic,

13 *Kis-Sárrét landscape at Biharugra*

Scientific study of Lake Balaton

Recognising the significance of scientific research on Lake Balaton and its environs, Lajos Lóczy *Sen. (1849–1920) initiated the setting up of the Balaton Committee within the Hungarian Geographical Society in 1891. Its goal was the publication of findings of research on the formation of the lake basin, its geography, geology, anthropology, hydrography and etnography in monographs. The experts participating in the 28-year-long programme has produced internationally acclaimed and unprecedented scientific results in Hungarian and German under the title Achievements of the scientific study of Lake Balaton (1897–1918). The about 3,000 pages of the 35 volumes for the first time explain the development history of Lake Balaton and its environs based on detailed field investigations and the rich professional experience of contributors.*

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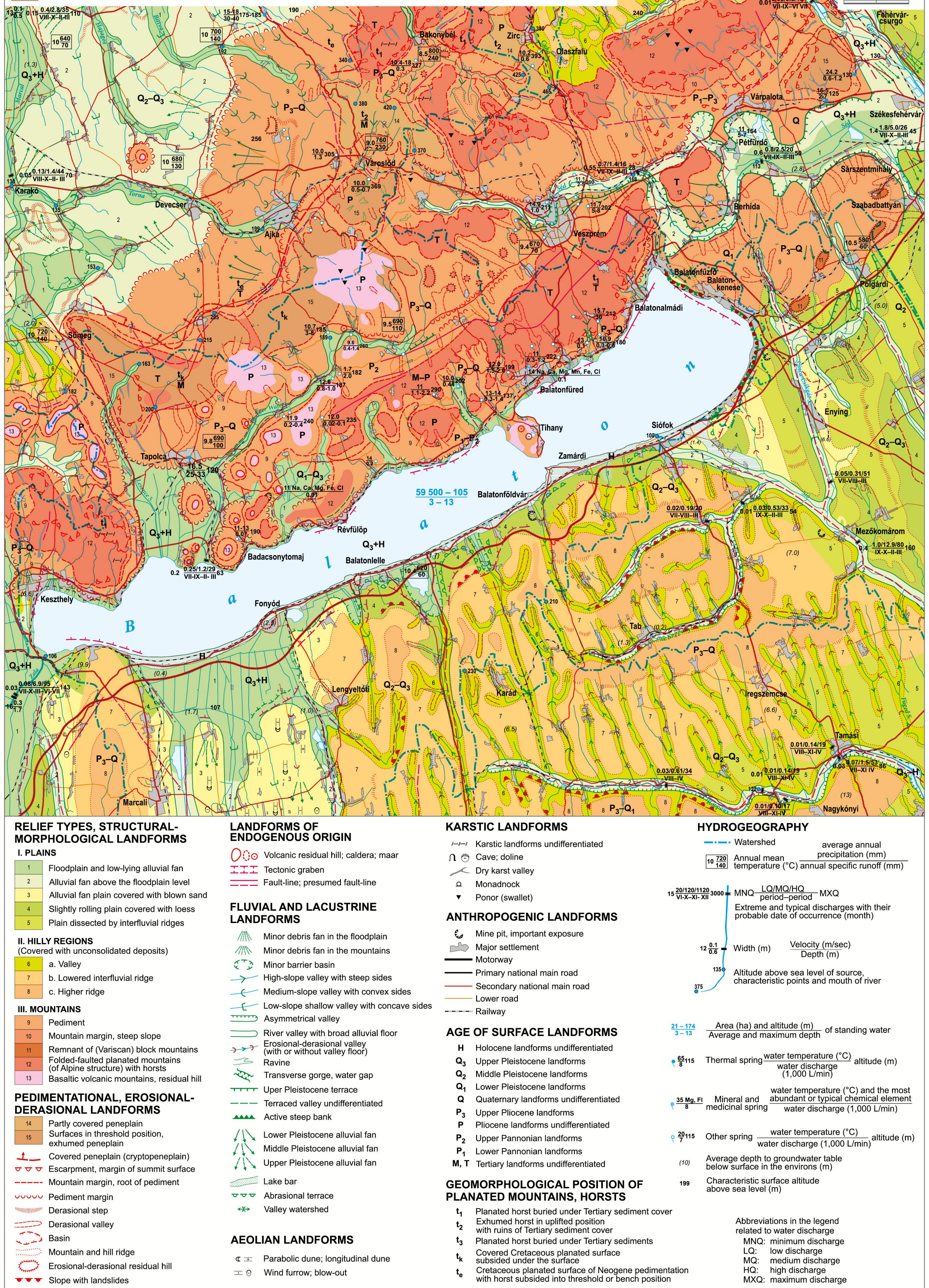
12 GEOMORPHOLOGY OF THE LAKE BALATON REGION



