World Geomorphological Landscapes

Dénes Lóczy *Editor*

# Landscapes and Landforms of Hungary

Springer

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*Authors dedicate this volume to the 60th birthday
of the Editor, Prof. Dénes Lóczy*

# Series Editor Preface

Landforms and landscapes vary enormously across the Earth, from high mountains to endless plains. At a smaller scale, nature often surprises us by creating shapes which look improbable. Many physical landscapes are so immensely beautiful that they receive the highest possible recognition—they hold the status of World Heritage properties. Apart from often being immensely scenic, landscapes tell stories which not uncommonly can be traced back in time to tens of million years and include unique events. In addition, many landscapes owe their appearance and harmony not solely to natural forces. For centuries, and even millennia, they have been shaped by humans who have modified hillslopes, river courses and coastlines, and erected structures which often blend with the natural landforms to form inseparable entities.

These landscapes are studied by geomorphology—'the science of scenery'—a part of Earth Sciences that focuses on landforms, their assemblages, surface and subsurface processes that moulded them in the past and that change them today. To show the importance of geomorphology in understanding the landscape, and to present the beauty and diversity of the geomorphological sceneries across the world, we have launched a book series, *World Geomorphological Landscapes*. It aims to be a scientific library of monographs that present and explain physical landscapes, focusing on both representative and uniquely spectacular examples. Each book will contain details on geomorphology of a particular country or a geographically coherent region. This volume presents the geomorphology of Hungary—a country that may seem small but presents a remarkable diversity of landscapes, from vast plains to spectacular karst plateaus and ruined volcanic landforms. Nearly 30 case studies introduce the finest examples of geomorphology in Hungary, providing guidance to geoscientists as to where to go to enjoy the very best scenery.

*The World Geomorphological Landscapes* series is produced under the scientific patronage of the International Association of Geomorphologists (IAG)—a society that brings together geomorphologists from all around the world. The IAG was established in 1989 and is an independent scientific association affiliated to the International Geographical Union (IGU) and the International Union of Geological Sciences (IUGS). Among its main aims are to promote geomorphology and to foster dissemination of geomorphological knowledge. I believe that this lavishly illustrated series, which sticks to the scientific rigour, is the most appropriate means to fulfil these aims and to serve the geoscientific community. To this end, my immense thanks go to Prof. Dénes Lóczy—a long-standing supporter of the IAG activities and its past Secretary—for adding to his agenda the hard task of editing this volume and successfully coordinating the large team of authors. I hope he is as pleased with the final outcome as I am. I also acknowledge the excellent work of all individual authors who accepted to share their expert knowledge of the country with the global geomorphological community.

Piotr Migoń

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Part III Geoheritage

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# 1 Introduction

Dénes Lóczy

The novelty of this publication is that this is the first which intends to be a modern introduction to the most interesting geomorphological sites of Hungary—at least in the English language. The idea of such a book has been long raised by several Hungarian geomorphologists (including the present editor), but none of the manuscripts has ever reached the stage of completion.

It cannot be claimed, however, that the book has no precedents at all. In the early decades of the 20th century, an eminent geomorphologist and our most prolific geographical writer, Cholnoky (1929), published numerous books, both academic and popular, with valuable geomorphological descriptions in his unimitable style, including a "Geography of Hungary". In order to enhance public knowledge on the earth sciences, a scientific guidebook entitled "Geological Excursions around Budapest" (Schafarzik et al. 1929) was published in the same year. Although much of the information contained is still valid today, no further update after the 3rd edition, issued exactly half a century ago, has come out.

To meet an increasing demand for geological guides presenting other parts of Hungary too, a popular series of geological guides (Budai et al. 2002) was launched by National Park directorates in cooperation with the Geological Institute of Hungary. The well-illustrated summary of spectacular sights in one of Hungary's most scenic landscapes, based on decades of detailed mapping in the Balaton Highland by the team of authors, was favourably received in the circle of geomorphologists, but the first volume printed in a relatively small number of copies has not been followed by further volumes. A new series of geological guides written by geologists of the Eötvös Loránd University has just begun to be published by Hantken Publishers (Pálfy and Pazonyi 2007; Palotai 2010). However, inventories of the key geological sections have never been supplemented with the descriptions of related landforms. The closest attempt was made by Juhász (1987) in his popular summary of earth history on the territory of Hungary and in a geological atlas for tourists (Budai and Gyalog 2010).

Although the publisher of agricultural books has been showing respectable steadfastness in regularly issuing monographs on the National Parks of Hungary since the 1970s, an interested reader can find very little and mostly outdated geomorphological information there. Likewise, earth sciences monographs (for instance, Karátson 1997; Mészáros and Schweitzer 2002) only rarely give some space for a brief description of typical geomorphological sites.

The most painful gaping hollow on the bookshelves of Hungarian geomorphologists, however, is the lack of a new regional geomorphology of Hungary, which could be the source for an English translation.

Under the above presented circumstances, it is a fortunate coincidence that the *Landscapes and Landforms* series was just recently launched by Springer publishers (modelled on the book *Geomorphological Landscapes of the World*—Migoń 2010) and the Hungarian efforts to the end of producing a comprehensive introduction of geomorphological sites in Hungary could be successfully channelled in this direction. This does not mean that the book is striving for completeness: the limitation of space only allows for the presentation of a *selection of sites*. From a class of landforms the most spectacular example is included and presented in some detail (Fig. 1.1), while others have to be 'satisfied' with only brief mentions.

Some chapters focus on classical examples of landforms, which regularly appear in the standard geomorphological/geographical textbooks, old and new (for instance, the dunes of blown-sand areas or oxbows on lowland floodplains). They are so typical for the country that simply cannot be left out. Others are exactly at the other end of the scale and, as a consequence, may be even more interesting: they are relatively unknown even to Hungarian geographers, such as the karst features under and around the basalt lava cap of Kab Mountain. These are mostly presented here by the teams of researchers who first described them.

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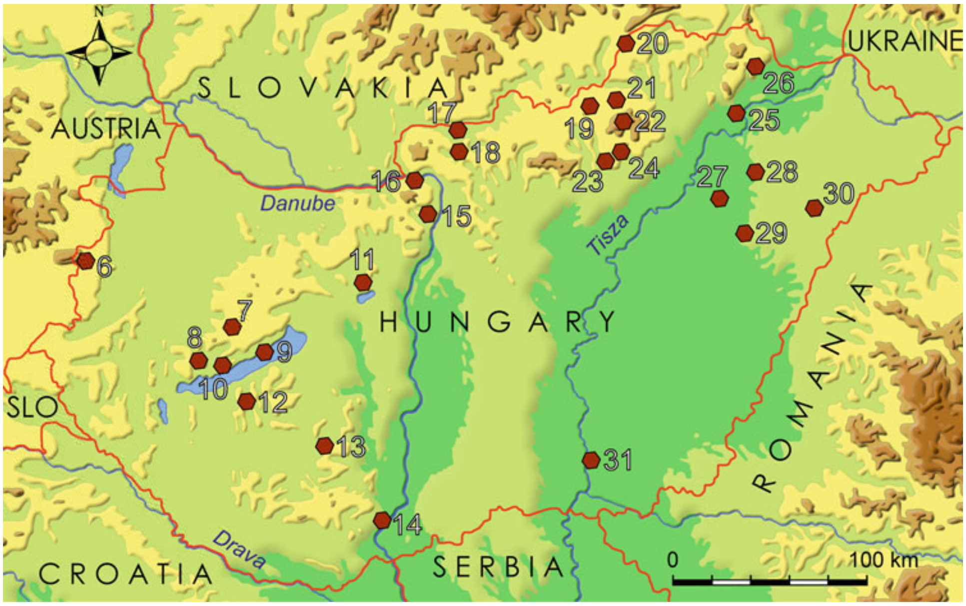

