

A photograph of a rocky cliff face with a wooden fence and autumn foliage in the background. The cliff face is composed of large, layered rock blocks. The background features a wooden fence and dense trees with vibrant red and orange autumn leaves. The foreground is slightly blurred, showing some dry grass and foliage.

Bakony-Balaton

Geopark

Annex 2

Geological Heritage of the
Aspiring Bakony–Balaton Geopark, Hungary

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Bakony-Balaton
Geopark

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For reason of simplification, Bakony–Balaton Geopark (or BBGp) is used in this application dossier in the meaning “The candidate, Bakony–Balaton Geopark, being proposed for nomination as a European Geopark”.

Body text is set in Monotype Janson® which is the name given to an old-style serif typeface named for Dutch punch-cutter and printer Anton JANSON. Research in the 1970s and early 1980s, however, concluded that the typeface was the work of a Hungarian punch-cutter named **Miklós (Nicholas) TÓTFALUSI KIS** (1650–1702). He travelled to Amsterdam in 1680 to apprentice under Dirk VOSKENS and cut several typeface while working under him, producing a roman text face c. 1685 upon which present-day Janson is based. For more info (in English) please visit: <http://web.archive.org/web/200101060425/http://web.idirect.com/~nfhome/kis.htm>

B. Geological Heritage

Bakony–Balaton Geopark: land of the calmed-down volcanoes and dinosaurs (*a preface in 150 words...*)

The proposed Geopark area is a geological–geomorphologic mosaic on 3100 km² in West Hungary comprising 171 different formations: Ordovician metamorphites, Permian sandstone, Alpine Triassic carbonate succession near Central Europe’s largest, shallow-water lake, the Lake Balaton; Ammonite-rich Jurassic and new dinosaur genera-bearing Cretaceous above bauxitic tropical tower karst, Eocene large foraminifers and Miocene mollusc fauna with several hundred genera in the Bakony Mountains. The former Lake Pannon’s diverse endemic mollusc fauna is unique in limnic facies in the Earth’s history. Silicified sandstone cemented into ‘seas of stones’ around the Káli Basin; outstanding remnant hills of one of the “densest” volcanic fields in Europe (Mio-/Pliocene) that formed a dramatic landscape; almost 700 caves in gorges and on karst plateaus; hundreds of sinkholes; a 9-km-long thermal-water maze under a town and more than 1600 clear-water springs—these are all under the nature conservation supervision of a National Park Directorate: the Geopark candidate.

B.1. Location

The proposed Bakony–Balaton Geopark is located in Eastern Central Europe, in the central part of Western Hungary (Transdanubia). The Geopark can be reached by car within 1,5 hours from the Hungarian capital (Budapest), from Slovakia, Austria, Slovenia and Croatia. For more location details please refer to Chapter A.2., under Regions.

Extent of the proposed Geopark in geographic coordinates:

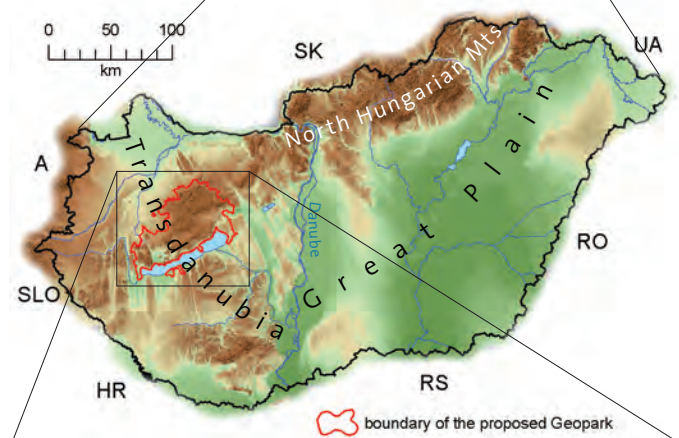
N 47° 24' 36,35" on the North
N 46° 40' 18,14" on the South
E 17° 08' 11,67" on the West
E 18° 15' 41,80" on the East

B.2. General geological description

History of Geological Recognition

From a geological point of view the Bakony is one of the areas of the Transdanubian Range that have been studied *for the longest time and in the most detailed way*. The first geological observations—written in the first half of the 19th century—can be found in travel reports. The first scholarly but sporadic observations were made by the French BEUDANT (1822), the Austrian ZEPHAROVICH (1856) and the Hungarian Flóris RÓMER (1860). In the course of the investigations the next milestone was the *geological surveying of the territory* of the Austro-Hungarian Monarchy. The geological mapping of the Bakony was carried out in 1860–61 by the geologists of the Geological Institute of Vienna. HAUER and his colleagues identified and distinguished the major lithostratigraphic units and pointed out their close relationship to the Alpine realm (HAUER 1870).

After the founding of the *Geological Institute of Budapest* (1869), geological research work of the Hungarian territories got under way. One of the first target areas of a more detailed geological mapping was the Bakony area, in which János BÖCKH (1872, 1873, 1874) and Károly HOFMANN (1875–78) played an outstanding role. The most significant milestone in the research of the Balaton Uplands (which form the southern wing of the Bakony Mountains) was the publishing of the ‘*Balaton monograph*’. Lajos LÓCZY sen. published his epoch-making work, i.e. “*Geological Formations of the surroundings of the Lake Balaton and their setting in the different areas*” in 1913. A detailed geological map on a scale of 1:75 000 was also compiled (LÓCZY 1920). In the geological appendix of the volume a detailed description of the geology of the surroundings of Veszprém was provided by Dezső LACZKÓ (1911), and a summary of the basalts of the Balaton region was given by István VITÁLIS (1911). In the palaeontological appendix issued in four volumes, the most famous scientists of Central Europe gave an overview of the knowledge that had been gained about the fossil record of the Balaton Uplands, until that time. Many fossils have been



described from the Balaton Uplands and this is reflected by the names of some of them (for example *Hungarites*, *Balatonites*, *Arpadites* etc.)

After the First World War an intense raw material research commenced in the area of the Transdanubian Range. It resulted also in the compilation of a *detailed geological map* of the Bakony Mountains (TELEGI RÓTH 1934). After the Second World War the progress of geological knowledge was also in close connection with the research of raw materials (predominantly coal and bauxite), resulting in the publishing of new maps, among others a map representing the area of the North Bakony (NOSZKY in BARNABÁS et al. 1957). From the middle of the 1960s until the end of the 1970s the *engineering geological mapping of the shoreline areas* of the Lake Balaton (BOROS et al. 1985) and the *systematic geological mapping* of the Bakony Mountains (CSÁSZÁR et al. 1981, GYALOG, CSÁSZÁR 1990, BENCE et al. 1990) were performed. The latest geological mapping of the Balaton Uplands on a scale of 1:10 000 started in 1982. It was carried out in



Geological map of the Balaton Uplands by S. BEUDANT (1822)

the frame of the regional mapping programme of the *Geological Institute of Hungary*. As a result of the work a *regional geological map* on a scale of 1:50 000 and an *explanatory book of the geological map* were published (BUDAI, CSILLAG 1998; BUDAI et al. 1999a, 1999b).

The general description of the geological build-up of the Bakony Mountains can be found in several handbooks, which give comprehensive summaries about the geology of Hungary (JUHÁSZ 1983, TRUNKÓ 1996, HAAS ed. 2001, BUDAI, GYALOG eds. 2009.)

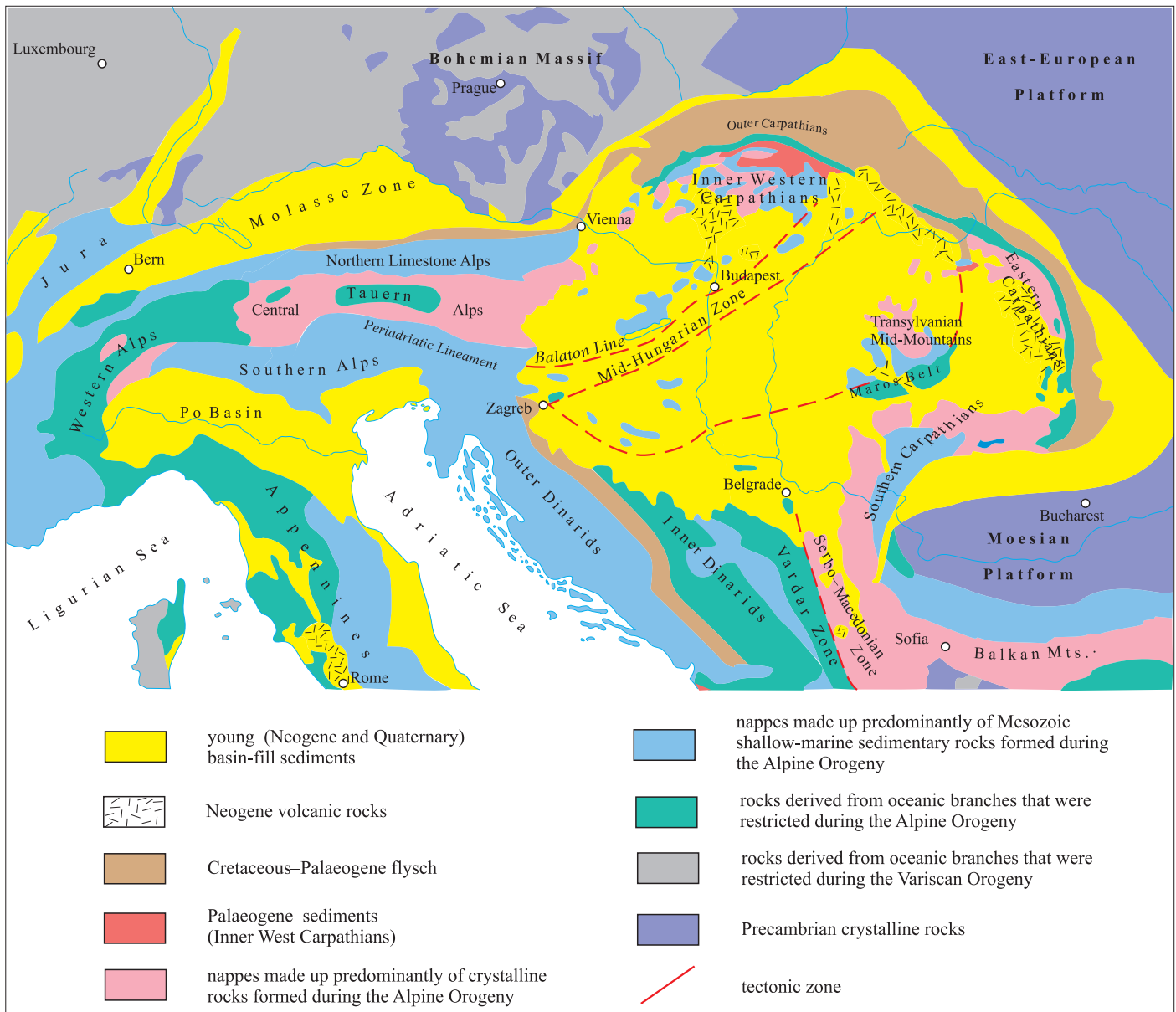
At the beginning the geomorphologic investigations of the area were closely associated with geological surveying. Jenő CHOLNOKY was a prominent scientist of the first half of the last century. Landscape studies—organized by the *Geographical Research Institute* and led by Márton

PÉCSI—started in the 1960s in the Bakony Mountains. The results of the geomorphologic studies were summarized in a *landscape monograph in two volumes* (ÁDÁM–MAROSI–SZILÁRD 1987–88). Additionally, *numerous publications are available* which deal mainly with the question of volcanic remnant hills and karst phenomena. Nowadays cadastral survey of protected caves, sink-holes and springs is being carried out.

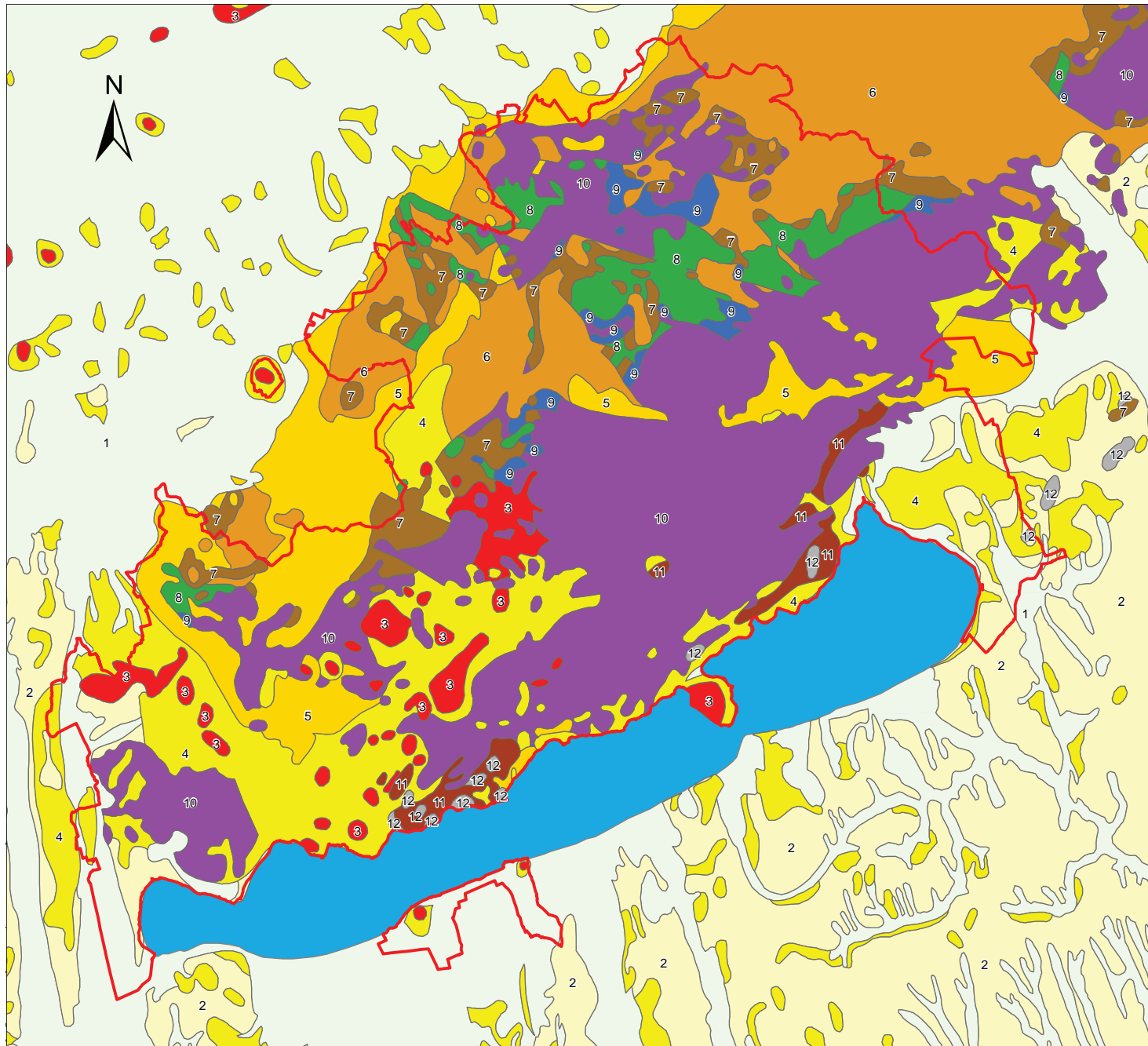
Geological build-up

The area of the Geopark is made up of sedimentary rocks of different geological ages, which have been formed within approximately 500 million years. The areal extent of magmatic rocks is subordinate, metamorphic rocks can be found only in small patches on the surface. The bulk of the mountains are built up of *shallow-marine carbonates (limestone and dolomite) of Triassic age* with a thickness ranging from 2.5 km to 3 km. The geological build-up of the Bakony (and of the entire Transdanubian Range) is significantly different from the surrounding areas (i.e. the basement of the Little Plain and the area located S of the Lake Balaton. Based on geological data derived from surficial observations and from boreholes, and according to palaeogeographic and tectonic interpretations of these data, the Transdanubian Range has been shifted to its current place from its probable *original position in the Alps as a result of large-scale movements*. According to the currently-accepted tectonic models, the *Bakony Mountains belong to the East Alpine Nappe System*, and are situated in the highest position, above the nappes that form the basement of the Sopron Mountains and the Little Plain.

From a geological point of view, in the SE the Bakony area is bordered by the tectonic zone of the Balaton Line, whereas from a geomorphologic point of view it is bordered by the northern rim of the basin of



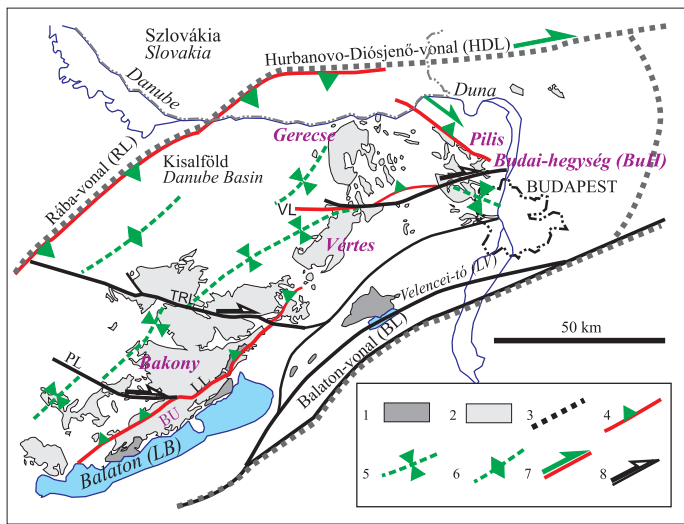
Geological setting of the Carpathian Basin within the Alpine Mountain System (after HAAS et al. in MÉSZÁROS, SCHWEITZER eds. 2002)



Simplified geological map of the proposed Bakony-Balaton Geopark

- 1 Quaternary fluvial sand, clay, limnic ooze, paludal clay, peat; slope sediments
- 2 Pleistocene loess with palaeosols
- 3 Pliocene basalt, pyroclastics
- 4 Upper Miocene sediments of the Lake Pannon: silt, sand, clay, abrasional gravel, travertine, siliceous sandstone
- 5 Miocene marine clay, clay marl, sandstone, gravel; shallow-marine biogenic limestone
- 6 Oligocene fluvial variegated clay, sand, gravel
- 7 Eocene pelagic marl; shallow-marine foraminiferal limestone, brown coal
- 8 Cretaceous shallow-marine crinoidal and bivalve-bearing limestones; pelagic marl, clay marl; platform and reef carbonates, bauxite, brown coal
- 9 Jurassic limestones of deeper-marine facies (ammonitico rosso), cherty limestone, radiolarite, manganese ore
- 10 Triassic shallow-marine marl, dolomite; limestones and marls of basin facies, cherty limestone; platform Main Dolomite and Dachstein Limestone
- 11 Permian alluvial red sandstone, siltstone, conglomerate
- 12 Ordovician-Silurian quartz phyllite, slate, metabasalt, metarhyolite

1 : 500 000 0 10 20
km



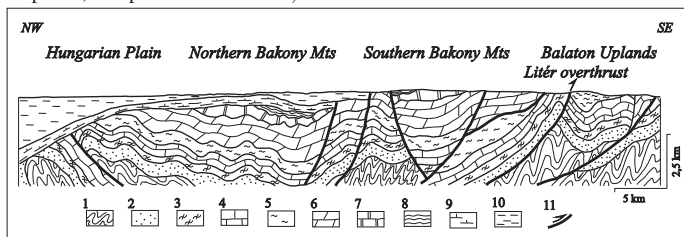
Simplified geological map of the Transdanubian Range Structural Unit with the surficial extent of Palaeozoic and Mesozoic formations (after Balla, DUDKO, TARI, FODOR). Legend: 1. Palaeozoic formations; 2. Mesozoic formations; 3. Boundaries of the Transdanubian Range Unit; 4. Mesozoic overthrust; 5. Cretaceous syncline; 6. Cretaceous anticline; 7. Cretaceous lateral fault; 8. Cenozoic lateral fault. LL – Litér Line; PL – Padragkút Line; TRL – Telegdi Roth Line; VL – Vértesszlő Line; BH – Balaton Uplands

the Lake Balaton. In the NE—towards the Vértes Mountains—it is bordered by a more peculiar tectonic structure, i.e. the Mór Trough.

