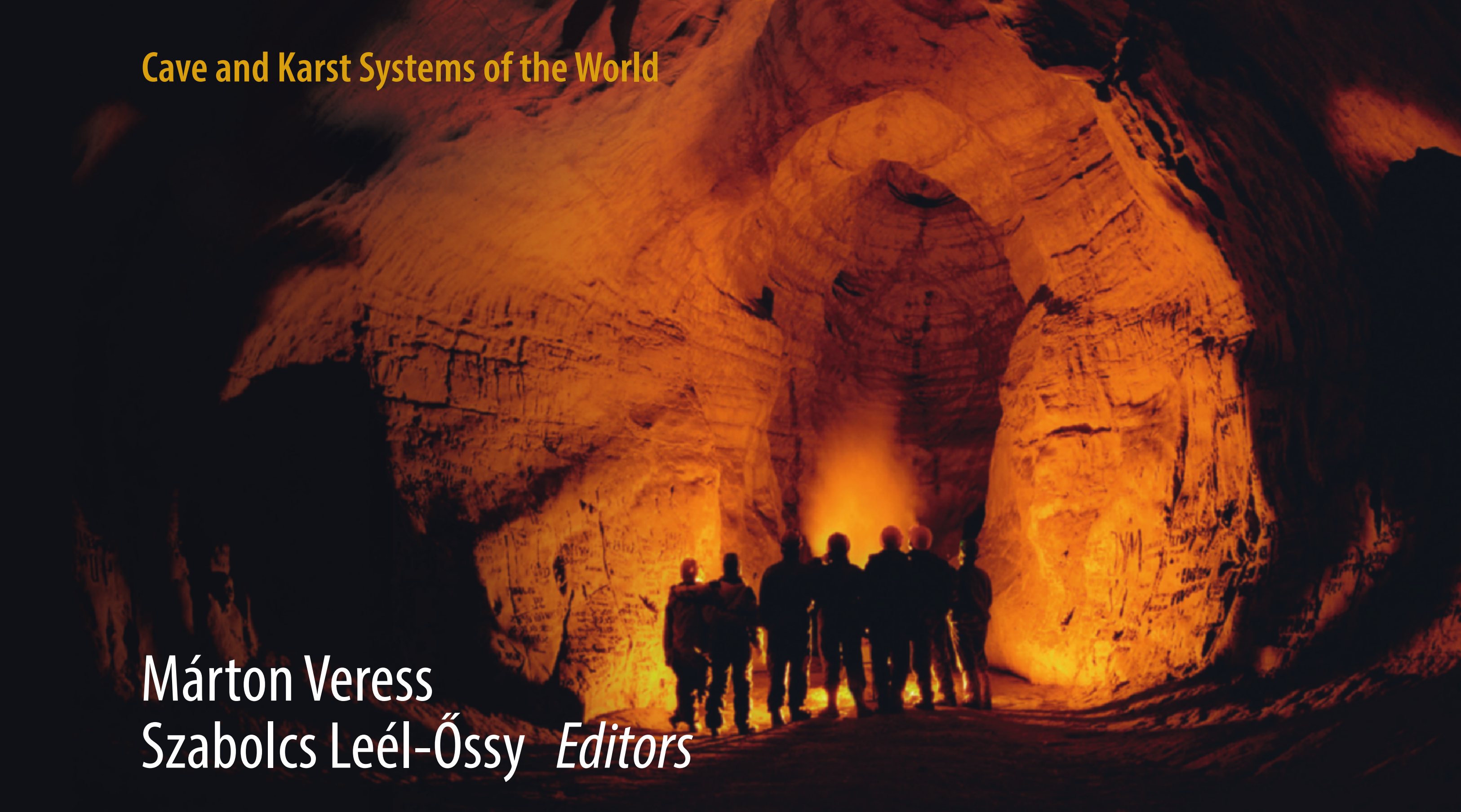

Cave and Karst Systems of the World

Márton Veress
Szabolcs Leél-Őssy *Editors*

Cave and Karst Systems of Hungary

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In memory of Jakucs László

Preface

This book describes Hungarian karst areas in a versatile and complex way from an analytical point of view. It may not be unfounded to say that it is the most detailed and most comprehensive work that has ever been done also including the latest research results.

Hungarian karst areas do not constitute uniform karst regions such as the karst areas of the Alps and China. Disregarding some exceptions, karst features are not large, some features are absent or their occurrence is rare (collapse dolines, karren features of bare surfaces). Despite this, karst features and karst processes are diverse. However, Hungarian karsts are rich in caves (more than 4000 caves are known), hypogene caves being rich in hydrothermal crystals are significant. The surfaces of these karsts may be good examples of temperate karsts which developed on the peneplain parts of former tropical karsts simultaneously with powerful fluvial surface formation, being affected by hydrothermal impacts in some places.

Forty-five authors participated in the preparation of this book who are experts of various disciplines, many of them are internationally acknowledged researchers. They work at different places such as at universities, in museums, research institutes, and national parks. The age of the authors is also various, there are retired researches, but Ph.D. students may also occur among them.

This book has 21 chapters. Two chapters deal with the geological–hydrological background, one chapter is about paleokarst, three is about the surface of karsts, one chapter focuses on the general description of Hungarian karsts and one concentrates on the history of karst and cave research. Seven chapters deal with caves, three chapters are about the biology and ecology of karsts, and two chapters deal with the concretions of the karst. We are thankful to the authors of the chapters and those who had technical contribution to this book.

Here, we would like to draw the reader's attention to the fact that karst areas have dual or different names in the various chapters. Names of some karst areas used in international publications on geology can also be found in some chapters. Thus, "Hills" occurs at Szalonna Karst (or at Esztramos) as well as at the Buda Mountains, Gerecse Mountains, and Pilis Mountains, while "Range" is used at the Transdanubian Mountains. However, these are mountains and plateaus according to both their geological (structure, built-up) and geographical (morphology, altitude) characteristics and to their name as well, though it is without doubt that their elevation may be partly below 500 m and parts of hill type also occur in their areas.

This book was written with the moral support and the contribution of several members of the *Hungarian Speleological Society*.

Szombathely, Hungary — Márton Veress
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A General Description of Karsts in Hungary

Márton Veress

Abstract

The general characteristics of the karsts in Hungary are surveyed. The main properties of karst areas are described: their position, elevation, expansion, division, geomorphology and karst types.

Keywords

Carpathian Basin • Karst area of Hungary • Karst type

1 Introduction

Hungary (its area is 93011 km^2) is situated in Central Europe, in the Carpathian Basin, between the latitudes of 45° 48′ N and 48° 35′ N, in the temperate zone, in the catchment area of River Danube. Its crust developed from microplates with a different origin (Géczy 1973; Haas et al. 1999). Among them, the most important is the Alpaca Macrostructural Unit and the Tisza Macrostructural Unit (Fülöp 1989; Nagy 1971; Fodor and Csontos 1998; Haas 2015). The Alpaca Macrostructural Unit includes the Transdanubian Mountains and a part of the North Hungarian Mountains, in the south it originates from the environment of the Southern Alp, and from the southern margin of the Tethys sea arm. The Tisza Macrostructural Unit which originates from the northern margin of the Tethys sea arm involves the Great Hungarian Plain and a part of Transdanubia southwards from Lake Balaton (Laubscher 1971; Nagy 1971; Haas et al. 1999). Thus, the collision of the Tethys sea arm took place by the inversion of the positions of the two microplates. As a result of this, some karst areas being close to each other have a mainly Haas.

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During the collision of the oceanic arms of the Carpathians and the Dinarides, frictional heat was generated to the effect of the subducting oceanic crust which resulted in the development of mantle plume (Stegena et al. 1975). The flow of the mantle plume has thinned out the lower part of the crust since the Middle Miocene, which resulted in the isostatic subsidence of the crust, the formation of tensile structures, high heat flux and basalt volcanism (until the end of Pliocene) (Stegena et al. 1975; Haas 2015). The Carpathian Basin is a sialic basin according to plate tectonics (Stegena et al. 1975), within which the area of Hungary is separated into larger and smaller basins of Miocene age or younger than this (Kőrössy 1963, 1970). Between the basins, there are low-elevation mountains with a small expansion, which bear the karst areas of Hungary.

2 A General Description of the Karstification of the Karsts of Hungary

Karst occurs in the following regions (mountains) in Hungary: Aggtelek-Rudabánya Mountains, Bükk Region, Nézsa-Csővár Hills (North Hungarian Mountains), Bakony Region, Vértes-Velence Mountains, the Gerecse Region (Gerecse Hills), Buda Mountains (Buda Hills), Pilis (Hills) Mountains (Transdanubian Mountains) and the Mecsek Region (Western Mecsek), and southwards from it the Villány Mountains and the Beremend block.

The proportion of karst areas in the country's total area is not significant. Karst covers 1.45% of the area of the country, and their total expansion is 1350 km^2 (Jakucs 1977). Hungary's karsts are of small expansion, and the expansion of homogenous karst areas is between some 10 and 115 km^2 (Bükk Plateau). According to expansion, Leél-Őssy (1959) distinguished karst plateaus, karstic block plateaus and karst blocks. The surface elevation of karst areas is below 900 m, and their elevation as compared to the local base level of erosion is some 100 m at most. The small

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proportion of the karst in the total area of the country can be ascribed to the characteristics of lithogenesis and to the significant expansion of basin areas. However on its low karsts with small expansion, the karst features are diverse, but there are significant differences between various karst areas regarding the size and density of the features. According to Hevesi (1991a), the present karstification in the karst areas of Hungary can be traced back to the Upper Sarmatian.

Non-karstic rocks often occur in Hungarian karst areas and in their environs. According to Leél-Őssy (1959), there are karst areas which are independent karst micro regions (as can be seen below, there is also a microregion group among them; for example the Buda Hills), the area of which is homogenous karst. In addition, there are karst areas within other areas built up of non-karstic rocks (for example the Tapolca Basin).

The karst areas are significantly separated and dissected. This did not favour the development of expanded, homogenous karst systems. The nature of separation is manifested in the fact that the karst areas are surrounded and separated by basins and basin structures. The karst areas are dissected by stream valleys, the wedged-in non-karstic rocks and the blocky structure (Láng 1952). This latter character is also present even in karst areas with nappe structure. The blocky structure causes a dissected character because the blocks with a lower elevation being covered by non-karstic rocks favour the separation and limited local development of karstic systems within a karst area.

Solitary horsts with the small area may rise over their non-karstic environment. There is no significant surface karstification on them, at most subsoil karren occur. The Villány Mountains are a good example of this, where a rounded head of bed remnants (bed head karren) was formed below the soil by dissolution along the bedding plane.

Leél-Őssy (1959) classified Hungarian karst areas according to their altitude. He distinguished more elevated medium mountain karst (with an elevation of 600–950 m). Good examples are the Bükk Plateau and some areas of the Transdanubian Mountains (for example some parts of the Bakony Mountains), lower medium mountain karst (with an elevation of 300–600 m) and karst of basin floor (for example the karst in the environs of Tapolca in the Tapolca Basin).