**Fig. 1.1** Locations of the geomorphological sites presented in the volume. Chapter numbers: *6* Kőszeg Mountains; *7* Kab Mountain in the Bakony Mountains; *8* Tapolca Basin; *9* Tihany Peninsula; *10* Kál Basin; *11* Velence Mountains; *12* Somogybabod gully in the Somogy Hills; *13* Kapos Valley; *14* Dunaszekcső loess bluff; *15* Caves in the Buda Mountains; *16* Danube Bend; *17* Medves region; *18* Kazár in the Nógrád Basin; *19* Vajdavár Hills; *20* Baradla–Domica cave system; *21* Uppony Hills; *22* Bükk Mountains; *23* Egerszalók; *24* Beehive rocks in the Bükk Foothills; *25* Tokaj Hill; *26* Megyer Hill in the Tokaj Mountains; *27* Hortobágy puszta; *28* Nagyhegyes Crater Lake; *29* Lyukas Mound; *30* Southern Nyírség; *31* Mártély oxbow

The question arises: how 'final' are the conclusions on the origin of the individual landforms? We can never be absolutely sure about the validity of our interpretations, but while the development of some landforms seems not to present a problem any more, the origin of others is still unresolved. The stages and chronology of the evolution of the picturesque Visegrád Gorge (Danube Bend) has been and remains to be among the great puzzles geologists and geomorphologists keep trying to solve time after time. We do not know who carved the niches, certainly anthropic features, into the "beehive rocks" or built the numerous tumuli. At any rate, the volume reflects the state-of-the-art explanations of geomorphological features of variable size and age. The age of landform is probably an issue still open to debate in many cases since novel geophysical dating methods may change the views of researchers at this point even overnight.

The lack of space has prevented most of the authors to include cultural geography in more detail. In some chapters, however, in addition to the preservation of geoheritage, some insight is also provided into the social, cultural and economic significance of landforms.

The sites are arranged geographically. Starting in the west, the reader is guided across Transdanubia to Budapest and then on to northern Hungary and the Great Hungarian Plain. Although very few of the landforms presented in this volume are unique to Hungary, the editor hopes that the curiosity of the reader will be satisfied and his/her interest in the topical issues of the geomorphology of Hungary maintained.

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# Part I

# Physical Environment

# Geological and Tectonic Background

# 2

János Haas

**Abstract**

The Pannonian region (the Pannonian or Carpathian Basin and the surrounding mountain ranges) is part of the Mediterranean Mountain System, which was formed during the last plate-tectonic cycle since the latest Paleozoic times. In Europe it is an about 300–800 km wide belt (Neo-Europe) accreted to the previously consolidated parts of Europe (Hercynian/Variscan Europe or Meso-Europe) as a result of the Alpine orogeny caused by convergence of the European (Eurasian) and African Plates. The present-day geological structure of the region is mostly determined by the evolution of the Tethys and Atlantic Ocean systems, i.e. the dismembering of the European and African continental plate margins during the early evolutionary stages and their tectonic deformation and uplifting as consequences of plate and microplate collisions. Plate-tectonic processes led to the formation of the large Pannonian Basin in the Late Cenozoic times. Hungary lies in the central part of the Pannonian Basin that is actually a system of several basins separated by isolated ranges of Palaeozoic and Mesozoic, sedimentary, magmatic and metamorphic formations and Cenozoic sedimentary and igneous rocks.

**Keywords**

Plate tectonics • Pannonian Basin • Tisza Megaunit • ALCAPA Megaunit

## 2.1 Geological Evolution of the Pannonian Region

The pre-Neogene structure of the Pannonian (Carpathian) Basin exhibits a complex mosaic-like collage structure (Fig. 2.1). The basement is divided into two large structural units by the Mid-Hungarian Lineament trending east-northeast to west-southwest (Csontos et al. 1992; Fodor et al. 1999; Haas and Kovács 2001; Schmid et al. 2008; Haas et al. 2010). These large units, namely the Tisza and Alpine-Carpathian-Pannon (ALCAPA) Megaunits, show markedly different geological features and evolution history (Fig. 2.2).

The Tisza Megaunit consists of blocks accreted during the Late Paleozoic Variscan (Hercynian) orogenic phases, when it formed a part of the European Variscan Belt. It separated from this belt in the Middle Jurassic and since the late Early Cretaceous it has moved as a separate entity, i.e. a microcontinent. The Variscan crystalline complexes are covered by Upper Paleozoic continental siliciclastic series, and continental, and shallow-marine Triassic formations (Bleahu et al. 1994; Haas 2012). The Jurassic is typified by facies diversification with coal-bearing and then neritic and deep-marine siliciclastic formations in the Lower and lower Middle Jurassic and deep-sea cherty limestones in the upper Middle and Upper Jurassic in the Mecsek Zone and condensed swell facies in the Villány-Bihor Zone. The Lower Cretaceous is characterised by basic volcanites and conglomerates and sandstones derived from the coeval volcanic rocks in Mecsek Zone whereas shallow-marine limestones prevail in the Villány-Bihor Zone (Haas and Péró 2004). The Paleozoic–Mesozoic series of the Tisza

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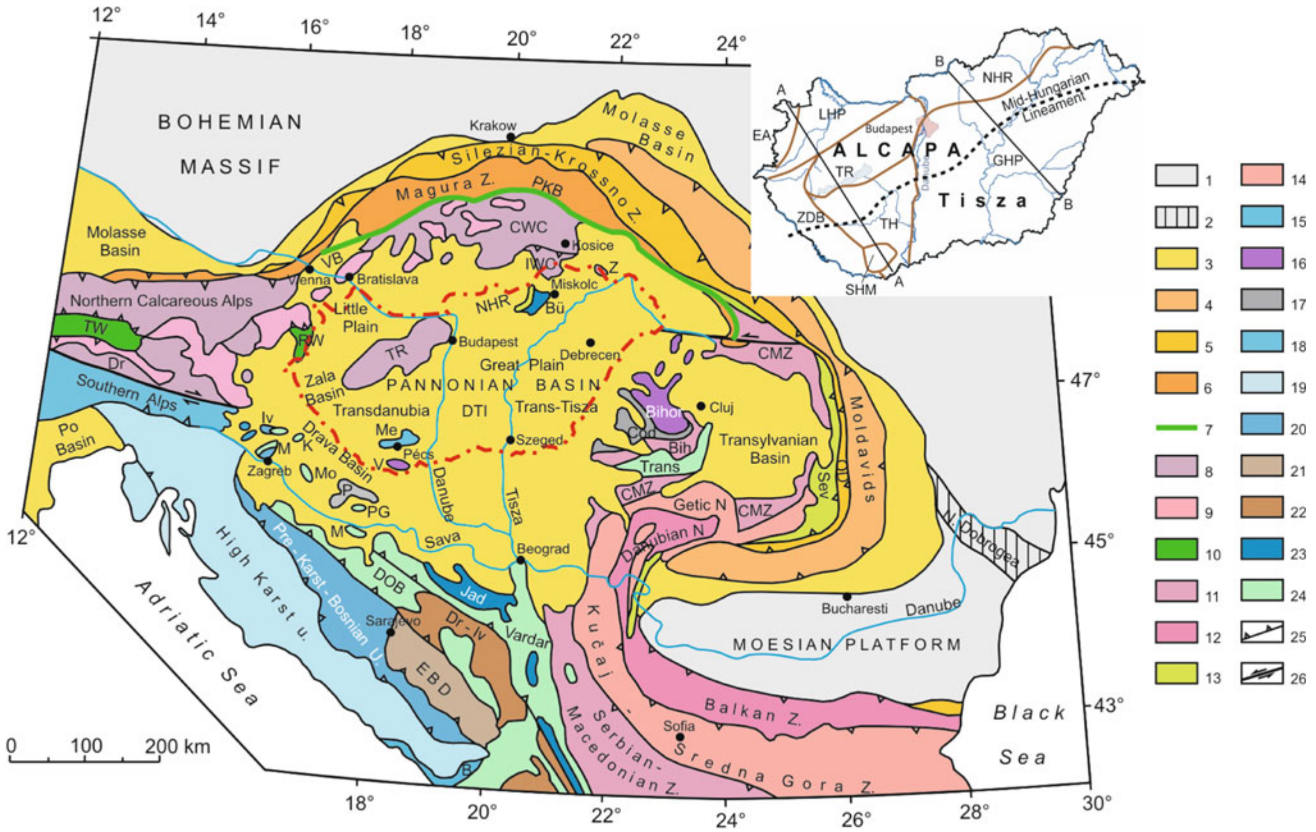