The structure of the Bakony Mountains is determined by a syncline of a SW–NE axis. Its south-eastern and north-western limbs are made up of the oldest (Palaeozoic–Triassic) sequences, whereas towards the axial zone of the syncline increasingly younger (Jurassic–Cretaceous–Palaeogene) formations can be observed. The Balaton Uplands and the Veszprém Plateau form the south-eastern limb of the syncline, where Palaeozoic and older Triassic rocks can be traced on the surface. Beds preferentially dip north-westward and their general strike is approximately similar to that of the axial direction of the syncline. This general tectonic structure is complicated by longitudinal (SW–NE) compression structures of different amplitudes, folds and reverse faults. The most significant one is the Litér overthrust, which determines the structure of the Balaton Uplands and the Veszprém Plateau and along which the Permo-Triassic sequences are repeated within two slivers thrust over each other. The tectonic boundary of the Balaton Uplands and the South Bakony (in the strict sense) is determined by an overthrust line, the so-called Veszprém Fault.

Besides the longitudinal compressional tectonic structures transverse ones (of NW–SE and WN–ESE directions) are also of determining significance. These structures in the sliver located S of the Litér Fault Line are mostly of compressional character. Anticlines, synclines and overthrusts (e.g. the horse-tail structure at Dörgicse), which can be observed in the central part of the Balaton Uplands, belong to these structures. A large-scale anticline structure can also be outlined within the sliver situated N of the Litér Fault Line, in the vicinity of Hidegkút and Tótvázsony. This structure is accompanied by a disintegrated syncline structure along the northern margin of the Pécsely–Balatonszőlős Basin.

Transverse tectonic structures include dextral strike-slip faults with amplitudes of several km (Telegdi-Roth Line, Herend–Márkó Line, Úrkút–Padragkút Line) and the curving faults which turn from an approximately N–S direction into NE–SW direction. These faults delineate the margins of the Csehbánya Basin and the Ajka–Nyirád Basin. The formation of the Miocene basins of the Bakony Mountains (Várvolgy, Tapolca, Várpalota Basins etc.) was in connection with such structures.



Simplified geological cross section of the Bakony Mts (TRUNKÓ et al.).

Legend: 1. Early Palaeozoic basement; 2. Upper Permian sandstone; 3. Lower Triassic formations; 4. Middle Triassic carbonates; 5. Upper Triassic marls; 6. Upper Triassic dolomites; 7. Dachstein Limestone; 8. Jurassic formations; 9. Cretaceous formations; 10. Tertiary formations; 11. Reverse faults

Geological History

Based on the geological setting and tectonic characteristics, the geological history of the Geopark can be divided into the following periods.

Pre-alpine history

The oldest formations of the Bakony Mountains are represented mainly by marine clastic sediments, which were deposited during the Early Palaeozoic (approximately 500–360 million years ago) and subsequently, during the Variscan orogeny, underwent metamorphism. The grey, anchimetamorphic slate and metaaleurolite, which make up the succession, crop out at two places in the Balaton Uplands (at Alsóörs and Révfülöp), whereas slightly East of the Lake Balaton the pre-existing rocks underwent stronger metamorphism (Balatonfőkajár Quartz Phyllite). Based on palaeontological data the deposition of the succession of originally deep-sea environment commenced at the beginning of the Ordovician and took place until the middle of the Devonian. It was interrupted twice by significant volcanic events, which resulted in the formation of the Lower Ordovician Alsóörs Metarhyolite and the Silurian Révfülöp Metaandesite and Litér Metabasalt.

In the middle period of the Devonian clastic sedimentation was replaced by carbonate sedimentation in the pelagic basin. The red, nodular Kékkút Limestone, which was exposed by boreholes, yielded characteristic fossils (conodonts and tentaculites). Younger marine sediments of Palaeozoic age are unknown in the Balaton Uplands.

Variscan orogeny took place in the early period of the Late Palaeozoic, during the Carboniferous. It resulted in the folding and transformation (metamorphism) of sedimentary rocks dating from earlier times. These processes took place about 325–310 million years ago.

Alpine history

Continental and shallow-marine sedimentation during the Late Permian

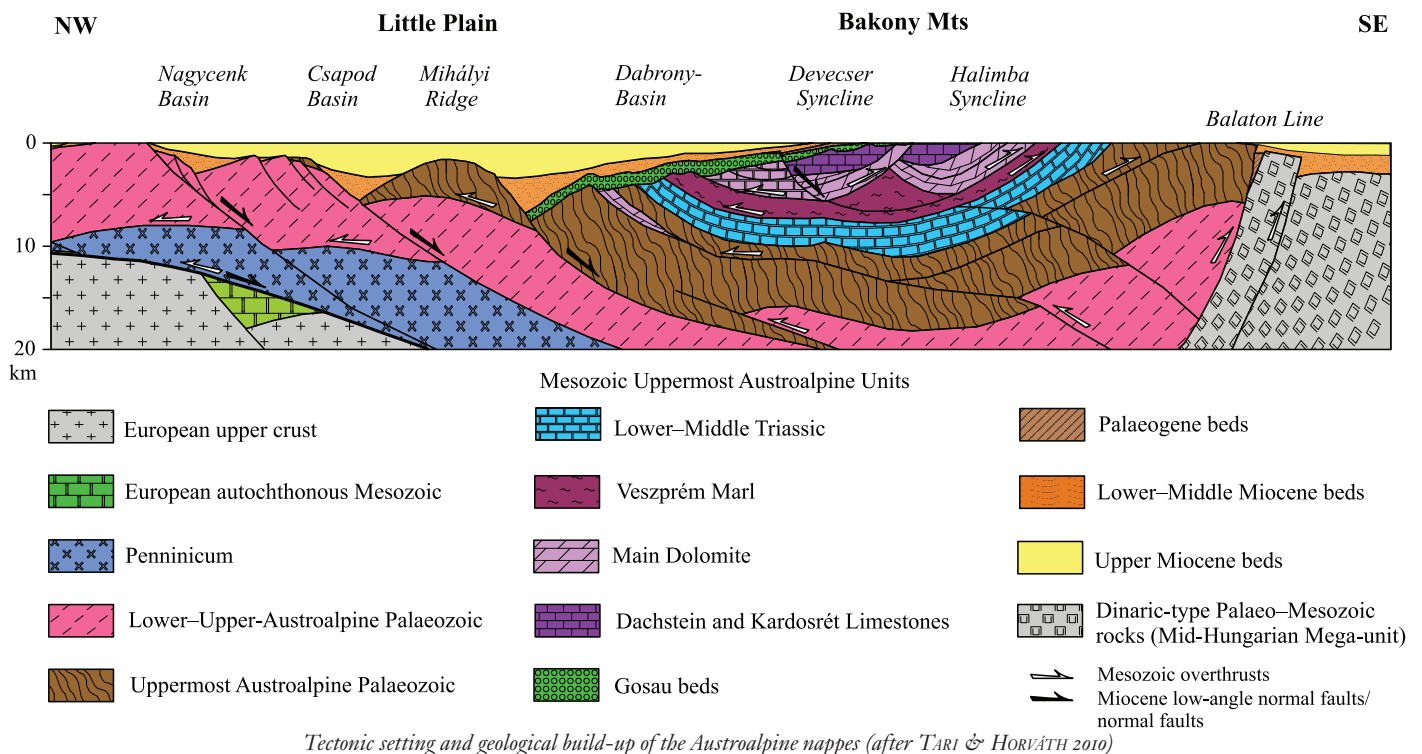
In the final period of the Palaeozoic, approximately 300–250 million years ago, denudation of the mountains (which had been folded and uplifted during the Variscan orogeny) and the deposition of the eroded debris took place. The closure of the earlier oceans, which had existed between the ancient continents, led to the formation of a supercontinent (Pangea) in the Permian. One of the most characteristic formations of this period is represented by a succession cropping out in certain areas of the Balaton Uplands and in the Veszprém Plateau. It is made up of red sandstone, pebbly sandstone, conglomerate and siltstone and characterised by a thickness of several hundred metres. Based on the study of sporomorphs belonging to one-time plants and derived from the Balaton-féldévidék (Balaton Uplands) Sandstone, a fluvial and limnic (i.e. continental) depositional environment can be reconstructed for the end of the Palaeozoic. The red, purplish-red colour which is characteristic of the succession indicates that these beds were deposited in an oxidative sedimentary environment under semiarid conditions. Fossils of the rock are unique; besides the plant remains a foot print of an ancient reptile is known from the Pálköve quarry.

Shallow-marine siliciclastic–carbonate ramp in the Early Triassic

The alluvial plain of a large areal extent, which came into being by the end of the Palaeozoic, was inundated by the sea at the beginning of the Mesozoic, about 250 million years ago. The deposition of fine-grained siliciclasts and carbonates started in the area of the shallow-marine shelf. In the south-western part of the Balaton Uplands the succession is represented by the light-grey, sandy Köveskál Dolomite, whereas NE of the Tihany Peninsula it is made up of the grey Arács Marl.

Deposition of the red sandstone (Zánka Sandstone) in the middle of the Early Triassic indicates the increase of terrigenous influx (i.e. the increase of denudation of the continental terrain around the sea). The sandstone is overlain by the gypsum-bearing beds of the Hidegkút Dolomite, which indicate the temporary shallowing of the sedimentary basin and the development of restricted, periodically hypersaline lagoons.

The sea-level rise, which took place in the second half of the Early Triassic, resulted in the development of an open shelf basin. Besides the fossils of ammonites, skeletal fragments of gastropods, bivalves and crinoids are frequent in the lower section of the Csopak Marl.



Formation and development of shallow-marine carbonate platforms in the Middle and Late Triassic

After the infilling of the Early Triassic basin—at the beginning of the Middle Triassic (about 240 million years ago)—a tidal flat of a large areal extent came into being. Sedimentation started in a dry and warm climate under desert conditions, in a hypersaline, shallow-marine lagoon, which temporarily dried up (*Aszófő Dolomite*).

Subsequently, the relative sea-level rise resulted in the development of an inner shelf lagoon-system, which was temporarily restricted from the open sea. The lower section of the dark-grey, bituminous *Iszkabegy Limestone* of laminated structure was deposited in a poorly-ventilated seafloor. Due to the gradual shallowing of the sea, a gently-sloping, well-lit shallow-marine ramp developed, where carbonate sedimentation continued (*Megyebegy Dolomite*).

By the middle of the Triassic (approximately 235 million years ago) the undisturbed development of the sedimentary basin was stopped by a sudden, drastic geological event. This period of the geological history is called ‘Pelsonian’ all over the world, after the Latin name of the Lake Balaton (i.e. Lacus Pelso). Dilatational tectonic movements resulted in the disintegration of the previous uniform basin floor; different parts of the dissected area were characterised by different sedimentation patterns. In the area of the uplifted blocks shallow-marine carbonate sedimentation continued until the end of the Anisian Age. The sedimentary environment was similar to that of the Bahama Bank, i.e. carbonate sedimentation took place on submarine ridges in a shallow-marine, intertidal environment (*Tagyon Limestone*).

Simultaneously, in the down-faulted depressions between the submarine ridges (island platforms) narrow and deep basins were formed, in which ammonitic, bituminous limestone developed. The massive occurrence of the fossils of shallow-marine organisms (crinoids and brachiopods) in certain horizons of the *Felsőrs Limestone* indicates that from time to time a significant amount of sediments was re-deposited from the submarine ridges into the basin.

Probably as a result of the former tectonic movements *tuff explosions* of the submarine volcanism, which took place at the Anisian/Ladinian boundary (about 233 million years ago), were particularly intensive at the end of the Anisian (*Vászoly Beds*). The coeval sea level rise manifested in the “drowning” of the shallow-marine platforms. During the Triassic the deepest basin was formed by this time. It is indicated by the ammonitic, nodular and cherty *Nemesvámos Limestone*— which alternates with volcanics— and the thin layers made up of the siliceous skeletons of protozoan organisms (radiolarians) which are called radiolites.

At the beginning of the Late Triassic the shallow-marine platforms of the Balaton-felvidék significantly expanded replacing the basin areas,

in which the accumulation of calcareous mud took place, which had been redeposited from the platforms. This resulted in the formation of a popular building stone of the Balaton Uplands region: the light-grey, thick-bedded *Füred Limestone*, which contains chert lenses and stringers, and the *Berekbegy Limestone* which occurs on the Veszprém Plateau.

During the Carnian the predominant part of the Balaton Uplands was occupied by a basin, which was encircled by carbonate platforms. This basin was filled up with terrigenous siliciclasts (clay and silt) derived from distant continental terrains (*Veszprém Marl*). The marl sequence is divided by the nodular, cherty Nosztor Limestone of a thickness of 10 m to 20 m. A similar basin existed in the area of the North Bakony, whereas the Veszprém Plateau and the East Bakony were dominated by platforms.

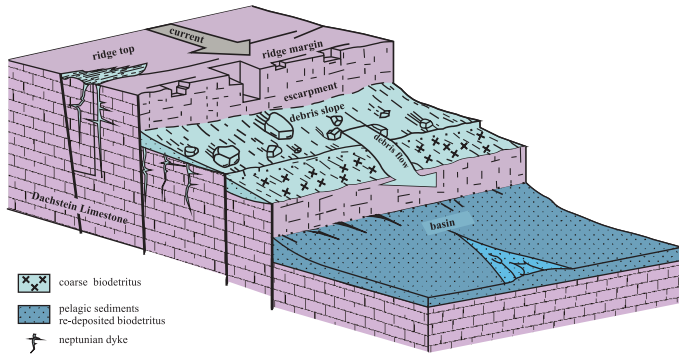
By the end of the Carnian Age the terrigenous influx resulted in the gradual filling up of the basin. Coevally, its areal extent decreased between the platforms. This led to the formation of a poorly-ventilated, hypersaline lagoon which was followed by the development of a normal shallow-marine environment (*Sándorbegy Limestone*) after a temporary sea level rise.

The Carnian basins were separated from each other by submarine ridges and platforms on which the sedimentation of shallow-marine carbonates took place. The *Ederics Limestone* (characterised by sponges and other reef organisms) and the *Sédvölgy Dolomite* were deposited. Carnian platforms of large areal extent can be traced SW of the Balaton Uplands (in the Keszthely Mountains) and NE of it (over the Veszprém Plateau). By the end of the Carnian Age (approximately 220 million years ago) basins were completely filled up, and the progradation of the surrounding platforms resulted in the development of an uninterrupted and relatively flat terrain (i.e. a uniform platform). Carbonate sedimentation took place on a shallow-marine undersea ridge, which was similar to the present-day Bahama Platform but was significantly larger than this one. Initially carbonates were deposited under a dry climate and subsequently under a humid and warm climate. The approximately 1.5 km-thick Main Dolomite and the 200–500 m-thick *Dachstein Limestone*— which make up the predominant part of the Bakony Mountains— are the touchable evidences of this type of sedimentation.

As a result of tectonic movements during the Norian, about 210 million years ago, the Late Triassic platform was dissected resulting in the formation of smaller and larger, semi-restricted basins. In their poorly-ventilated sea floor organic-rich, laminated, cherty dolomite (*Rezi Dolomite*) and marl (*Kössen Marl*) were deposited in the area of the Keszthely Mountains and in the South Bakony.

Formation of submarine highs and basins in the Early Jurassic

As a result of the opening of the Neotethys Ocean, tectonic segmentation of the Late Triassic platforms significantly intensified at the beginning of the Jurassic. In certain uplifted areas of the Bakony Mountains carbonate platform evolution continued in the Hettangian (*Kardosrét Limestone*), but in later periods of the Early Jurassic the intensified tectonic subsidence led to the drowning of the platforms. In the area of the earlier



Sedimentary model of the Transdanubian Range in the Early Jurassic (GALÁCZ, in HAAS ed. 2001)

platforms submarine highs were formed, which were characterised by temporary carbonate sedimentation. For the most part, the surfaces of the downfaulted blocks were inhabited by rich, shallow-marine biotas, in which brachiopods and crinoids dominated (*Hierlatz Limestone*). Red, thick-bedded limestone (*Pisznice Limestone*) was deposited in the deeper sea basins; locally with chert intercalations, which are derived from the skeletons of siliceous sponges (*Istizmér Limestone*). The deep basins between submarine ridges were also characterised by low sedimentation rates and the deposition of nodular, ammonitic limestone and clayey limestone (*Tűzkövesárók Limestone*, *Kisgerecse Marl*). In many cases planktonic bivalves occur in large numbers in these types of sediments (*Tölgybát Limestone*, *Eplény Limestone*). Manganese ore deposits accumulated in the close vicinity of the submarine ridges (*Úrkút Manganese Ore*) indicating a global anoxic event in the area of the Jurassic basins of the Bakony Mountains.

Deepening and filling up of the basin in the Middle and Late Jurassic

The Jurassic basin of the Bakony area may have reached its maximum depth during the middle of the period (about 170–160 million years ago) when the extensive proliferation of radiolarians (planktonic protozoans with siliceous skeletons) resulted in the formation of siliceous marl (*Lókút Radiolarite*). Subsequently, in the Late Jurassic, due to the resuming of tectonic mobility the sea basin gradually became shallower; nevertheless, open-marine carbonate sedimentation continued in the area of the Bakony. In the early period of the Late Jurassic red, ammonitic limestone—containing planktonic crinoids in rock-forming quantity—was deposited (*Pálibálás Limestone*), whereas at the end of the Jurassic a white, laminated, cherty limestone (*Mogyorásdomb Limestone*) was formed; this rock is made up of the skeletons of planktonic unicellular organisms.

Evolution of the sea basins in the Early Cretaceous

In the south-western areas of the Bakony Mountains the sedimentation of open-marine carbonates of *Maiolica facies*—which started in the Late Jurassic—continued in the early period of the Cretaceous, whereas in the North Bakony the so-called *Szentivánbegy Limestone* was formed. This rock is yellowish-white or light red and locally, contains *belemnite guards* and *brachiopod shells* in large quantities. In the later period of the Early Cretaceous an increased influx of fine terrigenous material occurred in the area of the South Bakony (*Sümeg Marl*). Coevally, in the North Bakony the shallow-marine crinoidal–brachiopod-rich *Borzavár Limestone* was formed.

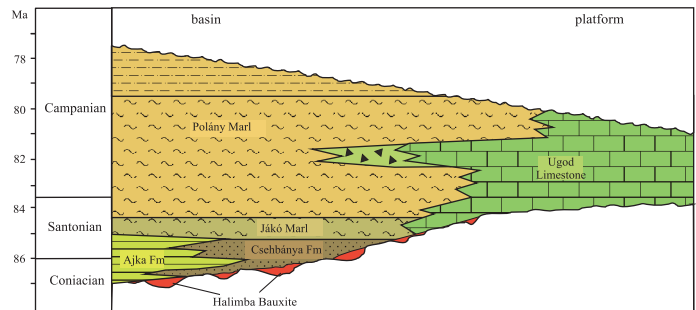
Orogeny and denudation in the middle of the Cretaceous

The closure of the several Tethyan oceanic branches led to orogenic movements in the Alpidic region. Due to compressional tectonic movements a large area of the Bakony was exposed at the surface during the Aptian Age which resulted in the denudation of the previously formed rocks. As a result of the late Aptian transgression, crinoidal limestone

(*Tata Limestone*) was formed all over the area. This event was followed by a much stronger uplifting and denudation in the Albian Age (*Austrian Orogenic Phase*). The compression (which accompanied the orogeny) led to the formation of the syncline structure of the Bakony and the longitudinal reverse faults and folds characteristic of the limbs of the syncline. In the middle period of the Cretaceous the sea invaded the basin of the Bakony area again. The coastal areas were characterised by *brackish-water* environments (*Tés Clay Marl*), whereas in the shallow-marine areas carbonate sedimentary environments came into being characterised by patch reefs which were inhabited by large-size bivalves and gastropods (*Zirc Limestone*). Due to the further sea level rise an open basin developed in which carbonate–siliciclastic sedimentation took place (*Pénzeskút Marl*) at the beginning of the Cenomanian Age, approximately 100 million years ago.

