Chapter 9
Recent Landform Evolution in Hungary

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Abstract Fluvial geomorphic processes (channel and floodplain evolution) are widespread in the extensive lowlands of Hungary. Since flow regulation in the nineteenth century, river channels have shown adjustments of considerable degree. Some agricultural areas in hills and low mountain basins are seriously affected by water erosion, particularly gully development on loess. Although all sand dunes have been stabilized by now, historically wind erosion has also been a major geomorphic agent in blown-sand areas. The areas affected by mass movements and karst processes are limited but their processes still operate – partly in function of the changing climatic conditions. Applied geomorphological research focuses on ever intensifying human impact on the landscape (particularly in mining districts), which has become the primary driver of recent geomorphic evolution in Hungary, too.

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9.1 History of Geomorphological Research in Hungary

Dénes Lóczy

Hungarian geomorphological research has developed in close association with
Central European geomorphology (Lóczy and Pécsi 1989; Pécsi et al. 1993; Pécsi
1999). Its first major representative was J. Hunfalvy (1820–1888), who published a
Description of the Physical Conditions of Hungary in three volumes between 1863
and 1865. The first systematic research into the physical geography of a region, in a
true Humboldtian conception, was conducted by a populous group of scientists in
the *Lake Balaton basin* under the guidance of L. Lóczy Sen. (1849–1920), the most
eminent figure in Hungarian geology and geography. The findings, summarized in a
monograph series of 32 volumes, include observations related to the origin and
evolution of the lake basin. Lóczy's student, J. Cholnoky (1870–1950) was primar-
ily engaged in geomorphology, particularly in the investigation of fluvial (river
mechanisms, terrace formation) and aeolian action (blown-sand movements, traces
of arid conditions in the Carpathian Basin), karst, and periglacial processes as well
as long-term landform evolution. Cholnoky was a prolific writer, who published 53
books (mostly popularizing science at high standards) and 160 academic papers in
physical geography. Gy. Prinz (1882–1973) put forward the first coherent theory
(the *Tisia concept*) for the evolution of the structure of the Carpathian Basin, which
had been prevalent in geosciences until the advent of plate tectonics.

In the post-war period B. Bulla (1906–1962) was an outstanding investigator of
fluvial and glacial processes, loess formation, and chronological problems. His
climatogenetic approach to *geomorphology*, similar to J. Büdel's, is manifested in
his concept of rhythmical geomorphic evolution, which explains landform evolution
on the basis of contemporary theories of Tertiary climatic and Pleistocene glaciation
cycles. He described the geomorphology of Hungarian landscapes in his book
The Physical Geography of Hungary (1964).

In the late 1950s and 1960s geomorphological investigations are performed in the
framework of *complex landscape research* at mesoregion scale (Marosi 1979). In
the monograph series *Landscapes of Hungary* the geomorphic evolution of the six

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macroregions were presented in detail along with the assessment of utilization opportunities of landforms for various purposes. For the detailed field survey of topographic features a uniform legend for geomorphological mapping was proposed in 1963 and detailed *geomorphological maps* were drawn at 1:10,000 and 1:25,000 scales for a number of meso- and microregions. Hungarian geomorphologists had a prominent role in compiling the Geomorphological Map of the Carpathian and Balkan Region (Pécsi 1977) and the geomorphological sheet in the Atlas of Danubian Countries (Pécsi 1980). In the 1970s *applied research* was encouraged and engineering geomorphological maps for construction purposes were prepared and the areas of Hungary endangered by mass movements were surveyed. The physical environments of settlements were first studied at Pécs (F. Erdősi, Gy. Lovász).

Loess studies, led by M. Pécsi, have been central in Hungarian geomorphology. They are concerned with the definition, classification, origin, dating, and geomorphological significance of *loess deposits* (Pécsi and Richter 1996). In addition to loess-paleosol sequences, *Quaternary research* also involved the study of river terraces, travertines, and vertebrate fauna in order to solve chronological problems like identifying the Plio-Pleistocene boundary. From the analysis of finely laminated slope deposits with seasonal cycles, it was deduced that in the Pleistocene glacials *periglacial processes* (gelisolifluction, sheet wash, creep and deflation) operated over extensive surfaces and were collectively described by M. Pécsi as *derasion* (Pécsi 1967). He pointed out the significance of derasional processes in the transformation of the slopes of mountains, foothills and loess hill regions in Hungary (Mezősi 2011).

The reconstruction of long-term relief evolution has long been in the focus of geomorphological research (Pécsi and Lóczy 1986). The climatic conditions favoring the formation of *erosional surfaces* (summit planated surfaces, pediments, and glacis) were identified in the 1960s and 1970s and the polygenetic models of planation were applied to the mountains of Hungary by M. Pécsi (1970a) and his co-workers (J. Szilárd, L. Ádám, F. Schweitzer and Á. Juhász). Recently, geomorphological surfaces are reconstructed by GIS methods (e.g., Bugya and Kovács 2010).

Quantitative methods were first introduced into Hungarian geomorphology in the 1970s. *Morphometric analyses* and *modelling* of geomorphic processes based on *field and laboratory experiments* were pioneered at all the most important geomorphological schools in Hungary. Soil erosion investigations on experimental plots were launched by L. Góczán and Á. Kertész at the Transdanubian field stations of the Geographical Research Institute of the Hungarian Academy of Sciences and now continued by Z. Szalai and G. Jakab. At the University of Debrecen experiments were initiated by L. Kádár (to solve problems of river mechanism transitions, sediment transport, meandering and terrace formation) and his students, Z. Borsy (blown-sand movements, introduction of new dating techniques), Z. Pinczés (frost shattering), complemented by field surveys led by A. Kerényi (splash erosion and sheet wash), J. Szabó (mass movements) and J. Lóki (wind action). Through such investigations landscape ecological research was founded (A. Kerényi, P. Csorba). At the Eötvös Loránd University of Budapest the comparative volcano-morphological investigations of A. Székely from the 1960s to the 1980s have been further developed using remote sensing, morphometric and stratigraphic methods by his students (A. Nemerkényi, D.

Karátson). Drainage system evolution was reconstructed by Gy. Gábris applying various approaches. At the University of Szeged geoecological mapping (G. Mezősi) and fluvial geomorphology (T. Kiss) are predominant. Karst morphological research has several centers: Szeged (L. Jakucs, I. Kevei-Bárány), Budapest (L. Zámbó), Miskolc (A. Hevesi), Pécs (P.Z. Szabó, Gy. Lovász), and Szombathely (M. Veress).

The new generation of geomorphologists, who began their career after 1990, are engaged in both fundamental (novel techniques in landform dating; river, wind and soil erosion measurements; floodplain accumulation investigations; volcanic reconstructions; field surveys of anthropogenic and karst processes) and applied geomorphological research (GIS applications for landscape analyses and geomorphological hazards assessment; land reclamation and site selection for waste disposal and other infrastructural projects) – often in international cooperation. A collection of papers on the rates of active geomorphic processes have recently been published (Kiss and Mezősi 2008–2009).

9.2   Tectonic Setting

Dénes Lóczy

Hungary (93,030 km^2) is a landlocked country, located in the central Carpathian (Pannonian or Middle Danubian) Basin, which is surrounded by the Alpine, Carpathian, and Dinaric mountain ranges (Kocsis and Schweitzer 2009). The basin is a Tertiary depression, formed as a consequence of plate tectonic movements and the uplift of the encircling mountains. Naturally, the tectonic setting of the country, briefly treated here, can only be described in the context of the entire Carpatho–Balkan–Dinaric region (see Chap. 1 in this volume).

The first *plate tectonic models* for the evolution of the Carpathian Basin emerged in the 1970s and 1980s (treated in Pécsi 1999). The basement is made up of two basic components: the ALCAPA (Alpine-Carpathian-Pannonian) Mega-unit of African origin and the Tisza-Dacia Mega-unit of European origin (Haas and Péró 2004). According to a generally accepted concept, the indentation of the Adria Microplate of African origin and the subduction of the European plate margin led to the extension and eastward rotational movement ("escape") of ALCAPA and the opposite rotation of the Tisza-Dacia Mega-units during the Paleogene (Horváth and Royden 1981; Balla 1982; Kázmér and Kovács 1985; Csontos et al. 1992; Márton 1997; Fodor et al. 1999). The juxtaposition of the two mega-units completed by the Early Miocene. In the Middle Miocene *synrift stage* of the back-arc basin formation, the crustal extension resulted in andesitic and partly dacitic volcanism (Horváth 1993). The Late Miocene *post-rift stage* involved accelerated subsidence, high-rate sedimentation, and locally alkali basalt volcanism (Fodor et al. 1999). In the Pliocene north-to-south compression resulted in the termination of subsidence and even caused uplift in some parts of the basin (Horváth 1993; Horváth et al. 2006). The

Quaternary activity and geomorphological significance of the main tectonic lines and the subordinate fault patterns are strongly debated (Síkhegyi 2002).

9.3 Geomorphological Units

Dénes Lóczy

On the basis of the overall character of topography (elevation, relative relief), structure (lithology and tectonics), and geomorphic processes traditionally six geomorphological macroregions are identified (Bulla and Mendöl 1947; Pécsi and Somogyi 1969; Pécsi 1970b – Fig. 9.1):

1. The Great Hungarian or Middle Danubian Plain (Alföld or Nagyalföld);
2. The Little Hungarian or Little Danubian Plain (Kisalföld);
3. The Alpine foothills or Western Transdanubia (Alpokalja);
4. The Transdanubian Hills;
5. The Transdanubian Mountains;
6. The North-Hungarian Mountains with its intramontane basins.