16 *Völgység landscape near Nagyhajmás*

Mecsekhát, Völgység) 16. The near-surface basement of the heavily dissected hills is built of Pannonian clays and sands, covered with a thick loess mantle. Below the loess Pleistocene fluvial sands of locally considerable thickness are intercalated. On the southern edge of the Baranya Hills rise the *Villány Hills*, another narrow horst series of carbonate rocks. The Palaeozoic granite mass of the *Mórágy Block* is located between the two horst series, attached to the eastern foreland of the Mecsek Mountains.

The *Transdanubian Range* represent a folded-faulted horst mountain type, primarily built of limestones and dolomites and dissected by graben-like basins of various size. Attached to this mountain type, there are smaller units, partly older metamorphic or granitic blocks and partly groups of younger volcanic hills (basalt-capped residual hills).

The most extensive member of the range is the Bakony Mountains, separated from the Vértes Mountains in the east by the Mór Graben. To the north and east the Dunazug Mountains follow (Buda, Pilis and Gerecse Mountains). In Mesozoic times the Transdanubian Range were peneplanated under tropical climate. Intense weathering produced bauxite, locally accumulated in great thicknesses. In the Tertiary denudation continued on surfaces uplifted and karstified to various degrees, while in subsided intermountain basins and mountain margins and grabens sedimentation happened. These medium-height mountains were only uplifted above its neighbourhood at the end of the Miocene. The Cretaceous peneplain of the Transdanubain Range was dismembered by major and diverse horizontal displacements caused by plate tectonics and then uplifted into different elevations.

Between the limestone and dolomite horsts of the Transdanubian Range karstic valleys formed along faultlines are found. In their majority, they are dry for most of the year. Certain sections are gorge-like. Along the margins abundant karstic thermal springs are common, particularly in the Buda Mountains along the Danube. The thermal springs are probably associated with past tectonic events (uplifts, faults). Being active from the end of the Tertiary to our days, the springs which issued in floodplains at the foot of the mountains covered the river terraces with precipitated travertines.

The slopes and basins of the mountains are mantled with slope loess in various thickness. Between finer stratified loess pockets sands and rock debris are intercalated. On surfaces covered with loess and loess-like deposits flat-floored dry derasional ('cradle-shaped') valleys are common. Deep ravines and gorges are partly the results of human intervention.

The *Bakony Mountains* are the most extensive and diverse member of the medium-height mountain range. Carbonate and volcanic rocks with their typical Mesozoic horsts and basalt-capped residual hills, respectively, equally occur. The main mass is constituted by plateaus of Triassic–Cretaceous limestones and dolomites at variable elevations (e.g. the Tés Plateau 17), separated by tectonic basins and grabens.