Although there are karst areas with a fold and nappe structure (Fodor and Csontos 1998) (Bükk Mountains, Aggtelek Karst), they are basically of blocky structure. This is particularly the characteristic of the Transdanubian Mountains, but the Aggtelek Karst also developed into such a karst.

Karst areas are surrounded by the so-called deep karsts that are thickly covered and buried by impermeable beds (Alföldi and Lorberer 1976). There is water transmission (Alföldi and Lorberer 1976; Erőss 2010) and thus, dissolved material transmission between karst areas and the deep karsts of their environment. Partially water flow takes place from the karst into the sediments of the basins (Sárváry 1971; Mádlné Szőnyi and Tóth 2015), but karst areas receive water from their environment too. The heating up water of the basin sediments or surface streams, e.g., the water of the River Danube, is added to the karstwater of the Transdanubian Mountains (Papp 1942; Bodor et al. 2014).

The karstwater or waters of other origin are heated up because of low reciprocal gradient (its value is 20–22 m/°C), which can be explained by the upper mantle of high elevation and flowing upwards from a great depth it is mixed with the karstwater of karst areas. Thus, the hot water effect is significant in several karst areas (e.g. Buda Hills) in karstification.

In some karst areas of Hungary, volcanic rocks are also present mainly in the form of Pliocene basalt volcanism triggered by mantle plume (Lóczy 1913). Therefore some karstic terrains (e.g. Kab Mountain) were covered by basalt to various degrees.

Karstification took place several times on the karsts of Hungary during the history of geology. Its features can be mainly studied in the area of the Transdanubian Mountains and also in the karsts of the North Hungarian Mountains and on the karst of the Mecsek (see chapter "Paleokarst in Hungary"). According to Hevesi (1991a), its tropical karst landforms were destroyed due to the lack of adequate (consolidated rocks) caprock. The terrain of karst areas is mostly exhumed Late Cretaceous tropical karst peneplain or younger abrasion surface and pediment. Features that developed during older karstification may also affect recent karstification. Thus, above covered karstic mounds, where the superficial deposit is thin (Veress 2009, 2016) or in karstic depressions (Veress and Zentai 2009; Veress 2016). In the former case, karstification is favoured by the thin superficial deposit, while in the latter, the water accumulates in the depressions. Non-karstic rocks (volcanic rocks, gravel, loess etc.) survived in a significant distribution in the recent past, but partly today too because of the low surface elevation of its karst areas. However, the presence of non-karstic rocks was also contributed by the young evolution of some of them (e.g. loess, gravel). Therefore, karst areas are fluviokarsts or karsts that developed from fluviokarsts. However, among the karsts of Transdanubian type and of Aggtelek type, only those of Aggtelek type (see below) can be regarded as typical fluviokarst. The karst areas of Transdanubian type are specific fluviokarsts since there are no ponors with blind valleys (except Kab Mountain) in their areas. Among karst types, soil-covered karsts are of the greatest expansion, but the distribution of concealed karsts is also significant (Bakony Mountains and Mecsek Mountains, Veress 2010). Buried karst also occurs here (some blocks of the Bakony Mountains and the southern part of Aggtelek karst). Bare karst is absent except in some larger and smaller patches (walls of gorges, doline slopes). In case of adequate slope conditions, mixed autogenic-allogenic karsts (Aggtelek Karst, Bükk Mountains, Kab Mountain) also developed at non-karstic rock intercalations and caprocks.

The karstic rocks of karst areas are often vertically separated from each other by non-karstic intercalations too (e.g. the Bakony Mountains). This favours the development of local flow systems and local cavity formation.

The climate of karst areas slightly differs because of the short distances between them, but it is different to a larger and smaller extent from the climate of their environment as a result of their larger elevation. According to the Trewartha system, the climate of Hungary belongs to the continental climate subtype (Mezősi 2011, 2016). According to the Köppen climate classification, the northern part of the Transdanubia (Transdanubian Mountains) belongs to the uniformly warm-moderate climate with long and cool summers (fb), The North Hungarian Mountains and thus their karsts have a uniformly wet-boreal climate with long summer periods (Dfb), and the southern part of Transdanubia with the Mecsek Mountains has a uniformly wet, warm-temperate climate with long and hot summers (Cfa) (Bartoly and Pongrácz 2013). The annual average temperature of the karst areas is 8–11 °C, but in the Bükk Mountains it is below 8 °C (Mezősi 2011, 2016). However, during the summer months the temperature may also be below 0 °C in the dolines of the Bükk plateau at night (Kevei Bárány 2018). The amount of precipitation is 550–800 mm in the karst areas, but this value may be above 800 mm in the northern part of the Bakony Mountains and in the middle part of the Bükk Mountains (Mezősi 2011, 2016). The vegetation in karst areas are oak, hornbeam-oak and beech (Zólyomi 1989); their soil is brown forest soil and its black variety, the rendzina soil (Bulla 1964).

Karst areas are cultural landscapes where human activity has been present for a long time. For example, in the Bakony Region this is proved by graves and fortresses from the Bronz Age (Éri et al. 1969, Dax et al. 1972). However, the original forests of some karst areas were preserved for a long time. Thus, during the Hungarian conquest, there was a continuous forest cover in the Hungarian mountains (Bartha and Orbán 1995). The first significant deforestation took place during the times of Ottoman conquests because of castle buildings (Medzihradszky 1996). In the Bakony Region, the disintegration and shrinking of untouched forests can be connected to the glasshouses. The operation of glasshouses began in about 1715 in the mountains and lasted until 1859 with various sites (Éri 1966). The denudation of the superficial deposit may have become more intensive as a result of deforestation and later agriculture (from the beginning and more intensively the middle of the twentieth century). This may have resulted in the increased infilling and transformation of certain depressions, for example in Bakony Karst (Veress 1987).

A karstification of larger and smaller degree occurs in all macro regions of the country (the Great Hungarian Plain, the Little Hungarian Plain, the Transdanubian Hills, Alpokalja, North Hungarian Mountains, Transdanubian Mountains Fig. 1), except the two plain areas. According to Jakucs (1977), the karst areas are the following (Fig. 2):

- The karst landscapes of the Transdanubian Mountains are the Keszthely Mountains, the Balaton Uplands, the Tapolca Basin with its Sarmatian limestone terrain, the Northern Bakony Mountains and the Southern Bakony Mountains, the Vértes Mountains, the Gerecse Region (with the Zsámbék Basin), the Pilis Mountains (with the Pomáz calcareous tufa plateau) and the Buda Hills (with the Tétény Plateau and the Pest Plateau with its Lajta Limestone patches).
- The karstic inselbergs of Transdanubia such as the Lajta limestone karst of the shore of Lake Fertő (Alpokalja), the karst of the Mecsek Mountains, the karst of the Villány Mountains and the karst block of Beremend (the latter are the inselbergs of the Transdanubian Hills). Among them, in the area of the shore of Lake Fertő, the depressions are scars of quarrying. Only some cavities have depressions, which developed by collapse; thus, these areas are not dealt with here. The lack of karst features is also characteristic of the Villány Mountains as well as Szokolya Basin and Törökmező; thus, they are not described in other chapters of the book either.
- The karsts of the North-Hungarian Mountain Region, such as the South-Börzsöny Lajta limestone karst (Szokolya Basin, Törökmező), the limestone blocks of Cserhát Region (Naszály, Romhány Mountain, Csővár Mountain), the karsts of the Bükk Mountains with the Uppony block, the Aggtelek Karst Region with the karsts of the Rudabánya block, the Szalonna block and the Szendrő block.

The Kőszeg Mountains (Alpokalja) can also be mentioned where there are larger and smaller solution features in the greenschist with high calcareous content and in calcareous phyllite on the cliff walls and larger and smaller cavities also occur (Veress et al. 2015).

Among the listed areas, the karstification of the Aggtelek Karst (Aggtelek-Rudabánya Mountains), the Bükk Mountains (Bükk Region), Northern Bakony and Southern Bakony (the Bakony Region), and the Mecsek Mountains (Western Mecsek) is more significant as compared to the other areas. In brackets the presently used names of regions

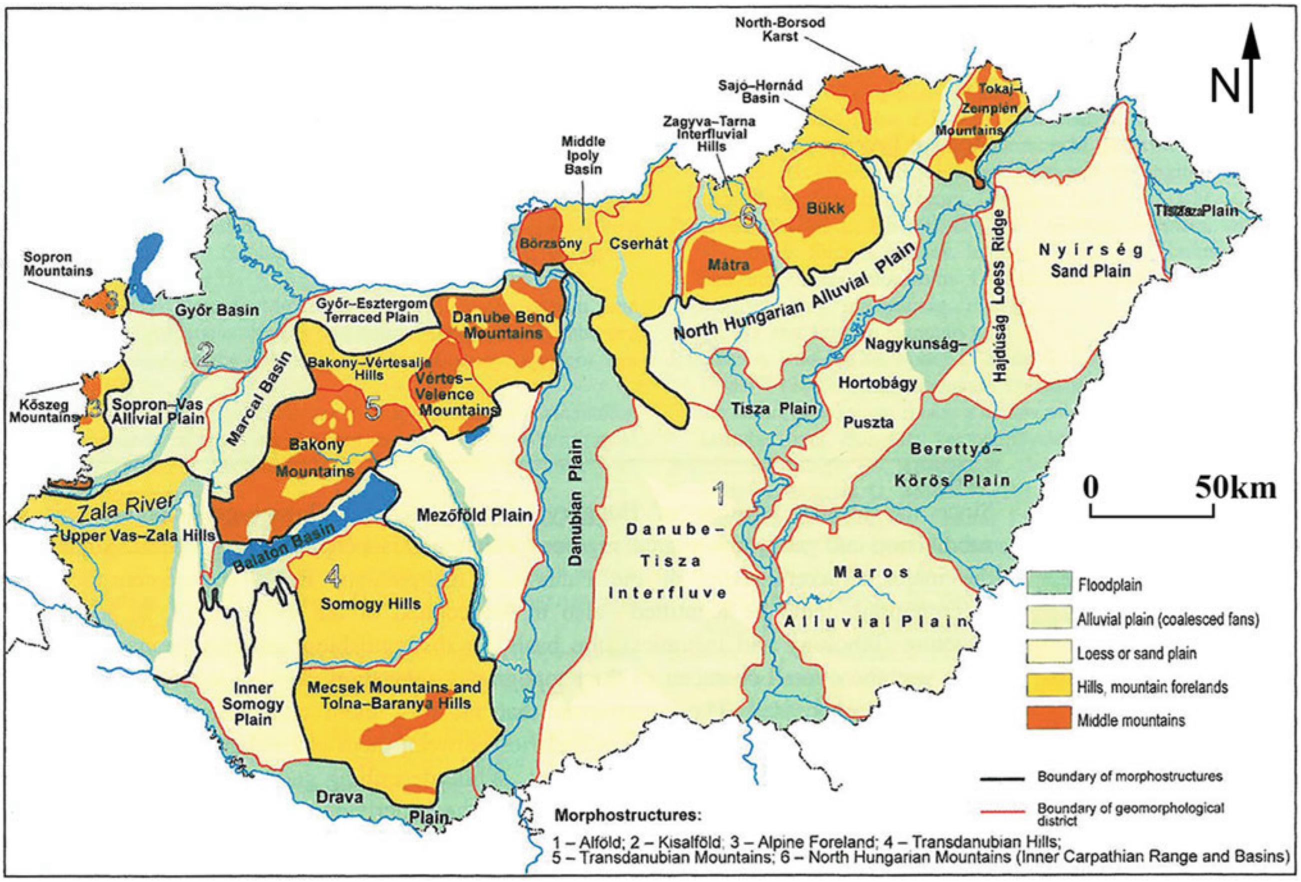

Fig. 1 Major geomorphological districts of Hungary (Lóczy 2015)