With the exception of the Transdanubian Mountains, all the geomorphological units continue beyond the country's borders and their boundaries closely follow those of the highest-level landscape units (Hajdú-Moharos and Hevesi 2002).
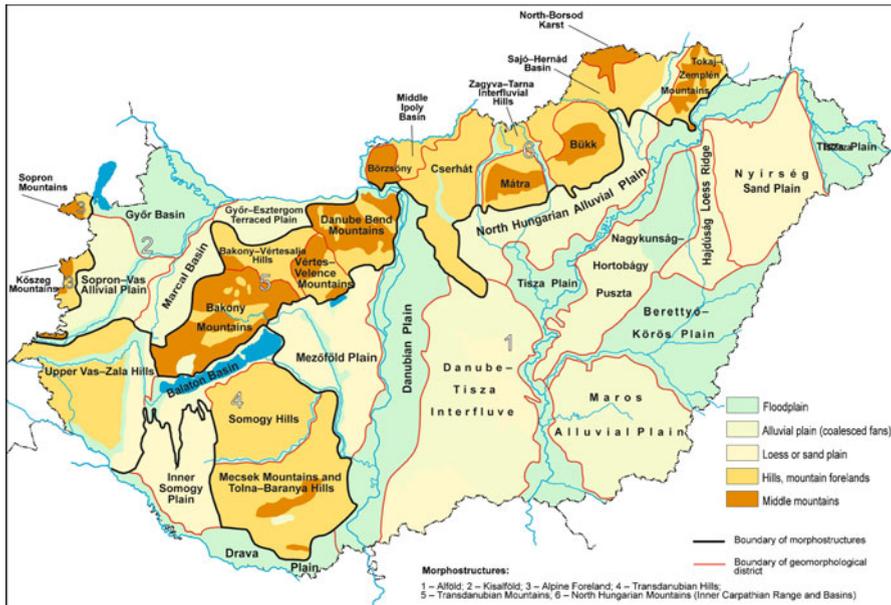

Fig. 9.1 The geomorphological divisions of Hungary (Simplified after Pécsi and Somogyi (1969); Pécsi (1970b))

The *Great Hungarian Plain* occupies two-thirds of the country's territory (62,300 km^2) and extends in all directions over the territory of neighboring countries (including the Danube Lowland, the East Croatian Plain, the Vojvodina Plain, the West-Romanian Plain, the Transcarpathian Lowland of the Ukraine, and the Eastern Slovakian Plain) with a total area of more than 100,000 km^2 and average elevation around 100 m. Along its margins there is a usually gradual transition to foothill areas. The surface was produced by Pleistocene and Holocene fluvial and aeolian accumulation and is subdivided accordingly to three types: alluvial plains, loess-mantled alluvial fans, and alluvial fans with blown-sand dunes. The protected floodplains and loess-mantled fans are presently shaped by human action (mainly arable farming), the blown-sand areas by seasonal wind action, and the active floodplains by fluvial processes.

In northwestern Hungary the *Little Plain* (5,300 km^2) encompasses the double Pleistocene alluvial fan and the right-bank terrace system of the Danube. Its subsidence and filling history resembles the evolution of the Great Hungarian Plain with the difference that most alluvial fans extended towards the center from the northwestern-northern direction. The main landscape types are cultivated floodplains and terraced plains. Today the impacts of cultivation and river deposition determine the character of the landscape.

Only a fraction of the *Alpine foreland* (750 km^2) belongs to Hungary. This is the geomorphological region with the smallest extension and the only one that – strictly speaking – falls outside of the Carpatho-Balkan-Dinaric region. Its landscapes are mostly formed on metamorphic rocks and the sediments from their erosion as well as on alluvial gravel fans. A large proportion of the vegetation cover is coniferous and deciduous forests and pastures with some arable land. Over the rock surfaces weathering and slow hillslope processes are predominant, while streams incise into the fan surfaces.

The *Transdanubian Hills* (10,200 km^2) include lowland as well as mountainous areas (Mecsek Mountains) but most of it is locally minutely dissected, loess-mantled, or sand hills of asymmetric topography and 200–300 m elevation with broad river valleys. The hill region is subdivided into independent hills and foothill areas both predominantly under crop cultivation. Sheet wash, intense rill, and local gully erosion as well as soil creep are the main geomorphic agents. Cultivation accelerates the removal of loose soil.

The *Transdanubian Mountains* (6,400 km^2) are a series of block-faulted and slightly folded-imbricated horsts of southwest to northeast general strike, separating two subbasins of the Carpathian Basin. The mountains were planated in the Mesozoic and a dense network of fractures dismembered them during the Tertiary into numerous plateaus at 300–700 m elevation (planated surfaces buried and exhumed on several occasions) separated by basins and grabens at various levels. Sparse drainage is typical with gorge-like valleys. Most of the forested, plateau-like Mesozoic and Cenozoic limestone mountains are affected by karstic processes, while surfaces of dolomite and andesite rocks show characteristic weathering phenomena and mass movements. The individual members are separated by tectonic valleys with present-day seismic activity.

Beyond the Danube Bend, the continuation of the Transdanubian Mountains of 8,000 km² area is called the *North-Hungarian Mountains*. It is a range of highly variable geological structure (member of the Inner Carpathian Range) and elevation (the only mountains reaching above 1,000 m), equally including mountains of Mesozoic-Paleogene sedimentary and Miocene-Pliocene volcanic rocks (rhyolites and andesites). The volcanic landforms are in various stages of erosional destruction. An almost continuous broad belt of pediments, glacis, and alluvial fans have formed along the southern margin of the range. The higher surfaces are forested, while foothills are used as arable land, southern slopes as gardens and vineyards. The present-day geomorphic processes also vary on a wide range: hillslope processes, mass movements, karstification, and all types of erosion by surface runoff. The members of the range are separated by broad fluvial valleys, draining to the south, towards the Tisza River.

9.4   Recent Geomorphic Processes

9.4.1   River Channel Processes

György Sipos
Tímea Kiss

The whole territory of Hungary belongs to the drainage basin of the *Danube* (total area: 817,800 km²). Arriving in the Carpathian Basin, the Danube channel slope drops to 35 cm km⁻¹ (0.00035). During the Pleistocene and Holocene, the river built a double alluvial fan with anastomosing (braided and meandering) channels. Except for the Danube Bend, where the river turns from a west-east to a north-south direction, river gradient is further diminished and to the south of Budapest the Danube forms another large sandy alluvial fan, the Kiskunság (Little Cumania) fan with sparse drainage and aeolian landforms (Mezősi 2011). The discharge of the Danube is influenced by the fact that it has no major tributary on either bank between the Ipoly (Ipel') and the 749-km long Drava in Croatia.

The eastern half of Hungary is part of the catchment of the *Tisza* River (157,135 km²), the largest left-bank tributary of the Danube and the hydrological axis of the Great Hungarian Plain. The Tisza in Hungary is a typical meandering lowland river of 2 cm km⁻¹ gradient (0.00002). The nineteenth-century flow regulations were even more drastic interventions into the life of the river than those on the Danube. As a consequence of numerous cut-offs river length was reduced from 1,419 to 966 km. The passage of flood waves was accelerated but the highly fluctuating river regime still causes serious problems of flood control (Szabó et al. 2008). Prolonged rainfalls or rapid snowmelt in the Slovak, Ukrainian, and Romanian Carpathians result in flood waves on both right-bank (like the Bodrog, Hernád/Hornad, Bódva and Sajó/Slaná) and left-bank tributaries (like the Szamos/Someş,

Kraszna/Crasna, Körös/Crişul, Berettyó/Barcău and Maros/Mureş). In addition to flow regulation, the greatest human interventions are the dams of Tiszalök and Kisköre on the Tisza.

In Hungary the evolution of river channels has been investigated since the mid-nineteenth century, the main period of channelization. The studies of river channel change rely on cross-section surveys made at every river kilometer (rkm) in 20–25 year time interval since the 1890s and on measurements of sediment discharge starting in the late nineteenth century. In the 1950s, river channel stabilization works gave a new impulse to hydrological mapping and analysis. Results were summarized in a series of atlases published by the VITUKI (Research Institute for Water Management) and river channel processes were described quantitatively (Szlávik and Szekeres 2003). The rates of processes like meander evolution and migration, width change, channel aggradation and incision, finally channel pattern metamorphosis are all influenced by variables of the fluvial system (water and sediment discharge, valley slope, sediment grain size, vegetation, human impact).

Before flow regulation Hungarian rivers generally flowed in anastomosing-braided-meandering channels on their gently sloping alluvial fans along mountain fronts and meandered in the flat central lowlands of the Carpathian Basin. Channelization works in the nineteenth century involved morphological changes. Comparing archive maps, Z. Károlyi (1960a) determined the changes in sinuosity and the downstream *migration of meanders*. The highest rate of migration between 1890 and 1951 was detected on the Upper Tisza (100–1,700 m, 1.6–27.9 m year^{-1}) with no bank stabilization. As pointed out by Csoma (1973) and Laczay (1982) from the analysis of hydrological maps, meanders with convex-bank point-bar formation migrate in a downstream direction. They also introduced to the Hungarian literature a meander classification scheme, which is still widely used. Somogyi (1974) investigated meander migration between 1783 and 1900 along the southern Hungarian section of the Danube River. By overlaying maps, he found that the lateral shifting and downstream migration rates of meanders were 16–50 and 20–38 m year^{-1}, respectively. Along the Hungarian upper and middle sections of the Tisza River meanders take ca 150 years to form and to be cut off (Somogyi 1978). Mike (1991) summarized the data on meander evolution on Hungarian rivers by using the VITUKI atlas series. Unfortunately, the studied parameters are not the same, and probably this is the reason why no conclusion is drawn in his study.

Meander evolution is intensive even on regulated rivers. On the Middle Tisza cross-section data indicate channel shifts of 200 m since flow regulations (rate: 1.8 m year^{-1}) and meander development *increasing channel length* by 16 km (Nagy et al. 2001). On the Lower Tisza the analyses of several cross-sections, maps, and aerial photographs (Fiala and Kiss 2005, 2006) showed that the length of a 25 rkm long study reach had increased by 6 m year^{-1} from the time of cut-offs (1860s) till the construction of revetments (1950s) (0.25 m rkm^{-1} year^{-1}), but from the 1970s this value dropped to 0.8 m year^{-1} (0.03 m rkm^{-1} year^{-1}). In the meantime the planform of some meanders has become distorted (sharpening, radius decrease). Along the Hungarian section of River Maros (Mureş) dendrogeomorphological and GIS studies (Blanka et al. 2006; Blanka and Kiss 2006; Sipos 2006) of quasi naturally developing and

artificially stabilized meanders suggested that since channelization in the 1850s the apex of some unregulated meanders migrated 250–300 m (1.7–2.1 m year⁻¹) downstream. Over the past 50–60 years the formation of point bars was also intensive (10 m year⁻¹), while concave banks only retreated at a rate of 2 m year⁻¹ (Blanka et al. 2006). On a 30 rkm section of the river, lacking bank stabilization the length of the center-line has grown at a rate of 2.5 m year⁻¹ (0.08 m rkm⁻¹ year⁻¹) since the regulations. On the River Hernád (Hornad) the length of an originally 5.7 rkm section has increased by 1.6 rkm between 1937 and 2002 (Blanka and Kiss 2006). In this case the change of meander parameters can partly be explained by tectonics. Exceptionally large floods are of increasing frequency since the 1990s (Kiss et al. 2009) and may cause bank shifting up to 16.7 m along the Hernád (as it happened in 2010), particularly along the high bluffs of overmatured meanders.

As opposed to meander evolution, *channel width* changes, partly due to natural channel development processes and partly to regulation measures, have rarely been investigated on Hungarian rivers. As consequence of the nineteenth-century artificial cut-offs, the width of regulated reaches decreased (Ihrig 1973), but after a decade the new channels began to broaden (Márton 1914; Tőry 1952; Lászlóffy 1982). Along some reaches of the Hungarian Upper Danube and channel width has generally decreased and islands coalesced with the banks parallel with riverbed aggradation (Laczay 1968). Recent studies report general width decrease along the Lower Tisza (16% since 1842, i.e., a 0.2 m year⁻¹ rate) (Fiala and Kiss 2006) and Maros Rivers (Sipos 2006; Sipos et al. 2007). Channel narrowing results from bank protection and also from incision. The Maros channel broadened after regulations, but since the 1950s has narrowed by 18–20% (0.3 m year⁻¹) along sections not affected by bank stabilization (Kiss and Sipos 2003, 2004; Sipos 2006). The process is driven by the stabilizing effect of vegetation, as also observed by M. Szabó (2006) on the Szigetköz section of the Danube.