**Fig. 2.1** Major structural units of the Carpathic–Balkan–Dinaric region (after the maps by Schmid et al. 2008; Zagorchev 1994, Dimitrijević 1997). *1* Precambrian–Paleozoic platforms; *2* North Dobrogea Unit; *3* molasse basins; *4–7* Carpathian Flysch Zone: *4* Moldavides; *5* Silesian–Krossno Zone, Outer Dacides (*OD*); *6* Magura Zone; *7* Pieniny Klippen Belt (*PKB*); *8* Upper Austroalpine Unit, Transdanubian Range Unit, Fatric, Hronic and Silicic Units; *9* Lower Austroalpine Unit, Tatric, Veporic and Gemeric Units; *10* Penninic Unit; *11* Crystalline-Mesozoic Zone (*CMZ*), Serbian-Macedonian-Rodope Zone, Biharia Unit (*Bih*); *12* Danubian Nappes, Balkan Zone; *13* Severin Nappe (*Sev*); *14* Getic Nappes, Kučaj-Sredna Gora Zone; *15* Mecsek Zone (*Me*); *16* Villány (*V*)–Bihor Zone; *17* Papuk (*P*)–Codru (*Cod*) Zone; *18* Southern Alpine Units; *19* High karst Unit; *20* Pre-Karst–Bosnian Unit; *21* East Bosnian–Durmitor Unit (*EBD*); *22* Drina–Ivanjuca Unit (*Dr-Iv*); *23* Jadar Unit (*Jad*), Bükk Unit (*Bü*); *24* Vardar Zone, Transylvanian Nappes (*Trans*), Dinaridic Ophiolite Belt (*DOB*); *25* overthrust; *26* strike-slip fault. *Tw* Tauern window; *Rw* Rachnitz window; *Dr* Drau Range; *K* Kalnik; *Iv* Ivanscica; *Mo* Moslavačka Gora; *PG* Požekša Gora; *Z* Zemplén Mountains. *Inset map* Megaunits of Hungary with main lineaments and sites of profiles in Fig. 2.3. *AA* and *BB* sites of profiles. *EA* East-Alpine; *LHP* Little Hungarian Plain; *TR* Transdanubian range; *ZDB* Zala and Drava Basin; *TH* Transdanubian Hills; *NHR* North Hungarian range; *GHP* Great Hungarian Plain; *SHM* South-Hungarian Mountains

Megaunit are exposed in the Papuk Mountains in Croatia, in the Mecsek and Villány Mountains in South-Hungary and in the Apuseni Mountains in Romania. They were also recognised in a great number of wells in the basement of the Pannonian Basin.

Parts of the ALCAPA Megaunit constitute the basement of the northwestern segment of the Pannonian Basin as a continuation of the Austroalpine units exposed in the Eastern Alps (Fig. 2.2). The Transdanubian Range Unit is considered as an Upper Austroalpine-type nappe (Fodor et al. 2003; Tari and Horváth 2010). It is built up of a Lower Palaeozoic low-grade metamorphic complex, Permian fluvial sandstones and Triassic shallow marine sedimentary formations, mostly shallow-marine carbonates. The mostly deep-marine Jurassic–Lower Cretaceous formations are overlain by continental to deep-marine sediments formed by tectonically controlled transgression-regression cycles from the Late Cretaceous to the Paleogene (Haas 1991, 2012).

The Mid-Hungarian Zone is a narrow belt at the southern margin of ALCAPA containing strongly sheared, displaced elements of the South Alpine and Dinaridic origin. The Bükk Unit, exposed in the Bükk Mountains, Northeast-Hungary, is considered as part of the Mid-Hungarian Zone. It is composed of low-grade metamorphosed Upper Paleozoic to Jurassic sedimentary and volcanic rocks, which are overthrust by mélange with fragments of the Neotethys accretionary complex (Haas and Kovács 2001).

Large-scale strike-slip movements and coeval opposed rotation of the megaunits led to the juxtaposition of the basement units during the Early Tertiary (Csontos et al. 1992; Fodor et al. 1999; Csontos and Vörös 2004). These motions were controlled by indentation of the Adria