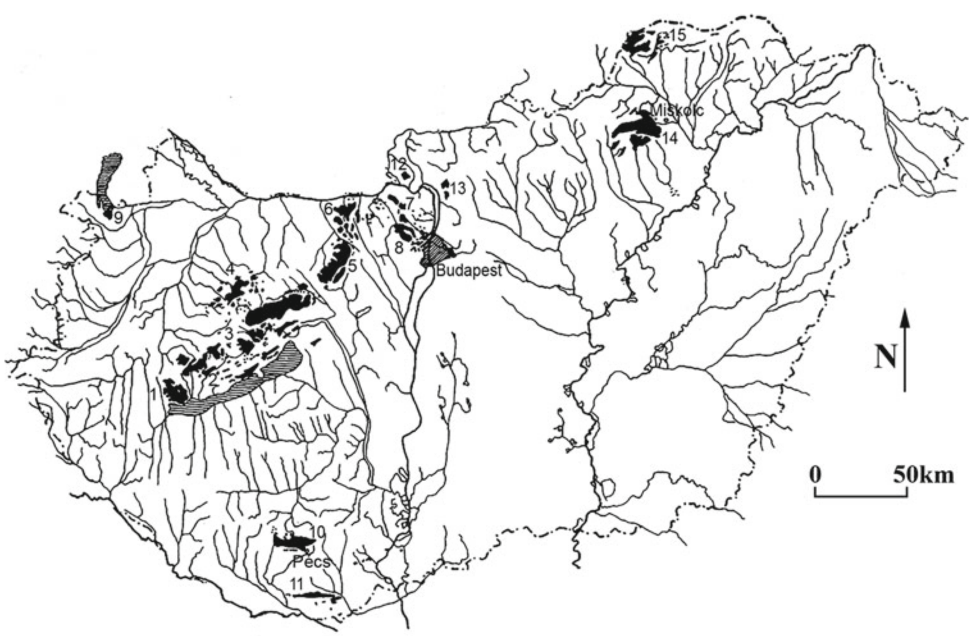

Fig. 2 Karst areas of Hungary (Jakucs 1977). Legend: 1. Keszthely Mountains, 2. Balaton Uplands with Tapolca Basin, 3. Southern Bakony, 4. Northern Bakony, 5. Vértes Mountains, 6. Gerecse Region (with the Zsámbék Basin), 7. Pilis Mountains (with the Pomáz calcareous tufa plateau), 8. Buda Mountains (with the Tétény Plateau), 9. karst near Lake Fertő, 10. Mecsek Mountains, 11. Villány Mountains and the Beremend karst block, 12. South-Börzsöny Lajta Limestone karst, 13. limestone blocks of the Cserhát Region, 14. Bükk Mountains (with the Uppony block), 15. Aggtelek Karst Region (with the limestone areas of Rudabánya block, Szalonna block and the Szendrő block)

and a more exact region classification can be found. If we estimate the proportion of surface karstification and subsurface karstification as compared to each other among the karst areas, we can see that this proportion is similar to the case of the Aggtelek-Rudabánya Mountains, the Bükk Region and the Bakony Region. In the Mecsek Mountains, surface karst is dominant, while in the Buda Hills and on the karst block of Beremend, subsurface karst is significant. The degree of karstification of the above-mentioned areas as compared to each other can also be estimated. Thus, based on the estimated value of calcareous tufa formed at karst springs, the most karstified mountains are the Bükk Region, which are followed by the Aggtelek-Rudabánya Mountains (though, the larger amount of calcareous tufa of the former can be attributed to the larger mass of the mountains), the Western Mecsek and the Bakony Region. The Gerecse Region and the Buda Mountains also have a significant amount of calcareous tufa. However, their calcareous tufa is older and are not connected or only partially connected to the present karstification of the mountains (Schweitzer 2002; Leél-Őssy 2012).

Leél-Őssy (1959, 1960) and, then elaborating his theory, Jakucs () put Hungarian karsts into two categories from an evolutionary point of view taking their karstification characteristics (karst features) into consideration: the Transdanubian type and the Aggtelek type. The former includes the karst areas of the Transdanubian Mountains, while the karsts of the North Hungarian Mountains (Aggtelek Karst and Bükk Mountains) belong to the latter. Although the karst of the Mecsek Mountains is situated in Transdanubia, it was regarded as a transitional and classified as a member of the Aggtelek type, while although the limestone blocks of the Cserhát Region are located in the North Hungarian Mountains they were put into the Transdanubian type. He drew attention to the fact that although there is a short distance between the karsts of the two types, they are significantly different regarding their karstification characteristics. According to him, there is a lack of karren, dolines (solution dolines), ponors, erosion caves in the area of the Transdanubian type, but the crumbling (physical weathering) of dolomite triggered by the effect of hydrothermal water is characteristic. In addition, caves of hydrothermal origin or those being exposed to hydrothermal effect are widespread. On the contrary, on the karsts of Aggtelek type, there are karren, well-developed (solution) dolines, doline systems, uvalas, ponors with blind valleys and erosion caves. (We also mention that spring caves are also characteristic in addition to erosion caves on the latter, which cannot be found on karsts of the Transdanubian type or their occurrence is only subordinate.)

Taking into consideration the karst built up of non-karstic and karstic rocks and also non-karstic rock covering the karst, Hevesi (1986a) classified karst and developed a nomenclature for the different types. Elaborating Jakucs's interpretation on the landforms of the karsts of the Aggtelek and the Transdanubian character (Hevesi 1991a), and then adopting his classification he classified the karst types occurring on the karst areas of Aggtelek and Transdanubia (Hevesi 1991b).

If we consider the characteristics of Aggtelek karst and Transdanubian karst, we can state that mixed autogenic-allogenic karsts are widespread on the Aggtelek karsts, while concealed karsts with subsidence dolines are specific of the Transdanubian karsts, which are mainly of suffosion origin. On Transdanubian karsts there are not only concealed karsts, but also soil-covered karst and mixed autogenic-allogenic karst. Mixed autogenic-allogenic karsts can only be found in the Bakony Mountains (Kab Mountain) and (according to Hevesi 1991b) in the Pilis Mountains. In addition, buried karst occurs on Kab Mountain (Veress and Unger 2015), on Fekete Mountain (Southern Bakony), and in the Gerecse and the Pilis Mountains in patches. Thus, on karsts of the Transdanubian type, in the above-mentioned areas, ponors with blind valleys and caprock dolines also occur (the latter for example on basalt, sandstone and marl).

Concealed karst also occurs on Aggtelek karst subordinately in larger karst depressions for example in dolines filled with superficial deposit or in ponors (Veress and Zentai 2009; Veress 2016). Although soil-covered karst, as it has already been mentioned, also occurs on the karsts of the Transdanubian type, there is an almost complete lack of solution dolines. The karst of the Mecsek Mountains is a transition between the two types because concealed karst with landforms specific of concealed karst developed on the terrain dissected by karst landforms which are characteristic of the karst of Aggtelek type. Considering the karsts of the two types, further distinctions can be described. Thus, they are not only different regarding the quality (type) of the features, but also the quantitative characteristics of the forms. On the karsts of the Aggtelek type, the density of depressions is probably larger by order(s) of magnitude than on the karsts of the Transdanubian type. The size of the features is also larger in case of the karsts of Aggtelek type. While disregarding DSDs (see chapter "The Surface Morphology of Karsts in Hungary"), the diameter of the features is some metres or maybe some 10 m on the karsts of the Transdanubian type, depressions with a diameter exceeding 100 m often occur on karsts of the Aggtelek type. If we compare the complexity of landforms, we can state that the depressions of the karsts of Aggtelek type are more complex (karst features are built up of several partial features and larger features contain smaller forms). The size of caves and thus the quantity of dissolved material is greater on the karsts of Aggtelek type. Here, disregarding the hydrothermal caves of the Buda Hills and the cave system of Tapolca, there are several caves the size of which exceeds the size of the caves of the karsts of Transdanubian type. However, present cave explorations indicate that on karsts of the Transdanubian type, the length, and mainly the depth, of caves that developed in the vadose zone does not lag behind the karsts of the Aggtelek type. However, undoubtedly, influent caves of erosional origin and through caves are specific of karsts of the Aggtelek type. However, the number and density of caves are not smaller on all karsts of Transdanubian type. Thus, for example in the Bakony Region, more than 700 caves occur though with those of non-karstic origin together (Eszterhás 2013). This can be attributed to the fact that larger and smaller phreatic cavity systems were dissected into several short cave-remains by downcutting streams (Veress 2000a, b, 2016).

However, there is also a difference in the extent to which the karst areas are dissected. While the karsts of Aggtelek type are less dissected and thus, they constitute plateaus of great expansion, the karsts of Transdanubian type are mountain tops of small expansion (Leél-Őssy 1959; Hevesi 1991a). Therefore, on the latter, despite the former existing cover, no stream and valley network could develop on the blocks with small expansion either (Hevesi 1991a).

According to Jakucs (1977), the reason for the differences regarding the landforms is that the karsts of Aggtelek type have been continually karstified since the end of the Cretaceous period, while karstification was interrupted on the karsts of Transdanubian type as a result of their burial and this process could only continue after they became exposed. However, the karsts of Aggtelek type became also covered several times at least partially (Láng 1955; Vass et al. 1994; Hevesi 1978, 1991a; Sásdi 1990; Császár 1997; Gyuricza and Sásdi 2009) thus, and their continuous karstification at least in their whole area has not been able to take place since the end of the Cretaceous. However, it is indisputable that the covering of the karsts of Transdanubian type (terrains built up of Mesozoic rocks) was of larger extent and duration and also the fact that their terrains built up of Mesozoic rocks became covered with consolidated rocks (limestone, sandstone) to a greater degree than the karsts of the Aggtelek type. It is also unquestionable that the denudation of their superficial deposits is of a smaller degree even today than that of the karsts of Aggtelek type.

However, the covering of various degrees of the karsts of the two types is hardly sufficient to interpret morphological differences. On the karsts of the Transdanubian type, there is a lack of drawdown dolines disregarding two exceptions. These two areas are the Tapolca karst and the Devecser karst (Móga et al. 2011; Veress and Vetési-Foith 2019a, b). But just these areas are built up of young limestones (Tapolca karst Sarmatian limestone, Devecser karst Lajta limestone). Thus, solution dolines can not only develop on older areas built up of limestones, that is on old surfaces which have been karstifying for a long time, but also on young surfaces too. However, morphological differences cannot be explained by the young uplift mentioned by Láng (1958) because it would follow that there is no solution dolines on terrain sections of low elevation. However, as it has already been mentioned, solution dolines occur on such surface (the karst around Tapolca in the Bakony Mountains) where the altitude of the surface is low (120–180 m).