Changes in channel depth and *cross-section* shape are primarily related to incision, aggradation, or change of slope. Kvassay (1902) investigated vertical channel change along the Danube, Tisza, and their tributaries. According to his calculations, flood levels on the Lower Tisza increased by 250–300 cm, while the level of low waters decreased by around 110 cm between 1830 and 1895 (rate 1.6–1.8 cm year⁻¹). This explains cross-section alterations. Fekete (1911) compared cross-sectional surveys at three dates (1842, 1891, and 1906–1909) along the entire Tisza and found that mean depth increased by 140 cm on the Lower Tisza (2.2 cm year⁻¹), meanwhile the area of cross-sections at certain reaches changed (decreased or increased) by 100 m². He also calculated a riverbed aggradation of 5.1 million m³ in 15 years (3,400 m³ rkm⁻¹ year⁻¹) for the Lower Tisza (now in Serbia). Félegyházi (1929) claims that in many cases the low stage cross-sectional area increased as the channel incised. Károlyi (1960a, b) identified up to 300 cm *incision* (a 2.6 cm year⁻¹ rate in extreme cases) from low stage water level drop. Repeated channel surveys were applied by Laczay (1967) to investigate morphological change induced by the 1965 flood on the Hungarian Upper Danube. He found that during the flood certain riffles rose to the water level suitable for navigation during low stage periods. He also emphasized the role of low and medium stages in redistributing bedload. On the longer term, between 1903 and 1967, at same site 58,000 m³ year⁻¹ sediment accumulation was observed (Laczay 1968).

Dredging became necessary and resulted in 10% growth of cross-section area (a sediment loss of 1,650 m³ rkm⁻¹ year⁻¹ – Csoma and Kovács 1981). From stage-discharge curves analyses Csoma (1987) identified a 30–40 cm incision for the Danube upstream of Budapest as a result of dredging. The Hungarian Lower Danube experienced scouring to 3 m depth locally since channelization.

Along a 25-km section of the Lower Tisza the consequences of various river management strategies between 1890 and 2001 were assessed by Kiss et al. (2002, 2008b). Varying with the morphological situation and the intensity of human intervention, the area of bankfull cross-sections decreased by 4–21% while depth increased by 5–45% due to building bank revetments. Novel technology (seismic measurements of river bed morphology) applied to establish the rate of alluviation on the Middle Tisza yielded no evidence of significant sedimentation and at several locations even large pools were observed (Nagy et al. 2006). In the meantime, channel capacity on the Middle Tisza at Szolnok decreased significantly (Illés et al. 2003a), since, at the same stage and water surface slope, the river channel conveyed 250–300 m³ s⁻¹ less discharge in 1998 than during the 1979 flood. By analyzing the 100-year-long data series of the Szolnok gauge station Dombrádi (2004) claims that cross-section change is no ready explanation for the recent increase of flood stages.

Riverbed morphology is associated with *sediment waves* moving through the channel. For the Hungarian Maros section, repeated channel surveys (Sipos 2006; Sipos et al. 2007), made at both similar and very different water stages, resulted in 55,000 and 89,000 m³ sediment accumulations in two consequent years during spring floods and no variation in accumulation during low stages. From the analysis of a 15-year data series of low-water cross-sections on River Maros no channel incision could be identified (Kiss and Sipos 2007) – although the studied reach became narrower (Sipos 2006). Studied by analyzing daily cross-sectional data at gauges on the Tisza and on the Maros, the response of the riverbed to the 2000 flood event is very similar – in spite of different morphological and hydrological characteristics (Sipos and Kiss 2003; Sipos et al. 2008).

Channel pattern is a complex indicator of alluvial river behavior (Gábris et al. 2001) as it is closely related to the climate and geology of the catchment. (discharge, slope, sediment amount and type, vegetation). The issue of drivers was first raised in Hungary by Kádár (1969). Recently, Gábris et al. (2001) determined channel pattern changes over the past 20,000 years through the planimetric analyses of palaeo-channels, palynology, and radiocarbon dating. Transitions between braided and meandering patterns were caused twice by climatic (water and sediment discharge) and once by tectonic (slope) change. Particularly in the Körös Basin tectonic movements could overwrite climatic changes (Gábris and Nádor 2007). The impact of neotectonic movements on channel parameters are considerable along the Tisza (Timár 2000, 2003). The reaches of high sinuosity coincide with areas of intensive subsidence, increasing local slope. At certain cross-sections the increase of flood levels is partly caused by uneven tectonic subsidence.

On the Hungarian section of the Maros River *human impact* remarkably modified natural processes (Sipos 2006; Sipos and Kiss 2006; Kiss and Sipos 2007). Due to numerous nineteenth century cut-offs the slope of the riverbed doubled and

meandering-anastomosing was replaced by braiding. Where further bank stabilization did not involve channel narrowing, decrease in mid-channel island number, i.e., reduction in braided character, is observed. The recovery of a meandering pattern cannot be expected sooner than in 1,000 years.

9.4.2   Floodplain Evolution

Dénes Lóczy

Floodplain areas are the most extensive geomorphological units of the Carpathian Basin (Fig. 9.2). During the Quaternary both hydrological axes of the Carpathian Basin, the Danube (Pécsi 1959) and the Tisza (Bulla 1962), suffered major shifts in their courses that involved far-reaching consequences for the geomorphic evolution of the Great Plain. There have been several attempts at the *reconstruction of* the complete *paleo-drainage network* and, thus, the location of floodplains, for the various stages of the Quaternary (Borsy 1990; Mike 1991; Félegyházi et al. 2004). (It is interesting to note a marked extremity of opinion: the creationist or 'intelligent design' thought, popular internationally, under a mystic varnish also emerged concerning drainage evolution – Burucs 2006) The most often applied *methods* of scientific reconstructions are palynological and sedimentological analyses of channel
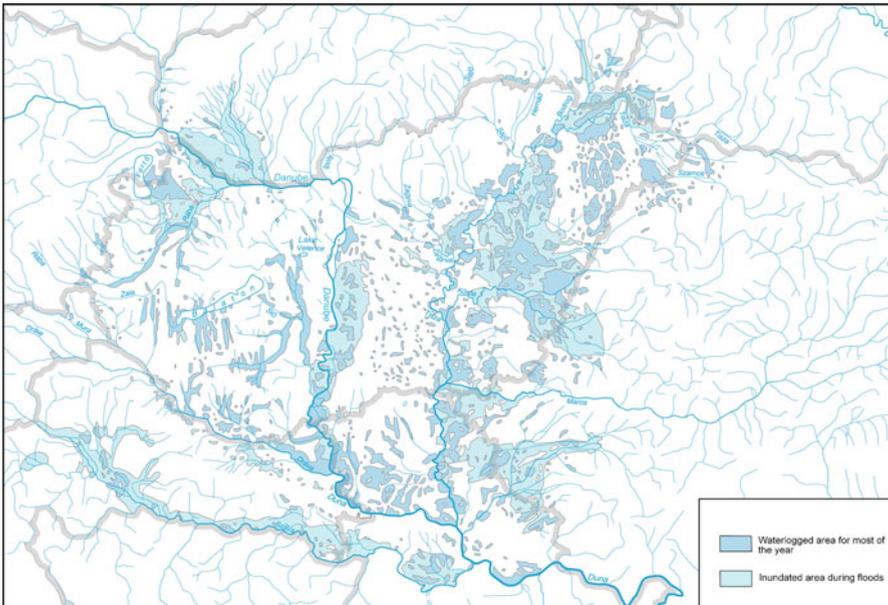

Fig. 9.2 Map of regularly inundated and seasonally waterlogged areas in Hungary before flow regulations
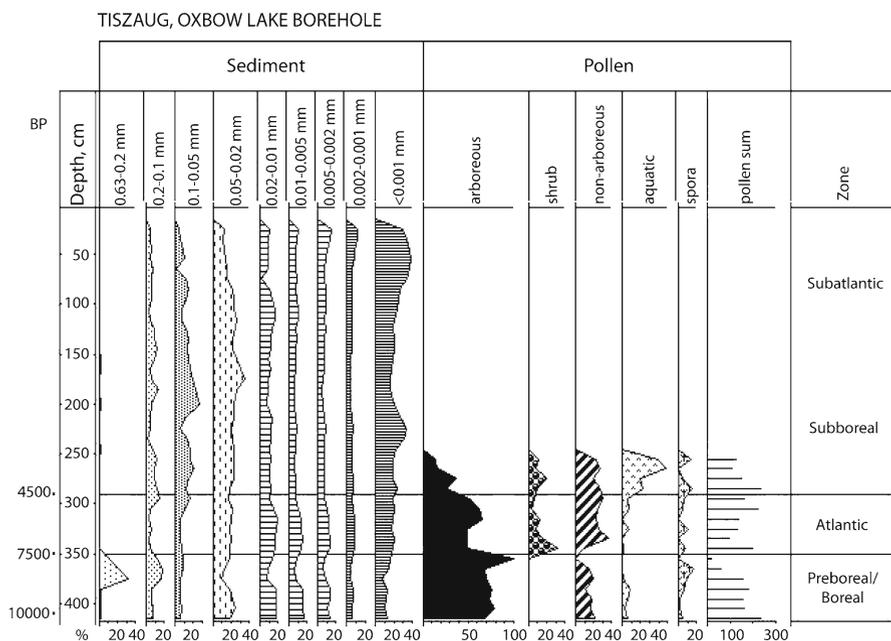
Fig. 9.3 Sedimentological and palynological profiles of an oxbow on the Tisza floodplain (By Félegyházi)

fills for the northeastern Great Hungarian Plain (Fig. 9.3 – Borsy and Félegyházi 1983; Félegyházi 2001); estimation of one-time water discharge from radioactive isotope dating and also palynological investigations for the Middle Tisza region (Gábris et al. 2001); application of remote sensing data, field surveys using GPS and dendrochronology (Sipos and Kiss 2001); GIS interpetation of archive data and channel profiling by radar (Sipos and Kiss 2003).

Channelized watercourses, flood-control dykes, and drainage ditches attest to the largest scale of human transformation of floodplains. *Channel alterations* over historical time have been recorded on the map sheets of the Research Institute for Water Management (VITUKI) Hydrographical Atlas series since the 1970s. For instance, along the Bodrog River (VITUKI 1974), the impacts of damming at Tiszalök on the channel were analyzed on the basis of maps from 1979 to 1986. The results did not show significant rates of alluviation or horizontal channel shift (Szeibert and Zellei 2003). Surveying continued along the Hungarian-Slovak joint section in 1990 and 70 cross-sections were completed. Recently, investigations resumed in order to support the hydrological modeling necessary to assess the changes that occurred during the 1998 and 1999 floods. However, the geomorphological interpretation of the data collected by hydrologists and flood control experts is usually lacking.