Formation of shallow-marine ridges and basins in the Late Cretaceous

In the early phase of the Cretaceous the Bakony area became a continental terrain again. Intense tropical karstification commenced and *bauxite* was formed under a warm and humid climate (*Halimba Bauxite*). In certain parts of the surface fluvial sediments were deposited, in which fossiliferous beds—rich in fossil reptile bones—can be found (*Csebbánya Beds*). In other areas swamps came into being, and coal deposits began to form (*Ajka Coal*). Subsequently, due to the gradual sea level rise, a shallow-marine environment evolved and this was followed by the development



Theoretical profile of the Late Cretaceous formations in the Bakony Mts (HAAS ed. 2001)

of a much deeper, open sea basin in the area of the Bakony syncline; carbonate sedimentation and the deposition of fine siliciclastic material started about 85 million years ago (*Jákó Marl* and *Polány Marl*). Coevally, reefs were formed on the shallow-marine ridges which dissected the sea basins. These reefs (*Ugod Limestone*) were made up of large-size bivalve molluscs attached to the hard ground (hippurite rudists).

Denudation at the beginning of the Palaeogene and transgression in the middle Eocene

Compared to their earlier positions, the arrangement of continents and oceans significantly changed during the Cenozoic. The convergence of Africa towards Europe led to the gradual closure of the Tethys Ocean and the orogenic folding of the Alpidic chains. At the beginning of the Palaeogene (i.e. in the Palaeocene and in the early Eocene) there was a pause in sedimentation in the Bakony syncline, which had been formed in the Middle Cretaceous. This period was characterised by a warm and humid climate under which tropical karstification took place. Over the limbs of the Bakony syncline a several-hundred-metre-thick succession was eroded and in many places of the Bakony Mountains karst bauxite was formed.

Due to the transgression from the SW, the area of the Bakony was invaded by the sea in the middle of the Eocene, about 50 million years ago. Successions deposited in the coastal marshes comprise coal seams which are overlain by marine sediments of the inundating sea (*Csernye Marl*). Subsequently, the pelagic areas were characterised by the deposition of marl (*Csolnok Marl* and *Padrag Marl*), whereas in the uplifted areas shallow-marine carbonate sedimentation took place (*Szóc Limestone*). Eocene sediments are usually rich in fossils; beside bivalves and gastropods large foraminifers (among others nummulites) occur in rock-forming quantities.

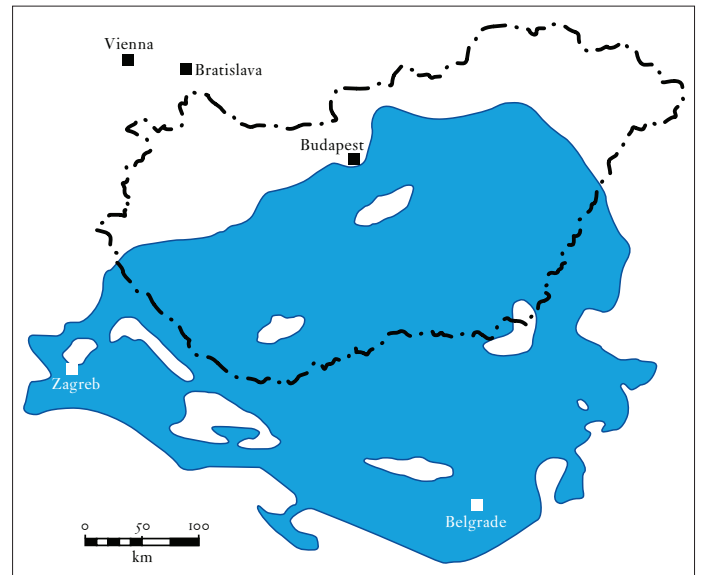
Denudation in the Oligocene and transgression in the early and middle Miocene

The Alpine orogeny was manifested in the closure of the seaways between the branches of the one-time Tethys and the world seas. In this period, the area of the Transdanubian Range belonged to the *Paratethys Sea*. During the Oligocene, as a result of the orogenic movements of the Alps, a series of basins of approximately E–W direction developed in Central and East Europe. These basins stretched from the northern foreland of the Alps towards the present Aral Lake. This series of basins were temporarily invaded by the sea or became flat plains due to fluvial deposition.

During the Oligocene and the early Miocene the Bakony area was a continental terrain, on which a clastic succession of a considerable thickness was deposited by rivers (*Csatka Formation*). In a later period of the Miocene the sea invaded the basins which had been opened as a result of lateral tectonic displacements. Clastic and calcareous sedimentation took place in them. In the Várpalota Basin and the Herend Basin coal-bearing sequences were deposited in the middle of the Miocene (*Hidas Brown Coal*). Middle Miocene shallow-marine limestones, which were formed 15–12 million years ago, are represented by the largest areal extent in the area of the Bakony Mountains and the Balaton Uplands. The *Lajta Limestone* of Badenian Age and the *Timnye Limestone* of Sarmatian Age were deposited in a shallow-marine, reef archipelago environment, which was inhabited by a biota made up predominantly of bivalves, gastropods and protozoans (foraminifers).

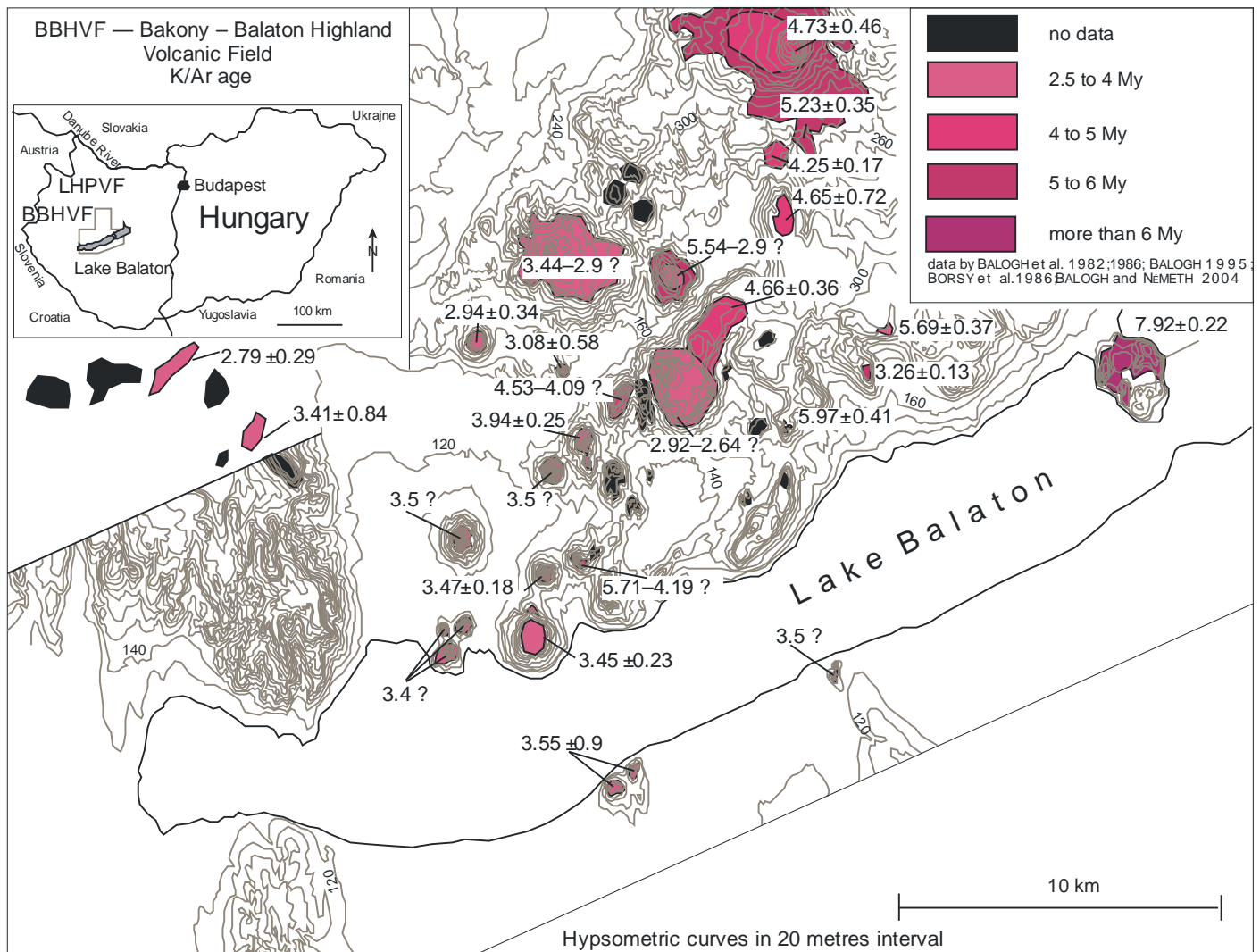
The development of the Pannonian Inland Sea and the basalt volcanic activity in the late Miocene

At the beginning of the late Miocene (approximately 11.3 million years ago) an *inland sea* came into being, which was separated from the other basins of the Paratethys Sea. It became diluted by the rivers running into it and, by the end of the Miocene, it was filled up with sediments transported by streams. The *Lake Pannonian* of a huge areal extent oc-

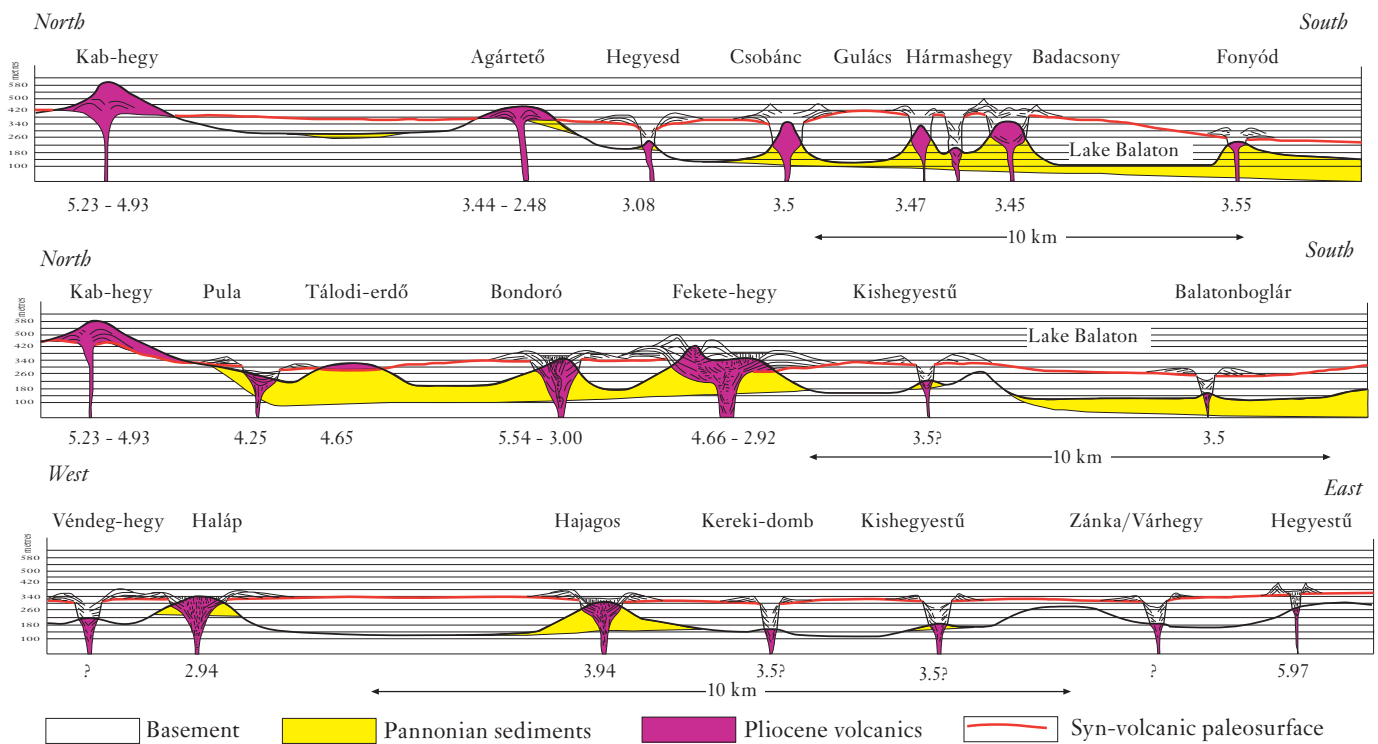


Extent of the Lake Pannonian 9 million years ago

cupied the predominant part of the Carpathian Basin, and throughout 4–4.5 million years it covered the prevailing part of the Transdanubian Range and encircled its higher areas which rose above the water surface. Its characteristic sediments are wide-spread in the Balaton Uplands, in the Keszthely Mountains and in the Bakony Mountains, as well. On the southern slopes of the hills rising above the *'Balaton Riviera'* as well as along the hillside of the Keszthely Mountains the abrasional *Días Gravel* can be traced; it outlines the wave-agitated shoreline of the lake. The type area of the sand and gravel deposits (*Kálla Gravel*)—which were transported by creeks and rivers running down from the increasingly elevating Bakony Mountains and spread over certain areas of the



K/Ar age distribution map of the Bakony–Balaton Highland Volcanic Fields (after BALOGH et al., BORSY et al., and BALOGH & NÉMETH)



Reconstruction of syn-volcanic (Pliocene) paleosurfaces (NÉMETH K.)

Balaton Uplands—is the Káli Basin. In the internal parts of the Lake Pannonian basin and in the inlets fine-grained sand, silt and later clay and carbonaceous clay were deposited (*Somló* and *Tibany beds*). In the calm water of the restricted basins separated from the lake by the ranges of the Balaton Uplands and the Bakony Mountains, lake marl was also formed (*Kapolcs Limestone*, *Nagyvázsony Limestone*). Among endemic molluscs the most frequent bivalves of the Pannonian sediments are represented by the bivalve species of *Congerina* and *Lymnocardium* genera and a gastropod species which belong to the *Melanopsis* genus.

The last phase of the Alpine orogeny—in connection with the upwarping of the mantle, along faults within the crust—molten basaltic lava rose up to the surface and the development of one of the most crowded volcano field in Europe: almost 50 volcanoes erupted in the area of the Balaton Uplands, in the northern foreland of the Keszthely Mountains and in the South Bakony, as well as along the rim of the Little Plain. The initial phase of the intense basaltic volcanism provided a small amount of pyroclastics and lava during the late Miocene. *Phreatomagmatic explosions* started at this time (approximately 8 million years ago) in the area of the Tihany Peninsula (the explosive nature is due to the hot magma with water or sediments of high water content). Subsequently, the predominant part of the volcanoes in the Balaton Uplands were characterised by a calmer activity producing *lava fountains* and *cinder cones*, nevertheless, the activity that produced lava flows was the most common one.

Volcanism in the Pliocene, continental sedimentation and denudation during the Pliocene and the Quaternary

After the termination of the Pannonian sedimentary cycle the present relief of the Bakony Mountains began to form at the end of the Miocene. Earlier subsidence was replaced by uplift in a significant part of the area (hitherto the average value of the uplift amounts several hundred metres). This process manifested in the erosion of the previously deposited sediments. The evolution of the present network of *watercourses* and the development of the large *gorges* may have been started at this time.

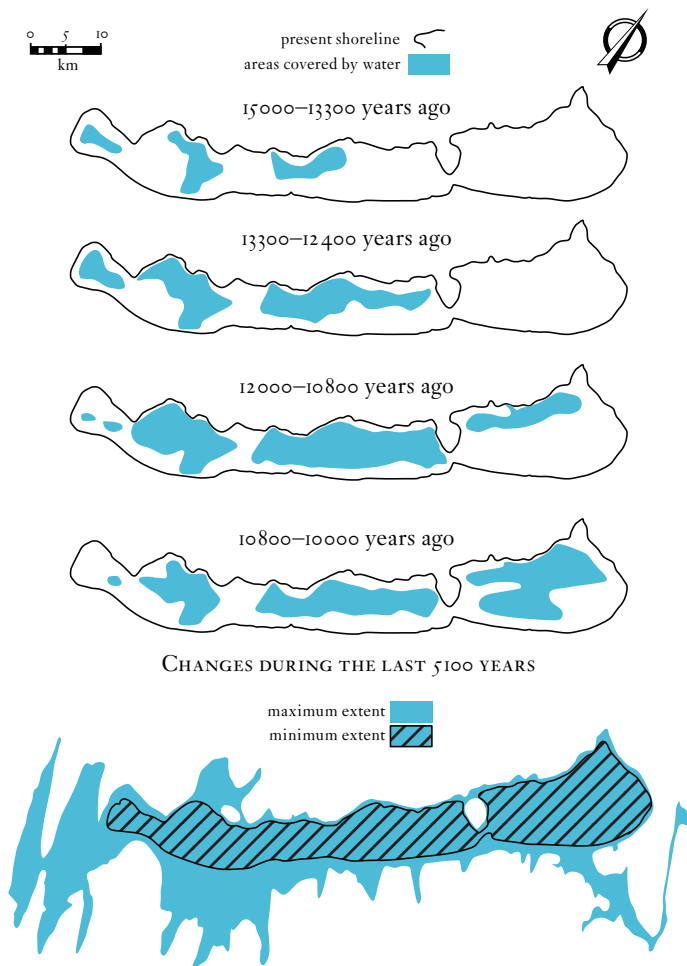
Phreatomagmatic explosive volcanic activity started in the Tapolca Basin and Káli Basin over the Pliocene erosional surface. Extensive *lava fields* developed in the areas of the *Kab Hill* and the *Agár-tető*. In the lakes which came into being inside the tuff rings of the volcanoes, volcaniclastic deposits accumulated, or—under favourable conditions—thick, *lacustrine successions* were formed. The high organic matter content of the layers has been transformed into oil shale. Meanwhile denudation processes took place, thus erosional surfaces and different levels of the Pannonian sedimentary sequence have been overlain by the volcanic

formations. In the northern areas of the Keszthely Mountains a significant part of the magma was trapped at shallow depths under the surface in the Pannonian strata.

Post-volcanic activity resulted in the formation of the well-known *geyserites* in Tihany. *Thermal springs* reached the surface along volcano-tectonic fractures. Carbonates and dolomitic sediments were precipitated from their water which was rich in dissolved substances. The subsequently precipitating silica saturated the lacustrine sediments. The formation of the *Lóczy Cave* (Balatonfüred) is also in connection with thermal water activity.

Strong *climatic fluctuations* during the Pleistocene created variable landforms and peculiar sediments. Due to frost disintegration, mainly slope debris accumulated on retrograding hillsides in the dry and cold periods (periglacial). In areas exposed to strong winds polished rock surfaces and faceted pebbles (*ventifacts*) were formed. During interglacial periods watercourses—fed by the abundant rainfall—carried a significant amount of *loose sediments* away. This led to the formation of the *basalt-capped volcanic remnant hills* in the Tapolca Basin, in the northern areas of the Keszthely Mountains and at the margin of the Little Hungarian Plain. A considerable amount of *debris* has accumulated in the piedmont areas, and in the mouth of the valleys large *alluvial fans* were formed. Warm climate was favourable for weathering processes and the formation of *red clays*, which have been preserved mostly in buried soil sections or in the form of cave deposits. During the last cold period (Würmian) the terrain was covered by a *loess* sheet. It is derived from aeolian dust and locally its thickness reaches 10–15 m. The increased rainfall during the Holocene favoured fluvial erosion; water courses incised gullies into the loose sedimentary surfaces and the alluvial fans have been disintegrated.