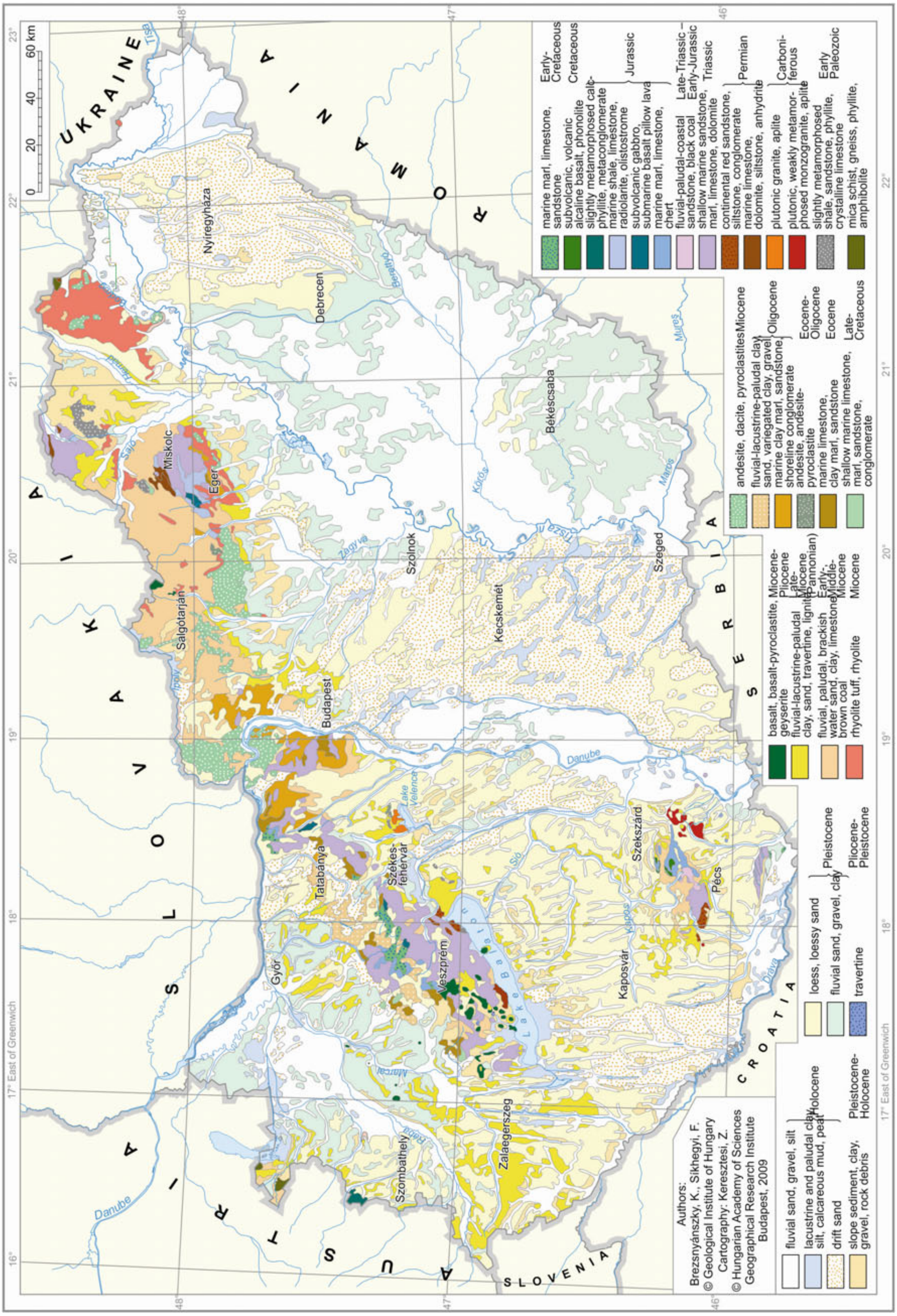

**Fig. 2.2** Geological map of Hungary (Brezsnyánszky and Síkhegyi 2009)

Microplate and rollback of the subducting slabs along the European Plate margin which led to the formation of a young basin system through crustal thinning beneath the area (Horváth et al. 2006). The phase that formed the Pannonian Basin was initiated by attenuation of the crust, leading to intense volcanism and significant but uneven subsidence during the Miocene. An andesite-dacite stratovolcanic chain, sub-parallel to the Carpathian arc, was formed 17–12 Ma ago (Harangi et al. 2007). It was followed by intense subsidence and sedimentary upfilling of the basins between 11.5 and 5 Ma. In the meantime, due to uplift of the Carpathian arc the previous connection with the Black Sea had ceased to exist and a large lake (Lake Pannon) took shape (Magyar et al. 1999). Parallel to the intense subsidence, basalt volcanism started in some parts of the Pannonian Basin ca 8 Ma ago (Németh and Martin 1999; Harangi 2001). Sediments derived from the rising Alps and Carpathians gradually filled up the lake, step-by-step through advancing deltas (Juhász et al. 2007; Magyar et al. 1999). By the Pliocene, a fluvial-lacustrine system with large swamps and wetlands replaced the lake. An intense uplift of Transdanubia, the western part of the Danube-Tisza Interfluve, and of the present-day mountains began 5 Ma ago, whereas the subsidence of the deep basins continued, giving rise to the deposition of thick fluvial sediments during the Pleistocene.

The main stages of the evolution of the geological structure of the Pannonian region can thus be summarized as follows:

1. Pre-Alpine, mostly Variscan, evolution that determined the geological structure of the plate margins at the beginning of the Alpine plate-tectonic cycle. Large fragments of the Variscan Belt became dismembered from the margins and incorporated into the Alpine orogenic system.
2. The early stage of the Alpine plate-tectonic cycle is characterised by the opening of oceanic basins: the western Neotethys Ocean from east to west from the Middle Triassic to Early Jurassic and the Penninic branch of the Atlantic Ocean from west to east from the Middle Jurassic to Early Cretaceous.
3. The stage of the mountain building processes that was the consequence of closure of the Neotethys basins from the Middle Jurassic to the Late Cretaceous–earliest Tertiary and of the Penninic basins ('Alpine Tethys') from the early Late Cretaceous to the Early Miocene.
4. Development of molasse basins in the foreland of the Alpine nappe stacks and in backarc setting related to the subduction of the European Plate in the Late Cenozoic.

## 2.2 Regional Geological Units

### 2.2.1 East Alpine Ranges in Western Hungary

Metamorphosed Palaeozoic and Mesozoic complexes representing the continuation of the East Alpine ranges are exposed in the northwestern corners of Hungary, in the Sopron and the Kőszeg Mountains, along the Austrian border. The Sopron Mountains consist of mica-schist and gneiss formations which can be correlated with the Raabalpen "Grobgneiss" Complex of the Lower Austroalpine (East Alpine) Nappe System (Fig. 2.3a). The history of metamorphism for these rocks commenced probably during the Caledonian orogeny, and continued during the Variscan phases. They were also affected by shearing in connection with the Alpine nappe movements (Lelkes-Felvári et al. 1984).

The rocks of the Kőszeg Mountains (belonging to the Rechnitz Window) and to Vashegy Hill (forming an independent window) appear from beneath the Austroalpine nappes in two blocks. There is a metasediment complex of Jurassic age, made up of quartz-phyllite and calcareous phyllite with coarse-grained meta-conglomerate bodies, and an ophiolite complex with serpentinised ultramafic–metagabbro–greenschist and blueschist rock associations of Early Cretaceous age. Both complexes were subject to very low to low-grade Alpine metamorphism (Koller 1985).

After a long period of continental erosion, the deposition of fluvial clastics and coal-bearing lacustrine clayey, silty, sandy sequences initiated in small basins of the Sopron Mountains during the Early Miocene. The Middle Miocene (Badenian) transgression led to the deposition of conglomerates followed argillaceous sedimentation under relatively deep marine conditions. The upfilling of the basins was reflected in the deposition of shallow marine biogenic limestones. The late Middle Miocene (Sarmatian) sedimentation is characterised by coarse-grained delta facies and the deposition of gravelly and sandy sediment continued during the Late Miocene lacustrine stage (Pannonian).

### 2.2.2 Little Hungarian Plain

The Little Hungarian Plain Basin (Danube Basin in Slovakia) is a large sub-basin of the Pannonian Basin system (Fig. 2.3a). The Lower and Upper Austroalpine nappes and Paleozoic and Mesozoic formations of the Transdanubian Range unit form the basement of the basin on the territory of Hungary. Parallel with intense subsidence, deposition of terrestrial clay, breccia and conglomerate began in the central part of the basin during