The westernmost member is the *Keszthely Mountains*, an uplifted horst of Triassic limestones and dolomites with karst features, bordered by depressions formed along faultlines. To the north and east, remnants of Pannonian volcanism, well-known worldwide, are found. In the Tátika group basalt dykes most often form ridges, while the extraordinary landscape elements of the *Tapolca Basin* are the basalt-capped residual hills, similar in origin to Somló (see the chapter on *Geology* 1), including the Csobánc, Badacsony, Szent György Hill and Haláp Hill, almost totally destroyed by quarrying. These hills rise more than 300 m above the basin floor. The Miocene limestone in the basement of the Tapolca Basin, in which the Tapolca lake cave was formed, is overlain by hundreds of metres of clayey, sandy, gravelly sediments. The land surface of the unconsolidated marine deposits first underwent pedimentation, then basalt volcanism followed, at first lava flow, then tuff and lava mounds were built upon the eroded Pannonian strata. Recent datings indicate that the volcanoes were not active simultaneously, but in distinct stages within the 5–2.5 million years time interval. After the eruptions post-volcanic geysers and thermal springs were typical in the area. The latter produced geyserites and travertines and the still active medicinal springs with carbon-dioxide-containing water also ensue from post-volcanic activity. Of the same genesis is the cone of the Aranyház (Golden House) on the Tihany Peninsula and the gaseous springs of the Kál Basin are also of post-volcanic origin.

The *Balaton Uplands* is an uneven plateau 150–200 m above Lake Balaton, south of the Bakony, on the northern shore of the lake. They are predominantly built of Permian and Triassic sediments. The volcanism of the Tapolca Basin affected this area, too: a hallmark in the landscape is a volcanic neck remnant, Hegyes-tű Hill (see the chapter on *Geology* 8). In the north the Veszprém–Nagyvázsony–Tapolca lineament separates the Uplands from the Bakony Mountains.

17 *The Tés Plateau in the eastern Bakony*

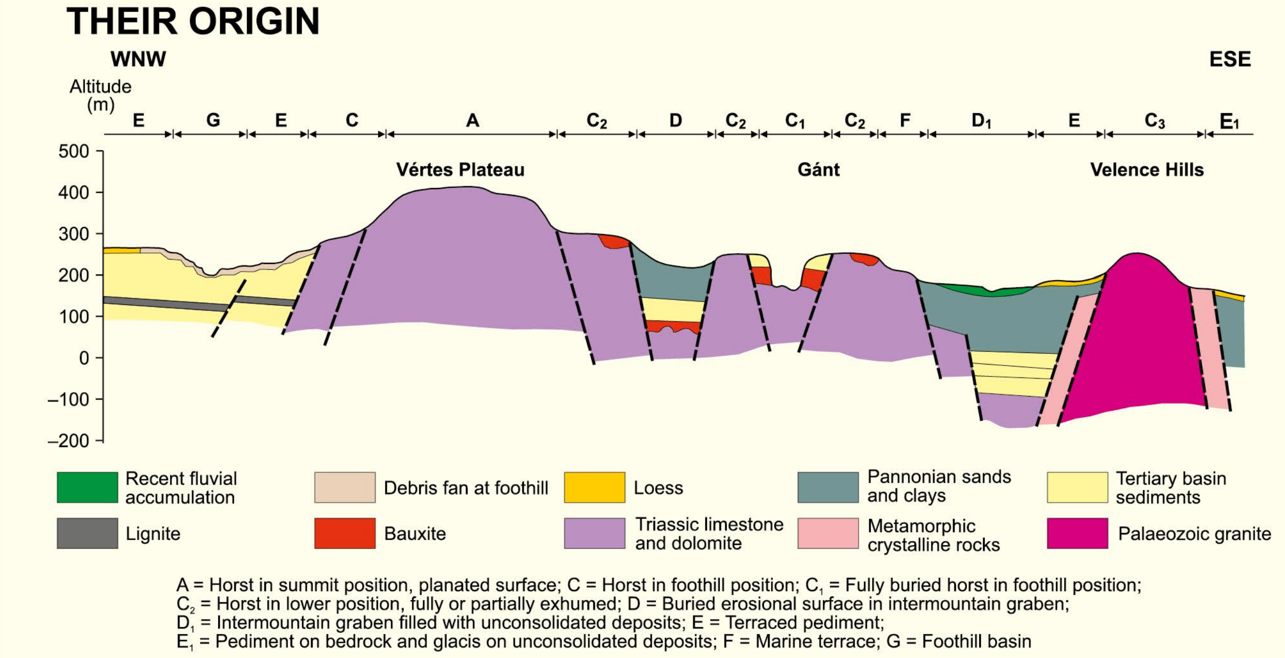
The Mór Graben is the boundary between the Bakony and the *Vértes Mountains,* a mountain mass mostly built of dolomite and limestone, bordered by steep slopes along marked faults 13. Like in the Bakony, in the Vértes, too, prevail tropical planated surfaces with late Cretaceous weathering products, including bauxite. They have been removed from the higher surfaces, but are retained in the basins (e.g. at Gánt) buried under younger deposits. On the northern margin, coal measures attest to Eocene transgression (at Tatabánya and Oroszlány).