The evolution of *Balaton basin* (that is covered with water) took place in several phases. At the beginning of the Pleistocene (about 2 million years ago) small rivers and brooks running down from the Balaton Uplands towards the S could directly reach the depressions of the *Sárvíz* or the *Kapos*. The gradual deepening—resulted by multiple faulting of the Balaton basin—can be explained partly by tectonic movements (i.e. uplift of the surrounding area and the subsidence of the basin along faults respectively) and partly by the devastating effect (deflation) of the strong winds which were characteristic of the cold periods of the Pleistocene. The lake appeared at the end of this long process of several thousand years, approximately 15 000 years ago, in the so-called postglacial period of the late Pleistocene. At the beginning numerous shallow lakes—separated from each other—developed independently. As climate became more humid the water level increased. Ramparts



Development of the Lake Balaton (CSERNY, T.)

which surrounded the small lakes were washed away by the waves, and *about 5000 years ago an uninterrupted water surface came into being*. The lake's present-day water level of 104 m a.s.l. has not been constant throughout historical times. Compared to its present-day position, the water surface—reaching a level of 112–113 m a.s.l.—occupied a much larger area in certain periods characterised by abundant precipitation. The areas of the Tapolca Basin and the *Nagyberek* were also covered by the water of the lake; the hills of Szigliget, Tihany and the hills of Fonyód were islands rising above the water. However, in warm and dry periods the lake shrunk and certain sub-basins became swamps or temporarily completely dried up. Due to human impact of modern history—as a result of artificial drainage—the western part of the lake became a swamp and the Kis-Balaton ('Small Balaton') has been formed.

The significance of the Geopark and its most outstanding values

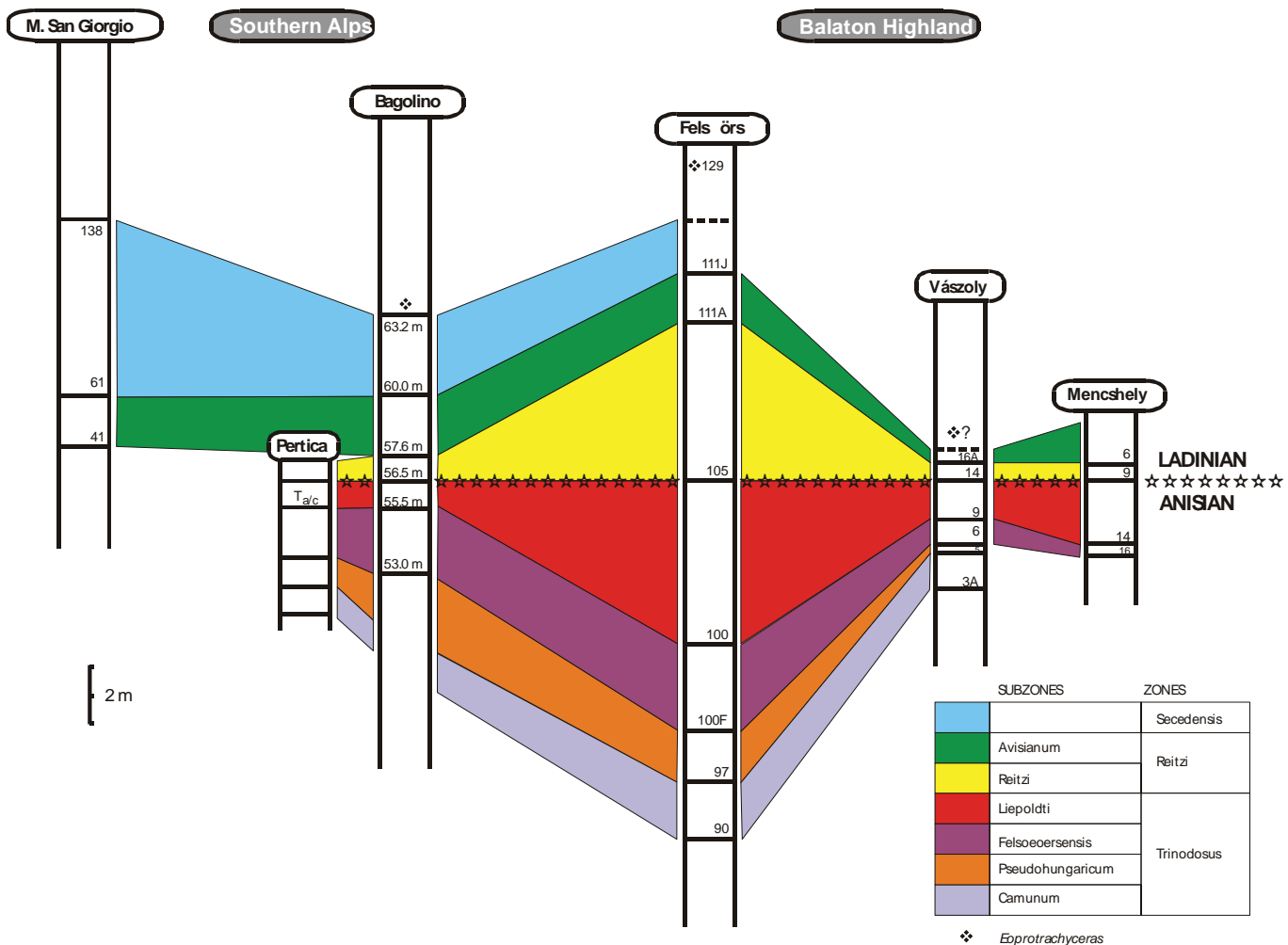
Due to the exceptionally favourable coincidence of the events in geological history, the Bakony–Balaton Geopark possesses peculiar local conditions. The rocks, fossils and geomorphology of the area (covering a square of side length 80 km) reflect the effects of geological processes of *almost 500 million years* from the Ordovician up to now, represented by more than a hundred excellent outcrops. Its outstanding geodiversity Europe-wide is due to the prevailing morphotectonic situation of the Bakony area—representing a *nappe of the Alps*, which had broken off and drifted to its present-day position. While the surface gradually rises from the Lake Balaton towards the NW, the deep structure forms a syncline. Consequently, due to the erosion, the Palaeozoic rocks (which make up the basement) are exposed on the south-eastern wing, in the vicinity of the lake. On the other hand, towards the axis of the syncline, the entire Triassic sequence crops out to the surface and on the ranges of the Bakony Mountains Jurassic and Cretaceous rock types of a great variety are exposed. This some-km-thick Mesozoic succession (including almost 50 formations) is overlain by Tertiary (mainly Eocene, Oligocene and Miocene) sediments in patches. The area has been eroded during the recurring erosional phases and the basement formations became visible on the surface; at the same time, locally, the cover beds have been preserved. Along the axis of the syncline (NE–SW), in

the line of strike, a shift in facies of the one-time neighbouring areas can be observed within the rock types of the different geological ages. The fairly complex palaeogeographic setting has become even more difficult due to the impact of different tectonic movements. This peculiar geological and morphological build-up made the Bakony area a *giant geological puzzle*. The area of excellent conditions has been already studied for half a century by the participants of numerous international conferences on stratigraphy and palaeogeography. The area represents *one of the most exhaustively elaborated and well-published areas in Europe*. Among others, the *Anisian/Ladinian boundary at Felsőörs* is internationally noted; moreover, fifty further (mainly Triassic and Jurassic) key sections are regarded as references to the geological history of the Tethys.

The geology of the area became more diverse: the central part of the Bakony Mountains and the higher parts of the Balaton Uplands rose above the *Pannonian Inland Sea* of the late Miocene, forming islands with broken shorelines. Besides the diverse abrasional formations and morphology (Keszthely Mountains), the sediments of the filling inland sea of a decreasing salinity can be found at several places (Tihany, Balatonkenese, Fonyód). They are characterised by a definitely *endemic mollusc fauna*. Their preservation (a lucky coincidence again) is due to the final *basalt volcanism of the Pannonian Basin in the Miocene and Pliocene*, which resulted in the activity of about 50 volcanoes in this area. The solidified lava cap protected the underlying Pannonian sediments from the erosion. As a result of phreatomagmatic eruptions *exceptional volcanoclastic successions* were formed (Káli Basin, Tapolca Basin and Tihany Peninsula); their scientific elaboration has still been carried out by international cooperation. Participants of the *Second International Maar Conference* organized under the sponsorship of the *IAVCEI (International Association of Volcanology and Chemistry of the Earth's Interior)* in the autumn of 2004 in Hungary also visited the area. In the Tihany Peninsula the *post-volcanic thermal water activity* has created geomorphologic values of European significance: almost one hundred spring cones rise in the area, and even spring caves have been preserved in some of them. Considering the rich geological heritage this was the *first announced landscape-protection area of Hungary in 1952*. The unique nature of the area (and National Park) has been acknowledged by the *European Diploma of Protected Areas*, which was granted by the Council of Europe to the area in 2003. The famous *'seas of stones'* of the Káli Basin has been sculptured by cementation processes due to subsurface waters and later erosion. Apart from this there is only one area in Europe with such exceptional features. The rock surfaces of the large blocks are pitted by small depressions, the so-called *'gnammas'* ('gnamma holes').

Vertical tectonic movements which intensified in the Pleistocene enriched the geological scenery. Spectacular *gorges* have been incised into the surface between the rapidly emerging blocks (Bakonybél, Balatonfüred, Csesznek, Veszprém), most of the extinct volcanoes became *volcanic remnant hills* (Badacsony, Szent György Hill). The panorama from the Szépkilátó at Balatonyörök provides a spectacular view of these hills. On their hillsides rows of gigantic (30–50 m high) basalt organ pipes (with a diameter of 1–2 m) can be traced over several hundred metres. Rocks underwent weathering-out by frost erosion in the Ice Age and *bizarre cliffs, concave rock walls* and *bogbacks* have been sculptured (Padrag Cliffs, Malom Valley, Tekeres Valley). *Loess*—which was deposited during the Würmian—has not covered the whole area; it has been eroded in the uplifting mountainous region and due to its redeposition it played a role in the evolution of the covered karst landscape (Tés Plateau, High Bakony). A new and determining element of the landscape came into being not more than some thousand years ago: the uninterrupted water surface of the *Lake Balaton*. 20–50-m-high bluffs have been formed in the sandy, Pannonian sediments by the swelling waves. Such features are missing from the shores of any European lakes.

Especially in a morphological and sedimentological point of view, other features of outstanding value in the Geopark are represented by the *palaeokarst* phases which can be traced from the Mesozoic. The process was strongly promoted by the geological build up of the mountains, i.e. the predominance of carbonate rocks. Palaeokarst phenomena can be observed already in the successions of Triassic marine limestones and dolomites (Litér, Sóly). The remarkable, fossil tropical karst features of the Bakony Mountains are in close connection with bauxite sedimentation from the end of the Cretaceous until the Eocene. As a result of the intense dissolution 50 m to 100-m-deep huge *dolines* and *sink-boles* came



Correlation of Felsőörs and other key Anisian/Ladinian boundary sections in the Balaton Highland and Southern Alps (Vörös et al.)

into being about 100 million years ago (Iharkút). In the whole area of the Transdanubian Range the underlying rocks of the bauxite (which are predominantly made up of Triassic dolomite) are characterised by karstified surfaces, which have been exposed in the course of mining operations. Such a nature conservation area is the pit of an exploited bauxite lens at *Darvastó*, which stretches along 500 m and characterised by shallow dolines. The nature conservation area of the 30-m-deep, precipice-like palaeokarst at *Úrkút* also shows palaeokarst features. Because of its well-preserved one-time relief (due to the hand-held mining) and its peculiar oxidic manganese ore filling the site has gained a world-wide fame. The bottom of the dolines — which have been formed in the pink, Jurassic limestone — can be accessed by stairs. The area is designated as an exhibition site.

In the lower hall of the *Ördög-lik cave* (located near Dudar) the abrasional deposits of the one-time sea shore can be seen, which date back 50 million years. Similar sediments are exposed in a small cave of the *Cuba gorge*, where the karstified Triassic basement is also overlain by nummulitic limestone. Such an exposure in a cave has never been found on Earth.

The *Keszthely Mountains* represent an especially interesting karst terrain. In the vicinity of Czerszegtomaj and in the area of the Billege Forest near Uzsa cauldron-like dolines — with Miocene kaoline in them — have been exposed and in some cases their depth exceeded 100 m. The labyrinth-like system of passageways of the *Kútbarlang* ('Well Cave') run-

ning 50 m beneath the village of Czerszegtomaj, is a unique formation all over the world. The karstic *karrenfeld* of the Triassic dolomite (dissected by shallow dolines) is overlain by Miocene sandstone. Due to the subsequent thermal water activity a cave has developed at the boundary of the formations, thus the *negative image of the karst topography* — characteristic of the end of the Miocene — has been preserved.

A dolomite terrain stretches between Veszprém and Várpalota and over the area in the vicinity of Ódörög. It is characterised by old, *exhumed dolines* and *conical features* of a height of some tens of metres (however, their exact age is unknown).

Karst features developed at and under the rim of the basalt lava — which rests on the limestones of the *Kab Hill* — represent a different type of forms belonging to the "basalt karst". An exceptionally spectacular sink-hole is the so-called Macskalik, which is related to rock boundaries.

The more than 700 caves of the mountains are the touchable evidences of a strong subsurface karstification. Most of them are *senile remnant caves*; nevertheless, some of them contain valuable palaeokarstic fills. Caves developed in *basalt*, as well as in *siliceous sandstone*. Mostly the Keszthely Mountains are characterised by caves, which came into being by the combination of spherical niches formed by *thermal waters*. The strictly protected *Lóczy Cave* with free public access is of the same origin. The *Lake Cave of Tapolca* was also formed by lukewarm waters. Every year more than 100 thousand visitors make boat trips in it under the streets and houses of a town. The neighbouring 'Hospital Cave' is used in the



One of the most dramatic landscapes of Hungary: volcanic remnant hills in the Tapolca Basin

treatment of respiratory tract infections.

It is worth mentioning the *Csodabogyós Cave*, which was formed along huge *tectonic fissures*. Its upper section is opened for candidates for adventure tours in caving overalls. The several hundred-m-long, narrow passage system of the *Szentgáli-kőlik Cave*, which was formed by vertical fractures in well-bedded *Main Dolomite*, is also accessible to the public. The approximately several hundred young sink-hole caves can be found mainly in the covered karst of the *Tés Plateau*. The karst water system in the Mountains is fed by narrow *shaft caves* (Csengő, Háromkürtő and Jubileumi Shafts) reaching a depth of more than a hundred metres.

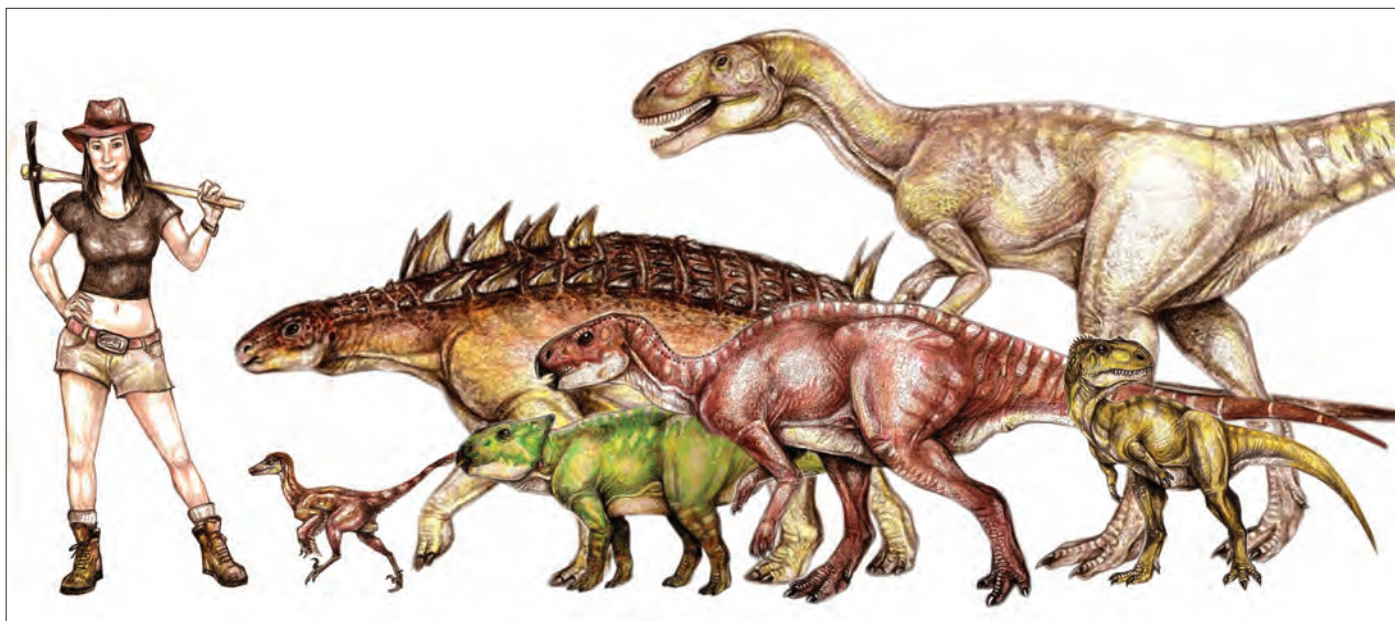
The extraordinarily rich palaeontological record, which can be found partly in the collection of the *Bakony Natural History Museum in Zirc* and partly in collections of Budapest, is due to the long geological time and the great variability of facies represented by the rocks of the Geopark. Without claim to completeness only some particular findings and localities are mentioned here. First of all, the “flat-plate turtle” (*Placochelys*) should be mentioned; it was a world sensation at the time of its discovery. Such a fossil reptile has never been discovered earlier. *Placochelys placodonta* was a reptile which possessed an armoured shell and lived in the Late Triassic.

Successions in the Balaton Uplands are extremely rich in different Triassic fossils. Fossils (mainly ammonites, brachiopods and bivalves)—among which numerous finds have been described from this area—have been studied by Hungarian and foreign palaeontologists for a century. Fossils could aid in reconstructing the palaeogeographic relationships between the Bakony and the Alp–Mediterranean area. Ammonites and brachiopods derived from the Bakony Mountains also play a significant role in the international research on Jurassic. Biostratigraphic studies which have been continued at *Lókút* and *Hárskút* (Bakony Mts) promoted the correlation of these sediments with similar formations in Europe. Simultaneously, palaeontologists performed detailed examinations of other groups (brachiopods, bivalves, gastropods, conodonts and radiolarians). There are further ‘curiosities’ represented by *fish remains* derived from the *manganese-bearing sequence at Úrkút*. Sediments of the Cretaceous Period also yield a rich fossil record; besides ammonites (at Pénzesgyőr) first of all the shallow-marine fauna is worth mentioning. The reef-forming pachiodont bivalves (*Hippurites*) at Sümeg, reaching a size of 1 m, and the well-known coral “*Cyclolites*” are not only notable but also very spectacular. A fossil turtle of Late Cretaceous age has also been found here. The *Eocene* subtropical shallow-marine environments of the Bakony area were *extremely rich* in living creatures with calcareous skeleton: bivalves, gastropods, corals, echinoids and the gigantic protozoans, among others the nummulites lived there. Hungarian foraminifer studies are well-known all over the world just like the investigations focused on the very well-preserved *Miocene mollusc fauna of international importance* found in the sand pit at *Várpalota*. It was highly commended also by the participants of the *International Palaeontological Regional Meeting* (1928) held in Hungary (in the town respectively), the *Colloquium on*

Neogene Stratigraphy (1969) and the *Neogene Congress* (1975). The locality is a protected area, which has been designated as a geological exhibition site. It yielded *more than 400 bivalve and gastropod species*. Due to its characteristic shape, the bivalve *Congerina unguicapra* became famous world-wide among the endemic bivalves of the Pannonian Inland Sea of decreasing salinity. Besides the “*goat booves*” of *Tibany* further bivalve and gastropod species can be found in the key section of the Fehér-part; these species can be found exclusively in the Carpathian Basin. Almost the whole skeleton of a *fossil rhino* (*Stephanorhinus megarhinus*) and fragmentary remains of half a dozen further specimens have been found in the oil shale at *Pula*. These finds are of European importance among the fossil vertebrate remains. Besides leaf impressions this peculiar locality (the laminated sediments of a maar lake) yielded thousands of fossilized *fishes* and some *insect* remains.