The monitoring of *hydrological conditions* is indispensable for the study of floodplain evolution. Water discharge measurements of scientific precision began along the Danube in the 1950s. From 1999 on discharge at extreme water levels was repeatedly recorded along all the tributaries of the Tisza. At flood stages experts of the

Eötvös József College at Baja investigated *sediment transport* along the Middle and Lower Tisza (Zellei and Sziebert 2003) and the Bodrog (Szeibert and Zellei 2003). During the March 2001 flood wave the concentration of suspended load was found to be as high as 1,372 mg L^{-1} at Kisköre and 1,195 mg L^{-1} in the Szolnok section (Szlávik and Szekeres 2003). The difference proves deposition in the Lake Tisza reservoir. It is a remarkable observation that sediment transport in suspension – at least along this river reach – attains its maximum before bankfull stage and, therefore, most of the material transported is deposited in point bars and – in spite of previous expectations – relatively small proportions serve the accretion of natural levees and more remote floodplain sections (Szlávik et al. 1996; Szlávik and Szekeres 2003; Pálfai 2003). The impact of *individual floods* on floodplains resulted in both accumulation and erosion in the Szatmár plain (Borsy 1972); along the Körös rivers (Rakonczai and Sárközi-Lőrinczi 1984) and the Maros and Middle Tisza (Oroszi et al. 2006). Recently, the hydrological, geomorphological and soil conditions of flash floods are intensively studied using GIS modeling (e.g., Czigány et al. 2010).

Human impact has been observed on all the rivers of Hungary (Somogyi 1978, 2000; Csoma 1968). Channel dredging, gravel extraction, confluence replacement, and, along the Danube, even flow diversion (Laczay 1989) brought about major channel and floodplain changes (Lóczy 2007). Since channelization in the nineteenth century sedimentation in study areas on the active Tisza floodplain amounts to 2–3 m for natural levees (Nagy et al. 2001; Schweitzer 2001), the average rate of sedimentation is ca. 3.8 mm year^{-1} (Gábris et al. 2002), for a flood year 18.9 mm year^{-1} (Sándor and Kiss 2006, 2008 – Fig. 9.4), while along the Maros it was 6.3 mm year^{-1} in backswamps and 2.3 mm year^{-1} on inactive natural levees (Oroszi and Kiss 2004; Oroszi et al. 2006) and 1.5–1.8 m on the Körös floodplains since regulations (Babák 2006). New techniques also serve this kind of research, like magnetic susceptibility analysis and x-ray measurements (Sándor and Kiss 2006). Mapping projects show that over the flood-free alluvial terrain large-scale farming gradually obliterates the traces of fluvial processes from the surface (Kis and Lóczy 1985; Balogh and Lóczy 1989; Lóczy and Gyenizse 2011). Recently available digital terrain models, however, present a still highly variable microtopography of floodplains, also useful for practical purposes like the identification of the capacity of designed emergency reservoirs along the Tisza River (Illés et al. 2003a, b; Gábris et al. 2004).

9.4.3 Soil Erosion by Water

Ádám Kertész

Soil erosion is a major environmental problem in agricultural landscapes. In Hungary about 35% of agricultural land is affected (8.5% severely, 13.6% moderately and 13.2% slightly eroded – Stefanovits and Várallyay 1992) as first shown on a soil erosion map at 1:75,000 scale (Stefanovits and Duck 1964), established according to the percentage of soil eroded from an intact soil profile (100%). For large-scale farming 50 million m³ of annual soil removal from hillslopes in Hungary was estimated (Erődi
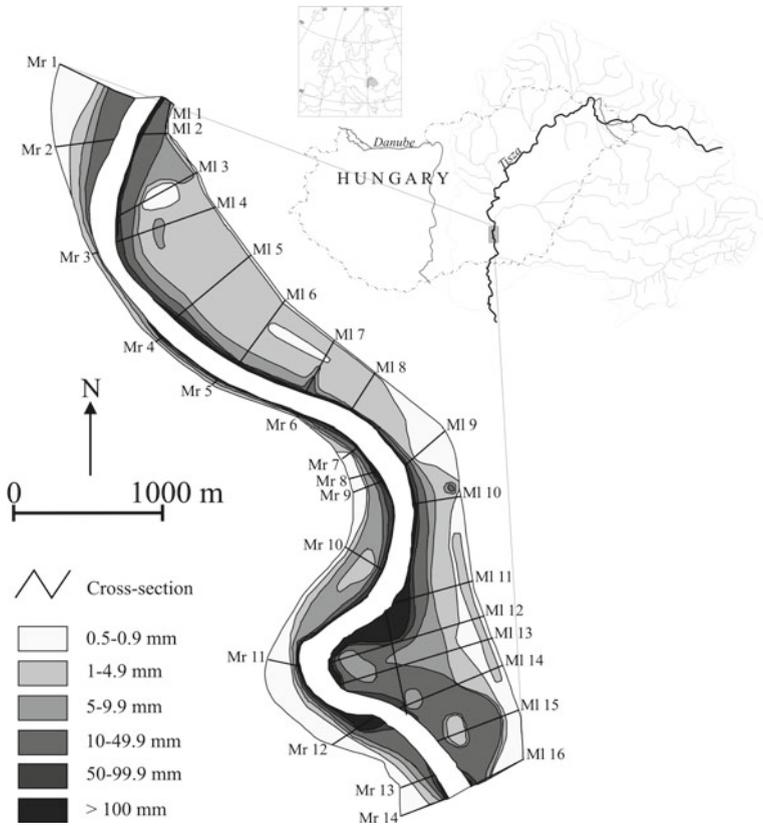
Fig. 9.4 Channel aggradation on the Lower Tisza River at Mindszent caused by the 2006 spring flood (After Sándor and Kiss (2008))

et al. 1965). Erosion-generating extreme (>30 mm day^{-1}) rainfall recurs 4–12 times a year during the growing season (Stefanovits and Várallyay 1992).

Water erosion mostly involves *sheet wash*, *rill*, and *gully erosion* on agricultural land left barren after crops are harvested (Kertész 2008). Limited infiltration due to surface compaction, sealing, crusting and subsurface pan formation intensify sheet and rill erosion on large arable fields (Kertész 1993; Kertész et al. 1995a, b, 2000, 2001, 2002). Gully erosion can reach development rates of 0.5 m per rainfall event and may supply half of sediment delivery from a catchment. Soils formed on loose deposits, such as loess or loess-like sediments in two-thirds of the area, are generally highly erodible. Even lowlands covered by deep loess mantles are prone to gully formation. Large gullies cut into riverbank bluffs (e.g., along the Danube). Loess hill regions with high relative relief (e.g., the Somogy, Tolna, and Szekszárd Hills), particularly if deforested and cultivated, also have dense gully and ravine networks (Jakab et al. 2010). Forest roads make even forested mountains prone to gully erosion.

Soil erosion research, which began in the 1950s (Mattyasovszky 1953, 1956) with the application of the Universal Soil Loss Equation (USLE), was continued with soil erosion mapping projects in the 1960s and 1970s within the framework of landscape studies (Marosi 1979). Fieldwork of landscape ecological approach was combined with laboratory experiments at the University of Debrecen, focused on rainsplash erosion (Kerényi 1991). Complex soil erosion mapping of test areas, primarily the vineyards of the Tokaj-Hegyalja region (Kerényi 1984, 1991; Boros 1996, 2003; Marosi et al. 1992), the Lake Balaton catchment (Dezsény 1984; Kertész et al. 1995a, b; Kertész and Richter 1997), and in Velence Hills (Mezősi et al. 2002) provided data on erosion rates for soils on weathered igneous rocks.

Soil erosion hazard is usually associated with slope inclination categories. In addition to large-scale arable fields of 5–12% slope, most endangered are deforested and cultivated slopes in the 17–25% and 12–17% classes, representing 3.4% and 4.2% of the country, respectively. The local rate of soil erosion is estimated at *plot*, *hillslope*, or *small catchment* scales (Kertész and Góczán 1988; Kertész 1993; Kertész et al. 1995a, b, 2000, 2001, 2002; Kerényi 1984, 1985, 1991; Krisztián 1998; Marosi et al. 1992; Jakab et al. 2010) with the help of rainfall simulation (Csepinszky and Jakab 1999; Centeri 2002a), pioneered in Hungary by B. Kazó (1966). Among the various factors influencing soil erosion, rainfall erosivity, soil erodibility and vegetation (Centeri 2002a, b), and land cover and tillage (Pinczés et al. 1978; Kertész 2008) were investigated.

The types and rates of hillslope erosion are studied at *test areas*, at first near the villages of Szomód and Bakonynána in northern Transdanubia (Góczán et al. 1973), then at Pilismarót in the Danube Bend (Kertész and Góczán 1988). Runoff, soil loss, redeposition on slope, and nutrient, fertilizer and pesticide losses (Farsang et al. 2006) were measured. Erosion rates under traditional and minimum tillage are studied in the Zala Hills and the efficiency of geotextiles is investigated at Abaújszántó (Northeast-Hungary).

Recently erosion models like EUROSEM (Barta 2001), EPIC (Mezősi and Richter 1991; Huszár 1999) and WEPP are applied (László and Rajkai 2003). Satellite images are also interpreted for estimating soil erosion rates on the catchment of Lake Velence (Verő-Wojtaszek and Balázsik 2008). The Soil Conservation Information and Monitoring System (TIM) operates 18 measurement sites for practical purposes (Nováky 2001). Splash, sheet, rill, and gully erosion are equally intense in the dissected hill regions of Hungary (in the Tolna Hills studied by Balogh and Schweitzer 1996 and in Tokaj-Hegyalja by Kerényi 2006). Detailed investigations of microrill, rill, and gully erosion have begun recently (Jakab et al. 2005; Jakab 2006; Kerényi 2006; Marton-Erdős 2006). The rate of gully erosion is studied using ^{137}C isotope (Jakab et al. 2005).

The rate of soil loss is characterized by the following categories: The average rate of soil formation (2 tons ha^{-1} year^{-1} – Stefanovits 1977) is regarded the upper threshold of sustainable farming and ca 80% of Hungary's area falls within this category. The next limit is 11 tons ha^{-1} year^{-1}, which involves the highest still allowable nutrient loss, based on US experience (14% of Hungary). In areas (6% of

Hungary) with soil loss higher than that arable farming is only possible observing strict regulations (Kertész and Centeri 2006).