From the Vértes a minor graben separates the *Velence Hills*, a member alien in all physico-geographical properties to the medium-height mountains. Its core consists of a Palaeozoic granite batholith. The several kilometre-deep rock load has been removed by erosion and a slightly dissected hill surface not higher than 250–300 m remained. Very special landforms are the woolsack-shaped weathered granite blocks, the pedestal rocks.

18 *The Lower Gerecse Mountains near Tarján*

The Gerecse, Pilis and Buda Mountains of mostly limestone and dolomite and the volcanic Visegrád Mountains (more correctly grouped with the North Hungarian Range) were first collectively called Dunazug Mountains by the well-known geographer Jenő Cholnoky (1870–1950). The largest member is the *Gerecse*, built chiefly of Mesozoic limestone, dismembered by north-to-south faults in addition to the 'usual'

13 MAIN LANDFORMS OF THE VÉRTES MOUNTAINS WITH THE AGE OF THEIR ORIGIN



19 *Middle Triassic dolomite horsts in the Buda Mountains, near Budaörs*

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20 *The Teve-sziklák (Camel Rocks) in the Pilis, near Pilisborosjenő*

23 *Hilly landscape in the Cserhát with the double peak of the Szanda dyke in the background*

25 *The Mátra Mountains with Kékes, the highest peak of Hungary*

northwest-to-southeast directed tectonic lines. The structure is characterised by four series of plateaus, basins and erosional valleys 18. The horsts rich in karstic landforms have only been denuded moderately because of the karstic rocks. The springs and even the streams deposited travertines at the footslopes.

Traits typical of the Gerecse, i.e. horsts divided by basins 19 and valleys, also appear in the *Buda Mountains*. The travertine deposits are also arranged in horizons. An important difference is that, besides Triassic limestones and dolomites, Tertiary rocks (such as Eocene limestone, Oligocene Hárshegy sandstone, Buda marl) are also common. To the northeast the Dorog–Pilisvörösvár faultline separates the Gerecse from the Pilis.

The *Pilis* is the highest part of the mountain group (Mt. Pilis, 757 m). It is a narrow series of horsts of limestone and dolomite, dismembered by northwest-to-southeast transverse faults. On the steep marginal slopes spectacular erosional features, pinnacles, rise 20.

21 *The Visegrád Mountains with the Visegrád castle in the Danube Bend*

The *North Hungarian Range* comprises two main mountain types, which are fundamentally (morphologically and structurally) different. The first type is represented by members of the Inner Carpathian *volcanic chain*. These stratovolcanoes were mainly built during the late Tertiary volcanism. In one of the largest volcanic ranges of Europe eruptions shifted in time from west to east. In the Danube Bend 21 the Visegrád and the Börzsöny Mountains along with the volcanic Cserhát and the Mátra originated in the Middle Miocene and the Tokaj–Slanec Mountains in the Late Miocene–Early Pliocene. The series of volcanoes continues towards the east and southeast in the Vihorlat–Gutâi and the Călimani–Gurghiu (Görgény)–Harghita (Hargita) Range, where activity ceased at the Ciomatu (Csomád) Mts. about 32,000 years ago.