Last but not least, from a palaeontological point of view the most valuable site is the *dinosaur locality at Ibarkút* (High Bakony), which was discovered a decade ago. Its *international importance* is confirmed by the paper about a new dinosaur species described from here; it was published last year in the journal *Nature*. The Late Cretaceous (85 million years old) sandy-clayey sediments of fluvial–alluvial plain facies are approximately 10 million years older than those of the localities in France and Romania. Thus, fossil vertebrate remains found here are unique all over the world. Based on more than 10 000 isolated bone and tooth remains the presence of 30 (!) vertebrate groups could have been revealed by the ongoing research work, so far. Skeletons of *armoured dinosaurs* (*Hungarosaurus tormai*), fossil remains of *herbivorous* and *carnivorous dinosaurs*, *fish*, *amphibians*, *turtles*, and the *Mosasaur* find (of fresh-water habitat), *land lizards*, *crocodiles* (i.e. the extraordinary, heterodont *Ibarkutosuchus makadii*), the jaws of flying reptiles—the pterosaurs (*Bakonydraco galaczi*) and the bones of ancestral-type birds have been collected. Based on the studies of bivalves, gastropods and the plentiful fossil plants (fruits, leaves, flowers and trunks) which were found together with the above-mentioned finds, the entire ecosystem can be reconstructed.

From the geological history of the Geopark Man should not be ignored... Two *flint* and *chert mines* of European significance can be found in the area. People of the *Neolithic Age* mined the excellent Cretaceous chert with the help of tools made of antlers. The radiolarite mine of Jurassic age—which had been extracted for some thousand years—was encircled by 8 settlements of the Bronze Age near *Szentgál*. Stone blades found here are known from archaeological records from areas over the Carpathian Basin. Based on investigations the excellent material has been transported even *to the area of the present-day Benelux states* and to the surroundings of the Baltic Sea. In the neighbouring cave (Szentgáli-kőlik) human skeletons, large urns and a Moon idol have been found dating from the Bronze Age. These finds indicate that this site may have been a cultic burial-ground. Half a dozen of further small caves (for example the *Odvaskő Cave*, *Öreg-Szarvadárok Cave*, *Csesznek Cave* and *Nagy-Pénzlik*) yielded different remains of the prehistoric man.



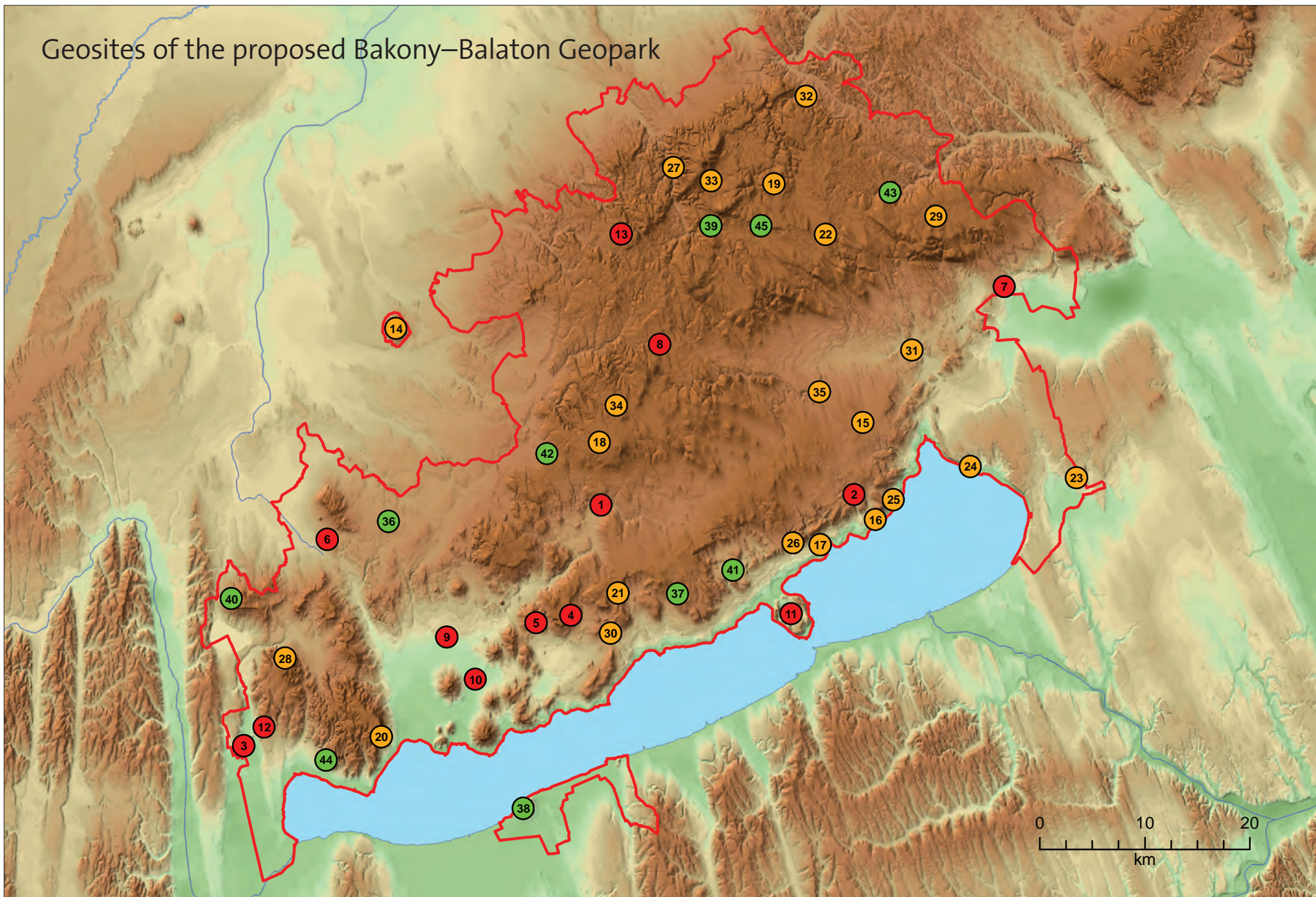
Size-scaled gallery of the six Hungarian dinosaurs discovered in Ibarkút. The generally small size of these 85 million years old animals is explained by the isolation of the Hungarian fauna during the Cretaceous (drawing by Tibor PECSICS)

B.3. Listing and description of geological sites, details on the interest of these sites

<i>Id</i>	<i>Name of the geosite</i>	<i>Site type</i>	<i>Importance</i>	<i>No access</i>	<i>Scientific</i>	<i>Educational</i>	<i>Touristic</i>
G-01	Volcanoes of the Eger-víz valley	G/N/C	INT		x	x	x
G-02	Felsőörs, Anisian–Ladinian boundary on Forrás Hill	G	INT		x	x	x
G-03	Lake Hévíz	G/N/C	INT		x		x
G-04	Volcanoes of the Kál Basin	G/N/C	INT		x	x	x
G-05	Seas of stones in the Kál Basin	G/N/C	INT		x	x	x
G-06	Sümegegy Mogyorós-domb Nature Conservation Area	G/C	INT		x	x	x
G-07	Várpalota Sand Pit Nature Conservation Area	G	INT		x	x	x
G-08	Szentgál, prehistoric chert mines, cave, etc.	G/C	INT		x	x	x
G-09	Lake Cave of Tapolca	G	INT			x	x
G-10	Volcanic remnant hills in the Tapolca Basin	G/N/C	INT		x	x	x
G-11	Tihany Peninsula	G/N/C	INT		x	x	x
G-12	The Kút (Well) Cave in Cserszegtomaj	G	INT	x	x		
G-13	Iharkút Cretaceous dinosaur locality	G	INT	x	x	x	
G-14	Somló Landscape Protection Area	G/N/C	NAT		x	x	x
G-15	Szentkirályszabadja, the Middle Triassic of the „airport quarry”	G	NAT		x	x	
G-16	Alsóörs, key section of the Alsóörs Metarhyolite	G	NAT		x	x	
G-17	Csopak, Permian–Triassic boundary	G	NAT		x	x	
G-18	Kab Hill, Basalt-covered karst	G/N	NAT		x	x	x
G-19	Zirc, road to Borzavár, cross-bedded crinoidal limestone	G	NAT		x	x	
G-20	Csodabogyós Cave	G	NAT		x	x	x
G-21	Balatoncsicsó, the Triassic of the Csukréti ditch	G	NAT		x	x	
G-22	Olaszfalu, Eperjes Hill geological key section	G	NAT		x	x	x
G-23	Balatonfőkajár, quartz phyllite on the Somlyó Hill	G	NAT		x	x	x
G-24	Bluff at the Lake Balaton and Pannonian beds	G/N/C	NAT		x	x	x
G-25	Balatonalmádi, Permian key section of the Lake Köcsi quarry	G	NAT		x	x	x
G-26	Balatonfüred, Koloska Valley and Lóczy Cave	G/N	NAT			x	x
G-27	Bakonyszücs, Odvas-kő and its caves	G/N/C	NAT			x	x
G-28	Key section of the Rezi Dolomite, hydrothermal caves	G/N/C	NAT		x	x	x
G-29	The karst area of the Tés Plateau	G/N/C	NAT			x	x
G-30	Monoszló, the volcanic neck of the Hegyestű, geological demonstration site	G	NAT		x		x
G-31	Hajmáskér, Berek-hegy Limestone	G	NAT		x	x	
G-32	Csesznek, Fortress Hill	G/N/C	NAT			x	x
G-33	Bakonyszücs–Fenyőfő, Százhalom: mound graves, sink-hole, brook meanders	G/N/C	NAT			x	x
G-34	Úrkút Palaeokarst Nature Conservation Area	G	NAT		x	x	x
G-35	Veszprém: meandering gorge in the town	G/C	NAT			x	x
G-36	Darvas-tó Exploited Bauxite Lens Nature Conservation Area	G	REG		x	x	
G-37	Dörgicse, Kő Hill	G/N	REG		x	x	x
G-38	Fonyód, Fortress Hill	G/C	REG		x	x	
G-39	Pénzesgyőr, Kerteskő Gorge	G/N	REG		x	x	x
G-40	„Basalt street”, Kovácsi Hills	G/N	REG			x	x
G-41	Pécsely, quarries on the Meggy Hill	G	REG		x	x	x
G-42	Ajka, Padrag cliffs	G/N	REG			x	x
G-43	Bakonynána, Roman Bath: gorge with waterfall, cave, geological key section	G/N	REG		x	x	x
G-44	The Vadlány-lik (Cave) in Gyenesdiás, key section of the Diás Formation	G	REG		x	x	x
G-45	“Cockpit karst” near Zirc	G/N	REG		x	x	

LEGEND | **Site type:** G - geological, N - natural, C - cultural/historical
Importance: INT - international (red circle on the map), NAT - national (orange circle), REG - regional (green circle)

Geosites of the proposed Bakony–Balaton Geopark



Volcanoes of the Eger-víz valley (G-oi)



Spindle bomb at the foot of the slope of the Agár-tető crater

The picturesque valley of the Eger-víz leads along an extremely diverse volcanic area. The largest volcano of the Bakony–Balaton Uplands Volcanic Field (BBUVF), i.e. the *Kab Hill* rises above its source region. The *Pula maar* crater can be found on its southern slope. The volcanic mass of the *Fekete-hegy* and the maar volcano of the *Bondoró* are divided from one another by the gorge-like section of the valley beneath *Kapolcs*. The valley—which widens below—is bounded by the also volcanic *Sátorma* on the South and by the *Agár-tető* on the North.

A lot of visitors come to see the spectacular basalt “bastions” of

the *Királykő* above *Kapolcs*. The studied nearby outcrop reveals a considerably varied pyroclastic succession. The youngest maar volcano of the BBUVF, i.e. the 2.3-million-year-old *Bondoró*, rises opposite to it. The cone, which was built on the lava plateau, was formed due to scoria eruption and lava fountaining activity, resulting in small-volume lava

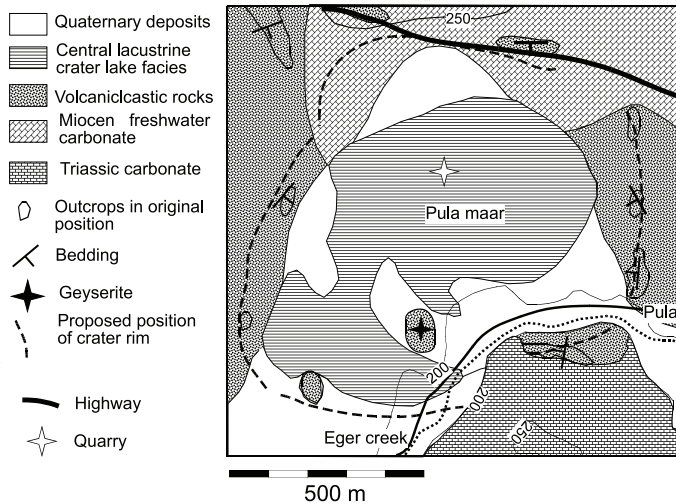


The columnar jointed basalt outcrops of *Királykő*, near the village of *Kapolcs*

flows. Spindle bombs as well as mineral and rock inclusions (olivine, lherzolite) derived from the mantle are frequent.

Agár-tető is a lava plateau of a diameter of 8 km; its activity lasted for a long time (5–2.8 million years ago). The still relatively intact crater rises on its north-western part. On its outer, steep slope and at the foot of the slope small lava flows can be identified.

The *maar* of a diameter of 800 m near *Pula* is one of the significant geological values of the Bakony–Balaton Geopark. The crater, which is



Simplified geological map of the *Pula maar* (NÉMETH)



Fossil remains of a *Stepanorhinus megarhinus rhinoceros*, exhibited in the Natural History Museum of Bakony, Zirc

thinly covered with young sediments, is filled with organic-rich lacustrine deposits of a thickness of a few tens of metres. The oil shale—made up predominantly of brown algae, and described as *alginite*—was penetrated by 40 exploration drillings which helped in the reconstruction of the palaeomorphology of the maar crater. The eruption may have taken place 3.9–4.5 million years ago. Periodically, sand- to pebble-sized basalt debris (derived from the tuff ring at the crater rim) spilled into the lake. These layers show spectacular load pressure and slump structures, as well as graded bedding.

A small quarry was opened for the exploitation of alginite; it makes the study of the rich flora and fauna of the succession possible. According to examinations the climate was warmer than it is today and was characterised by 1000 mm annual precipitation and the alternation of dry and wet seasons. The quarry has yielded nearly a dozen, fragmentary fossil remains of rhinoceros and an almost intact, 3-metre-sized specimen (*Stepanorhinus megarhinus*). The thousands of fish remains found in a bed are also important.

Felsőörs: Anisian–Ladinian boundary on Forrás Hill and the Szent-Kereszt Hill rock rib (G-02)



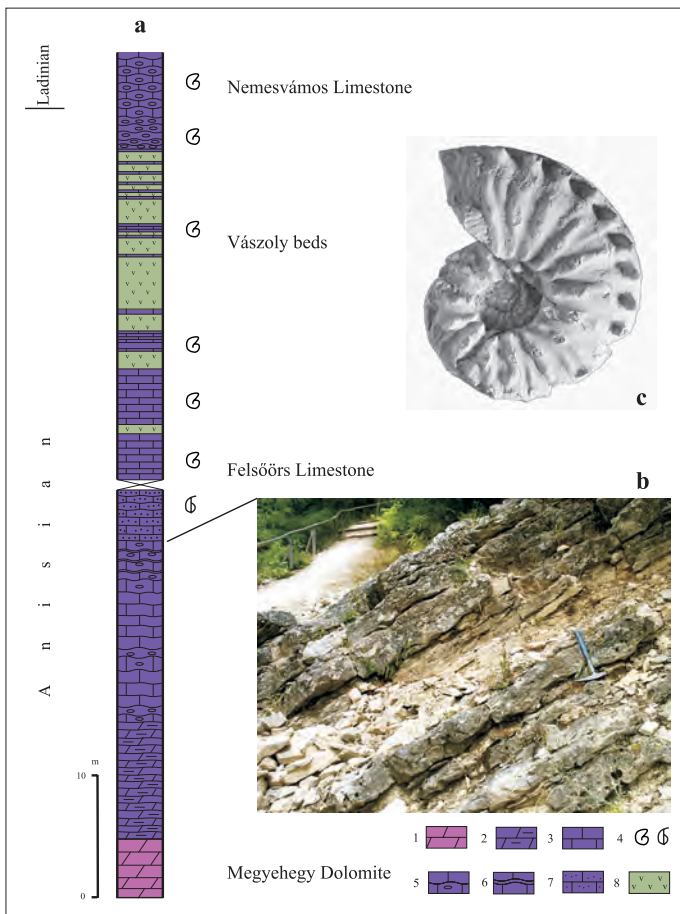
The upper part of the *Forrás Hill* section, protected by a canopy

The oldest and most well-known and world-famous geological key section in the Balaton Uplands can be found in the northern outskirts of *Felsőörs*, on the side of the *Forrás Hill*. The key section, in which a geological nature trail was developed recently, exposes the 242–238-million-year-old *Middle Triassic succession* ranging from the Middle Anisian up to the Middle Ladinian. The main geological events of this period are presented in tables which are set up along the section.

Near the stairs—which to the lower section—the uppermost beds of the *Megyebegy Dolomite* can be studied. It is overlain by a poorly-bedded marly dolomite, which can be seen along the path. The latter is overlain by the *Felsőörs Limestone*; its lower section is made up of thick-bedded limestone comprising chert nodules. Above this, the end of the lower section is made up of marly, poorly-bedded limestone, which contains crinoidal and brachiopod remains.

At the beginning of the upper section, the uppermost, well-bedded, bituminous and ammonite-rich part of the *Felsőörs Limestone* can be seen. The light green tuff layers of the overlying *Vászoly beds* are dissected by yellowish-brown, siliceous limestone layers and lenses. The lower part of the overlying *Nemesvámos Limestone* is made up of light grey, upwards pale red, considerably hard, siliceous, thick-bedded and nodular limestone which contains red chert. According to the studies on ammonites, radiolarians and ostracods, the sediments were formed during the Middle Triassic in an increasingly deepening open sea, where the deposition of carbonate mud was interrupted by submarine tuff explosions of shorter or longer durations.

The international reputation of the *Felsőörs* section is due to *biostratigraphic studies based on the very detailed, bed-by-bed examinations of different*



The profile of the Middle Triassic geological nature trail on the Forrás Hill in Felsőörs (a), the lower section of the Felsőörs Limestone (b) and a characteristic ammonite from the succession (c): *Kellnerites felsőeoersensis* (BUDAI 2006). Legend: 1. thick-bedded dolomite of shallow-marine ramp facies; 2. bituminous dolomite; 3. limestone; 4. ammonite, brachiopod; 5. nodular cherty limestone; 6. nodular limestone with marl intercalations; 7. crinoidal limestone; 8. tuff, tuffite



Rock rib made up of the nearly vertical beds of the Iszkahegy Limestone on the Szent-Kereszt Hill

fossils. With the help of ammonites, radiolarians, conodonts and phytospores the boundary between two stages of the Middle Triassic (i.e. Anisian and Ladinian) could be exactly defined. Such a detailed-studied and multilaterally elaborated section is scarcely known in the Alpine region. On the side of the *Szent-Kereszt Hill* a vertical rock rib extends over the valley. The beds, which are set on their edge due to tectonic movements, belong to the Middle Triassic *Iszkahegy Limestone*. The dark grey rock was formed at the low-energy, poorly-ventilated bottom of a lagoon which was restricted from the open sea.

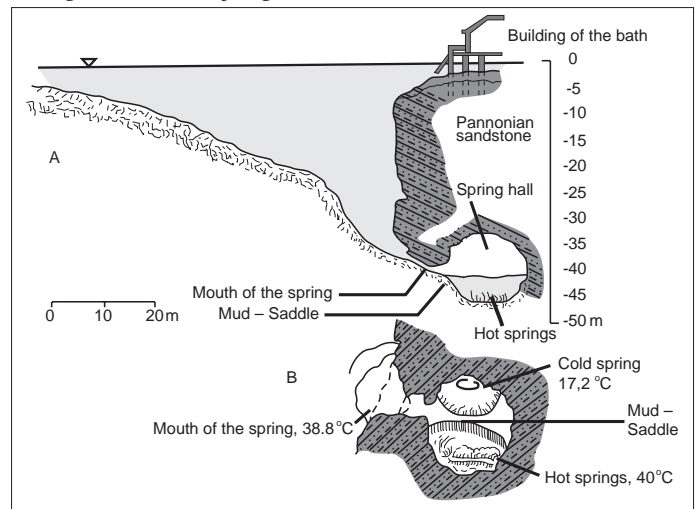
Lake Hévíz (G-03)

Lake Hévíz is one of the most well-known geosite of international importance in the Bakony–Balaton Geopark. The extremely large number of visitors is due to its warm, medicinal water, which has been utilized for centuries. Despite of its built-up, artificial environment it is a unique natural formation.