9.4.4 Mass Movements

József Szabó

The first geological, stratigraphical, and geomorphological study of mass movements in Hungary was the description of the 1877 landslide at Döröcske in the Somogy loess hills (Inkey 1877). In gentle valley slope segments the remnants of former landslides were recognized. In his stratigraphic descriptions he mentions more than half a dozen collapses, landslides and the resulting heaps, dislocated slices, and rolling surfaces. Mass movements can be decisive in the geomorphic evolution of a region and can significantly influence human activities (Cholnoky 1926).

The disastrous nature of rapid movements along rivers and lakeshores has been long known (at Lake Balaton – Bernáth 1881 and in Buda, the hilly part of Budapest – Schafarzik 1882). When the industrial town Sztálinváros (now: Dunaújváros) was built on the *loess bluff* of the *Danube* major constructions and settlements were found to be threatened by landslides (Domján 1952; Kézdi 1952). Along the right bank of the almost 200 km long Danube section south of Budapest, steep and 20–50 m high bluffs rise (Lóczy et al. 2007). The stratigraphic analyses of Pannonian (Upper Miocene) sediments and loess sequences in the bluffs provided valuable information on landslide generation and pointed out relationships between movements and the water levels of the Danube (Kézdi 1970; Horváth and Scheuer 1976; Pécsi et al. 1979, 1987; Scheuer 1979; Pécsi and Scheuer 1979; Fodor et al. 1983; Fodor and Kleb 1986). The Dunaföldvár landslide served as a textbook example of rotational ("sliced") slides (Pécsi 1971a, b, 1979). Based on the truncated ground-plans of Roman structures built right on the Danube bluff, a rate of bluff retreat of 5–15 m per 100 years over the last 2,000 years can be estimated (Lóczy et al. 1989). In the unusually wet year of 2010 loess bluff collapses became more frequent at several locations (Kulcs, Dunaszekcső-Újvári et al. 2009). Undercut high bluffs are also located along the Hernád/Hornad (Szabó 1995, 1996b, 1997) and Rába/Raab rivers.

Movements in *unconsolidated Tertiary sediments* are common in the Outer Somogy Hills (Szilárd 1967) and appear in even larger numbers in the Tolna Hills (Ádám 1969), where they are decisive agents of geomorphic evolution. In the 1950s Gy. Peja made observations in the northern foreland of Bükk Mountains of Tertiary sediments and set up a classification system based on age and landform (identifying "branch," "sister," twinned, and other types) as well as revealing the landslide-inducing impact of brown coal mining (Peja 1956, 1975). In Northern Hungarian landslide-modeled hill regions were studied by J. Szabó (the Sajó-Bódva Interfluve – Szabó 1971; the Cserehát Hills – Szabó 1978, 1985a).

In 1972 a large-scale *mass movement inventory* project was launched. It was coordinated by the Central Geological Office (KFH) and involving broad cooperation in earth sciences. By 1980 as many as 987 localities with mass movements had
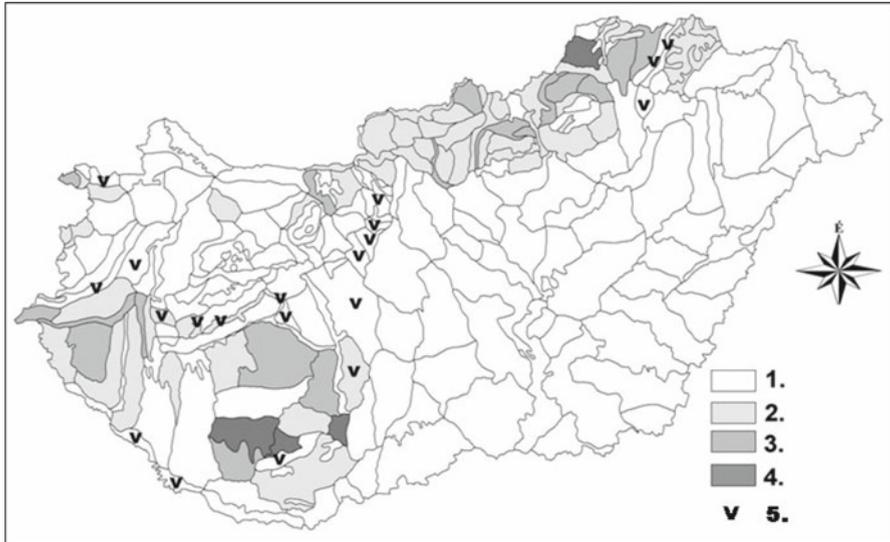
Fig. 9.5 Mass movement hazard in the microregions of Hungary. 1, negligible; 2, slight; 3, moderate; 4, serious; 5, partial areas with extremely high risk (Data from the KFH national inventory processed by Szabó et al. (2008))

been surveyed (Fodor and Kleb 1986; Pécsi and Juhász 1974; Pécsi et al. 1976), but only a fraction of the collected data have been evaluated (Szabó 1996a, b). The inventory has provided ample evidence for *landslide hazard of human origin* and for the significance of recent or presently active processes. In the North Hungarian Mountains man-induced movements amount to ca 29% of total (Fodor 1985). Their share reaches 50% in 14 landscape units (mostly in industrial or mining regions), while 15% of movements were inventoried as of mixed origin and 29% still active at the time of the survey (Fig. 9.5). In remote regions still unknown (mostly fossil) landslides were assumed (Szabó 1996a) and subsequently further areas of surface instability have been described from northern (Ádám and Schweitzer 1985) and southern Transdanubia (Juhász 1972; Lovász 1985; Fábián et al. 2006). The spatial distribution of rapid mass movement hazard can be established with high reliability today (Table 9.1).

In *mountains of volcanic origin* landslide features, only sporadically described before (Láng 1955, 1967; Székely 1989), are found to be decisive elements of the landscape in certain topographical positions – along mountain margins, in fossil caldera rims and valleys (Szabó 1991, 1996b). In addition to fossil landslides on weathered tuffs interbedded between hard lava beds or on unconsolidated bedrocks under volcanics, recent mass movements also occur in considerable number. In the heavily affected North Hungarian Mountains numerous movements are associated with roadcuts, mining, or irresponsible settlement development – as in the case of Hollóháza, North-Hungary (Zelenka et al. 1999; Szabó 2004).

Table 9.1 Description and typology of landslide processes and features in the various landscape types of Hungary (By Szabó)

Material	Location	Slip plane material	Slip plane position	Morphological position	Type	Activity
Hills						
Oligocene clays, marls, loess or travertine mantle	Around Budapest	Clay or marl	At variable depth	Terrace margins, quarry walls	Slumps, stratum slips	Man-induced (quarrying, construction)
Lower to Middle Miocene schlier (locally volcanic cover)	Heves-Borsod Hills, Baranya Hegyhát	Clayey schlier (locally sand)	Deep-seated but usually above base level	Valley slopes, tectonic lines	Stratum slips with huge heaps	Low and reducing activity (man-induced)
Pannonian clays, sands – deep loess mantle	Tolna, Zselic, Outer Somogy Hills	Pannonian beds, loam beds in loess	Deep-seated, close to base level	Marginal tectonic lines, valley slopes	Stratum slips with huge heaps	Low activity, many fossil features
Pannonian clays, sands – loam mantle	Vas Hegyhát	In or below loam	Close to surface, above base level	Valley slopes	Carpet-like slips (creeps)	Moderate activity, recent
Pannonian clays, sands – loess-free	Cserehát Hills, Sajó-Bódva Interfluve	Pannonian beds	Close to surface, above base level	Valley slopes	Stratum slips with heaps, carpet-like slips	Considerable activity, recent
River bluffs						
Pannonian clays, sands with thick loess mantle	Along the Danube	Pannonian beds, loam beds in loess	Deep-seated, often close to base level	Bluff margins	Sliced slides	Mostly recent, locally active
Pannonian clays, sands variable mantle	Lake Balaton	Pannonian beds	Deep-seated, generally close to base level	Bluff margins	Sliced slides, stratum slips with heaps	Considerable activity, mostly recent
Pannonian clays, sands with Plio-Pleistocene sand cover	Rába river	Pannonian beds	Deep-seated, close to base level	Bluff margins	Stratum slips with huge heaps	Recent

Pannonian clays, sands with thin or no loess mantle	Lake Fertő, Hernád river	Pannonian beds	Deep-seated, variable	Bluff margins	Stratum slips with heaps (frequent falls)	Recent, exceptionally active, maximum activity in Hungary
Mountains of volcanic origin						
Badenian and Sarmatan volcanites	Visegrád, Mátra Mountains, less typically: Börzsöny, Cserhát, Zemplén Mountains	Unconsolidated Oligo-Miocene sediments	Deep-seated, generally close to base point	Mountain margins, tectonic lines, caldera rims, slopes of deep internal valleys	Mountain slides, slides of large blocks	Mostly fossil, rarely recent, exceptionally active
Pliocene basalts	Tapolca Basin, Medves Plateau	Weathered tuff beds	Deep-seated, generally close to base point	Mountain margins	Mountain slides, slides of large blocks	Mostly fossil, rarely recent, exceptionally active

The new *mass movement map* of Hungary (Szabó et al. 2008 – Fig. 9.3) describes the risk of these processes by microregions. Among all movements 20% are considered completely inactive (Fodor and Kleb 1986). Even in microregions with the lowest risk mass movements used to be important in landform evolution (e.g., Danube Bend, Börzsöny and Mátra Mountains of andesite or basalt regions). Also in regions of low relative relief serious risk of mass movements is limited to narrow belts, almost negligible in size (e.g., high bluffs along the Danube and Hernad rivers). Such zones are marked by a V symbol (Fig. 9.3).

M. Pécsi's idea that in *landslide classification* the slip plane should be the fundamental criterion (Pécsi 1975) was elaborated into a complete system by J. Szabó (1983, 1985b). The system covers the origin of the slip plane (preformed or syngenetic), its position relative to the base of the slope, its angle with the slope surface, and the consistency of slope material, and thus achieves a natural classification.

For the purposes of prediction the dates of landslides are compared with *precipitation* amounts and the alternation of dry and wet spells (Juhász and Schweitzer 1989; Juhász 1999). The results from the Hernád valley and from hill regions (Szabó 2003) also support the claim that in Hungary mostly winter half-years of extraordinarily high precipitation generate major movements. Although according to the most probable climate change scenario for the country a trend towards Mediterranean conditions is expected, the predicted more arid climate does not reduce landslide hazard since precipitation – and particularly rainfall – will be higher in the winter half-year.

Recently, *new methods* have been introduced into landslide research. Stratigraphical analyses (Juhász 1972) are complemented by the palynological and radiocarbon dating of Holocene movements (Szabó 1997; Szabó and Félegyházi 1997). They indicate that – particularly in mountains of volcanic origin – the transitional warming period from the Late Pleistocene to Preboreal (the thawing of permafrost) significantly increased landslide activity. Most recent applied research is concerned with the complex monitoring of landslide evolution (e.g., Újvári et al. 2009), environmental impact assessment of engineering structures built in landslide-prone areas (Kleb and Schweitzer 2001) and the analysis of the relationship between landslide disasters and social responsibility (Szabó 2004).