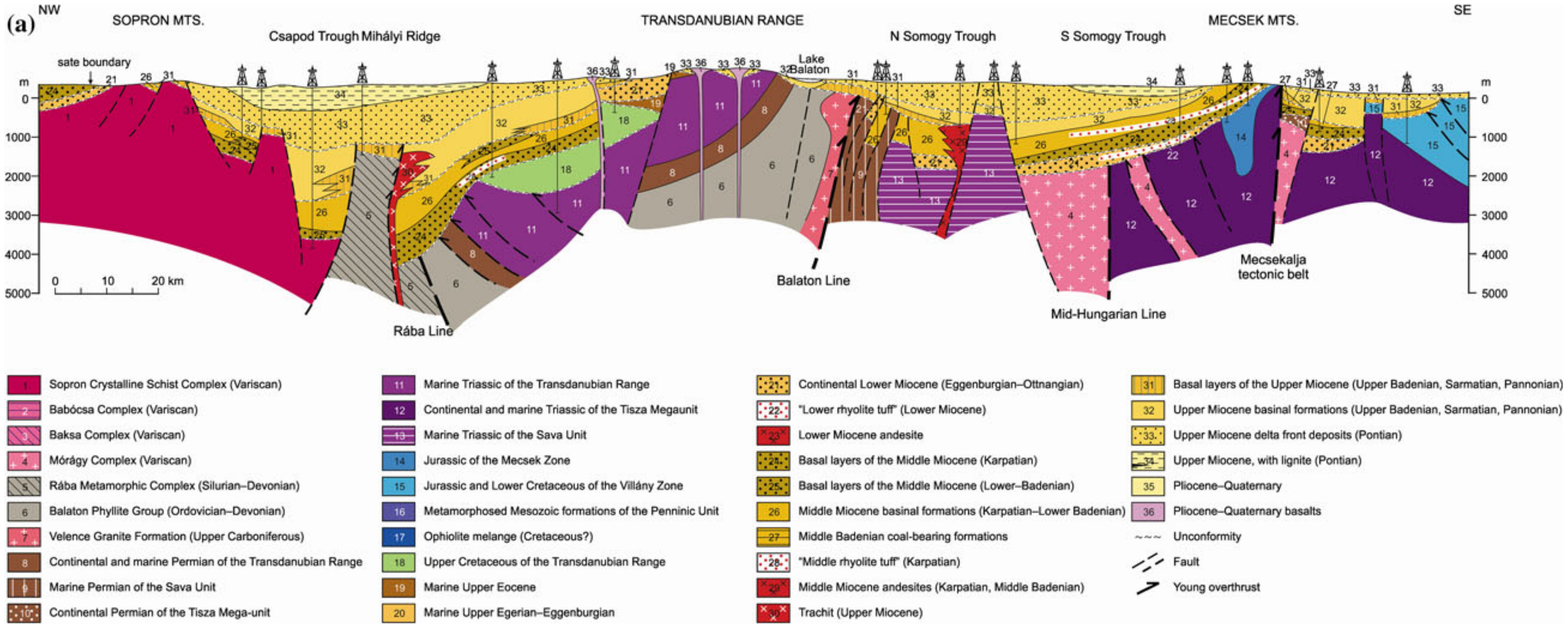

**Fig. 2.3** Profiles across Transdanubia (**a**) and eastern Hungary (**b**) (after Haas 2012)

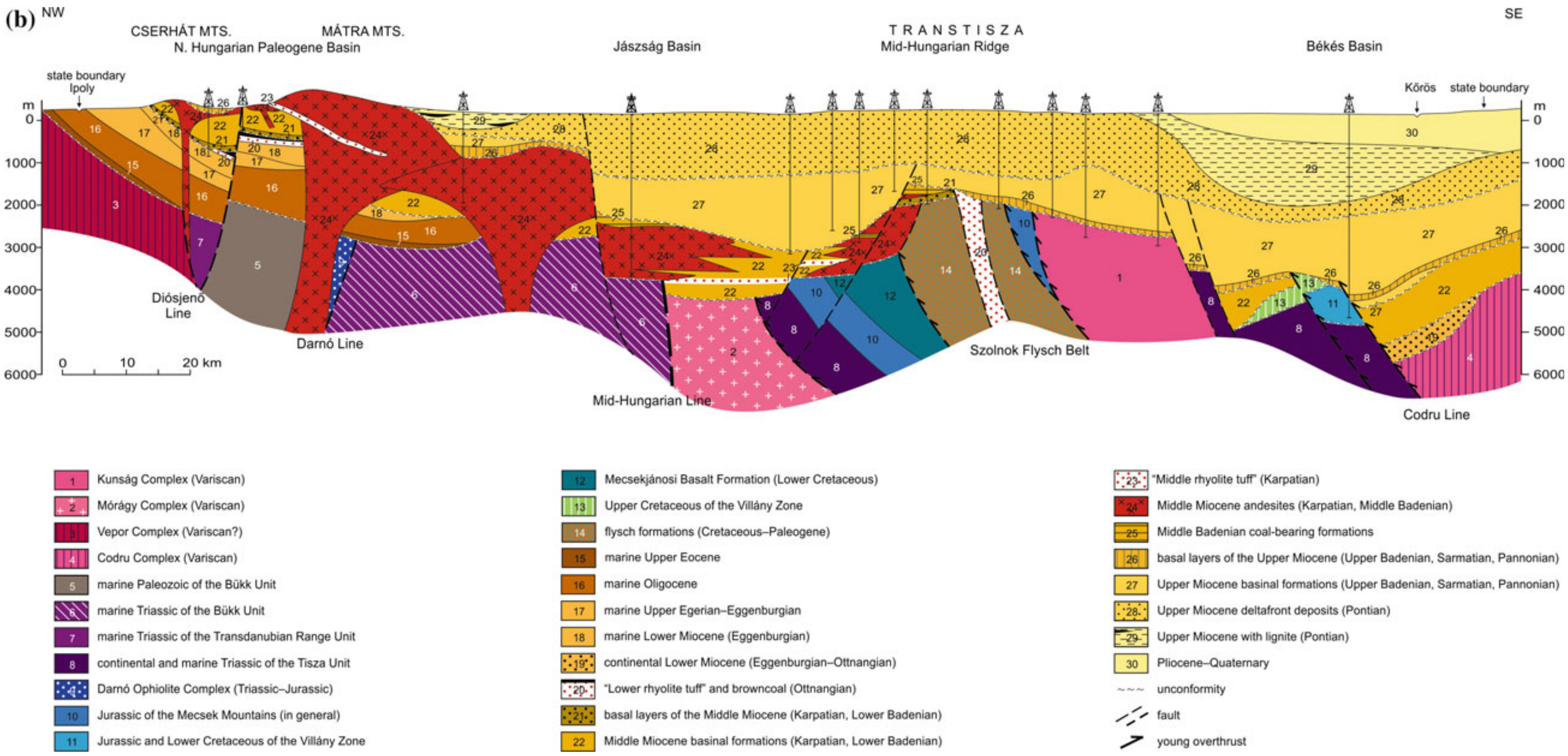

**Fig. 2.3** (continued)

the Middle Miocene (Karpatian, Early Badenian). It was followed by deposition of marine sandstone and limestone along the basin margins and clayey sediments in the deeper inner parts during the Badenian, while clayey marl, sandstone and tuffitic sandstone in the late Middle Miocene (Sarmatian) (Hámor 2007). Intense alkaline volcanic activity took place in the centre of the basin in the late Middle to early Late Miocene (Late Badenian to Early Pannonian) interval (Harangi 2001). At the beginning of the Late Miocene, i.e. in the Early Pannonian (11–12 Ma) lacustrine conditions already prevailed (Magyar 2010). Clayey sediments were deposited in the deeper sub-basins, whereas along the basin margins (Sopron Mountains, Transdanubian Range) and around elevated blocks (e.g. Mihályi High) conglomerates were formed from local sources. Then the southeastward prograding large Pannonian-delta reached the area between 9.7 and 9.0 Ma ago (Magyar 2010) and led to the deposition of predominantly sandy sediments in a thickness of several 100 to more than 1,000 m. It was followed by fluvial–lacustrine sedimentation of sand, sandstone, siltstone and variegated clay locally with lignite intercalations. The thickness of the Late Miocene to Pliocene fluvial succession may exceed 1 km. In the Pliocene, ca 5 Ma ago, explosive magmatic activity emerged at some sites of the Little Plain (Kemenesalja) that resulted in the formation of maar complexes and related tuff rings (Németh and Martin 1999 see Chap. 7). Intense subsidence of the area continued in the Quaternary; the thickness of the fluvial Quaternary formations reaches 450 m in the Győr Basin (Gábris and Nádor 2007).