The lack of solution dolines was also contributed by the fact that the inclination of the surface is large on the soil-covered karsts of the more elevated blocks with an incomplete superficial deposit of the Transdanubian Mountains. It was established that 85% of the dolines develop on terrains with a dip smaller than 12° in the Miroč Mountains in Serbia (Telbisz et al. 2007). However, on lower surfaces with a small inclination where there is an opportunity for doline development, the permeable superficial deposit (loess) survived. Although there are shafts below this permeable superficial deposit (Veress 2000a, 2018) they occur one by one probably due to the effect of the cover (Veress 2000a). Since the loess is washed in into the karst, the epikarst is probably poorly developed and it is different from the epikarst on typical soil-covered karsts. This does not favour the development of solution dolines. This fact is supported by the experience that on the gypsum karsts of Italy drawdown (solution) dolines are not characteristic (Waele et al. 2017) which is explained by the lack or the limited development of the epikarst (Waele et al. 2017; Ferrarese et al. 2002; Sauro 2003).

The covering of various types on the karsts of Transdanubia and Aggtelek may give an explanation for the differences in older karst landforms (paleokarst). Since consolidated caprocks are more widespread in the Transdanubian Mountains, the features of older karstification(s) could have been preserved. Some of the paleokarstic features (Cretaceous-Eocene) on karsts of Aggtelek type may have been completely or partially destroyed (Hevesi 1991a), probably during the denudation of loose superficial deposit (which is thus more easily destroyable). However, the depressions at (and around) which no denudation took place, on the contrary they become filled in or even covered, could have survived such as the Dász doline in Aggtelek karst or the depressions bearing the ponors of Baradla cave (Veress 2017).

The various distribution of concealed karst and its features on the karsts of the two types can be attributed to the presence of loose superficial deposits (mainly loess) of different degrees which can be ascribed to the different elevation of the karst surfaces of low inclination of the karsts of Aggtelek and Transdanubian type according to us. (Unconsolidated, cohesive superficial deposit being characteristic of concealed karst only occurs subordinately.) The development of loess has an elevation limit which is 400 m (Mezősi 2011), but loess can even be found over 400 m on the Tés

Plateau (Bakony Region). However, while for example the most karstic terrain can be found above 450 m (Kis Plateau) in the Bükk Mountains, and the Nagy-Plateau is located above 650 mm, the majority of the blocks of the Transdanubian Mountains with a small inclination are situated below 500 m (see chapter "The Surface Morphology of Karsts in Hungary"). Thus, a significant proportion of the blocks of the Transdanubian Mountains is a surface of a low inclination which belongs to the zone of loess development. Loess could have survived on these especially if the block is of large expansion and because streams are absent and the mounds of the bedrock hinder denudation, ensuring the development of concealed karst and its features. The survival of loess (and in general of the superficial deposit) was also contributed by the fact that the uplift of the Bakony Mountains, which is the most peculiar concealed karst area of the Transdanubian Mountains, is young (Láng 1958); therefore there has not been enough time for the denudation of the superficial deposit. Here, we mention that since concealed karst features mainly developed on loess, loess formation affects not only their distribution but their age too. For example, the loess is of Würmian age in the Bakony Region (Pécsi 1982; Sás 1987). Older features could only be formed during the reworking of the older superficial deposit (gravel cover) or above bedrock passages that had developed during an earlier karstification process. On karsts of Aggtelek type, concealed karst is more subordinate probably because on more elevated terrains of the Bükk Mountains there are only patches of slope loess (Hevesi 1978). However, loess (Tóth 1986) and its mixed variety is mentioned in karstic depressions (Veress and Zentai 2009). On Aggtelek karst it is subordinate and red earth is more widespread (Zámbó 1970) which is less permeable and this does not favour concealed karstification. The close relation between the survival of loess and the development of surface karst features is proved by the features of Mecsek karst that developed on abrasional terraces (Lovász 1981) and which belongs to Aggtelek karsts (Hevesi 1991b). The low elevation levels of this karst (250–380 m and 450–470 m) favoured loess development, while the hardly dissected nature of the surface favoured the survival of loess. Regarding their areas, the dolines occur on surfaces with an inclination of 2°–7° in the greatest proportion (Lippmann et al. 2008). The features of concealed karst, the subsidence dolines occur on terrains dissected by older solution dolines (Szabó 1968) and covered with loess in significant distribution and in the greatest density as regards Hungary.

The Aggtelek and Transdanubian karsts are not individual karst types since considering all their characteristics other non-Hungarian karst areas cannot be classified as these karst types. However, taking some of their characteristics into consideration, these, especially the karst areas of the Transdanubian type, can also be put into several karst types (karst of mountains of medium height, soil-covered karst, concealed karst, autogenic karst etc.) They cannot be ranked among evolutionary types as only some of their characteristics can be explained by different evolutionary events. Thus, it is better to use the 'of…character' expression used by Hevesi (1991a, b) instead of the term 'type'. However, creating these two larger units, Hungarian karst areas can be compared and distinguished according to their features. In our view, the differences of Transdanubian and Aggtelek karsts cannot be explained by only one cause. The presence or absence of some characteristics (for example the presence or lack of mixed autogenic-allogenic karst and the features related to that) can be traced back to evolutionary characteristics. Others, like the features of concealed karst or soil-covered karst deduced from the characteristics of the epikarst. The reason for the latter distinction is that the constituting blocks (plateaus) are covered to various extents, which can be explained by their different elevation, expansion, and by the inclination of the surface. These differences can be explained by tectonic reasons. The differences regarding hydrothermal nature can be interpreted by the difference in the distance between the karst and the magma below the surface. There may be several reasons for the lack of erosional caves on Transdanubian karsts (thus, the small area of blocks and the small non-karstic catchment area, the young erosional denudation of short duration, the nature of the superficial deposit, the erosional denudation of karstic cavities in the gorges etc.).

3 The Parts, Morphology and Karst Types of Hungarian Karst Areas

At the division of karst areas, the works of 'the Inventory of microregions in Hungary' (Marosi and Somogyi 1990) and 'The Physical Geography of Hungary' (Bulla 1964; Mezősi 2011, 2016) and some articles (Ádám 1983, 1984) were taken into consideration. During the categorization of the landscapes macro regions, meso regions, micro region groups and micro regions are distinguished. The description of the distribution of karst areas follows this categorization.

Hungarian karst areas occur in three macro regions: North Hungarian Mountains, Transdanubian Mountains and Transdanubian Hills.

3.1 The North Hungarian Mountains and Their Karsts

The North Hungarian Mountains are a macro region situated in the north-eastern part of Hungary between the River Ipoly and the River Bodrog, north from the Great Hungarian Plain, but on their southwestern part they reach beyond the River

Danube (Visegrád Mountains). The majority of their area is constituted by mountains which belong to the inner volcanic zone of the Carpathian Mountains (Visegrád Mountains, Börzsöny, Cserhát Region, Mátra Region, Tokaj-Zemplén Mountains). In their eastern part, two karst areas are wedged in between the volcanic mountains, the Bükk Region and the Aggtelek-Rudabánya Mountains (Fig. 3). In the west, some smaller karstic blocks occur in the Cserhát Region.

The Aggtelek-Rudabánya Mountains (Aggtelek-Rudabánya Hills)

They are a meso region surrounded by the valleys of Bódva, Sajó and Csermoslya, and they are separated into two micro region groups: the Aggtelek karst and the Rudabánya-Szalonna Mountains. Westwards from the River Bodva the Aggtelek Karst and eastwards from it the Rudabánya Mountains and the Szalonna Karst (Estramos or Szalonna Mountains) are situated. The latter is called Szalonna Plateau or Estramos Hills. However, according to the latest region classifications, the Szalonna Karst does not belong to the Aggtelek-Rudabánya Mountains. (This meso region, the parts of which called Szilice Plateau and Kecső Plateau reach into the area of Slovakia, is also called Gömör Torna Karst and Northern Borsod Karst.) The Aggtelek Karst micro region group is separated into two micro regions: the Aggtelek Mountains and the Alsó-hegy Plateau. The Aggtelek Mountains is surrounded by the valleys of Sajó, Bódva and Ménes, the area of which is 135 km^2 and its elevation is 350–500 m, but some mounds may be more elevated than 500 m (Nagyoldal 604 m).

The Aggtelek Mountains are separated into plateaus which are the following (Fig. 4): in the north, the Haragistya Plateau, the Jósvafő Plateau, the Nagyoldal Plateau and the Szinpetri Plateau, southwards from these the Aggtelek Plateau and the Galyaság. The latter is separated into four plateaus or parts by Móga (2002a). These are the following from W to E: the western part of Galyaság, the plateau around Mount Pitics, the Teresztenye Plateau and the eastern part of Galyaság. The plateaus are Late Cretaceous tropical karst peneplains (Mezősi 1984), while according to other opinion (Zámbó 1998) pediment parts elevated to various elevations. The area of Alsó-hegy Plateau is 50 km^2, its elevation is 400–500 m, its western part is the Derenk Plateau and its eastern part is the Szilasi Plateau, but the Dusa Plateau (Páska-Bükk) also belongs to this area (Móga 2002b).

In the area of Aggtelek Karst, the plateaus are separated from each other by valleys having permanent streams. Mass movements occur frequently in the valleys. On the plateaus there are epigenetic, erosion valleys and in some places grabens with creeks and gullies occur in the thick cover. Its plateaus are separated into two levels: a more elevated level with mounds and a lower, less dissected level. According to its development, its karst is renewed allogenic covered karst (Veress 2016). This type develops from cryptokarst in a way that the karst becomes separated from its non-karstic sediment sources or from its non-karstic environment in an

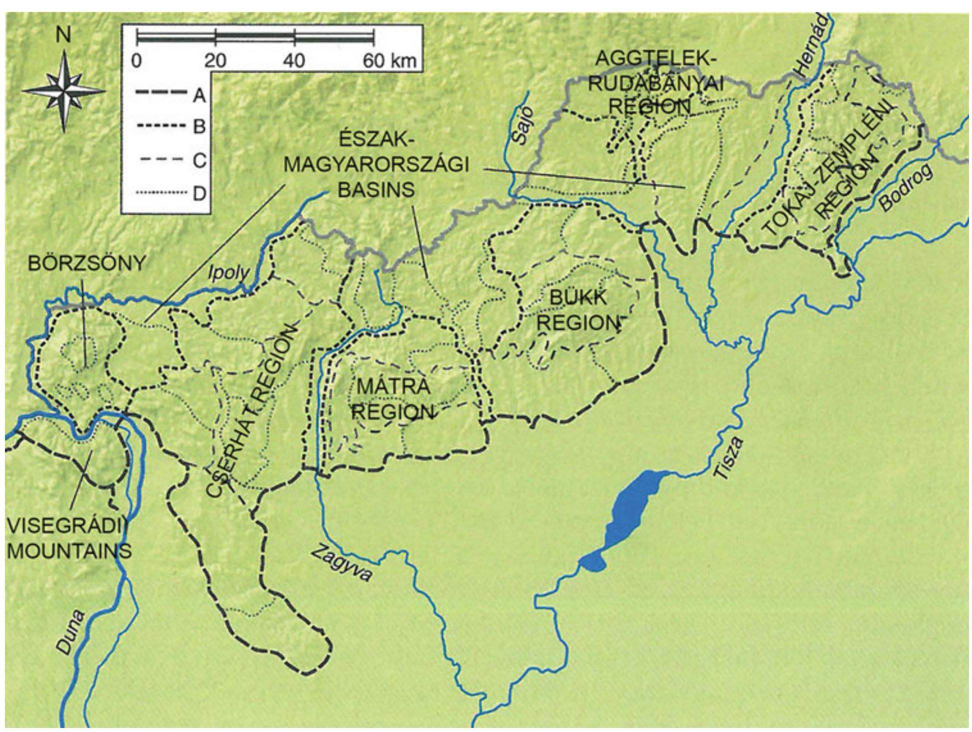

Fig. 3 Landscape geographical division of the North Hungarian Mountains (Mezősi 2011). Legend: A. border of macro region, B. border of meso region, C. border of micro region group, D. border of micro region