22 *The volcanic range of the Börzsöny viewed from Nagybörzsöny*

All the volcanic mountains are surrounded by a gently sloping *foothill* foreland on unconsolidated rocks at 200–300 m elevation, dissected into a hilly landscape of interfluvial ridges at the end of the Pliocene and during the Pleistocene.

The *Visegrád* and the *Börzsöny Mountains* 22 now separated by the Danube show very similar geological structure, processes of origin and set of landforms. On the carbonate basement Oligocene and Early Miocene marine deposits (sands and clays) accumulated in great thicknesses. They are overlain by volcanites, initially (about 16 Mya) produced by shallow-sea eruptions, but later by a heavy dacite-producing activity. The subsequently built volcanic cones, later transformed into calderas, resulted from andesitic volcanism 13–15 Mya.

The *Cserhát region* is the lowest member (of rather hilly character) but also the most diverse in geological composition. In fact, the Western Cserhát is the continuation of the Transdanubian Range of carbonate rocks. The Mesozoic karst plateaus subsided in the Oligocene and were buried under Hárshegy sandstone strata. The central and eastern sections of the mountains were covered by extensive andesite lava masses in the Middle Miocene. In the Northern Cserhát the surface was eroded to the volcanic roots and only necks, former volcanic vents, and narrow dykes 23 rise above the surface of Upper Oligocene formations, predominantly sandstones. The erosional valleys follow tectonic lines and are often asymmetrical. The Central Cserhát is constituted of dismembered and tilted lava plateaus. In the south Late Miocene–Pannonian layers covered with loess and loam are

24 *The Medves Region with the volcanic neck of Somoskő (Šomoška) Castle*

found. Here a glacis surface was planated in the Upper Pliocene. The truncated surface was dissected by asymmetrical valleys and the interfluvial ridges gradually smooth into the broad terraced valley of the Zagyva River. Moving to the south we find a deeper and deeper loess mantle. The Pannonian deposits of the neighbouring *Gödöllő Hills* are overlain by the fluvial sands of the Carpathian rivers (such as the Ipoly/Ipeľ). The *Karancs* and *Medves Regions* are composed of exposed Miocene andesite laccoliths, Pliocene basalt sheets, volcanic necks 24 (see chapter on *Nature conservation* 10) and residual hills. The terrains around volcanic masses, on Miocene coal measures and Oligocene clays, marls and sandstones, were shaped into hills by erosion.

The highest peak of present-day Hungary, Mt. Kékes (1014 m), rises in the *Mátra Mountains* 25. Its basement is composed of Eocene volcanites and carbonates, but predominantly Oligocene marls and clays. The main mass is dated to the Middle Miocene (13–19 Mya), when volcanic activity produced several hundred metres of stratovolcanic sequence. In the western section huge crater ruins (Galya and Kékes craters), while in the east stratovolcano remnants of andesite and rhyolite banks are assumed. In the upper Miocene the volcanic edifice was tilted to the south and that is the structural reason for the contrast between the gently sloping southern foreland, the Mátraalja, and the steeper northern Mátrahát (or Mátralába).