### 2.2.3 Transdanubian Range

The Transdanubian Range, extending for 250 km in a NE–SW direction, consists of hills and mountains with a great variety of geological components (Fig. 2.3a). Lower Palaeozoic phyllite and carbonates are known north of Lake Balaton (Balaton Highland), while Early Permian granite makes up a great part of the Velence Hills located northeast of the Balaton. In a narrow belt north of Lake Balaton Lower Paleozoic rocks are overlain by Permian terrestrial red conglomerate and sandstone and a Lower Triassic succession of alternating marl, siltstone, limestone and dolomite formations. Other parts of the Transdanubian Range (Keszthely, Bakony, Vértes, Gerecse, Pilis and Buda Mountains) are built up mainly of Triassic dolomites and limestones of 2–3 km in thickness (Fig. 2.4a—Haas 2012). The Jurassic and Lower Cretaceous formations occur in the central zone of a large syncline, which was created by compressional tectonic movements in the middle Cretaceous. The Jurassic sequences are characterised by red pelagic limestones and in the Middle to Upper Jurassic segment also by radiolarites. The Lower Cretaceous is mostly represented by cherty deep marine limestones in the Bakony and marls, sandstones and conglomerates also of deep sea facies in the Gerecse Mountains. The orogenic processes in the middle Cretaceous were also manifested in uplifting, subaerial exposure of a significant portion of the Transdanubian Range and deposition of karstic bauxites in the Bakony, followed by a transgression and accumulation of marine limestones and marls of several 100 m in thickness. The next deformation phase during the Late Cretaceous caused even more intense denudation, karstification and deposition of bauxites of commercial value. The older Mesozoic formations are unconformably covered by continental and shallow marine Upper Cretaceous formations in the western Transdanubian Range (Bakony). General uplifting took place after the Cretaceous and created terrestrial conditions all over the Transdanubian Range area, intense karstification and bauxite deposition (Haas 2012). After a long continental period marine transgression resumed only in the Middle Eocene and deposited coal seams, and mostly clayey formations in the basins and carbonates in the shallow marine margins. Subsequent to the Early Oligocene uplift and erosion, fluvial sedimentation prevailed over the predominant part of the area during the Late Oligocene, whereas in the northeastern Transdanubian Range (Buda Mountains), which belonged to the North Hungarian Paleogene Basin, mostly clayey sediments were deposited from the Late Eocene to the Oligocene in a relatively deep marine basin (Nagymarosy 1990). In the Miocene the overwhelming area of the Transdanubian Range was exposed but several sub-basins formed with the deposition of shallow marine gravelly–sandy sediments and limestones. During the early Pannonian times the range constituted a large peninsula surrounded by shallow lacustrine environments with gravelly-sandy sediment deposition from local sources near the shore and clayey sedimentation in the deeper offshore zones. Later on, as a result of rising lake level, a significant portion became inundated (Magyar 2010). The basaltic volcanic activity in the South Bakony–Balaton Highland area began in the latest Miocene (7.9 Ma—Balogh and Németh 2005) and continued till the Late Pliocene.

### 2.2.4 Zala and Drava Basins

The Northern and Southern Zala and the Drava Basins are located in Southwest-Hungary and extend over the territory of Slovenia and Croatia. The basins began to take shape during the Lower to Middle Miocene and became sub-basins of Lake Pannon during the Late Miocene. Reflecting their different pre-Miocene evolution, the basements of the basins are significantly different. The basement of the Northern Zala Basin belongs to the Transdanubian Range structural unit. Accordingly, it is composed of Paleo-Mesozoic and Paleogene formations akin to those in the western part of the Transdanubian Range. The Miocene sequence begins with

**Fig. 2.4** Widespread rock types of geomorphological significance in Hungary. **a** Triassic (Dachstein) limestone slope at Kesztölc in the Pilis Mountains, Transdanubian Range (Photo by János Haas); **b** Triassic dolomite cliff in Veszprém, Bakony Mountains, Transdanubian Range (Photo by János Haas); **c** Main Conglomerate of Jakab Hill, Mecsek Mountains (Photo by János Haas); **d** Loess bluff of the Drava River at Heresznye, Inner Somogy Hills (Photo by Dénes Lóczy)

Karpatian to Badenian conglomerates or sandstones overlain by silt and clay with marine fossils; the Sarmatian is represented by marl and sandstone. The thickness of the Middle Miocene succession may exceed 1,000 m (Hámor 2007). Clayey marl of pelagic lake facies was formed in the early times of the Late Miocene. This sub-basin was approached by the south-eastward prograding delta 8.9–8.6 Ma ago (Magyar 2010), leading to the deposition of a 1 km thick sand-dominated succession. It was followed by the deposition of a fluvial–lacustrine series, ca 1.5 km in thickness.

The basement of the Southern Zala Basin is assigned to the Mid-Hungarian Zone. In a belt south to the Balaton Lineament displaced fragments of the South Karavanken and Julian–Savinja Units consisting of Permian and Triassic formations form the basement. Further southward slightly metamorphosed Triassic and Jurassic rocks and ophiolite mélange of the Kalnik Unit were encountered below the Miocene formations (Haas 2012). In the depocenter above terrestrial conglomerate about 3 km thick Middle Miocene (Badenian) marine clayey marl was formed. This sub-basin may have been reached by the large Pannonian delta somewhat later, in the 8.6–8.0 Ma interval. Otherwise, the Pannonian succession is similar to that in the Northern Zala Basin.

In the Drava Basin a basement of Paleozoic medium-grade metamorphic rocks and Mesozoic carbonates was detected. The Neogene started with Lower Miocene non-marine conglomerates, sandstones and clayey marls in a thickness of 2 km. The Middle Miocene is represented mostly by marine marls and clays in the inner part of the basin and shallow marine carbonates along the basin margins. The Pannonian delta may have occupied this area ca

6.8 Ma ago. Above the 1 km thick delta-related lacustrine sequence 2.5 km thick fluvial-lacustrine series was formed. In the axial belt of the basin the thickness of the Quaternary is more than 250 m.

### 2.2.5 Transdanubian Hills

This area is located in southern Transdanubia between the Transdanubian Range and the Mecsek Mountains and bordered by the Dráva Basin to the southwest and the Great Hungarian Plain to the east. Late Paleozoic to Mesozoic predominantly carbonate formations of the Mid-Hungarian Zone and Paleozoic metamorphic complexes and Mesozoic formations of the Tisza Megaunit form the basement of the Neogene sedimentary sequences (Fig. 2.3a—Haas 2012). In the Early to early Middle Miocene a fluvial conglomerate and sandstone succession was accumulated in a remarkable thickness (0.8–1.2 km) in a tectonically controlled continental basin. Continuing subsidence led to transgression and establishment of open marine conditions during the Badenian, followed by shallow marine sedimentation in the Sarmatian. The Pannonian lacustrine-pelagic conditions were changed in this area in the 8.6–7 Ma interval due to the effect of the prograding delta system that led to deposition of ca 1 km thick turbiditic sandy sediments and a subsequent fluvial-lacustrine succession. However, in contrast to the Dráva Basin in this area the subsidence was followed by Pliocene and Quaternary uplift in the inversion phase of basin evolution (Horváth et al. 1988).