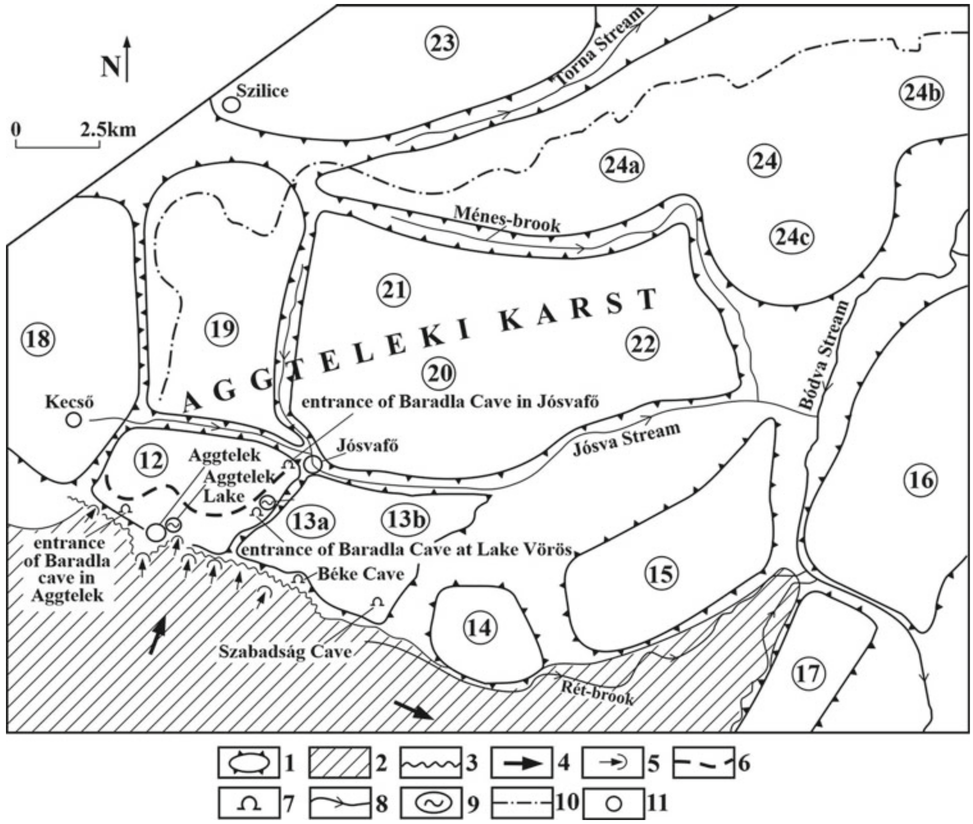

Fig. 4 Aggtelek-Rudabánya Mountains (Veress and Unger 2015). Legend: 1. karst plateau, 2. buried karst, 3. rock boundary, 4. dip of buried karst, 5. ponor, 6. Baradla Cave, 7. cave entrance, 8. stream, 9. doline lake, 10. national border, 11. settlement, 12. Aggtelek Plateau, 13a. Western Galyaság, 13b. Mount Pitics, 14. Teresztenye Plateau, 15. Eastern Galyaság, 16. Szalonna Plateau (Estramos), 17. Rudabánya Mountains, 18. Kecső Plateau, 19. Haragistya, 20. Jósvafő Plateau, 21. Nagyoldal, 22. Szinpetri Plateau, 23. Szilice Plateau, 24. Alsó-hegy Plateau (24a. Derenk Plateau, 24b. Szilas Plateau, 24c. Dusa Plateau)

erosional or tectonical way. Subsequently, the karstification is renewed and modified during the partial denudation of the superficial deposit. The Aggtelek Karst became separated from its northern, non-karstic environment by the development of the Torna valley and has been separated into three zones (Veress 2014). The northern zone is separated into two subzones: an autogenic karst, which the Alsó-hegy Plateau belongs to. Here, soil-covered karst is dominant, but concealed karst and mixed autogenic-allogenic karst also occur locally. The southern part of this zone can be found southwards between the Ménes valley and Jósva-valley (the area of Haragistya plateau and Szinpetri plateau), on its autogenic karst plateaus there is soil-covered karst, but concealed karst is also more expanded. The middle zone reaches from Jósva valley to the valley of the Rét Stream. Its western part was renewed and was transformed into a mixed autogenic-allogenic karst. On its autogenic karst plateaus (Aggtelek Plateau, Mount Pitics, Teresztenye Plateau, the eastern part of Galyaság) soil-covered karst and concealed karst occur. Southwards from the Rét Stream buried karst can be found. Karst features being characteristic of this karst type are widespread on the above mentioned soil-covered karsts. The area of Rudabánya Mountain (micro region) is 20 km^2, and its elevation is 158–376 m. It is buried karst and concealed karst dissected by gullies. The Szalonna Mountain (micro region) is an exhumed horst, its area is 50 km^2 and its elevation is 160–520 m. Its karst is concealed karst (Hevesi 1991b, soil-covered karst), but its karst landforms are not significant. Its subsurface karst shows warm water effects.

The Bükk Region

The Bükk Region (meso region) is surrounded by the River Tarna in the west, by the River Sajó in the north and east and by the Great Hungarian Plain in the south (Borsodi-Mezőség). Its area is 1795 km^2. The elevation of the surface is the largest here among Hungarian karsts. Eleven mounds are situated above an elevation of 950 m, but none of them reaches 1000 m.

The area of the mountains was denuded into a tropical peneplain (Pinczés 1968), during the Lower Eocene (Hevesi 1978), from the Upper Cretaceous-Middle Cretaceous to the Eocene (Pinczés 1980), and between the Upper Cretaceous and the Miocene (Tóth and Fejes 1984). Taking into consideration the elevation distribution of spring caves, Tóth and Fejes (1984) described two denudation levels on the Bükk Plateau, the level consuming the tropical peneplain and a level where the tropical peneplain develops (an older and a younger one of Pliocene age). The Bükk Region is separated into three micro region groups: the Központi Bükk (Central Bükk), the Bükkalja and the Bükklába (Fig. 5). The micro regions of the Central Bükk are the Bükk Plateau, the

Northern Bükk and the Southern Bükk. The Bükk Plateau with an expansion of more than 20 km in NE-SW direction and with an area of 115 km^2 is separated into two areas by the valley of Garadna Stream downcutting into non-karstic rock. One area is the Small Plateau with an elevation of 450–500 m and situated north from the Garadna Stream and the other is the Great Plateau with an elevation of 650–850 m and situated in the south. The separation of the surface into two levels is particularly characteristic of the Great Plateau: the upper, more elevated which is not uniform, but is separated into mounds and the lower which is slightly dissected by epigenetic valleys.

The Northern Bükk (its area is 100 km^2) is a pediment dissected by gullies and interfluves bordering the Small Plateau. Here, a smaller karstic area (Kemesnye Mountain) can be mentioned. The Southern Bükk is a micro region situated south from the Great Plateau, its area is 335 km^2 and its elevation is 210–790 m. It is separated into two parts: the Southwestern Bükk and the Southeastern Bükk, which are separated by the Hór Valley from each other. In the area of the Southeastern Bükk the karst is less widespread, while it is more widespread in the area of the Southeastern Bükk (in the latter area the superficial expansion of karstic rocks is larger).

Bükkalja is separated into the Tárkány Basin, and the Eger Bükkalja and Miskolc Bükkalja micro regions. The Tárkány Basin (its area is 30 km^2) is a pediment dissected by erosion-derasion valleys and derasion valleys. No karstification occurs in its area (buried karst). The Eger Bükkalja (its area is 480 km^2) is also a pediment transformed in an erosion way (hilly region) without karstification. The Miskolc Bükkalja (its area is 240 km^2) is a pediment dissected by valleys and built up of non-karstic rocks.

The northern part of the mountains is the Bükklába which is separated into the Tardona Hills (its area is 260 km^2) and the Uppony Mountains (its area is 240 km^2). The Tardona Hills are a micro region which is a pediment dissected in an erosional way. No karstification occurs in its area. The Uppony Mountains is a micro region dissected by erosion valleys and karstification is present in its area.

The uplift of the Bükk Region took place by upwarping (Moldvay 1969). Its central part uplifted mostly and the earliest. Therefore, it is upwarping karst according to development (Veress 2000b) where karstification gradually decreases towards the margins and probably it is rejuvenated too. Its karst is most sharply developed on the Bükk Plateau (both surface and subsurface karst) where karst features are present at both levels, but they are particularly prevailing at the lower. Its Small Plateau is allogenic karst, autogenic karst, mixed autogenic-allogenic karst, with soil-covered karst on its autogenic karst sections (Hevesi 1991b). The Great Plateau is autogenic karst, mixed autogenic-allogenic karst, with soil-covered karst on its autogenic karst sections (Hevesi 1991b) and in patches with concealed karst (Veress