9.4.5   Aeolian Processes

József Lóki

In Hungary, there are three major *blown-sand regions*, located on Pleistocene alluvial fans: Inner Somogy southwest of Lake Balaton (Marosi 1970; Lóki 1981), the Kiskunság (Little Cumania) on the Danube-Tisza Interfluve (Bulla 1951), and the Nyírség (Borsy 1961) in the northeastern corner of the country (Fig. 9.6).

There are considerable variations in their physical environments and, consequently, in their landforms. In the most humid of the sand regions, the lower-lying *Inner Somogy*, the depth of alluvial sand accumulation and the maximum height of sand landforms is 5–8 m. Numerous stabilized rounded blowouts of less than 40 m
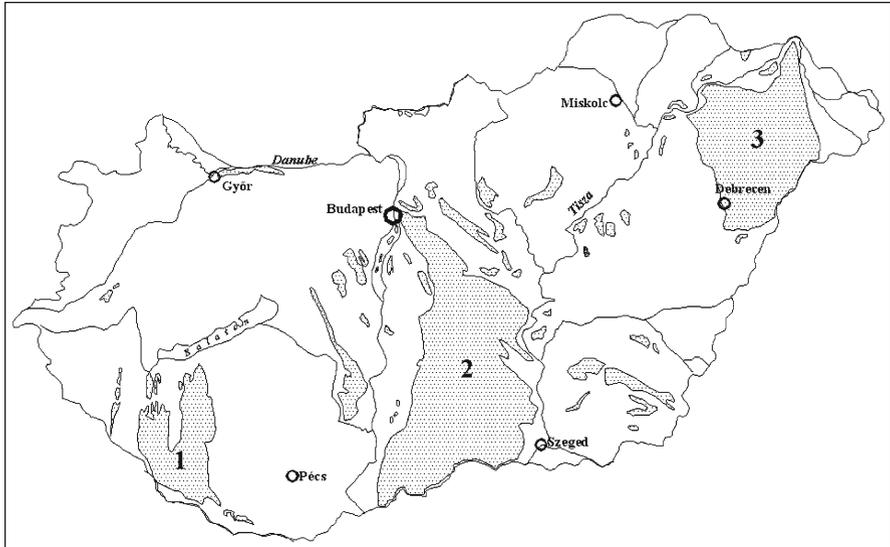
Fig. 9.6 Blown-sand regions in Hungary. 1, Inner Somogy; 2, Kiskunság; 3, Nyírség

diameter, formed on alluvial fans with shallow groundwater table, are most typical. Residual ridges between wind furrows, protected by vegetation from erosion, are also relatively common. Their maximum height does not reach 10 m. (The investigation of sand regions and wind erosion started with papers on wind furrow/blowout dune assemblages and separating residual ridges – Cholnoky 1902 – and on river bank dunes along the Tisza River – Cholnoky 1910). Extensive sand sheets also occur (Marosi 1970). In the *Kiskunság* even more extensive flat sand sheets and narrow stripes of sand accumulation are characteristic. Wind furrows are deepened into blown sands redeposited in several stages of the Last Glaciaton. Blowout dunes of longitudinal type (accumulations of sand arranged in winding ridges of up to 1,500 m length and occasionally 10 m high – Kádár 1935) are common alternating with deflation flats (locally with saline ponds). In the northeastern *Nyírség* the greatest variety of landforms occurs: markedly elongated wind furrows and blowout dunes (up to 18 m height) (Borsy 1961), while in the deep sand accumulation of the southern Nyírség, asymmetric dunes and marginal dunes are predominant. The most widespread landforms are parabolic dunes, developed around blowouts of oval shape and regarded the counterparts of desert barchans in sand regions of the temperate belt (Kádár 1938). Regular parabolic dunes are rather rare, they are mostly asymmetric with poorly developed western horns. Their shape is equally controlled by wind, topographic and vegetation conditions (Lóki 2004). The abundant recharge of sand promotes the formation of regular parabolic dunes. In the case of reduced recharge and wind blowing out sand sideways from oval blowouts asymmetric dunes with longer horns develop. The largest landforms of blown-sand regions are irregular closed deflational flats of locally more than 2 km diameter (mostly in the northern Nyírség).

Sand dune surfaces are artificially kept vegetation-free by the staff of the Kiskunság National Park in the environs of Fülöpháza in order to present sand movement to visitors. Elsewhere dunes are afforested by Robinias and Austrian pines as well as by the plantation of orchards (apricot) and vineyards.

Sand mobilization occurred in several *phases* in Hungary (Gábris 2003; Kiss in Mezősi 2011). Marosi (1967) claimed that alluvial fan building in the Carpathian Basin first ended in the Inner Somogy sand region, where aeolian action was the most enduring. In the driest spells of the Würm glaciation wind was the predominant agent of geomorphic evolution. The age of landforms is confirmed by periglacial features, ice wedge cast filled by sands with 'kovárvány' bands (Marosi 1966, 1967, 1970). In the Nyírség ^{14}C dating and on the northern Danube-Tisza Interfluve malacological and stratigraphical dating from fluvial deposits rich in shells revealed that blown sand was mobilized in the Upper Pleniglacial and again in the Dryas (Borsy et al. 1985; Lóki et al. 1993; Lóki 2004). Sand movements induced by human activities have been assumed for the Preboreal, Boreal, and Atlantic phases (Kádár 1956; Marosi 1967; Borsy 1977, 1991; Gábris 2003; Lóki 2004; Nyári and Kiss 2005; Ujházy et al. 2003). Subboreal wind erosion was also confirmed (Kiss et al. 2008a, b). Archaeological and OSL datings (Gábris 2003; Ujházy et al. 2003; Nyári and Kiss 2005, Kiss et al. 2006; Nyári et al. 2006, 2007) support the view that sand was blown on several occasions in the early Subatlantic Phase, in the Iron Age and during the Migrations. Bronze Age movements were caused by overgrazing (Lóki and Schweitzer 2001; Gábris 2003; Nyári and Kiss 2005). Historical sand movements in the eighteenth and nineteenth centuries are related to deforestation and arable farming (Marosi 1967; Borsy 1977, 1991).

In the mid-twentieth century, large-scale farming and improper agrotechnology led to increased wind damage on fields (Bodolay 1966). At *present*, *wind erosion* is limited to dry surfaces uncovered by vegetation, i.e., it takes place primarily on ploughed surfaces in spring or autumn as well as on surfaces without a snow cover in winter (Kiss et al. 2008a, b). At wind velocities of 5.5–6.0 m s^{-1}, sand motion reaches surprisingly high intensity (Borsy 1991). Deflation also affects dried marshes as well as heavier soils, which become dusty during tillage (Lóki 2004).

Wind erosion hazard affects 16% of Hungary (Stefanovits and Duck 1964). Not only sand and peat surfaces but even more humous and fertile soils are also affected (Stefanovits and Várallyay 1992). In soil conservation, environment-friendly solutions, optimal irrigation, vegetation cover, and tillage methods are sought (Lóki 2004). The erosion on berms of alkali flats in grasslands is also remarkable (Rakonczai and Kovács 2006). On the basis of measurements (e.g., on the Danube–Tisza Interfluve – Szatmári 1997) and experiments (Lóki and Négyesi 2003) the soils are referred to grades of wind erosion hazard (Fig. 9.7):

– Insignificant hazard (0): on silt-clay and clay soils, where >10.5 m s^{-1} wind speeds are necessary to generate sand motion (30.2% of the area of Hungary);
– Moderate hazard (1): on loam and silty loam soils with critical wind speeds between 8.6 and 10.5 m s^{-1} (43.3%);
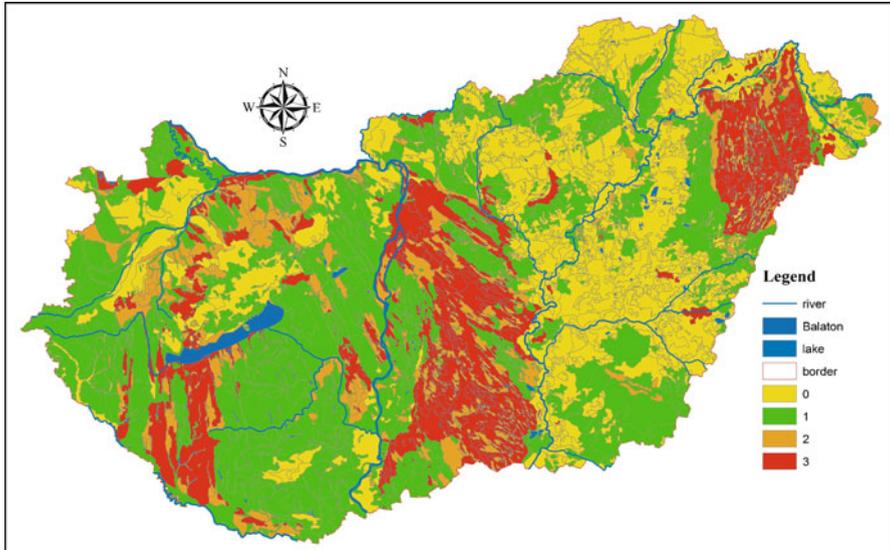
Fig. 9.7 Wind erosion hazard in Hungary (by J. Lóki). For explanation see the text

– Medium hazard (2): on sandy loam soils with thresholds of 6.5–8.5 m s^{-1} wind speeds (9.4%) and
– Serious hazard (3): on sand and loamy sand soils as well as peat and muck surfaces from which more than threefold more soil is removed by wind than in the "insignificant hazard" category. Critical wind speed here is below 6.5 m s^{-1}.

Global warming involves aridification and increasing weather extremities in Hungary. It is reflected in the alternation of spells of intensive rainfall with periods of severe drought, when wind erosion is expected to intensify.

9.4.6   Karstification

Márton Veress

Karstic rocks appear on 1.5% of Hungary's area: in the Bükk and Aggtelek Mountains in North-Hungary, in some members of the Transdanubian Mountains (Bakony, Vértes, Gerecse, Pilis and Buda Mountains), in the Mecsek Mountains and Villány Hills in Southern Transdanubia, and in the Balf Hills (Fig. 9.8). Significant parts of the Transdanubian Mountains and Mecsek Mountains are covered karst, both autogenic and allogenic, and there are also patches in the Bükk and Aggtelek Mountains.