### 2.2.6 South Hungarian Mountains

Carboniferous granite is exposed in the southeastern foreland of the Mecsek Mountains (Mórágy Hills). 3–4 km thick Permian and Early Triassic continental red-beds and 600–700 m thick Middle Triassic carbonate sequences constitute the anticline of the Western Mecsek Mountains (Fig. 2.3a), Jurassic sedimentary sequences and Lower Cretaceous magmatic and sedimentary formations constitute the syncline of the Eastern Mecsek. The thickness of the Jurassic is more than 3 km in the south and decreases to 500 m northward. The succession begins with a coal-bearing formation that is covered by shallow to deep-marine marls and sandstones of remarkable thickness. A thin series of deep-marine limestones represents the Middle and Upper Jurassic. Intense volcanism dominated the Early Cretaceous evolution producing a ca 1 km thick complex of alkaline basalt and marine sandstone and conglomerate consisting mostly of reworked volcanic rocks.

Located south of the Mecsek Range, the Villány Hills have an imbricate structure consisting mainly of Mesozoic carbonates; Triassic shallow marine dolomites and limestones, a condensed and discontinuous marine Jurassic succession and a thick Lower Cretaceous shallow-marine limestone formation.

In the early Cenozoic times the area of southern Transdanubia was an emerged land subjected to erosion. In the Early Miocene a large continental basin developed in the northern foreland of the Mecsek where thick fluvial formations were formed and similar sequences occur in sub-basins within the Mecsek Mountains. In the northern part of the Mecsek, above the Mesozoic basement or the Miocene terrestrial and rhyolite tuff succession, andesitic subvolcanic rocks occur. The marine sedimentation began only in the Badenian, when shallow-marine limestones deposited directly upon the bedrocks. However, large parts of the Mecsek–Villány area were probably still in emerged position. The Pannonian sequence commences usually with basal conglomerates that are overlain by calcareous marl and clayey marl of open lake facies and followed by sand-dominated delta successions.

### 2.2.7 North Hungarian Range

The North Hungarian Range is very complex geologically. In a geological sense the western Cserhát Hills (the Naszály and other Mesozoic blocks in its environs) belong to the Transdanubian Range unit. In contrast, the Visegrád Mountains, on the western bank of the Danube, is a part of the North Hungarian Miocene volcanic range.

The oldest formations occur in the northeastern part of the region, in the Szendrő and the Uppony Mountains where slightly metamorphosed Palaeozoic shallow and deep marine sedimentary rocks—phyllites and carbonates—outcrop. The Bükk Mountains is built mostly of slightly metamorphosed Upper Palaeozoic to Jurassic series. The northern part of the mountain consists predominantly of Carboniferous to Permian shales and carbonates. The Bükk Plateau is constituted mostly of Middle to Upper Triassic shallow marine limestones. Jurassic shales and conglomerates of deep-marine basin and slope facies and large basalt and gabbro bodies prevail in the western portion of the mountains. These complexes are locally covered by a marine Palaeogene sequence. The Rudabánya and Aggtelek Hills are built up of nappes of the Inner West Carpathian unit. The Rudabánya Hills contain non-metamorphosed and slightly metamorphosed Triassic and Jurassic shales and carbonates. The Aggtelek Hills consist of Triassic rocks, mostly shallow-marine limestones (Haas 2012).

The western North Hungarian Range consists of Paleogene and Neogene sedimentary formations and Neogene volcanic rocks. Metamorphic complexes of the Central Carpathian Vepor unit and Mesozoic sequences of the Transdanubian Range and the Bükk units form the basement of the Cenozoic formations. In the Paleogene Basin the Cenozoic transgression led to the formation of shallow-marine limestone in the Late Eocene, followed by the deposition of deep-marine marls in the Early Oligocene. During the latest Eocene–Early Oligocene the upbuilding of an andesitic stratovolcano in the Eastern Mátra Mountains started. Deposition of deep-marine marls and siltstones continued in the centre of the basin whereas shallow marine sandstones were formed along the margins during the Late Oligocene–Early Miocene. Subsequent uplift resulted in the establishment of terrestrial conditions and intense erosion that was followed by the deposition of rhyolite tuff over large areas in the late Early Miocene (Ottnangian). Transgression in the early Middle Miocene (Badenian) led to the deposition of clayey marine sediments in the deeper basins and sandy sediments and biogenic limestones in the shallow marginal zones (Hámor 2007), accompanied by intense volcanism. The bulk of the andesitic volcanic rocks that make up the Visegrád, Börzsöny, Cserhát and Mátra Mountains were formed in the Badenian, 15–16 Ma ago (Fig. 2.3b—Harangi 2001). The thickness of the lava, volcanic breccia and tuff succession of the stratovolcanic complexes may reach 1–2 km. Pliocene to Quaternary (5.6–1.8 Ma) basalts occur the Karancs–Medves area (Nógrád–Gemer Volcanic Field) and in the northern Cserhát Hills.

The eastern section of the North Hungarian Range includes the Cserehát Hills, which consist mostly of Neogene sedimentary rocks, and the Tokaj Mountains that are built up of Neogene and Quaternary deposits and volcanic complexes. Here volcanism began in the Late Badenian (13 Ma) and a 1–3 km thick stratovolcanic complex of rhyolite, dacite, andesite and their pyroclastics accumulated in the course of several eruptions until the earliest Pannonian (10.5 Ma) (Harangi 2001).

### 2.2.8 Great Hungarian Plain

Formed by upfilling of a large Neogene basin of articulated basement topography, it is an extensive plain area extending far over the territory of Hungary. The basement of the Great Plain is heterogeneous (Fig. 2.3b). The southern portion is assigned to the Tisza Megaunit, whereas the northern part belongs to the ALCAPA Megaunit and they are separated by the Mid-Hungarian Zone. Mostly Variscan medium-grade metamorphic complexes consisting of gneisses and mica schists form the basement of the Tisza Megaunit. These complexes are locally covered by Mesozoic successions. Highly deformed, Cretaceous to Paleogene imbricate flysch sequences occur in the northernmost belt of the Tisza Megaunit. North of the Mid-Hungarian Lineament, predominantly Mesozoic carbonates were encountered under the Cenozoic sequences.

Controlled by the Middle Miocene extensional tectonics, very deep sub-basins and intrabasinal highs developed. In the former, thick (3–7 km) and nearly complete Middle Miocene to Pliocene successions accumulated (e.g. Jászság, Nyírség, Derecske, Makó, Békés Sub-basins) whereas in the latter the Middle Miocene formations are usually missing and the thickness of the Upper Miocene (Pannonian) to Pliocene deposits is less than 2 km (Fig. 2.3b—Nagymarosy 1981). After transgression in the Badenian islands and shallow to deep-sea environments were established. This general paleogeographical setting prolonged to the Late Miocene, parallel to changes in the salinity of water. As a result of intense fluvial transport two large delta systems developed in the Pannonian which led to gradual upfilling of the basin from to NW and NE to SE during the late Pannonian (8–5 Ma—Juhász 1991; Juhász et al. 2007; Magyar 2010) and coeval extension of the fluvial-lacustrine sedimentary environments. The thickness of the Quaternary sediments is usually more than 50 m, but in the still subsiding parts of the basin it may exceed 500 m (Gábris and Nádor 2007).