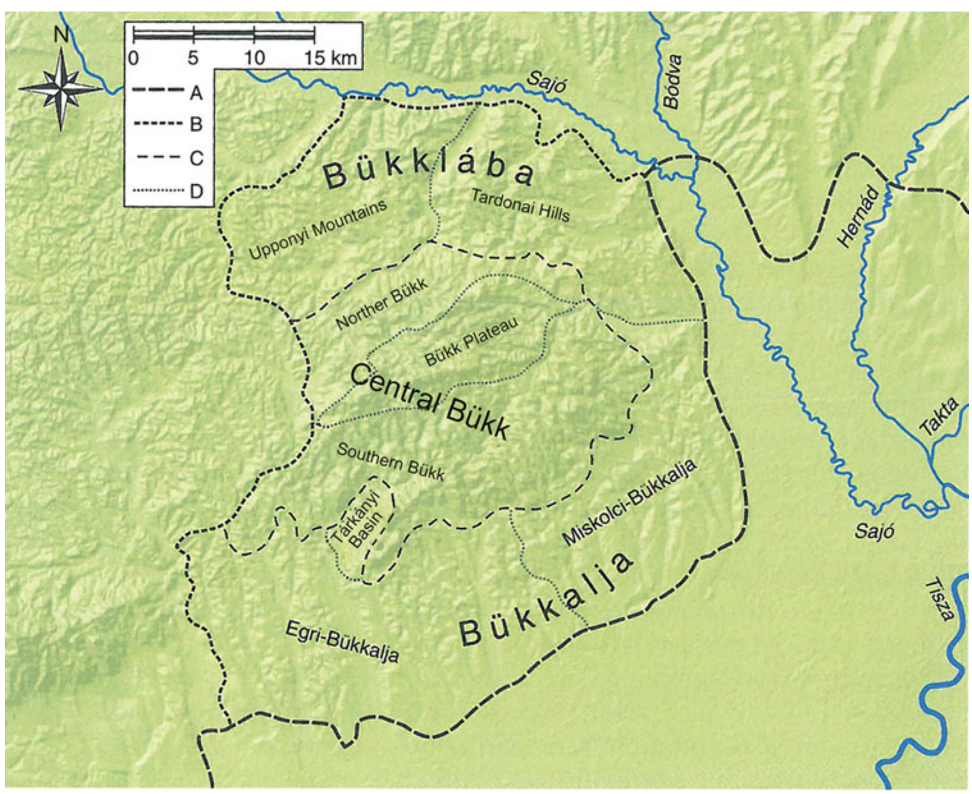

Fig. 5 Geographical regions of the Bükk Region (Mezősi 2011). Legend: A. border of macro region, B. border of meso region, C. border of micro region group, D. border of micro region

and Zentai 2009). In the area of the Southern Bükk, the limestone is disrupted by non-karstic intercalations. The non-karstic rocks prevail especially in the area of the Southwestern Bükk (intercalating and as a superficial deposit too). Consequently, the karstification of the Southeastern Bükk is more expanded. The Southeastern Bükk is autogenic karst, mixed autogenic-allogenic karst and buried karst to a small extent (Hevesi 1986b, 1991b), with soil-covered karst on its autogenic karst. The Southwestern Bükk is autogenic karst, mixed autogenic-allogenic karst and partially buried karst, with soil-covered karst on its autogenic karst sections (Hevesi 1986c, 1991b).

The Nézsa-Csővár Hills

They are a micro region belonging to the western part of the Cserhát Region (Western Cserhát), with an elevation of 155–442 m, and an area of 120 km^2, 15% of which is a block with horsts of the mountain range of medium height character. Its blocks are the Romhány Mountain, the Naszály Mountain and the Csővár Mountain. The area of the mountains is predominantly thus covered (crypto) by karst. Its surface karst features are not widespread, and its caves are more considerable. Its caves are affected by hydrothermal water (Ozoray and Láng 1957). Although these blocks do not belong to the Transdanubian Mountains geographically (the River Danube separates them from it), they do belong to it from a tectonic and historical geological point of view.

3.2 The Transdanubian Mountains and Their Karsts

The Transdanubian Mountains are a macro region, which is a block mountains with NE-SW direction, its expansion is 160 km in this direction and its area is 6810 km^2. The mountains are surrounded by the River Danube, the Great Hungarian Plain, the Little Hungarian Plain and the Transdanubian Hills. The mountains are separated into meso regions by faults with NW–SE direction. These are the Bakony Region, the Vértes-Velence Mountains and the Dunazug Mountains (Fig. 6). Their mountains are built up of blocks with different elevation and development which were formed by the dissection of the Late Cretaceous peneplain (Pécsi 1980, 1983).

The Bakony Region

The Bakony Region is the southwestern part of the Transdanubian Mountains. It is bordered by the Little Hungarian Plain in NW, by the Transdanubian Hills in W and SW, by

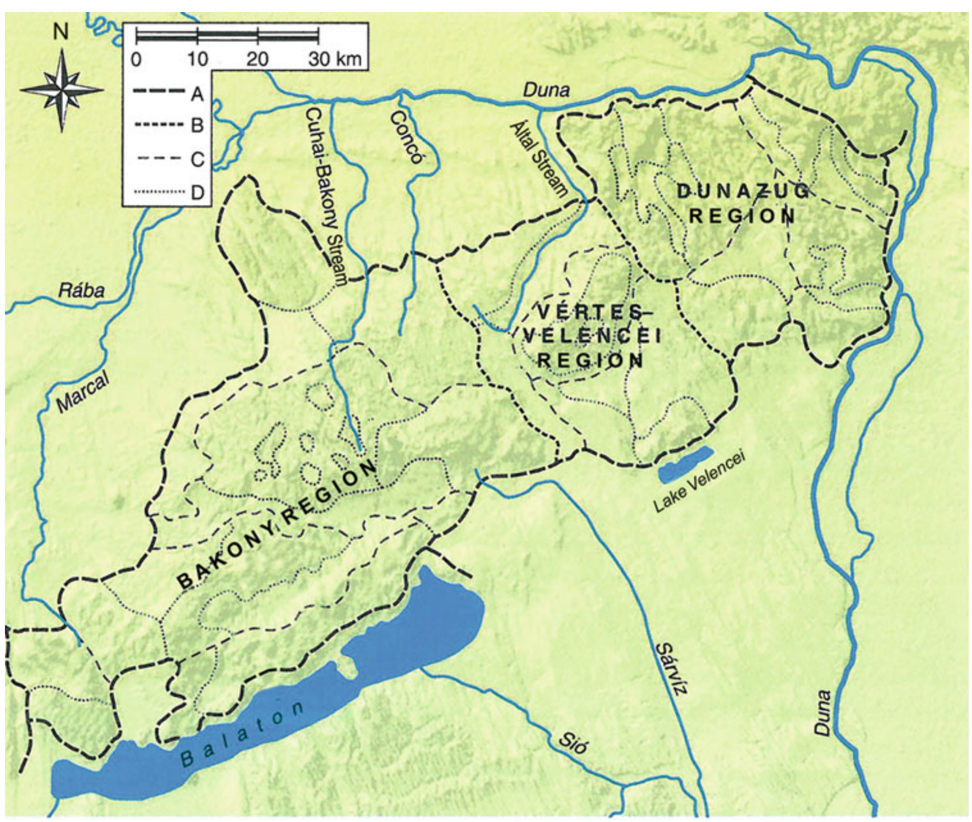

Fig. 6 Landscape geographical division of the Transdanubian Mountains (Mezősi 2011). Legend: A. border of macro region, B. border of meso region, C. border of micro region group, D. border of micro region

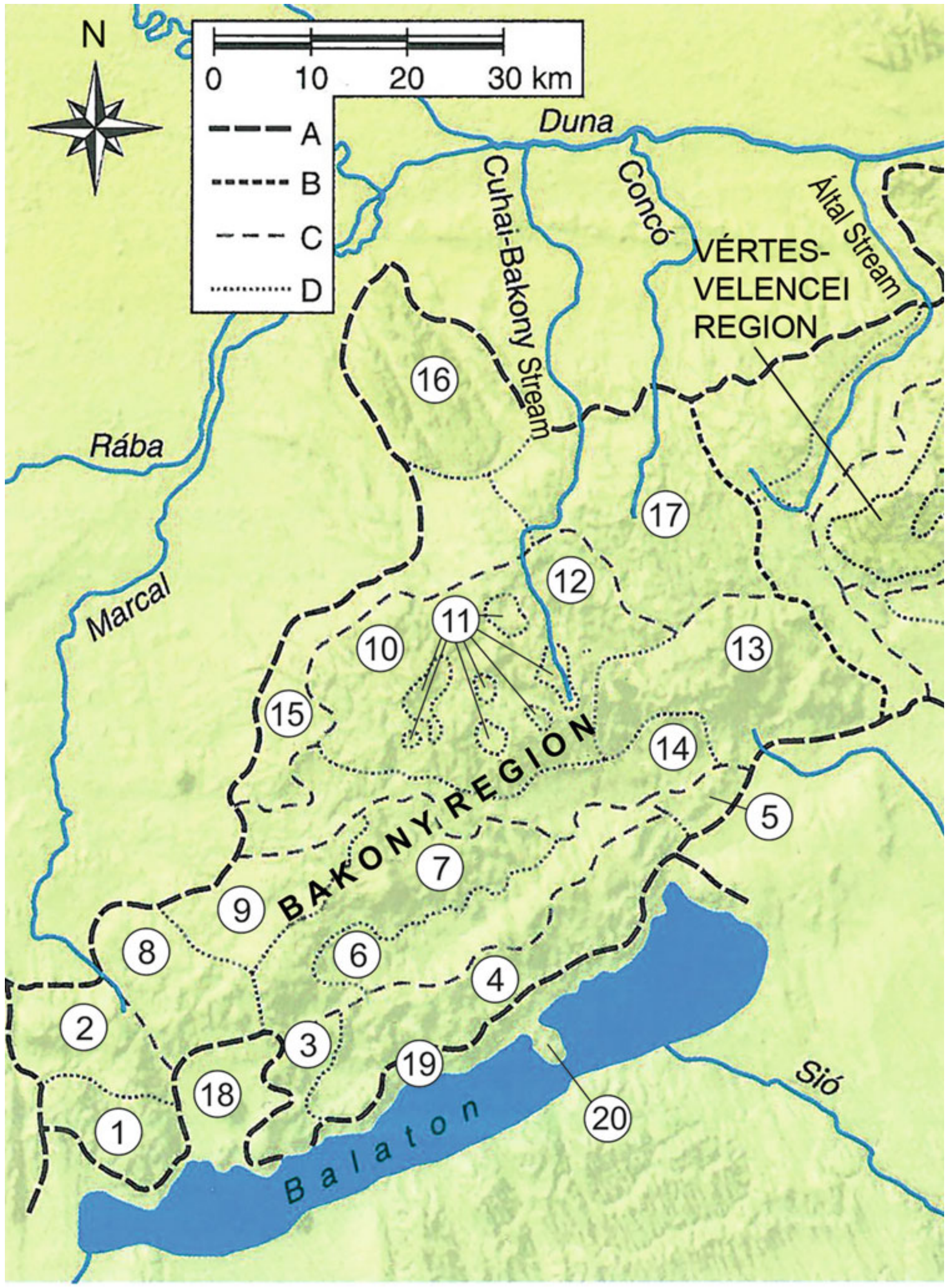

Fig. 7 Division of the Bakony Region (Mezősi 2011). Legend: A. border of macro region, B. border of meso region, C. border of micro region group, D. border of micro region, 1. Keszthely Plateau, 2. Tátika Group, 3. Badacsony-Gulács Group, 4. Balaton Uplands, 5. Vilonya Mountains, 6. Veszprém-Nagyvázsony Basin, 7. Mount Kab-Mount Agár Group, 8. Sümeg-Tapolca Ridge, 9. Devecser-Bakonyalja, 10. Öreg Bakony (Old Bakony), 11. Small basins of Bakony, 12. Sűrű Mountains Group, 13. Tés Plateau, 14. Veszprém-Devecser Graben, 15. Pápai-Bakonyalja, 16. Pannonhalma Hills, 17. Súri-Bakonyalja, 18. Tapolca Basin, 19. Balaton Riviera, 20. Tihany Peninsula

Lake Balaton, the micro regions of the Balaton Basin (Balaton-Riviera, the Tapolca Basin), by the Great Hungarian Plain (Mezőföld) in SE and by the Vértes Mountains (and the Mór Graben with a graben structure) in NE. The elevation of the Bakony Region is 150–700 m and its area is 4300 km^2. It is constituted by the Bakony Mountains (2200 km^2) and the surrounding regions with a lower elevation. It is separated into five micro region groups: Keszthely Mountains, Balaton Uplands, Northern Bakony, Southern Bakony and Bakonyalja (Fig. 7). The Northern Bakony and the Southern Bakony are separated from each other by the Séd Stream and the Veszprém-Devecser graben. The Northern Bakony is separated into micro regions called Old Bakony and Eastern Bakony by the Cuha Stream with NS direction.