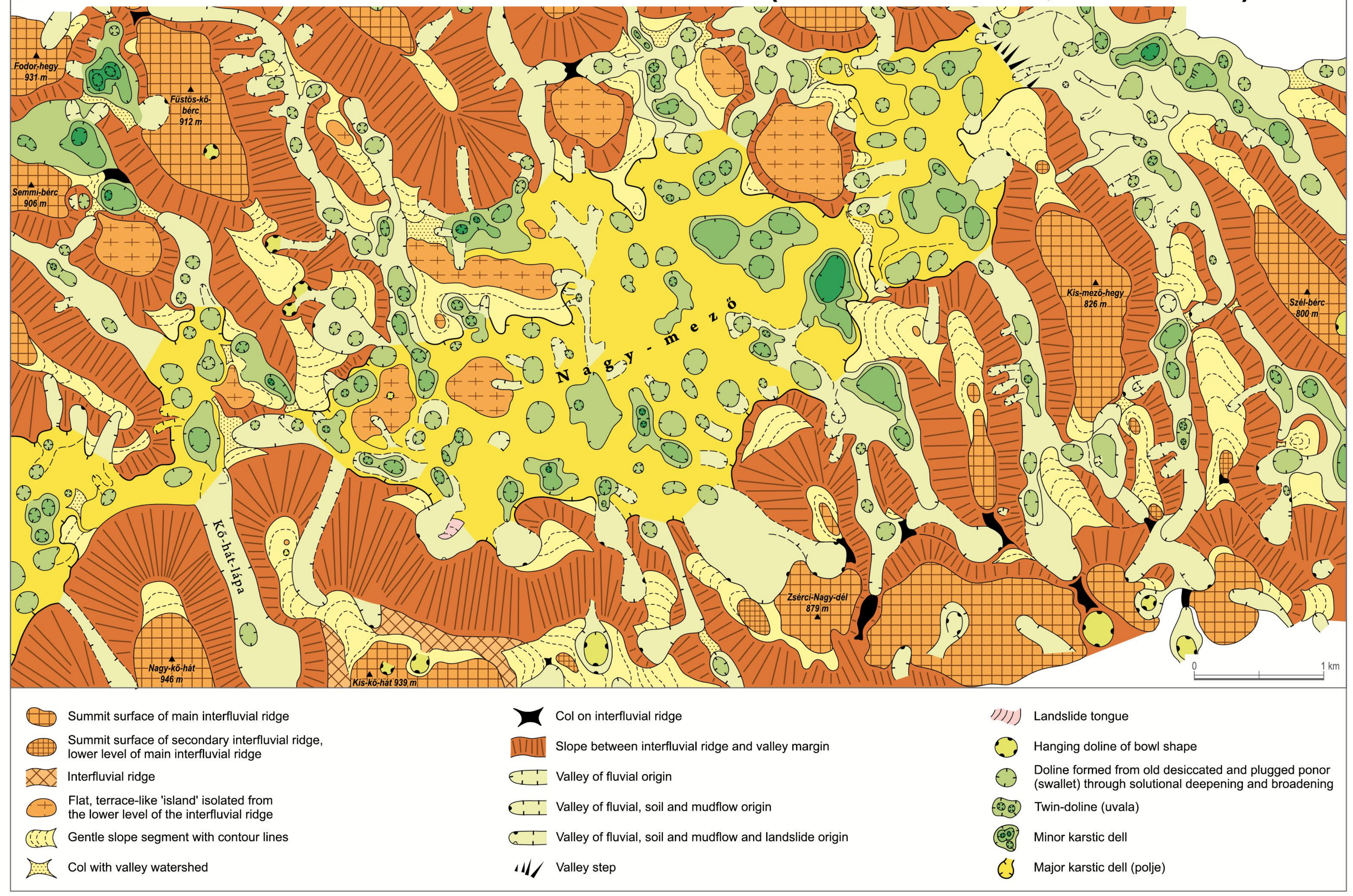
26 *The volcanic Sátor Hills in the Tokaj (Zemplén) Mountains at Sátoraljaújhely*

The *Tokaj (Zemplén) Mountains* is the easternmost member of the North Hungarian Range, between the Bodrog and Hernád Rivers. Although in the northeastern corner of the mountains the oldest rocks of Hungary (metamorphites, gneisses and schists older than 900 million years) are exposed on the surface, most of the mountains are composed of younger (11–15 million-year-old) volcanic rocks 26. The mountains are heavily dissected and basins are more numerous here than anywhere else in the North Hungarian Range.