Europe's largest warm lake was formed in the so-called Pannonian sandstone (*Somló Formation*) of Late Miocene age, in the fault zone that has formed the edge of the Keszthely Mountains. Its formation is associated with considerably interesting hydrogeological conditions, as the water of the lake is derived from a 17 °C cold spring and a 39 °C hot spring. Water gushes out from the two springs into a spring cave at a depth of 45 m under the water level. Due to the different discharges, the mixing of



these waters produces a 38.8 °C temperature of the emitted water. Although the cold and warm springs are located next to each other, their waters have different flow routes from the infiltration area right here. Cold water travels a relatively short way under the surface. A part of the karst water of the predominantly Upper Triassic dolomite mass of the Keszthely Mountains (which is located E of Lake Hévíz) reaches the surface here. Two-thirds of the area of the mountains belongs to the infiltration area of the lake. Based on studies in connection with the age of the spring water, the cold water travels a few thousand years from the infiltration area to the spring. Warm water travels a much longer distance as it is indicated by its age of tens of thousands of years; it has warmed up on its way in the subsurface carbonate rocks of the Transdanubian Range. The long, detour flow route of waters infiltrating in the western and south-western parts of the mountains, can be found at a depth of several km and is designated by the flow directions determined by the impermeable Upper Triassic and Cretaceous marls. At the end of this flow route water reaches the surface through the thermal spring of Lake Hévíz.



Section and bird's-eye view of Lake of Hévíz and the its spring cave (EMBER)

Volcanoes of the Káli Basin (G-04)

Almost all volcanic formations, forms and phenomena of the Bakony–Balaton Volcanic Field can be found in the relatively small area of the Káli Basin. Due to the various types of erosion, volcanic structures represent different erosion stages.

In the deepest part of the basin the remains of small diatremes such as the *Lapos-Hegyestű*, *Kis-Hegyestű*, *Harasztos-begy* and the *Kereki-domb* can be seen. The material of the latter is made up of unsorted lapilli tuff which steeply (>60°) dips eastwards. The unusually steep dip was caused by the collapse of the crater rim which subsided into the deeper zone of the crater.

The small crest of the *Harasztos Hill*—which can be seen a few metres above its surroundings—is built up of coarse-grained, unbedded and unsorted lapilli tuff. The similarly steeply-dipping pyroclastics are penetrated by lava rocks of radial columnar jointing. The 8–9 km² large area of the basalt plateau has developed by the amalgamation of four eruption centres. Its shape—rising up above its sur-



Overview of the Szentbékálla outcrop exhibiting a phreatomagmatic pyroclastic flow unit (lower part) overlain by dilute base surge deposits

roundings—and its formation is similar to those of the volcanic remnant hills of the Tapolca Basin. The one-time *maar craters* of the volcanic plateau were filled with the basalt of lava ponds and spatter cones. Depressions of an average diameter of 100 m can be found on the plateau. They are shallower than 10 m and characterised by small pools with peculiar living assemblages. The low ridges which divide them are probably the remains of one-time *lava flows*. The rim of the southernmost crater is cut by the *Vaskapu Valley* exposing the cooling structure of the lava flow which piled up in the internal side of the former tuff ring. The final stage of volcanism was characterised by *scoria eruptions*. Its most beautiful example is represented by the



Pyroclastics of the Szentbékálla outcrop (with peridotite xenoliths and pre-volcanic lithics)

Boncosos-tető, which rises 90 metres above the plateau. The one-time cinder cone is made up of porous, red and grey scoriaceous basalt. The intact cinder cone of the *Kopácsi Hill* is only 2.61 million years old; a 2-km-long pyroclastic flow of an earlier eruption event may have started from here. Its material, which filled the one-time valley above Szentbékálla, can be well studied in an outcrop, too. Both the central, unbedded facies and the bedded, marginal one can be seen. Locally the gas escape channels are also visible. The periglacial rock-stream on the northern slope of the *Kő Hill* is also notable.

'Seas of stones' in the Káli Basin (G-05)



Near Szentbékálla the most preserved 'sea of stone' can be seen

The most well-known and most famous geological formations, geomorphologic features of the Káli Basin are represented by the *gigantic boulders and groups of cliffs* which are strongly *cemented by silica*.

The seas of stones were formed by the subsequent cementation of *sand, pebbly sand and gravel* beds which had been deposited in the *Lake Pannon*. The *Kálla Formation* is built up of deltaic sediments of rivers coming from the Bakony and deposits of the near-shore currents which moved the deltaic sediments. The gigantic blocks cemented by silica and representing the material of the seas of stones can be found within the sand beds. They became exposed on the surface by the erosion of the overlying, non-cemented layers. The reason why silicification took place, the time when it happened and the formation of the seas of stones have long been debated. On the basis of a new theory the cementation process is similar to that of the Fontainebleau Sandstone in the Paris Basin. According to this they have been formed due to the dissolutional effect of infiltrating water and as a result of precipitation from solutions in the phreatic zone, near the local base level of erosion. Loosing their support, these peculiar-shaped blocks have often been tilted from their original position. One of them "functions" as a balanced rock. The formation of shallow depressions and hollows on the rock surfaces is not clear either. A part of them may have been formed due to the weathering effect of the organic matter (that accumulated in the meteoric water in the hollows) and of lichens and mosses. These water-filled depressions (*gnamma holes*) are mentioned by their colloquial name i.e. *'bird baths'* in the specialized literature. The bare rock surfaces are locally characterised by corrasional forms, i.e. shallow blowouts and strongly polished and faceted surfaces. Broken and polished quartz pebbles are also characteristic on the surfaces of the conglomerate beds.



One of the large-sized 'bird baths' (*gnamma holes*)

"Geological Paradise" in the surroundings of Sümeg (G-06)



Field trip for geologist students at the Mogorós Hill Nature Conservation Area

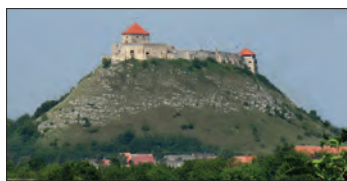
Besides its cultural and historical sights (i.e. medieval castle, former Episcopal see, etc.), Sümeg is famous also in a geological point of view. The *Sümeg Mogorós-domb Nature Conservation Area* reveals several rock types of the Bakony. On the SE the *Dachstein Limestone* and the *Kardosrét Limestone* is found, which represent Late Triassic – Early Jurassic age. Towards the NW they thrust over the Middle Jurassic *Lókút Radiolarite*. It is adjoined by the Upper Jurassic *Pálibálás Limestone* (ammonitico rosso) which is overlain by the key section of the *Mogorósdomb Limestone* (passing up into the Lower Cretaceous). The younger carbonate rocks of Cretaceous age (i.e. *Tata Limestone, Ugod Limestone*) are revealed by partly

still active quarries. On the surface—smoothened by the Eocene and Miocene abrasion—a part of the beds can be found in a vertical position. This made it possible to designate a long geological key section here. The marvellous ancient flint mine was discovered in the course of the preparatory works. The laminated limestone contains chert nodules, which were mined with tools made from deer antlers 5 000 years ago. A part of the prehistoric galleries functions as a geological exhibition site and is *protected by canopies*.

The abandoned *Sintérlap quarry* demonstrates the boundary between the Upper Cretaceous Tata Limestone and the overlying Ugod Limestone also in a key section. The latter locally contains the skeletons of large-sized reef-building bivalves called rudists. The better understanding of geological events is supported by a nature trail.

The neighbouring, reclaimed *Kecskevár quarry* yielded the 30-cm-sized skeleton of a turtle (*Senonemys sümegensis*) of Late Cretaceous age. Cretaceous limestone is being quarried in the *Gerinci quarry*, as well. In the red clayey filling of the exposed palaeokarstic depressions remains of Tertiary vertebrates have been found.

The *'Féber-kövek'* above the vineyard is *also a nature conservation area*. The 15–20-metre-high Eocene limestone walls were sculptured by the abrasion of the Lake Pannon. The panorama from their tops provides a marvellous view of the surrounding area.



The Castle Hill of Sümeg

The fantastic world of the Tertiary sea coast is revealed by sediments characterised by conglomerate beds comprising abrasional cliffs. These beds are exposed in a dozen places by the abandoned quarries of the *Rendeki Hill*. The Castle Hill's cone is made up of

Cretaceous crinoidal limestone. Its sides were washed by the waves of the one-time Lake Pannon. Fossil cormorant bones—found in the sandy filling sediments of a small cave—are the interesting palaeontological evidence for this.

Várpalota Sand Pit Nature Conservation Area (G-07)

The *Várpalota basin*—located in the south-eastern foreland of the Bakony—is filled with an almost 500-metre-thick, young *Tertiary sedimentary succession*, from which *brown coal* was mined over a long period of time. The *Miocene sand* of high quality, which can be found in the inner part of the town, was produced for decades. After realizing how significant the locality is in a palaeontological point of view, the production was stopped in 1954, and *one of the first nature conservation areas in Hungary was established*. The geological key section, which became an exhibition



The outcrop is protected by a canopy

site for today, is *protected by a wooden canopy* from the weather. The lower few metres of the almost 10-metre-high wall is built up of ochre, fine- and medium-grained *quartz sand* which was mixed with some clay. The shallow-marine sediments were deposited in relatively calmer water than those of the overlying littoral succession. It contains fewer molluscs but more foraminifers than the latter one. Almost 100 species could have been identified among these calcareous protozoans.

The upper section of the wall, comprising the greater, 4–5-metre-thick part of the succession, is made up of well-sorted, medium- and small-grained, cross-bedded sand. It contains calcareous-shelled mol-



Some specimens of the extremely rich fauna (a shark tooth in the middle)

luscs (gastropods and bivalves) in incredibly large quantities; it is no exaggeration to say that there are millions of specimens. Beside the ornamentation sometimes the original colour of the *very well-preserved calcareous shells* can also be seen. Several palaeontologists focused their studies on the determination of the extremely rich fauna. The list includes *more than 400 species*; the most frequent genera among them are the following: *Turritella*, *Pirenella*, *Natica*, *Dorsanum*, *Nassa*, *Tudicla*, *Ancilla*, *Arca*, *Anomia* and *Venus*. The large specimen number is due to the wave action that washed the shells together. A rich fauna like this and of the same age is known only from Southern France. According to foraminifera dating the succession represents the so-called “Upper Lagenid Zone” of the lower part of the lower Badenian (M4b).

The well-preserved, some-cm-sized fish remains—found in the micro-laminated siltstone (oil shale) of one of the open pit coal mines in Várpalota—are considered as unique and rare palaeontological finds. Together with several ten thousands of other palaeontological materials, these fossils are kept in the Bakony Natural History Museum in Zirc.

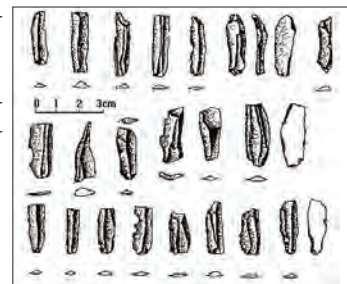
Szentgál: chert – Man – cave (G-08)



Near the entrance of the Tűzköves-hegyi Cave ('Cave of Flinty Hill')

One of the largest prehistoric chert mines in Europe is found in the outskirts of *Szentgál* in the Bakony Mountains. The locality—the Middle Jurassic radiolarite beds of which yielded an excellent lithic raw material—was discovered by the primitive man already in the Palaeolithic period. The chipped stone tools that were found in the red ochre mine in *Lovas* (which is several tens of thousands of years old) and in the filling of the *Szárász-Gerence Cave*, had been manufactured at this place.

The heyday of flint mining activity occurred in the Late Neolithic period. A group of the population of the Lengyel culture was specialised for flint mining here. For the protection of the locality they created a ring of settlements around the locality within a radius of 10 km; this is unique in the world. Mining and the stone core manufacturing escalated to industrial proportions. Based on data of archaeological excavations, left-behind chert chips can



Blades from the Szentgál locality, made of flint



Entrance of the strictly protected Szentgáli-kölik Cave

be found in considerably large numbers within a one-square-kilometre-area.

They provided with the characteristic, red-coloured stone tools not only the inhabitants of the stone-free regions in Hungary, but (due to more distant trade relationships), chert tools—derived from this locality—appeared in the area of the present Slovakia and Slovenia, moreover, in a site in the Netherlands (!), too.

The *Tűzköves-hegy Cave* was discovered in 1934 in the quarry that had produced the Lower Jurassic limestone of the Tűzköves Hill. Besides the spectacular solution forms in the cave (which is under special protection today), tectonic features are also predominant. In

addition to stalactites, the principal value of the cave is the hibernating bat population which is one of the biggest in Hungary.

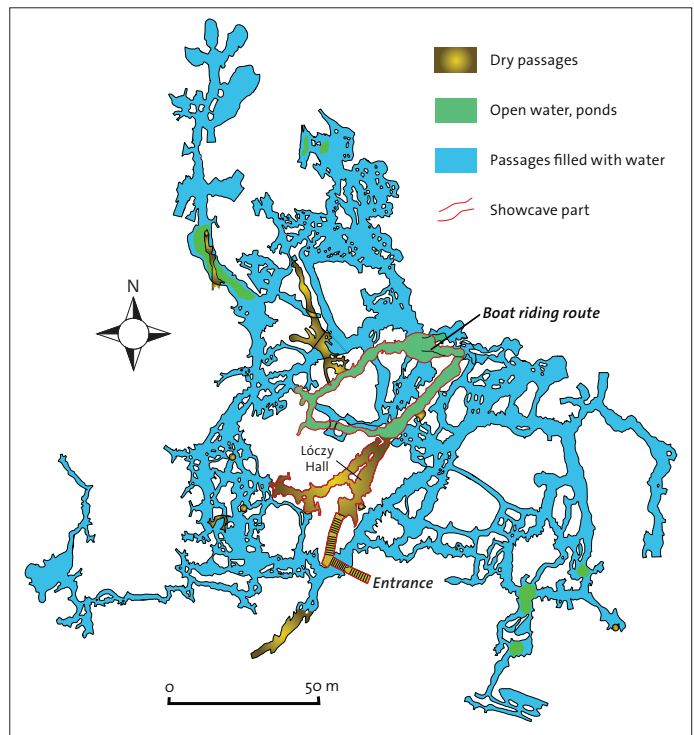
In the southern outskirts of the settlement a strictly protected cave, i.e. the *Szentgáli-kölik* can also be found. It is a multi-storeyed labyrinth of intersecting tectonic fissures formed in the Upper Triassic *Main Dolomite*. Its upper section has been made accessible to people taking tours in overalls by the Applicant. The cave—characterised by an interesting geological history—has yielded Copper Age earthenware remains, *Bronze Age urn* fragments, 6 human skulls, human and animal bones and an earthenware moon idol. According to archaeologists the cave may have been a cultic place.

Lake Cave of Tapolca (G-09)



There is a huge (more than 9-km-long) karstic labyrinth hiding beneath the town of *Tapolca*. It consists of several caves. The largest among them is the 3280-m-long Lake Cave of Tapolca, a few-hundred-metre-long section of which has been made accessible to visitors. The facility management and operational running of the cave are provided by the applicant Balaton Uplands National Park Directorate. After a walk along the accessible section, the hundreds of thousands of visitors who pass through here each year can make *boat trips* on the turquoise water along a passage which curves back towards the starting point. The 20 °C karst water keeps the temperature mild and the air humid throughout the whole year.

The cave was discovered in 1903 in the course of digging a well, at a depth of 14 m. Its formation is due to a lucky fact. A part of the meteoric water that infiltrates the karstified limestone and dolomite areas of the Bakony flows towards the marginal basins along the fissure network of the rocks. The other part of the water descends into a depth of several km, warms up and as thermal water it ascends near the surface. The two types of karst waters meet just in the area of Tapolca; the cavern system has been created by the corrosive effect of their mixture. The thermal



Map of the cave system (Zoltán SZABÓ)

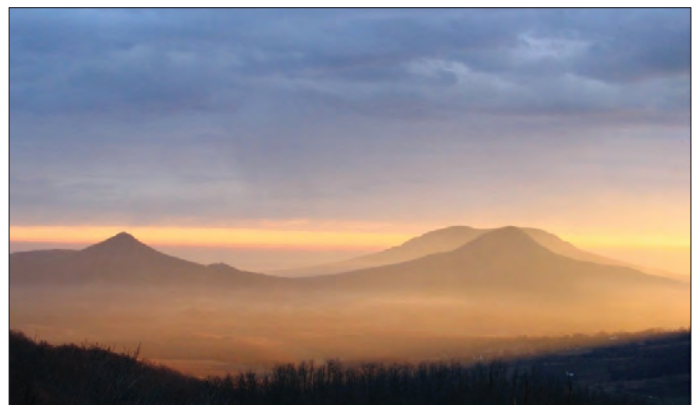
water origin is proved by spherical niches which are seen on the wall of the halls and passages.

Due to the small-scale uplift of the area the upper passages and a part of the middle (built) level has become dried up, whereas the deepest passages opening from the rowing section has remained under water. Solution of limestone is a still ongoing process in this zone which is searched by divers. Temporarily, karst water flows here from the neighbouring *Kórbáz-Berger cave system* through inaccessible passages. After leaving the southern part of the cave it reaches the surface through the springs of the nearby *Malom Lake*.

On the 8-m-high walls of the *Lóczy Hall* (named after the famous Hungarian geologist) the almost horizontal bedding of the 14-million-year-old shallow-marine limestone (*Tinnye Limestone*) can be observed. Halls and spherical niches are connected to each other by short passageways. The rowing section is somewhat similar to this; however, the smaller halls (having dome-like, higher ceilings) are connected by low tunnels. Dripstones have not been formed in the cave since water percolation from the surface is hindered by a few-metre-thick clayey zone.

An interesting cave dweller is the Eurasian minnow (*Phoxinus phoxinus*) which feeds on tiny crabs. The not more than 10-centimetre-long fish reach the cave from the Malom Lake through watery passages.

Volcanic remnant hills in the Tapolca Basin (G-10)



The unique landscape diversity of the Tapolca Basin is primarily due to its *basalt volcanic remnant hills*. The low-lying, flat basement is predominantly made up of *Miocene limestone*, which became overlain by the fine sandy *deposits of the Lake Pannon* 10 million years ago. The *alkaline basaltic magma* penetrated the moist sedimentary succession with huge explosions 3–5 million years ago. Dozens of *tuff rings* were formed, and later

they were filled with *lava lakes*. In the final stage of volcanism, *cinder cones* were formed. Where the surface was not protected by basalt caps the thick but loose Pannonian sediments have been removed by the erosion that started in the Pliocene. Simultaneously, erosion of tuff rings and, subsequently, of the basalt masses, started. Frost weathering in the Pleistocene intensified the process, and large *scree slopes* came into being. On the sides of the volcanic bodies, which became increasingly weathered out from their surroundings and cracked by cooling, the formation of *basalt organs*, *rock bastions* and *pinnacles* is an ongoing process.



Basalt 'organ pipes' of the Szent György Hill

Within this general model of formation each volcano has its own evolution and has a variety of geological–geomorphologic character. Some maar volcanoes (*Véndék-begy*, *Hegyesd*, *Szigliget*) have become eroded right to the diatreme, whereas others (*Badacsony*, *Szt. György Hill*) possess their red cinder cones. In some places (*Gulács*, *Tóti Hill*) basalt—migrating upwards along cracks—was trapped within the overlying sediments, therefore narrow ridges have been formed. Traces of different volcanic processes and the peculiar geomorphologic features can be well studied in natural outcrops and in the abandoned quarries. In the contact zone of the Tapolca Basin and the neighbouring Lake Balaton fresh meadows and inlets, changing into *swamps*, came into being. Nevertheless, the northern part of the basin (made up of carbonates) is characterised by dry grasslands and dolomite barren. Due to the combination of biodiversity and geodiversity, an incredible range of natural values came into being in the area. All these are demonstrated to the numerous visitors by *nature trails*, *information booklets* and various publications.