The geomorphology of the mountains is constituted by horst surfaces with various elevation which are Late Cretaceous tropical peneplains (Pécsi 1980), by fault scarps, while at the margin of the mountains, in the basins there are abrasion platforms of Miocene age and pediments of Middle-Oligocene, Middle-Miocene, Pliocene and Pleistocene age (Pécsi 1963, 1980, 1983, 1991). In addition, mountains with basalt cover and buttes (Mezősi 2011, 2016), erosion valleys being inherited to a various degree also occur, on the loess cover, creeks and gullies (Veress 2000a), and at the margin of the mountains, alluvial cones (Juhász 1983) occur.

According to its evolution, the karst of the mountains is karst with horsts (Veress 2016) since they are built of blocks with different evolution and elevation (see chapter "An Interpretation of Karstification and Karst Processes by Hungarian Researchers"), but the Kab Mountain is mantled allogenic-covered karst (where mixed allogenic-autogenic karst, concealed karst and buried karst occur). In case of this karst type, the consolidated impermeable rock covers the karst in large expansion (this cover is basalt on the Kab Mountain). On karst of horst type, karst type may be different on various blocks and thus, karstification may be of different character and extent on the various blocks (Veress 2016; Veress and Vetési-Foith 2019a). The subsurface karst of its southern part was also affected by hot water. The karstification of the mountains is in an initial phase.

The Keszthely Mountains is separated into the Keszthely Plateau and the Tátika group micro regions. (The western margin of the Keszthely Mountains is the Keszthely Riviera which belongs to the Basin of Lake Balaton.) The Keszthely Mountains (their area is 150 km^2, and their elevation is 350–450 m) are constituted by a horst group, at their margin there are fault scarps and its surface is dissected by epigenetic valleys. Their subsurface karstification is more significant than its surface karstification. They are characterized by soil-covered karst (without features that are specific of this karst type) and in patches by covered (concealed) karst. In the area of the Tátika group (its area is 200 km^2), there are volcanic features and no karstification takes place here.

The parts (micro regions) of Balaton Uplands are the Badacsony-Gulács group, the Balaton Uplands and their small basins and the Vilonya Mountains. In the area of the Badacsony-Gulács group (its area is 75 km^2), volcanic features are characteristic, where no karstification takes place. In the area of the Balaton Uplands and in their small basins (with an area of 320 km^2, and an altitude of 200–400 m) horsts, volcanic features, intermountain basins, erosion and derasion valleys and boulder fields alternate. Their karstic terrains are soil-covered karsts (without features that are specific of the karst type), without a significant feature development. The karren landforms are more specific, developed on the sandstone of boulder fields (Kál Basin). In the area of the Vilonya Mountains (with an area of 55 km^2) volcanic features and horsts of low elevation, mainly horst with dolomite, occur. The karstification of dolomite surfaces (soil-covered karst) is not significant. The Tapolca Basin with buttes and the Balaton Riviera, a part of which is the Tihany Peninsula, belong to the Balaton Basin (the Balaton Basin belongs to the Transdanubian Hills). The Tapolca karst is situated at the margin of the Tapolca Basin, where both surface (soil-covered karst and concealed karst) and subsurface karst are significant.

The parts (micro regions) of the Southern Bakony are the Veszprém-Nagyvázsony Basin (with an area of 250 km^2) the Kab Mountain-Agártető group (with an area of 340 km^2), the Sümeg-Tapolca ridge (its area is 180 km^2) and the Devecseri-Bakonyalja (its area is 180 km^2). In the area of the Kab Mountain-Agártető group, there are horsts, erosion valleys, volcanic cones and pediments. Surface karstification is significant on the Kab Mountain and in its environs. As already mentioned, its karst types are allogenic karst, mixed allogenic-autogenic karst (at the margin of the basalt cover and inside it at limestone outcrops), cryptokarst, concealed karst and buried karst. On the Sümeg-Tapolcai Ridge, mainly low, exhumed horsts are characteristic, the surface of which is exhumed, former tropical karstic peneplain (the environs of Nyirád).

The Devecseri-Bakonyalja is a pediment which is dissected by different, but generally low horsts, erosion valleys and alluvial cones; its karst is soil-covered karst (with features characteristic of this type) and some concealed karst patches.

The micro regions of the Northern Bakony are the Old Bakony, the small basins of Bakony, the Eastern Bakony and the Veszprém-Devecser graben. The horsts of Old Bakony (its area is 700 km^2) are of various elevation, but those with an elevation above 500–600 m are also characteristic such as the Kőris Mountain, the Som Mountain, the Hajag etc. In its area there are erosion valleys (the valley sections between the basins are gorges or of gorge nature), and loess and other loose sediments creeks also can be found, while at the margin of the blocks, glacis, pediment and abrasion platforms occur. It is one of the characteristics of concealed karst micro regions of the mountains.

In the area of the small basins of the Bakony Mountains (Bakonybél basin, Porva Basin,, Zirc Basin, Hárskút Basin, Lókút Basin, Pénzesgyőr Basin, Csehbánya Basin and the Dudar basin belonging to the Eastern Bakony) an erosion valley network is predominant. The area of the basins is buried karst, but in the basins with a higher elevation (Hárskút Basin, Lókút Basin, Porva Basin) both concealed and soil-covered karst (without features specific of soil-covered karst) are present.

More significant horst groups of the Eastern Bakony (with an area of 370 km^2) are the Sűrű mountain group and the Tés Plateau. In the area of the former there are erosion valleys with intermittent or permanent streams (which have sections with gorges on blocks of higher elevation). Its karst is soil-covered karst (without features specific of the type) and some concealed karst patches. Abrasion platforms, pediments and glacis are also characteristic at the plateau margins of the landforms of the Eastern Bakony. The area of the Tés Plateau is only dissected by some epigenetic dry valleys. Surface (but also subsurface) karstification is the most significant here in the mountains. The most widespread concealed karst of the Eastern Bakony (but of the whole Bakony Region too) can be found here.

In the area of the Veszprém-Devecser graben (its area is 300 km^2, its elevation is 100–400 m) remnants of tropical karst peneplains occur at the surface (landforms with cones) and buried. Its geomorphology is determined by abrasion platforms, pediments, erosion and derasion valleys. On its non-buried parts, soil-covered karst is characteristic.

The micro regions of Bakonyalja are the Pápa-Bakonyalja, the Pannonhalma Hills and the Súr-Bakonyalja. In the Pápa-Bakonyalja alluvial cones and pediments occur. The area of this micro region is one of the most important resurgence sites of the karstwater of the mountains (Tapolcafő). The areas of the Pannonhalma Hills and the Súr-Bakonyalja are dissected by erosion and derasion valleys. No karstification occurs in the area of these micro regions.

The Vértes-Velence Mountains

They are separated into Vértesalja Hills, the Vértes Mountains, the Velence Mountains and its environs micro region group. Micro regions of the Vértes Mountains are the Vértes Plateau, the margin area of Vértes and the Gánt Basin. The Vértes Plateau can be regarded as a karst area. The Vértes is separated from the Bakony Region by the Mór Graben from Gerecse by Vál valley and Tatabánya Basin, while in the northwest it is surrounded by the Little Hungarian Plain and in the southeast by the Zámoly Basin.

Because of its young elevation, the margins of Vértes Plateau are bordered by fault scarps in each side. Its area is 130 km^2 and its average elevation is 400 m; only some blocks have an altitude of 500 m (e.g. Körtvélyes 480 m). Although its exhumed horsts are of various elevation, it is plateau-like; only some basins deepen into its area, for example Gánt Basin or Kőbányapuszta Basin (Bulla 1964). Its valleys are epigenetic valleys that developed along structural lines. Pediments commonly occur at the margin of Vértes.

Soil-covered karst is widespread on Vértes Plateau (without features that are specific of the karst type) and some smaller concealed karst patches occur. On dolomite there are also bare karstic patches (Csillag and Fodor 2008). Neither its surface karstification nor its subsurface karstification is significant.

The Dunazug Mountains

The Dunazug Mountains are separated into the Gerecse Region, the Bicske-Zsámbék Basin, the Buda Hills and the Pilis Mountains. These are micro region groups.

The Gerecse Region is separated from Vértes by the Tatabánya Basin. In the north it is bordered by the River Danube, while in the east it is separated from Pilis by the Dorog Graben. Its area is 650 km^2. The elevation of its surface is 300–600 m, but a block with an altitude of over 600 m also occurs (Gerecse 634 m). The Gerecse Region is also separated into blocks and block groups of various elevations which developed by the dividing up of a Late Cretaceous tropical karst peneplain. Its parts (micro regions) are Western-Gerecse, Central-Gerecse, Eastern-Gerecse and the small basins of Gerecse (Fig. 8).

The surface morphology of Western-Gerecse is constituted by fault scarps, terraces, erosion valleys, erosion-derasion valleys, derasion valleys, abrasion platforms, pediments and features of mass movement. The

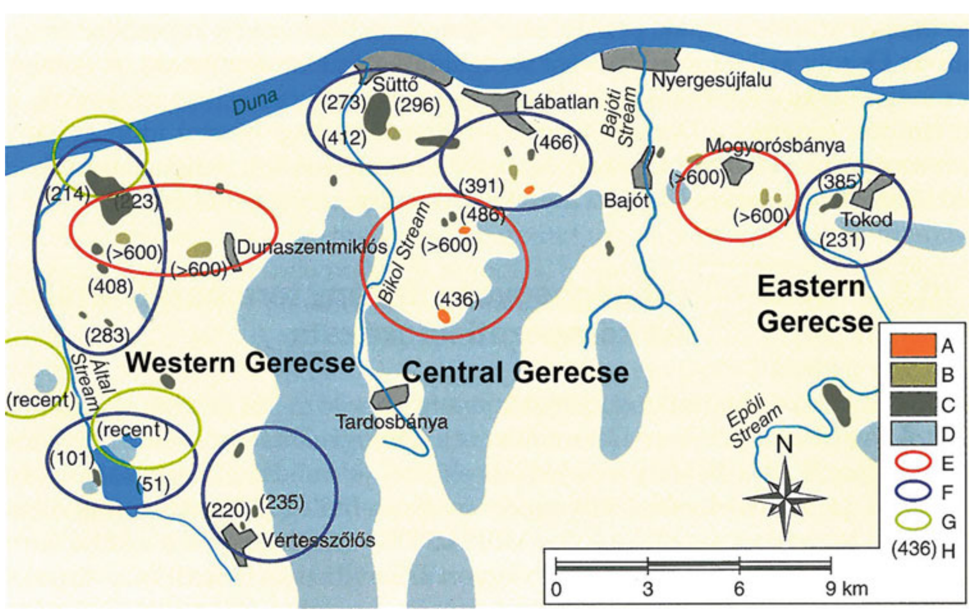

Fig. 8 Parts and calcareous tufa of the Gerecse Region (Mezősi 2011). Legend: A: Upper Pannonian springs and calcareous tufa, B: Upper Pliocene springs and calcareous tufa, C: Quaternary springs and calcareous tufa, D: Surficial distribution of Mesozoic Calcareous rocks, E: zones of spring outlets older than 600 thousand years, F: Middle and Upper Pleistocene zones of spring outlets, Holocene zones of spring outlets, H: elevation of spring

landforms of Central-Gerecse are fault scarps, erosion valleys (with sections of gorges), abrasion platforms, pediments and features of mass movement. Eastern-Gerecse is dissected by rows of horsts and basins with grabens. The slopes of horsts are surrounded by fault scarps, erosion and erosion valleys with terraces often occur. The small basins of Gerecse are dissected by erosion valleys; there is no karstification in their area (buried karst). The northern margin of Gerecse is lined by Danube terraces protected by calcareous sinter (Schweitzer 2002).