The origin of karst features like dolines, ponors, and poljes were first explained by J. Cholnoky (1926) and the significance of climatic and biogenic factors in
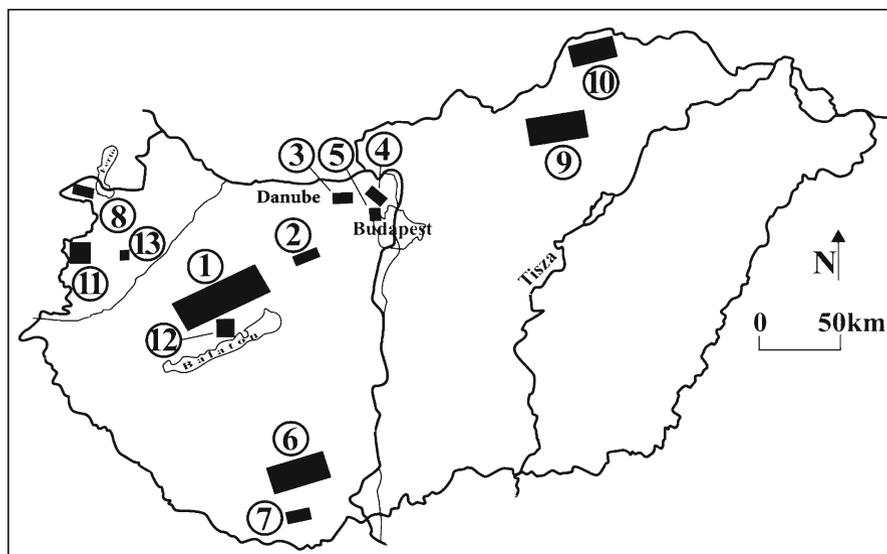
Fig. 9.8 Karst areas in Hungary (1–10) and the localities mentioned in the text (11–13). 1, Bakony; 2, Vértes; 3, Gerecse; 4, Pilis; 5, Buda Mountains; 6, Mecsek Mountains; 7, Villány Hills; 8, Balf Hills; 9, Bükk; 10, Aggtelek Mountains; 11, Kőszeg Mountains; 12, Kál Basin; 13, Bük thermal bath

karstification was underlined by L. Jakucs (1977, 1980). Based on decades of field measurements in the Aggtelek Mountains, L. Zámbó (1985) set up a hydrogeo-chemical model for the corrosional behavior of clay doline fills with different rates of solution in zones identified in cross-section. D. Balázs (1991) conducted labora-tory experiments on karst corrosion and classified tropical karst processes and land-forms observed on all continents.

Recent karst development involves primary or secondary processes. *Primary processes* are solution, mechanical erosion (in caves) and precipitation. *Solution* is the most diverse: it can be caused by *rainwater* or *thermal water* and it can take place *subsoil* and *under the karstwater table* (due to mixing corrosion or turbulent flow). In erosion caves, however, solution is only a secondary karst process. *Non-karstic processes* induced by primary karstification are collapses (in caves, on cov-ered karsts), sediment transport, reworkings (in caves or on covered karst by pluvial erosion), accumulations and piping in sedimentary cover (in depressions of covered karst).

Among surface features, *dolines* occur in high density on the Bükk Plateau and in the Mecsek Mountains, where two generations of them are distinguished (Szabó 1968). On the planated surface of the Balf Hills, near Lake Fertő/Neusiedlersee, there are shallow *uvalas* of a few 100 m diameter, developed on the porous Leitha limestone. The uvalas are still growing today as the roofs of minor cavities in doline walls cave in (Prodán and Veress 2006). Locally, there are canyon-like *epigenetic valleys* in limestone. *Ponors* (swallow holes) developed at junctions are connected

to erosional caves, mainly in the Bükk and Aggtelek Mountains (Baradla Cave – Jakucs 1977). *Karren* are less typical in Hungary. Grike karren and kamenitzas are produced by subsoil solution. Veress et al. (1998) claim that notches develop on any rock with calcareous minerals (e.g., in Kőszeg Mountains). Kamenitzas are also found on sandstones with amorphous silica (in the Kál Basin, Balaton Uplands).

Secondary karst landforms include *"transformed" ponors* (swallow dolines) in valley junctions. With the stream incising into the rock, the junction is retreating and a new ponor develops by solution and the former ponor becomes a doline (Hevesi 1980). Such forms predominate in the epigenetic valleys of the Bükk and Aggtelek Mountains. Today some of the epigenetic valleys are *blind valleys* and develop further by *corrosion* (e.g., in the Aggtelek Mountains). *Collapse dolines* do not often occur in the Hungarian karsts. Small-sized features due to collapse, however, are developing at present as the thin roofs of cavities close to the surface cave in. Such dolines are a few meters in diameter (in the Bakony Mountains – Veress 2000; in the Balf Hills – Prodán and Veress 2006).

Infiltrating waters mainly cause solution in the epizone of uncovered karst. The rock mass is fragmented by the solution of the water which percolates along crevices (Veress and Péntek 1996). As the debris is gradually dissolving, the surface is subsiding. *Solution dolines* develop in sites where the process takes place more rapidly. *Pits* develop on the limestone floor of covered karst where the sedimentary cover is thin. The void created at the pits is translated to the limestone floor and *covered karst depressions* develop (Veress 2000). *Karst gorges* occur on the covered karst of the Bakony Mountains (Kerteskő Gorge, Ördögárok). The gorge floors are above the karstwater table and function like ponors: the throughflowing waters partly seep into the karst. Solution by seepage contributes to their present incision (Veress 1980, 2000). Broad covered karst depressions develop in the sedimentary cover (like on the floor of Tábla Valley, Bakony Mountains, Veress 2006, 2007 – Fig. 9.9).

In the epiphreatic and phreatic zones, *cavities* of various size develop by mixing corrosion and turbulent flow under the karst water table, while *effluent caves* develop along the karst margin. The mode of cave development varies with to the position of the karstwater table. In Hungary there are almost 3,000 caves (cavities longer than 2 m): the longest is the Baradla Cave (25 km, Aggtelek Karst, with the highest chamber of 60 m) and the deepest is the István-lápa Shaft (250 m, Bükk Mountains).

Calcareous *precipitations* may develop from water flow on the surface or in caves (calcareous sinter), from dripping water in the epiphreatic zone (dripstones) and in the stagnant karst water zone. In Hungary major *travertine mounds* and *rimstone bars* are the Veil Waterfall (in the Szalajka Valley, Bükk Mountains), the Szinva Waterfall (in Szinva Valley, Bükk Mountains), at the Bolyamér Spring, at the Kecskekút Spring, at the Jósva Spring and along the bank of the Jósva stream (Aggtelek Mountains, Sásdi 2005), and the rimstone bars of the Melegmány Valley (Mecsek Mountains). Human-induced precipitation from the thermal (57°C) water of Bük spa (Vas County) with high Ca^{2+} and Na^+ ion concentrations (Veress 1998) is observed on the walls and pipes of the basins of the public bath.
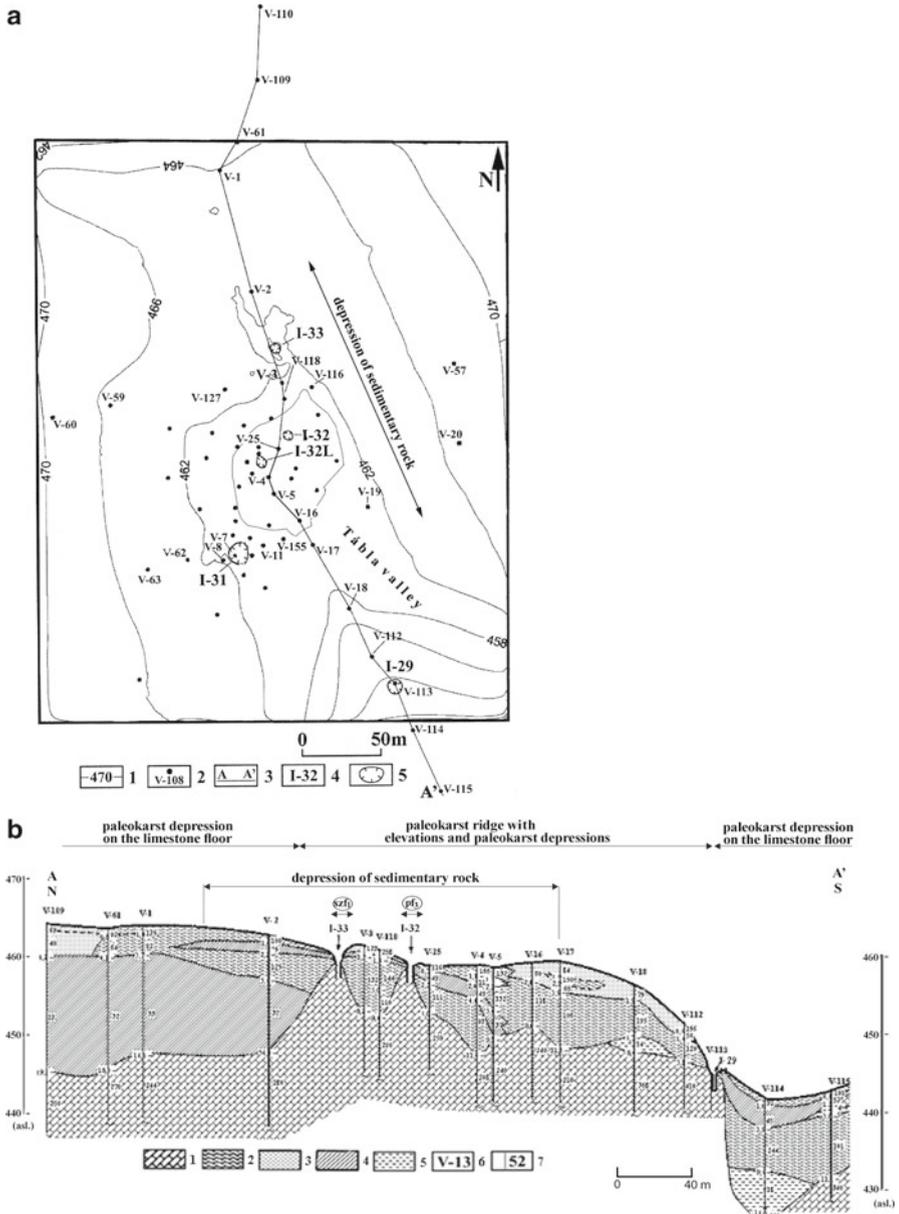
Fig. 9.9 A depression in the sedimentary cover on the floor of the Tábla Valley (Bakony Mountains – Veress 2006). (**a**) Vertical Electric Sounding (VES) profile. 1, contour line; 2, site of VES measurement; 3, location of profile; 4, mark of the covered karst feature; 5, covered karst feature. (**b**) Geological and morphological profile. 1, limestone; 2, limestone debris; 3–4, loess with debris; 5, clay; 6, VES number; 7, geoelectrical resistance (ohms)
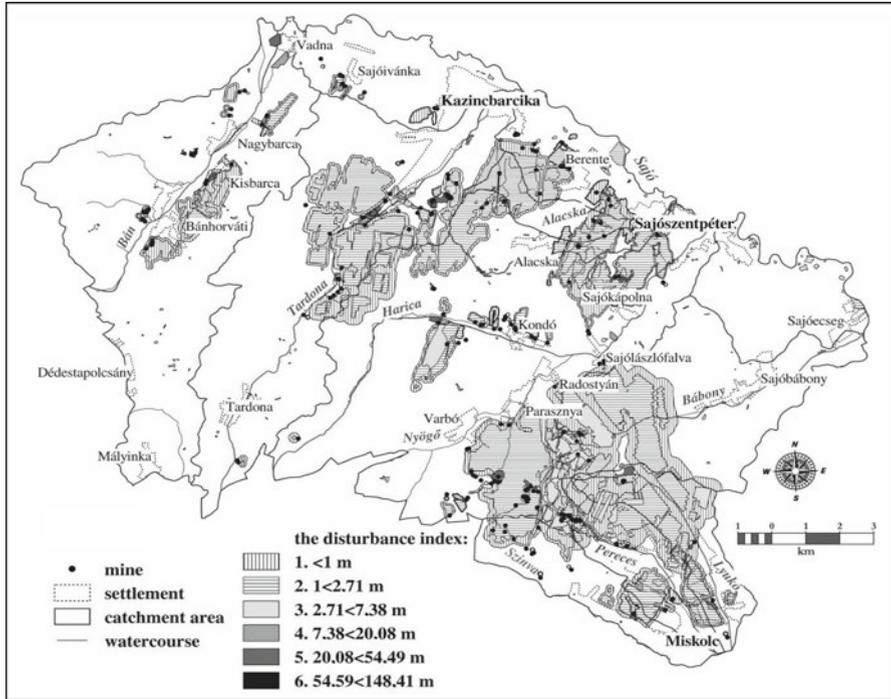
Fig. 9.10   Landscape transformation in the Borsod Coal Mining Area (Sütő 2000). The disturbance index shows how thick a layer was removed from the surface