Tihany Peninsula (G-11)



The pyroclastic succession of the former maar at the Monks' cells

The Tihany Peninsula—located on the northern side of the Lake Balaton—is one of the most popular tourist destinations in Hungary. Due to its unique geological–geomorphologic natural values it was declared protected in 1952 as the *first landscape protection area* in Hungary. Since 2003 it has been the holder of the *European Diploma*. Its almost thousand-year-old Benedictine abbey attracts hundreds of thousands of tourists. Most of them walk all over the geological values which can be found along the *Lajos Lóczy Nature Trail*. The new visitor centre of the Applicant, i.e. the 'Lavender House' was opened in 2011; at the same time it is the *Eastren Gate of the Bakony–Balaton Geopark*.

The basement of the peninsula is made up of the thick, sandy, silty sediments of the 10-million-year-old *Lake Pannon*. The fossil shells of the bivalve *Congerina unguilacaprae* have been washed out from the lower beds. There is a few-century-old legend attached to these fossils which have

been worn by the waves and resemble goat hooves. The *Tibany Formation*, representing the paludal, closing member of the Pannonian succession, crops out in a natural exposure of the Fehér-part which can be seen from a far distance.

The *first basalt volcano of Transdanubia erupted here 8 million years ago*. The *pyroclastic deposits* in the maar craters of the repeated volcanic activity are represented by very spectacular forms. The most well-known place is the surroundings of the "Monks' cells", where dwellings have been hollowed into the several-ten-metre-high walls by the one-time monks. Impact structures, made by *volcanic bombs* in the pyroclastic beds of variable grain sizes, can also be recognised.

The protruded cliffs of the *Kiserdő-tető* which are exposed to the wind and rain are the striking examples of selective erosion. In the nearby exposure, clasts derived from the basement rocks (i.e. Silurian phyllite, Permian red sandstone, Triassic dolomite and welded clay) and torn up by explosions can be studied. The panorama from the top of the cliffs provides a spectacular view of the bird paradise in the swamp of the Külső Lake.



The thermal spring cone of the Aranybáz ('Golden House')

There is a foot path along the western edge of the peninsula beneath the rock wall. This wall is built up of the *calcareous–siliceous sediments of thermal springs*, which overlie the deposits of the former maar lakes consisting of basalt clasts. The several-metre-thick succession—made up of mm-thick laminae—indicates a long-term seasonal rhythmicity of precipitation. While walking along the path tourists may visit a dome-shaped cave, as well; it was formed in the already deposited calcareous material by the dissolution effect of ascending thermal waters.

In the vicinity of the *Lake Belső* (Inner Lake) the field of spring cones which rise above the forest is the evidence of an extremely strong post-volcanic activity. The internal areas of the peninsula can be viewed from the largest cone called 'Aranybáz' ('Golden House'). The hill of the abbey church is of the same origin; a cave (having small halls) has been formed in its calcareous rocks by the dissolution effect of thermal waters.

The Kút (Well) Cave in Csersegtomaj (G-12)

In the neighbourhood of the world-famous medicinal spa Hévíz, an exceptionally unique geological formation is found. The cave was discovered at a depth of 50 m in the course of digging a well at the corner of the Csersegtomaj cemetery in 1930. Since the 1960s up to now a 3320-metre-long passage has been known, however, according to estimations, the same length is to be surveyed. Nevertheless, this relatively considerable length can be found within an area of a diameter of 120 m and a thickness of 12 m, in which passages form an intricate maze. Their average width rarely reaches 1 m, and their height only locally exceeds the same value. In their points of intersection a few-metre-sized halls are found, from which narrow passages start in several directions, frequently connecting back to the previous parts. The amazing features can be explained by its special speleogenesis, which, at the same time, gives a unique value to this geological formation.

The surface of the Triassic dolomite underwent karstification in the Miocene. Under the subtropical climate, peculiar morphological features—interspersed with crevices and funnel-shaped depressions—came into being. This surface was invaded by the Lake Pannon; subsequently, the deposited sand filled the unevenness of the basement, perfectly representing the former karst surface. Later clayey sediments

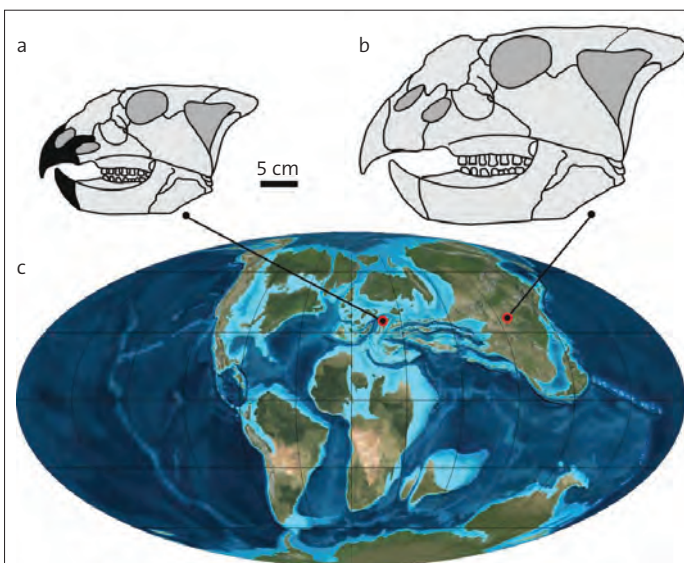


were deposited in a thickness of several tens of metres. In the Pliocene, the ascending thermal waters could not reach the surface because of the impermeable Pannonian clay. The trapped hydrothermal solutions have impregnated the Pannonian sand with silica and it has become a hard rock. Calcium carbonate has been dissolved from the underlying Triassic dolomite; therefore its upper part has become friable. The labyrinth-like passage network has been formed in this way along the dolomite/sandstone contact, within a few-metre-thick zone. Thus, the roof is made up of siliceous quartz sandstone, whereas the basement is of friable dolomite. The column-like sandstone features and crests hanging from the ceiling into the caverns represent, in fact, the negative forms of the former karst surface from a bottom view. That's what makes the Cserszegtomaj Kút Cave unique in the world.

Besides the exceptional morphology of the cave, noteworthy mineral precipitations can be seen. In some halls the walls are ornamented with haematitic coatings with blue and red tints and manganous coatings. In many places gypsum minerals are found; their formation is an ongoing process. Besides the tabular appearance, spirally twisted fibers, i.e. "gypsum flowers" are found. Decay of the pyrite content of deeper-lying rocks may play an important role in their formation. The cave also provides with a palaeontological speciality: locally, on the sandstone walls, impressions of plant stems—with a length of several spans and a width of a few cm—have been preserved.

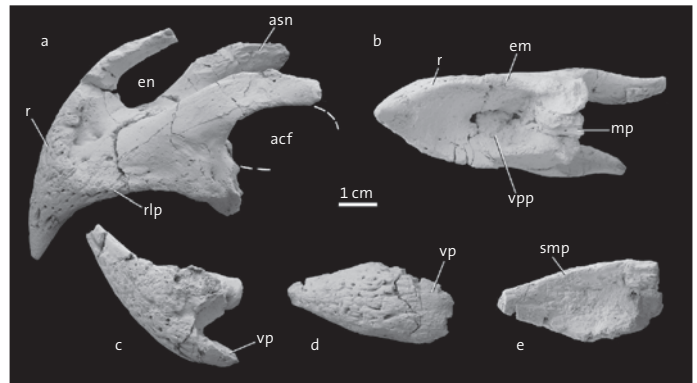
Iharkút Cretaceous dinosaur locality (G-13)

Until a few years ago, only fragmentary, scattered remains and footprints of vertebrates were known from the territory of Hungary from



Late Cretaceous palaeogeography and bagaceratopsid skull outlines. a, b, Skull outlines, to scale, for *Ajkaceratops kozmai* (a) (preserved bones in black, remainder of skull based upon *Magnirostris*) and the Asian bagaceratopsid *Magnirostris* (b). Although the exact phylogenetic position of *Ajkaceratops* is unclear it is probably closely related to the Asian bagaceratopsids *Magnirostris* and *Bagaceratops*. c, Late Cretaceous palaeogeographical map showing locations of *Ajkaceratops* and Asian bagaceratopsids – map courtesy of R. Blakey (Attila Ósi 2010)

the Mesozoic Era, which is also called the age of the reptiles. In 2000 the ice was broken: geologist Attila Ósi PhD discovered the first, systematically collectible continental vertebrate locality in the Bakony, in the outskirts of the village of Iharkút. 85-million-year-old Cretaceous sedimentary rocks (*Csebbánya Formation*)—cropping out along the slope of the abandoned bauxite pit—have yielded the *first dinosaur remains in Hungary*. The research work at this site has led to the discovery of a *worldwide unique* assemblage of fossil remains, in which the number of the predominantly isolated bones and teeth, and the subordinate skel-



Anatomy of *Ajkaceratops kozmai* gen. et sp. nov. a, b, Holotype MTM V2009.192.1, fused rostral and premaxillae in lateral (a) and ventral (b) views. c–e, Referred material MTM V2009.193.1, prementary in lateral (c), ventral (d) and dorsal (e) views. acf, inferred position of accessory fenestra between the premaxilla and maxilla; asn, articular surface for nasal; em, edentulous margin of premaxilla; en, external naris; mp, fragments of rostral processes of maxillae; r, rostral bone; rlp, lateral process of rostral; smp, sharp margin of prementary; vp, ventral process of prementary; vpp, vaulted premaxillary palate. (Attila Ósi 2010)

etons, exceeds ten thousand pieces for the moment. On the basis of fossil finds more than 30 different vertebrate species have been described from fish through amphibians, turtles, lizards, crocodiles, pterosaurs, dinosaurs and birds. Several species, such as *Hungarosaurus tormai*, *Bakonydraco galaczi*, *Ajkaceratops kozmai* and the *Iharkutosuchus makadii* have been known only from the Iharkút fossil site. Besides vertebrate finds an important mollusc fauna is also known. Moreover, a greatly rich assemblage of pollen and plant fossils (seeds, leaves, flowers, branch/trunk fragments) provides us with a more complete image of the Late Cretaceous ecosystem.

Besides the taxonomic and anatomical description of the finds discovered in the course of research works and belonging to new and already well-known groups, the palaeobiology of certain species could have also been studied. Moreover, zoogeographic relations of the Iharkút fauna could be outlined. One of the most well-known animals of the locality is the small, omnivorous Crocodile of a maximum length of 1 m, namely the *Iharkutosuchus*. The detailed examinations of skull, jaw and tooth remains have pointed out that—unlike the other crocodiles—this species was suitable for transverse jaw movements, and thus, it could efficiently grind food with its flat, multi-cusped grinding teeth.

The remains of more than 50 specimens of the flying reptile, i.e. the *Bakonydraco galaczi*—which has been discovered in Iharkút—indicate that this species was definitely frequent in this alluvial area (interspersed with river branches and riparian forests). For today, the description of the newly-found flying reptile remains has already been done. This contributes to the better understanding of this group, which was documented predominantly on the basis of rare and fragmentary finds.

In a faunistic and zoogeographic point of view the Iharkút fossil site is regarded as a *unique locality*. Although, at the family level a significant part of the collected vertebrate remains corresponds with the faunas of several European sites (in Romania, Austria, France and Spain), there are significant differences at the genus or species levels. Moreover, in case of amphibians, a new family of frogs has been revealed.

Many of the discovered species show ancient characters. The armoured dinosaur *Hungarosaurus* (described from Iharkút) is 30 million years younger, whereas an ancient form of the modern Eusuchia crocodiles, i.e. the *Iharkutosuchus* is 40 million years younger than their closest relatives. The relative prevalence of new species and the presence of ancient forms indicate that 85 million years ago, for a shorter or longer time, the present Bakony was an isolated region within the European archipelago that existed in the western end of the *Tethys Ocean*. Similarly to finds of other Cretaceous fossil localities in Europe, there are forms among the

Iharkút turtles, crocodiles and Theropod dinosaurs, which had relatives in the southern continents of the Gondwana. These species support the opinion according to which the archipelago of Europe was conquered by groups coming from Africa.

Another unique feature of the site is that it is a few million years older than the other European continental vertebrate localities of Late Cretaceous age. It represents a time interval which has been virtually unknown in Europe from the viewpoint of continental vertebrates. Thus, the bone record derived from the fossil site plays an *extraordinarily important role* in the better understanding of Cretaceous zoogeographic relations. Nothing proves this better than the recently found skull remains of *Ajkaceratops*, which are undoubtedly *the first Ceratopsid dinosaur remains in Europe*. This has disproved the earlier hypothesis that this dinosaur group (characterised by horns and frills) lived exclusively in the area of Asia and North America. The remains of *Ajkaceratops* also show that—probably together with other dinosaur groups—*significant faunal migrations* took place from East to West sometime in the Cretaceous Period. As a result of this, the groups—indicating basically Asian relationships—reached the European archipelago in the western end of the Tethys Ocean.

Somló Landscape Protection Area (G-14)



Vineyards under the basalt outcrops

The geological history of the solitary hill (432 m) is similar to those of the other basalt volcanoes in Transdanubia. Its *tuff ring* was formed due to a *phreatomagmatic explosive activity* 3,5 million years ago. The pyroclastic beds—which overlie the Pannonian sediments—were penetrated by magma, and this created fascinating transitions of rocks. In the northern valley of the Somló it can be observed that the adjacent Pannonian clay was “burnt” red by hot, molten rock. A hard, compact rock type of conchoidal fracture came into being which resembles ceramics.

In the second, more pronounced stage of volcanic activity the tuff ring was filled with lava in several phases. The cooling basalt solidified into *thick-bedded, massive blocky* structures. These structures on the cliffs—under the edge of the hilltop—can be seen even from a distance. The Somló is characterised by the so-called “sunburn basalt”. Its texture comprises about 1-cm-sized or smaller grains. When struck with the hammer or due to natural exogenic effects (frost, rain, roots) the seemingly solid basalt relatively easily falls apart into small pieces. In the final stage of volcanic activity the basalt of the cooled lava lake was penetrated by the repeatedly ascending, gas-rich melt, and a 30-metre-high cone of a diameter of a few hundred metres was formed, which is made up of red, porous, scoriaceous lava.

The morphology of the Somló is of a classical volcanic remnant hill from all sides. Its lower part is made up of loose sediments (Pannonian sand, silt, clay and pyroclastics) forming medium-angle slopes. Above these slopes—excellent for viticulture—very steep, in some places vertical basalt walls can be seen; locally their height reaches 50 m. The central cinder cone is situated on the almost flat hilltop (mesa) of a diameter of one kilometre. There is a lookout tower on it.

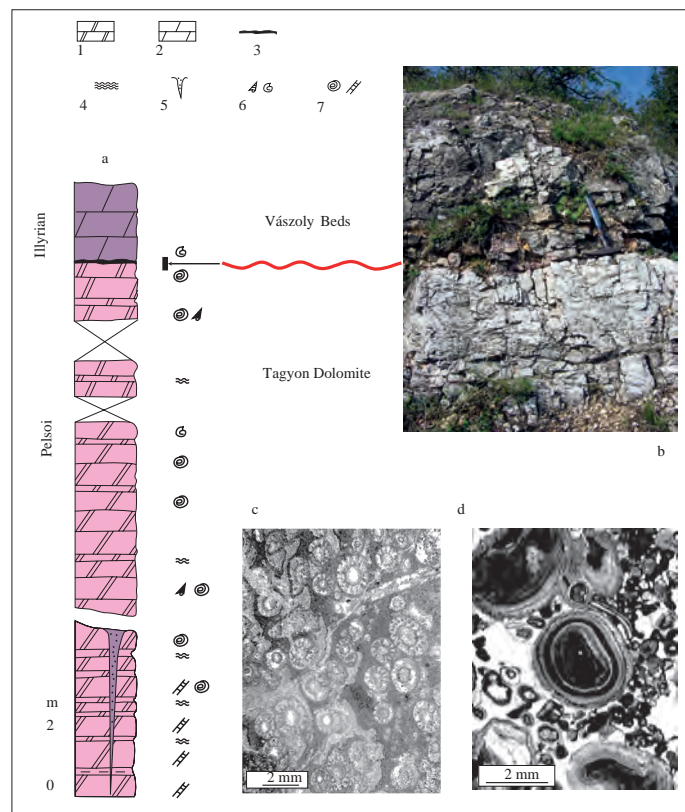
The integrity of the landscape is disrupted by a curved valley axis on the North. The valley cutting backwards at the bottom of the cauldron (which is likely to be of explosive origin) makes the hilltop accessible, which can be hardly reached by vehicles. These local natural conditions and the strategic importance of the place were realized by the fortress builders. After the 1200s a fairly large fortress was built on the basalt crest of the western side of the cauldron. Near the gate of the fortress—which looks formidable even in its ruined state—the exfoliating basalt bedrock can be seen.

Szentkirályszabadja, the Middle Triassic of the „airport quarry” (G-15)

A hill called *Péter-balma* is located 1,5 km to the North of *Szentkirályszabadja*. There is a disused quarry inside the fence of the former military airport, which exposes the middle section of the Middle Triassic of the Veszprém Plateau as a key section. The profile was presented during several international geological programmes.

In contrast to most parts of the Balaton Uplands—where the middle section of the Anisian stage is represented by the Felsőörs Limestone (deposited in a relatively deep basin of the open shelf)—in this profile the same stratigraphic interval is made up of shallow-marine platform carbonates. The succession of the *Tagyon Dolomite* of cyclic structure is made up of the rhythmic alternation of thick beds deposited in the subtidal zone and laminated beds of the intertidal zone. On the weathered surface of the bedding planes tower-like gastropods, the porous tubes of green algae (*Dasycladacea*) and coated grains (pisoids) of concentric structure—resembling botryoidal stalactites—can be observed. The succession exposed in the northern quarry yard is the only profile known, so far, in which the evolution of the Anisian carbonate platform—i.e. subaerial exposure, subsequent karstification and re-flooding—can be well documented on the basis of sedimentological features and the ammonite fauna of the layers. The Middle Anisian (Pelsonian) age of the shallow-marine *Tagyon Dolomite* is based on *Balatonites balatonicus*, whereas the ammonite assemblage (*Asseretoceras camunum*, *Lardaroceras krystyni*, “Hungarites” *inconstans*) of the brownish-grey, reddish-grey, crinoidal, dolomitised layers of the *Vászoly Beds* (overlying with a sharp contact) is indicative of the upper part of the Anisian stage (Illyrian). According to this, the time span of the hiatus between the two formations can be estimated for 1,5 million years. The red clay that covers the surface of the *Tagyon Dolomite* in a thickness of a few cm is the product of the karstification period that took place between the subaerial exposure and the re-flooding of the platform.

On the basis of the comparison between the Felsőörs and Szentkirályszabadja profiles, it seems to be proved that during the Middle Triassic, in the second half of the Anisian, relatively deep sea basins were formed on the Tethys shelf between the shallow-marine platforms. Disintegration of platforms was resulted by syn-sedimentary exten-



Profile of the Szentkirályszabadja airport quarry (a), the sharp stratigraphic boundary between the Middle Anisian platform carbonate and the Upper Anisian basin facies (b), green algae sections (c) and pisoids in the *Tagyon Dolomite* (BUDAI 2006). Legend: 1. platform carbonate; 2. carbonate of basin facies; 3. red clay; 4. stromatolite; 5. neptunian dyke; 6. gastropod, ammonite; 7. onkoid, *Dasycladacea*

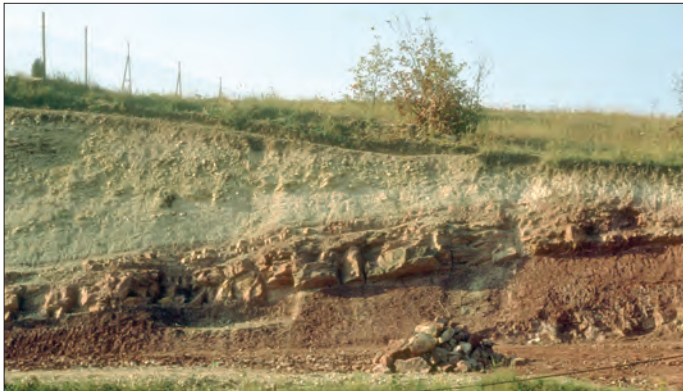
sional tectonic movements. An evidence for this can be found also in the Szentkirályszabadja quarry. The 1–2-m-thick dikes on the wall of the southern quarry yard, which intersect the succession of the white dolomite and are filled with red, crinoidal, dolomitised limestone, may have been formed in the course of the rifting of the platform margin and the subsequent filling of rifts with marine sediments.