Its karst is soil-covered karst (without features specific of this karst type), concealed karst, and in the area of the basins, buried karst. Its karstification, mainly its surface karstification, is not significant, but regarding its degree, it comes after the Bakony Region in the Transdanubian Mountains. Its surface karst (concealed karst) mostly occurs in Central-Gerecse and Eastern-Gerecse. The karstification of the surface is in an initial phase, and its larger and smaller patches are far from each other. Its subsurface karst was affected by warm water.

The Buda Mountain-Group is situated among the Danube Valley, Mezőföld (Great Hungarian Plain) and the Pilisvörösvár Graben. Their area is 500 km^2 and elevation is 250–500 m. They are separated into blocks, block groups and basins. Their parts (micro regions) are the Buda Mountains, the Tétény Plateau, the Budaőrs Basin and the Budakeszi Basin. The parts of the Buda Mountains are the group of Hármashatár Mountain (between the Hűvös Valley and the Pilisvörösvár Graben), the Szabadság Mountain (between the Hűvös Valley and the Budaőrs Basin), the Nagy-Szénás group (between the Nagykovács Basin and the Pilisvörösvár Graben), the Nagy-Kopasz (between the Nagykovács Basin and the Budakeszi Basin).

The area of the Budai Mountain-Group consists of horst assemblages of various elevation, which got into different altitude following the dissection of the Late Cretaceous tropical karstic peneplain. The landforms of its surface are diverse: fault scarps and erosion valleys occur in the mountains and area of blocks (basins) with a lower elevation, and there are valleys and pediments with different width and glacis. Regarding their karst, caves with a hydrothermal effect (Hármashatár Mountain) and freshwater limestones covering river terraces are predominant (Schweitzer 2002).

The Pilis is situated between the Pillisvörösvár Graben and the Visegrád Mountains (the latter belongs to the North Hungarian Mountains because it is built up of volcanic rock). Its micro regions are the Pilis Mountain-Group (130 km^2) and the Pilis Basins (120 km^2). The elevation of the surface of the Pilis Mountain-Group is 450–500 m, but some blocks with an elevation of over 700 m also occur. It is separated into horst groups by its erosion valleys such as the Kevély Mountain Group, the Hosszú Mountain, the Fekete-Kétágú Mountain Group and the Pilis Block. The roof levels of these mountains are also the elevated exhumed surfaces of the Late Cretaceous tropical karstic peneplain. Dry valleys commonly occur on its dolomite surfaces and there are alluvial cones at the feet of fault scarps. Its subsurface karst is more significant, and the cave development was influenced by hydrothermal effect. Its surface karst is soil-covered karst (without features specific of the karst type) and with some concealed karst patches and cryptokarst patches.

3.3 The Mecsek Region (Western Mecsek)

The Mecsek Region is a micro region group, which is part of the meso region of the Mecsek-Tolna-Baranya Hills. (The micro region groups of the meso region are the Mecsek Region, the Tolna Hills, the Baranya Hills and Zselic.) The meso region belongs to the Transdanubian Hills macro region. The Mecsek Region is separated into the Mecsek Mountains and the Baranya-Hegyhát micro regions. Karst can be found in the Mecsek Mountains. The Mecsek Mountains are enclosed by the Great Hungarian Plain (Sárköz), the South-Baranya Hills, the Zselic and the Völgység. The Villány Mountains (micro region) is a block of small expansion being separated from the Mecsek and is a part of the Baranya Hills.

The area of the Mecsek Mountains is 350 km^2; it is a system of peneplains with SSW–NNE direction and their elevation is 300–600 m. The Western Mecsek is a series of horsts with peneplains, while the Eastern Mecsek is built up of rows of horsts radiating from the Dobogó-Zengő group. The features of the mountains are the pediment half-planes, alluvial cones and erosion valleys. Their karst developed in the northern part of the Western Mecsek area with an expansion of 30 km^2. Western Mecsek is an anticline with a WE direction. This area is a pediment of Carpathian age. It is separated into two parts: a more elevated part (450–470 m) which is an abrasion platform of Middle Miocene age, and a less elevated part (250–380 m). This latter is also an abrasion platform of Pannonian age and dissected tectonically (Lovász 1971; Hevesi 2001). Its karst is separated into three parts (Fig. 9): the Abaliget karst west from the Szuadó valley, the Orfű karst in the east and the Misina Tubes karst area eastwards from the latter (Lovász 1977).

In the south, its karst is mixed autogenic-allogenic karst (Barta and Tarnai 1997), but in its northern part the autogenic part (Veress 2016) was transformed into concealed karst (Hevesi 2001). The area of the Misina Tubes is a karst, the more elevated part of which was autogenic karst according to Czigány and Lovász's data (2006), while its lower part was probably covered which turned into allogenic karst, but eventually losing its impermeable cover it became concealed karst. Therefore, these karst areas (as already mentioned) are regarded to be transitional between the karsts of

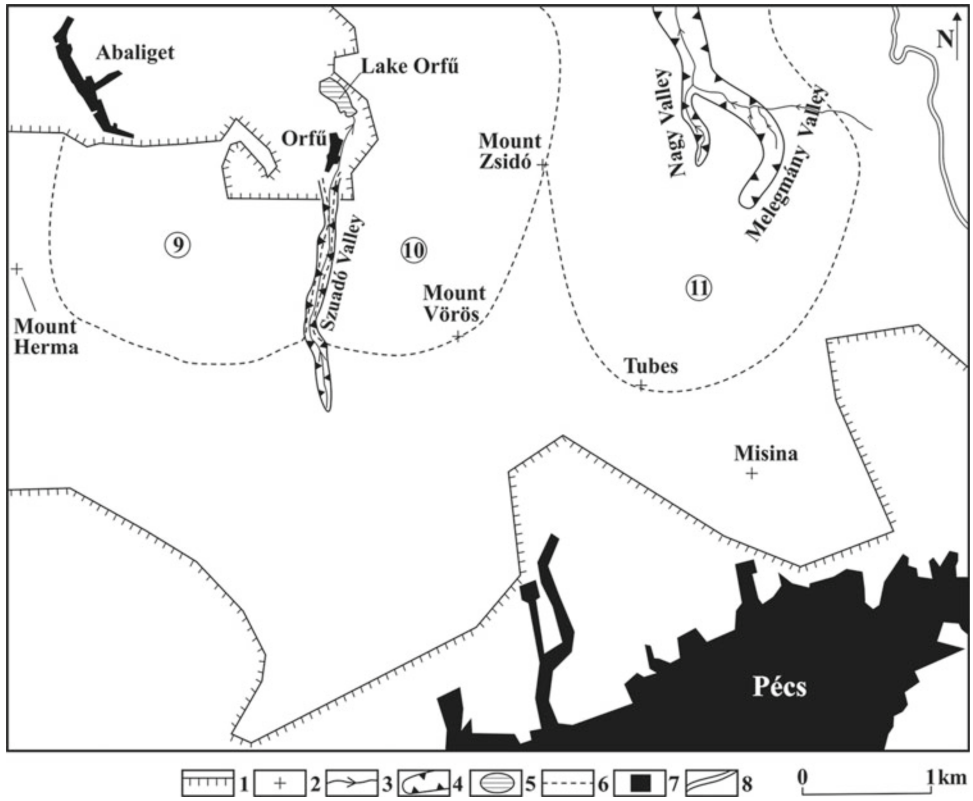

Fig. 9 Parts of Western Mecsek karst (Mezősi 2011). Legend 1. margin of mountains, 2. mountain, 3. stream, 4. valley, 5. lake, 6. border of karstic part area, 7. settlement, 8. road, 9. Abaliget Karst, 10. Orfű Karst, 11. Misina-Tubes Karst

Aggtelek and Transdanubian character. According to its evolution, it is semi-allogenic-covered karst. In such karst, the valleys of the non-karstic terrain surrounding the karst are the epigenetic valleys going through the karst, the streams of which transported or transport the superficial deposit of the karst or the rocks of the bordering non-karstic terrain (Veress 2016).

The Villány Mountains is (with an area of 50 km^2) surrounded by a pediment half-plane, above which there is an abrasion platform and above this are block sections with an elevation of 350–400 m. In a southern direction from the mountains, there are covered blocks of lower elevation, among which the most important is the Beremend block because of its subsurface karst. On the latter, a cave development of hydrothermal origin also played a role. The karst of the Villány Mountains is not significant. Their karst type is soil-covered karst (without features specific of this karst type), while bare karst occurs in some sites on its side slopes as a result of the denudation of the soil.

4 Conclusions

The main characteristics of Hungarian karsts were described. These are the following: their geological structure may be different (as a result of their various former development environment), they have a small area, they are dissected, they have a reversible hydrological relation with their environment, there is a strong hydrothermal effect in their area and paleokarsts are widespread. On its karsts, the fluvial surface formation was determined not only in the past but it is also important in the present. According to their karst landforms, Hungarian karsts can be put into two groups, the karst of Aggtelek group and the karst of Transdanubian group, but as a result of the presence of non-karstic rocks, several karst types are present in various karst areas. The karst types are of small expansion, partly because several types occur in the same karst area and partly because they are surrounded by non-karstic areas. Soil-covered karst, mixed autogenic-allogenic karst and concealed karst are the most widespread. According to their constituting rocks, they are mainly limestone karsts, but dolomite karsts are also widespread particularly in the Transdanubian Mountains. The climate, vegetation and soil of karst areas are not significantly different.

In Hungary, karst occurs in three macro regions: areas of the North Hungarian Mountains, Aggtelek-Rudabánya Mountains and Bükk Region (and on some smaller blocks). They are also found in the areas of the Transdanubian Hills, Mecsek Mountains and Villány Mountains (with the Beremend block); Transdanubian Mountains, Bakony Region, Vértes-Velence Mountains (Vértes Plateau), Dunazug Mountains (Gerecse, Buda Mountains and Pilis). The parts, expansion, elevation, geomorphology and karst types of these karst areas were also studied.

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