Other mountains in North Hungary are *horst series of carbonate rocks*. The largest in area are the *Bükk* and the *Aggtelek Karst*. Their geological evolution is similar to that of the overwhelmingly carbonaceous Transdanubian Range. The plateaus present the most typical karstic landscapes in Hungary. Among the karst phenomena dolines, uvalas, karren fields, inflow (sinkhole) and spring caves are very common 14.

The *Bükk* is the mountains with the highest average elevation in Hungary, rich in karstic landforms and caves. The Bükk plateau of 900 m average elevation is surrounded by a lower planated surface, a broad pediment dissected by valleys and further sloping accumulational surfaces 27. The rocks of the basement (calcareous, clayey and, to a smaller extent, dolomite and sandstone strata) originated on the North African margin of the Tethys Ocean between the Late Carboniferous and the Middle Jurassic. In the Triassic intense underwater volcanic activity produced andesite and basalt lavas and tuffs intercalated among the sediment strata. A geological speciality is the pillow lava of Szarvaskő, erupted on the ocean floor. In the early Eocene intense terrestrial denudation under tropical climate resulted in peneplanation (e.g. on the Nagy 14 and Kis Plateaus). At the beginning of the Miocene volcanism intensified and covered the area with ignimbrite (rhyolitic tuff). On the southern margin of the Bükk region Pannonian deposits are also found. By the end of the Miocene the central Bükk uplifted 300–400 m and turned into a mountainous terrain, dissected by deep valleys. The karstification, which is still going on, began at that time. Under the semidesert climate of the first half of the Pliocene pedimentation accompanied further uplift.

14 GEOMORPHOLOGY OF THE NAGY PLATEAU (GREAT PLATEAU, BÜKK MTS.)



27 *The Bükk and the Bükkalja near Noszvaj*

On the *Slovak* and *Aggtelek Karst* 28 tropical karstification took place and its remnants are locally still visible – e.g. near Lake Vörös ('Red Lake') of Aggtelek – in spite of the subsequent strong denudation. In the Pliocene karstification intensified again and led to the formation of a rich assemblage of surficial and underground features. The *Rudabánya Hills* and the *Szalonna Karst* on opposite banks of the Bódva River are different in their geological structure, but underwent similar geomorphic evolution. Their lower position and rocks less susceptible to karst formation explain why they do not abound in karst features.

The *Nógrád (Novohrad)–Abaúj (Abov) Depression* in the valleys of the Ipoly (Ipeľ), Rimava (Rima), Sajó (Slaná) and Hernád (Hornád) Rivers in the foreland of the North Hungarian Range stretches along about 180 km in the Hungarian–Slovakian border region. The depressions are rather closed but the broad terraced valleys of rivers between the members of the Range provide good links with the Alföld. In the warm and wet interglacials of the Pleistocene valley formation was the predominant process even in the hilly regions. In addition, landslides shaped the slopes and they are still efficient geomorphic processes today, mainly on clayey-loamy hilly surfaces (e.g. in the Sajó and Hernád valleys: see the chapter on *Natural hazards* 3 7). In this basin series, between the Bódva and the Hernád, we find the *Cserehát Hills* at 250–300 m elevation. This is a double-faced hilly region in basin position 29, above which the mountain frame rises by 300–600 m on the average. Compared to the mountain frame, the area is a basin, but viewed from the broad valleys of the Hernád and the Bódva it presents a hill character. It has virtually no loess on its surface. The recently slightly uplifted area is minutely dissected by streams regressing from the direction of the Hernád and Bódva valleys. On hillslopes landslides are common.

29 *The Vadász Stream valley in the Cserehát Hills*

The *Szendrő Hills* rise as an island from the soft sediments of the Cserehát and represent a detached block of the Southern Alps moved laterally far in northeastern direction. The building rocks (black slates, sandstones and various limestones) are of Palaeozoic age ranging from the Ordovician to the Lower Carboniferous and metamorphosed during the Alpine orogenies. Gorges deepen into the surface of hard rocks.

28 *The Slovak Karst with Turňa (Torna) Castle in the foreground*

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