9.4.7   Human Impact of Mining

László Sütő
Péter Rózsa

Human activity has become an immanent part of landscape evolution (Szabó et al. 2010). In 2005 there were 1217 listed mining sites in Northern Hungary alone (Farkas 2006). Major landscape transformation has been caused by the 250-year old *brown coal mining* (Fig. 9.10). During the "heroic age" of the coal mining – from the mid-eighteenth to the mid-twentieth century – manual chamber excavation with wood securing was applied. In the Borsod Coal Mining Area, near Arló village (south of Ózd town), a lake was formed by landslides as early as 1863, i.e., 11 years after the beginning of large-scale forest clearance for mining (Peja 1956; Leél-Őssy 1973). After World War II self-securing mechanized frontal excavation technology was introduced in most mines. It was more productive, but much larger connected cavities resulted.

   Undermining is another great problem, for example, in Lyukóbánya and Pereces (near Miskolc (Sütő et al. 2004)), where the total length of the mine galleries is almost 50 km (equal to that of the underground tunnels in Budapest).

Similarly, in the Salgótarján–Medves Hill area (northern part of the Nógrád Coal Mining Area) 268 of 543 depressions are attributed to coal mining. Prolonged *subsidence* is typical in the foothills of the North-Hungarian, Transdanubian, and Mecsek Mountains, where mines are closed now. In the vicinity of the huge open lignite pits in the Mátra and Bükk forelands ca 0.2 m ground subsidence has been recorded until the early 1980s (Fodor and Kleb 1986) and subsidence areas are also mapped in the Transdanubian Mountains (near Dorog, Tokod, Oroszlány, and Tatabánya – Juhász 1974). Above the northern mining field at Nagyegyháza, 99.9% of the total subsidence happened 8 years after mines were closed. For another mine (Mány I/a) 99.9% of subsidence is estimated to happen in 12 years after closing (Ládai 2002).

To eliminate water inrush risk, from 1965 to 1988, 300 and 600 m^3 min^{-1} of water was pumped out of coal and the *bauxite* mines, respectively. The discharge of many streams decreased, springs dried out, the water level of the Hévíz Lake and Tapolca Cavern Lake (both are well-known tourism attractions) dropped. This led to heated public discussion, which contributed to the decline of bauxite mining. Now the opencast bauxite mine near Gánt (southern Vértes Mountains) displays 28 m high walls with tropical cone karst (Dudich 2002).

According to F. Erdősi (1987), in the environs of Mecsek Mountains, 135 millions m^3 of earth was moved by hard coal mining activities since World War II. The biggest, almost 200 m deep opencast pits are now being reclaimed at Vasas and in Karolina Valley in Pécs. The largest subsidence in Mecsek is the Pécs-Somogy trough of 13.5 km^2 area and 27 m depth – sevenfold larger than the undermined area. In the Juhász Hill, near Nagymányok, *sinkholes* formed (Erdősi 1987). In some cases the surface may rise locally after mine closure. Near Pécs and Komló rises of up to 12 cm resulted from the hydration of near-surface clays and replenishment of confined water reservoirs (Somosvári 2002).

Among *accumulation* landforms, from 1950 to 1980, 248 *spoil heaps* of ca 200 million m^3 total volume were built in five mining counties of Hungary (Baranya, Borsod-Abaúj-Zemplén, Heves, Komárom-Esztergom, Nógrád) (Egerer and Namesánszky 1990). For instance, the total volume of the terraced twin tips of Béke and István Shafts near Pécs is 11.2 millions m^3, their maximum height is 67 m, and they cover a triangular area, 750 m long and 550 m wide (Erdősi 1987). Spoil heaps are affected by physical and chemical weathering, burning, deflation, intensive mass movements, and gully erosion. One of the largest in the Borsod Coal Mining Area is more than 100 m high and accommodates 1.2 million m^3 spoil (Sütő 2000, 2007 – Fig. 9.11). Slides cause 8 m high ruptures on its slopes (Homoki et al. 2000).

In Hungary *ore mining* (copper, iron, lead, zinc, uranium, and bauxite) induced locally significant landscape changes (at Recsk, Rudabánya, Gyöngyösoroszi, Telkibánya, Kővágószőlős, Gánt, Kincsesbánya, Nyírád). At Kővágószőlős (Mecsek Mountains), to obtain 20,300 tons of uranium, 46 million tons of rock had to be moved. The subsidence area is almost 42 km^2 and the groundwater regime is also altered. Nine 17-m high percolation prisms are under reclamation.

Stone quarrying is practiced around almost every settlement in the mountains of Hungary. In Mátra Mountains 57 major quarries of 240 ha are listed, and less than 10 of them are reclaimed (Dávid 2000). On Medves Hill (its area is a mere 32 km^2)
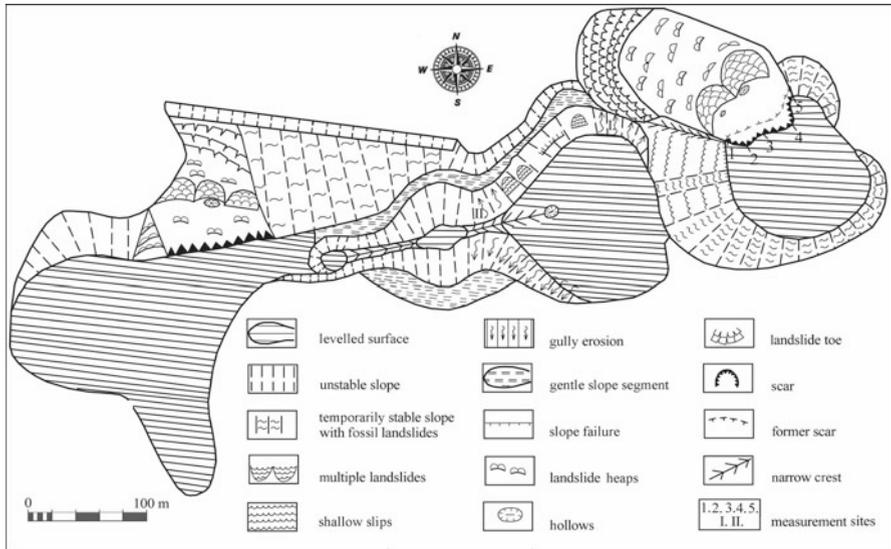
Fig. 9.11 Sketch of a spoil heap (in the Ádám Valley near Kazincbarcika) showing the geomorphic processes operating on them (Sütő 2000)

basalt quarries and their wastes cover 27 and 24 ha, respectively (Karancsi 2002; Rózsa and Kozák 1995). Quarry walls develop like natural cliffs: debris fans, gorges, block slopes, and, in pits, ponds can form. The lubrication of bedding planes by water may result in sagging (Karancsi 2002). Ponds in the abandoned quarries are often spectacular tourist attractions (like the "Tarn" in a former millstone quarry of Megyer Hill near Sárospatak town). Some quarries expose geological features and are sources of scientific information (e.g., Kálvária Hill of Tata, Ság Hill near Celldömölk, Hegyestű near Lake Balaton, Nagy Hill of Tokaj) (Rózsa and Kozák 1995; Pap 2008), presented by nature trails. Some quarries have almost demolished entire hills. (Esztramos Hill in North-Hungary was reduced from 380 to 340 m; the basalt hill near Zalahaláp was totally removed and 7 million m^3 of limestone was quarried from the Bél-kő within a century (Hevesi 2002)).

Following land reclamation, part of the abandoned open pits serve as recreation or exhibition areas (Pap 2008). Elsewhere rehabilitation takes place spontaneously (Szebényi 2002; Gasztonyi 2002; Kalmár and Kuti 2005). Opportunities for the *complex rehabilitation* and use of spoil heaps were investigated, among others, by Z. Karancsi (2002) for the Medves Hill area; by Hahn and Siska–Szilasi (2004), E. Homoki and co-workers (2000) and L. Sütő (2000, 2007) for the Borsod Coal Mining Area; by L. Dávid (2000) for Mátra Mountains and by P. Csorba (1986) for the Tokaj Mountains. The Tokaj Nagy Hill of 20 km^2 area is one of the best preserved volcanic cones in Hungary, is built up of locally several hundred meters thick pyroxene dacite lava flows, exposed in several quarries. A volcanological nature trail and a tourist resort next to the pond in the center of the quarry pit are proposed (Rózsa and Kozák 1995).

9.5   Conclusions

Dénes Lóczy

In the present-day Hungary of lowland nature fluvial geomorphic processes (channel and floodplain evolution) are of particular significance and intensively studied. Along some rivers significant adjustments of channel geometry have been observed since flow regulation in the nineteenth century. Almost all the area of hills and low mountains (if not forested) is affected by water erosion, particularly gully development in loess regions. The topography of the three major blown-sand regions and some other sand-covered alluvial fans and terraces is mostly due to aeolian erosion and deposition. All sand dunes, however, have been stabilized. Although the areas affected by mass movements and karst processes are limited in extension, they offer a variety of landforms for geomorphologists – some still actively evolving today. The modeling of such processes and the precise measurement of the rate of landform evolution is a central task of geomorphological research. Applied studies are directed at the estimation of the significance of ever intensifying human impact on the landscape, which has become the primary driver of recent geomorphic evolution in Hungary, too.

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