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# 3 Climate and Drainage

Dénes Lóczy

**Abstract**

Located in mid-latitude eastern Central Europe, Hungary has a moderately humid continental climate and, due to its situation in the Carpathian Basin, the basin effect is also observable. Regarding average conditions, the climate is rather humid than arid, water availability, however, is a decisive component of the climatic system and in most parts of the country drought is a recurring phenomenon. Since year-to-year or season-to-season variability is more remarkable than regional variations, long-term average values are not really informative as far as the climatic properties of individual regions are concerned. Warming and drying trends are predicted for the 21st century. The drainage system, developed since the Pliocene, is adjusted to two hydrographical axes: the Danube and the Tisza Rivers within the drainage area of the Danube. The water regimes of these rivers and their major tributaries depend upon the runoff conditions of their drainage basins: for the Danube first of all the Eastern Alps and for the Tisza River the Northeastern and Eastern Carpathians. The largest and best studied lake of Central Europe is the shallow Balaton. The single extensive reservoir was impounded on the Tisza River at Kisköre, mainly for irrigation purposes. As far as the groundwater resource is concerned, thermal, medicinal and mineral water reserves are particularly appreciated.

**Keywords**

Climatic regions • Basin character • Temperature • Precipitation • Winds • Runoff • Rivers • Lakes • Groundwater • Climate change

## 3.1 Introduction

It is difficult to overemphasize the significance of the climatic factor, i.e. past and present climatic conditions and events, in the physical environment in general and particularly in governing geomorphic processes. Equally important are rivers and groundwater conditions in landform evolution. Many of the geomorphological sites presented in this book owe their existence to a particular interplay between topography, climate and drainage in some period of geological history or even at present. This interconnectedness justifies that the climate and drainage of Hungary are treated jointly in this chapter.

## 3.2 Brief Climate History

To outline the climatic background to the geomorphic evolution of the Carpathian Basin (or the lands on its predecessor lithospheric plates), we have to reconstruct the conditions under which the surfaces now exposed were once formed. To this end, we have to reach back to the late Mesozoic and provide a brief overview of climate history since then—even if serious deficits exist in the data necessary for a more complete reconstruction.

Sedimentological evidence points to an extensive but generally shallow marine inundation in the Jurassic with equable and humid climate on the sporadic islands

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(Császár et al. 2008). Under the tropical warm and humid Cretaceous climate lateritic weathering provided favourable conditions for bauxite formation. The ore-bearing deposits were preserved in the depressions of the karst surface.

Recently, a short spell with rapid warming was identified in the sedimentological records of the Paleocene to Eocene transition (Paleocene/Eocene Thermal Maximum—Gingerich 2006). Subtropical to tropical ("hothouse") conditions survived well into the Eocene (Császár et al. 2008), when transgressions and regressions alternated in the area of the ALCAPA lithospheric plate. At the Eocene/Oligocene boundary (38 Ma ago) abrupt cooling is assumed. In addition to sedimentological evidence, it is also testified by a drastic drop in the level of world ocean. In the Oligocene a warm subtropical climate (mean annual temperature (MAT): 20 °C; annual precipitation (AP): ca 1,500 mm; both with marked seasonal variations) is assumed from the sporadic palynological data (e.g. the analysis of the Eger profile—Nagy 2005). In the Lower Miocene (Eggenburgian or Acquitanian) high temperatures (MAT: around 18 °C) and abundant rainfall (AP: 1,200–1,500 mm) with even distribution prevailed on the islands of the Carpathian archipelago (see also Chap. 4). Probably the dry season was longer than the wet period, but drought was moderate, possibly due to the proximity of the sea (Hably 1979). In the Ottnangian (Burdigalian) swamp forest conditions were typical with slightly lower temperatures (MAT: 16–17 °C), a marked cooler and drier season and probably somewhat lower (AP: 1,000–1,500 mm) precipitation (Nagy 2005). Simultaneously regional variations began to increase. In the largely marine Karpatian (Langhian) age subtropical climate dominated (MAT: 15–16 °C). Badenian (Serravallean) orogenic movements and volcanism (Chap. 4) further diversified the climate of the Carpathian Basin and in higher altitudinal zones temperate vegetation was also present (Hámor 2001). Tropical floral elements tend to disappear during the Sarmatian (Tortonian), while the surviving subtropical elements indicate connections towards the Near and Far East. The Carpathian Basin is in a transitional zone from the subtropical to the warm temperate zone with hot and dry summers and rainy winters (MAT: 14 °C, AP: 700–800 mm) close to the present-day values, also regarding its uneven distribution (Nagy 2005). Pannonian (Messinian) climate was expressedly warm temperate (MAT: 13 °C) of Mediterranean character, locally with particularly favourable conditions for vegetation growth. The existence of Lake Pannon attenuated climatic oscillations. In the mountain frame even conifer forests appeared.

During the complete upfilling of Lake Pannon, parallel to the Messinian Salinity Crisis, dry desert climate prevailed (AP: 150–250 mm) with wind action (Bérbaltavárian subage, 7–6 Ma ago). At the beginning of the Pliocene, the opening of the Gibraltar Strait restored water fill in the Mediterranean Sea (Császár et al. 2008; Schweitzer 2013). In the Ruscinian-Csarnótan subage (Zanclean-Piacenzan, 4.4–3 Ma ago) warm temperate (MAT: 12 °C) conditions with a summer dry season prevailed in the Carpathian Basin.

The Pleistocene began with warm and dry climate favouring pedimentation (Villányian, Calabrian, 3–1.8 Ma), followed by gradual cooling with loess and river terrace formation (Biharian, 1.8–1.2 Ma) (Schweitzer 2013). In the late Pleistocene cold and dry periods of periglacial climate alternated with warmer and wetter interglacials. The cyclicity of Quaternary climate is also detectable from an analysis of terrestrial deposits (e.g. loess-paleosol sequences or fluvial sequences from the Great Plain). Until ca 1 Ma ago the average length of the Milankovitch cycles was 40 ka and after that date 100 ka (Császár et al. 2008). At the peak of the last glacial (20–18 ka BP) MAT was −2 to 0 °C and AP 200–400 mm.

According to a recent Holocene chronology (Gábris et al. 2002), this age is subdivided into Bölling, Older Dryas, Alleröd, Younger Dryas and postglacial stages. In the last cold spell, the Younger Dryas (12.5–11.2 ka BP) July mean temperatures did not rise above 13 °C in the Carpathian Basin. Climatic amelioration (5–7 °C rise in MAT within millenia or even centuries) was a clear trend in the still cool Preboreal (11.6–10.2 ka BP; in July 18 °C) and in the Boreal stage (10.2–8.3 ka BP), when winters became mild. Among the stages the Atlantic (8.3–5.8 ka BP) stands out with its equable climate, probably warmer than today. Under the Boreal and Atlantic climates the hydrological cycle accelerated and this favoured fluvial erosion, which reached its maximum (Gábris et al. 2002). The wet and mild Subboreal stage (AP: 900 mm) was replaced by the moderately wet Subatlantic (AP: 750 mm) 2.5 ka ago, when human impact became decisive in the environmental history of the Carpathian Basin.

## 3.3 Climatic Influences and Regions

At present, Hungary lies in the temperate belt, in the zone of westerly winds, but in a relatively great distance from oceans. Its climate results from spatially and temporarily highly imbalanced Atlantic, Mediterranean and continental climatic influences, producing, on the whole, a moderate continental climate (Péczely 2009). The influence of Atlantic air masses is primarily manifested in milder winters, cooler summers and a more or less uniform distribution of precipitation (overwhelmingly rainfall) throughout the year. The most common area of origin for Mediterranean cyclones, the Ligurian Sea, lies even closer to the western borders of the country than the Atlantic Ocean: at a mere 600 km distance. The cyclones arriving from the Mediterranean bring rains in autumn and, with increasing frequency,