Alsóörs, key section of the Alsóörs Metarhyolite (G-16)



The abandoned quarry located on a plot at 46 Endrődy Street is the protected key section of the *Alsóörs Metarhyolite* of Early Palaeozoic age. This is the only outcrop of this rock type the length of which is about 50 m. The massive rock — which is exposed in a thickness of 1–2 m — was formed by the subsequent transformation of a deposit of a pyroclastic rock and ignimbrite of rhyolitic composition. The large-sized crystals, which can at least be seen by the naked eye, are made up of quartz, feldspar and biotite in a matrix consisting predominantly of fine-crystalline quartz. Volcanism took place at the late period of the Ordovician (about 450 million years ago). The acidic volcanic rock was deposited in the sea and this is indicated by its stratigraphic position within the *Lovas Slate* beds. Based on radiometric dating metamorphism of the succession may have taken place during the Variscan orogeny, about 315 and 330 million years ago.

Csopak, Permian–Triassic boundary (G-17)



One of the oldest protected sections in the Balaton Uplands is a railroad cut, which exposes the Permian–Triassic boundary. It is located W of Csopak (where there is the headquarters of the Applicant), on the side of Road No. 71. The succession — remarkable for its variable colours — was exposed approximately a hundred years ago during the construction of the North lake shore railroad. At present it is one of the most well-known key sections.

The lower part of the section is made up of the continental, Upper Permian *Balaton-felvidék (Balaton Uplands) Sandstone*, which is represented by purplish-red, cross-bedded sandstone and siltstone beds. The thickness of the beds ranges from 0.2 to 1 m. The grains are made up predominantly of quartz, whereas feldspars, micas and clay minerals are subordinate in quantity.

The Upper Permian sandstone — deposited under semi-arid climate in an alluvial plain environment — is overlain by a Lower Triassic shallow-marine succession which indicates the global sea-level rise that occurred at the Permian–Triassic boundary. The approximately 4-metre-thick, lowermost section of the Triassic succession is made up of grey, dolomitic siltstone and sandstone (*Köveskál Dolomite*). The sandstone is cross-bedded and ripple marks can be seen on the bedding planes. Some beds are characterised by ooids with quartz nuclei. Upwards in the succession the amount of debris gradually decreases, whereas carbonate

content increases; sandstone is replaced by yellowish-grey, thin-bedded, porous dolomite. The Lower Triassic succession has yielded few, poorly-preserved fossil bivalves (*Claraia*) and brachiopods (*Lingula*). The sparse occurrence of fossils indicates that the colonization of vacant shallow-marine niches did not occur for a long time after the Permo-Triassic mass extinction, which happened about 250 million years ago.

Kab Hill, basalt-covered karst (G-18)

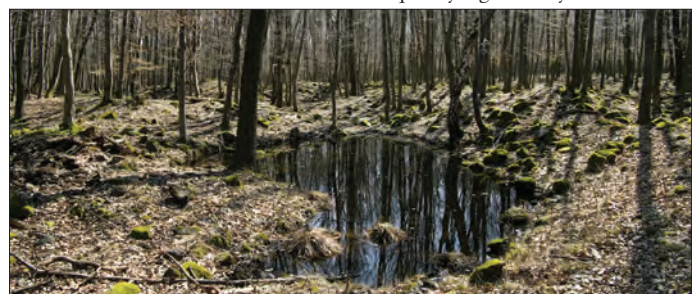
On the largest and highest (600 m a.s.l.) volcano of the Geopark (i.e. the *Kab Hill*) no tuff ring was formed during the Pliocene; the lava flowed freely down the slopes. The first stage of lava flows (5.23 million years) was followed by a longer pause. The warm and humid climate of that time resulted in the weathering of the basalt and the formation of a several-metre-thick pale red clay. In the second stage of volcanism the clay was mostly covered with the material of the renewed lava flows, nevertheless, locally it can be still seen. As a result of the two active stages an almost 20–40 metre-thick lava field came into being predominantly on the north-western and southern slopes of the hill; it is about 40 km² in areal extent. In the last stage of volcanic activity (4.73 million years) red, scoriaceous, vesicular basalt was formed around the present-day peak.

Lava flows covered the surface which is made up of Mesozoic and Eocene limestones and underwent karstification until the end of the Tertiary.



Due to the formation of the basalt cover the area suitable for surface karstification decreased, however, at the same time, the intensity of the process increased. The massive basalt and the intercalating clay are impermeable; thus water flowing on the surface and along shallow fissures can reach the edge of the basalt cover. At the rock contact water intensively dissolves the carbonates and creates sinkholes within a short time. The most beautiful sinkhole of the mountains, i.e. the still active *Macskalík* (see above), has been formed at such a basalt/limestone contact. The *Bújó-lik* is a sinkhole cave of similar appearance.

The area is enriched by another peculiar karst feature. Solitary and interlocking dolines and sinkholes were formed within the basalt cover. According to a probable theory of their formation the lava flows surrounded the one-time limestone elevations. Karstification started along such an internal contact of rocks and after a while morphological inversion came into being. A probable representative of the subsurface karstification is the *Pula basalt cave*; its development is due to the collapse of the rock into one of the cavities of the underlying limestone. According to another theory it is a collapsed vesicle. The '*Halász Árpád*' cave was also formed in basalt. The cavern — exposed in the course of quarrying — is considered as a lava tunnel. On the western and especially on the southern side of the Kab Hill there are about a dozen temporary ponds to be found (see below). Besides the natural karstic depressions there are hundreds of small, doline-like pits in the basalt. They are anthropogeneous forms: traces of the centuries-old basalt quarrying activity.



Zirc, cross-bedded crinoidal limestone near road to Borzavár (G-19)

In the vicinity of Zirc the well-bedded, easily carvable limestone — characterised by coarse-grained stripes — was mined for centuries. This is its only occurrence in the country. The popular building stone can be seen in the walls and fences of several houses in the surrounding area. The disused quarry near the road is a spectacular geological key section. The Lower Cretaceous *crinoidal limestone* is made up of two, similar formations of different ages; there is an about 5 million years hiatus between them. Its lower part is the pale red *Borzavár Limestone* (Valanginian, Hauterivian) comprising also chert nodules. However, the overlying grey (on the surface faded to yellow) — and also crinoidal — limestone belongs to the Aptian *Tata Limestone*.

The approximately 10-metre-thick succession was described in 1875 for the first time, and the latest summary was made in 2003. According to the latter the lower limestone is almost completely made up of the disintegrated, strongly-worn, few-mm-sized fragments of echinoderm skeletons. Locally recognizable remains of crinoidal (e.g. *Torinocrynus*) ossicles and calices (reaching a size of even 1 cm), moreover, the 1–1.5-cm-sized, club-like spines of echinoids can be observed. Brachiopods (*Pygites*) and *aptychi* are relatively frequent; however, ammonites, belemnites, sponge remains and fish teeth have also been found.



The mass of deposits — which is slightly thicker than 15 m and its surficial extent is a few square km — was deposited 130 million years ago within a short time period. The rich assemblage was swept away from a submarine high by strong bottom currents. Billions of *calcitic skeletal remains* were broken into tiny pieces, were deposited in the deeper water and became a well-bedded rock.

The causes of the hiatus spanning a few million years are unknown so far. The material of the upper limestone indicates similar palaeoecological conditions. This laminated, thin-bedded rock is also predominantly made up of the strongly-worn skeletal fragments of echinoids. Calcite grains are mixed with older (mainly Jurassic) limestone clasts. With the exception of some brachiopods and belemnites larger fossils can hardly be found. The cross-bedded limestone is a visibly unique formation of the quarry. The section of a *shaft cave* (see above) is also a curiosity. Its clayey deposits contained the hundred-thousand-year-old remains of tiny land vertebrates.

Balatonederics, Csodabogyós Cave (G-20)

The Csodabogyós Cave, which is located on the top of the steep, rocky slope above *Balatonederics*, is *one of the finest examples of the tectonic caves* in Hungary. Locally it is decorated with *stalactites* and *stalagmites*.

The *strictly protected*, 5.2-km-long and 110-m-deep cave comprises the labyrinth of *balls* and huge *crevices* and *shafts* running parallel and at angles to each other. The width of the passages is usually between 1 m and 4 m, whereas their height ranges from 10 m to 30 m. Some of the spacious crevice shafts — dissected by false floor levels and constrictions — are 40–50 m deep. This unique labyrinth is the network of fissures and crevices which have been formed due to the locally predominant dilatational tectonics. At the same time, traces of strike-slip and reverse faulting can be seen in the form of large slickenslides on certain walls.

The predominant part of the passages has developed in the Upper Triassic *Ederics Limestone*. This special rock type shows the most extensive



occurrence here within the area of the Transdanubian Range; however, its surficial extent is less than half a square kilometre, albeit its thickness is at least 300 m. The unusual three-dimensional shape is due to the fact that the limestone — interfingering with the dolomite — forms a one-time reef.

The light grey or snow-white, small- and coarse-crystalline host rock of thick-bedded or massive appearance represents platform carbonate facies. Its *typical facies* is characterised by *reef-dwellers* and *reef-builders*: the rich, tropical biota is represented by *green algae*, *foraminifers*, *calcareous sponges*, *corals* and *bryozoans* in large quantities.

Another interesting feature of the cave is that it forms a common air-flow system with a neighbouring cave. In winter the humid and warm air escapes through its entrance forming a vapour column. The upper, some-hundred-metre-long section of the cave has been opened to the public by the applicant Balaton Uplands National Park Directorate (i.e. the nature conservation management of the area) since 2006: the upper, some-hundred-metre long section of the cave can be explored during tours in “caving overalls” (please note: visitors can not access directly to the dripstones; the man in the photo is a professional caver). In small groups, every year thousands of visitors come to this unique geological formation.

Balatoncsicsó, the Triassic of the Csukréti ditch (G-21)

The Csukréti ditch — in which the *Csorszai Creek* flows — stretches between villages of *Balatoncsicsó* and *Monoszló* near the road that runs through the vineyard. The Upper Triassic (Carnian) *Veszprém Marl* (which is among the thickest formations in the Balaton Uplands) and the intercalating *Nosztor Limestone* are exposed in a few-hundred-metre-long section along the creek bed.



A small waterfall developed on the beds of the Nosztor Limestone in the ditch

The oldest formation which crops out in the creek bed is the Middle Triassic (Ladinian) *Nemesvámos Limestone*. In the course of former examinations some ammonites were found in the red nodular limestone beds. It is overlain by the Upper Triassic (Lower Carnian) *Füred Limestone* which forms a several-metre-high wall on the steep slope, on the downhill side of the opposite located *Kő Hill*. Some metres higher above the thick beds of the Füred Limestone, the thin, laminated-lamellar beds of the grey, dark grey, soft marl-clay marl crop out on the creek bed side; the lower part of the Veszprém Marl is made up of the latter rock. Along a 250-m-long section from here down to the mouth of the left creek branch the succession is fairly poorly exposed. However, in

the tributary channel and around the fork the layers can be well followed; their carbonate content gradually increases. The marl–clay marl is overlain by calcareous marl and marly limestone. 70–80 m far from the tributary channel an old road crosses the creek; here crops out the light grey, brownish-grey, thick-bedded *Nosztor Limestone*. It divides the marl sequence and the creek cascades over it like a small waterfall.

The outcrop continues in the upper section of the Veszprém Marl. Over a pretty long distance the creek flows in the same direction as the strike of the beds; thus, in the side of the creek bed, we can follow the some-square-metre-sized bedding planes of the layers over a long distance. Getting closer to the *Kő Hill spring*—which is located at the end of the series of outcrops—the soft marl is substituted by hard calcareous marl of splintery fracture.

Poorly-preserved, fragmentary fossils are frequent in the marl and clay marl beds. The most frequent remains are the few-mm-sized shells with concentric growth rings, which can be found in certain bedding planes in large quantities. Previously these tiny shells were considered as the remains of shelled phylloporids which belong to the genus *Estheria*. According to other opinions the fossils are the juvenile specimens of the bivalve *Halobia*, which is frequent in the Upper Triassic. Besides these remains, there are bivalves (*Halobia rugosa*, *Gonodus astartiformis*) and ammonites (*Neoprotrachyceras baconicum*), which are considered as rare fossils.

The Csukréti Ditch is *the only good outcrop of the thickest formation in the Balaton Uplands*, i.e. the Upper Triassic Veszprém Marl. Data derived from the detailed palaeontological studies and stratigraphic conclusions based on them were demonstrated in the *XXI. European Colloquium on Micropalaeontology* in 1989, in Hungary.

Olaszfalu, Eperjes Hill geological key section (G-22)



The *locally protected area* near Zirc has been studied for a century. The variable successions—with hiatuses—in *three artificial exposures*, developed to form key section, range from the upper Triassic *Dachstein Limestone* up to the Upper Albian *Pénzeskút Marl*. These are overlain by the patches of the Middle Eocene *Szóc Limestone* and the *Csatka Formation* of end-Oligocene age. The *nature trail*—which also presents the living natural values—was created in 2002 on the hillside which formerly was a wooded pasture. An explanatory booklet is also available.

The specific character of the Eperjes Hill was developed after the end-Triassic disintegration of the carbonate platform, at the beginning of the Jurassic. It represents the edge of the one-time submarine high that stretched south-eastward from here. It is cut by a considerable left-lateral strike-slip fault of N–S direction, thus two different facies of the Jurassic system can be studied here.

“Long Ditch”

Its 100-metre-long section exposes the Jurassic (Hettangian–Berriasian) with considerable hiatuses. In the lower third of the profile the fossil-bearing layers of the *Pálibálás Limestone* of ammonitico rosso facies can be seen. They are overlain by the Hierlatz-type, fossil-rich (ammonite-, brachiopod- and crinoid-bearing) Széllhegy Member of the *Szentivánbegy Limestone*. Around a third of the ditch, East of the strike-slip fault, different Jurassic formations can be found. Between the higgledy-piggledy blocks of the *Kardosrét Limestone*, as well as in an overlying position, the

reddish, microfossil-rich material of the *Szentivánbegy Limestone* can be observed. This megabreccia of peculiar arrangement may be associated with the collapse of the one-time platform.

“Stripped profile”

The spatial arrangement of the formations can be seen in a large area here. The blocks of the Kardosrét Limestone and the *Hierlatz Limestone* occur only near the northern end of the exposure, whereas in the southern part the Cretaceous *Tata Limestone* overlies the tilted blocks of the *Dachstein Limestone*. The purplish fissure-filling material of unknown age within the huge blocks in the middle section is also remarkable.

In one of the layers of the overlying Szentivánbegy Limestone the alternation of peaks—resembling stromatolites—and narrow troughs can be seen. These beds are especially rich in ammonite casts, aptychi and crinoid fragments; fossil brachiopods and solitary corals also occur.

“Profile on the hilltop”

The some-metre-high cliff which forms the crest of the hill, and the ditch perpendicular to the latter, expose the bassets of the Cretaceous *Zirc Limestone*, which underwent strong karren formation. The type locality of the lower section of the formation (Eperkéshegy Member) can be studied in the escarpment. The thick-bedded limestone of Urgon facies contains the shells of rudist bivalves in large numbers. In certain beds the bivalves—attached by byssus threads—can be observed even in groups. The beds of the Mesterhajag Member crop out at the upper end of the profile.

At present the Eperjes Hill is one of the best-documented geosites in the Bakony, which has been made comprehensive for the public by exposures, explanatory tables and publications.

Balatonfőkajár, quartz phyllite on the Somlyó Hill (G-23)

The *oldest formation* of Transdanubia, not only the proposed Geopark area—which forms the crystalline basement of the Bakony—crops out to the surface on the Somlyó Hill which is located NE of *Balatonfőkajár*. The *quartz phyllite* and the subordinate *chlorite-sericite phyllite* are exposed in a disused quarry at the south-western foot of the hill. The white quartz veins (see below, in the front of the snail) are very impressive in the grey, greenish-grey, strongly-folded rock. Besides the bi-directional, low-angle schistosity the slightly-metamorphosed rock shows recumbent folds and flattened quartz strips between the foliation planes. Among the rock-forming minerals quartz, feldspars and micas can be identified.



Ordovician–Silurian formations—originally made up of clastic sediments (sand and subordinately clay) and acidic volcanic interbeddings were deposited in the Southern Hemisphere, 450–420 million years ago. Based on radiometric dating on micas their metamorphism of greenschist facies took place during the Variscan orogeny, about 340–320 million years ago. The main direction of the compressional deformation was NNE–SSW and it was in connection with a nappe-forming event of SSW direction. The results of investigations in the quarry and on the succession of the borehole deepened in it were summarized in several monographs. In 2010 volunteers of one of the most active civil partners of the Geopark candidate, namely the Pangea Association, cleaned out the exposure, moreover, an information board has been placed in it.



The eastern shore of the Lake Balaton rises above the lake in the form of a 50-metre-high steep wall. The whitish-yellow shoreline—which can be seen from a distance—was undercut by wave action caused by the water of the lake. The lower clay beds, saturated with water, were affected by slump movements of considerable areal extent. A hundred years ago—due to such a disaster—even the railway track slid into the lake. The margin of the *Mezőföld* of this place is built up of the succession of the one-time *Lake Pannon*; it is composed of Upper Miocene *sand, silt* and *clay*. At Balatonkenese a cyclic sedimentary succession of the *Tibany Formation* can be studied (see above). It represents the near-shore facies of the lake of decreasing salinity. Sediments ranging from wave-base to swamp environments locally yield the remains of fossil bivalves and gastropods. The topmost part of the succession comprises grey, organic-rich clay, i.e. a palaeosol bed.

In the past centuries cave dwellings (*Tatár hollows*) were hollowed into the bluff by the people who lived here. The panorama from the lookout tower (built on the hilltop) provides a spectacular view of the eastern basin of then Lake Balaton. The former loess-steppe and steppe vegetations have been preserved; a strictly protected botanical value is found among them, i.e. the *Crambe tataria* which has a spectacular inflorescence.



Some specimens from the rich mollusc fauna of Papvászár Hill (Lajos KATONA in press)

The neighbouring *Papvászár Hill* vineyard also reveals interesting formations from a geological-morphological point of view. The Pannonian succession of the abandoned sand pit reveals younger beds than those of the Kenese bluff. On the hilltop the freshwater limestone deposits of Pleistocene springs can be found. The weathered-out surfaces of the blocks show spectacular, laminar-nodular carbonate precipitation patterns.

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Balatonalmádi, Permian key section of the Köcsi Lake quarry (G-25)

One of the most significant formations of the Balaton Uplands, i.e. the Late Permian *red sandstone* is exposed in a small, disused quarry, which is located behind the children's camp at Káptalanfüred (which belongs to Balatonalmádi).

The *Balaton-felvidék (Balaton Uplands) Sandstone* is divided into three groups; its *lower part* overlies the older, folded Palaeozoic basement with a *coarse-grained, red conglomerate*. The *middle third* of the succession is characterised by the alternation of *red sandstone and siltstone*, whereas in the *upper third* the repeated *coarsening of sediments* occurs with the appearance of conglomerate interbeddings. The coarse-grained sediments which were deposited in one-time riverbeds cyclically alternate with the fine-grained sediments of *alluvial sedimentary environments*.



The *lower section of the succession*—exposed in the quarry near the Köcsi Lake—is represented by a poorly- or slightly-bedded *conglomerate*. It is overlain by *cross-bedded, pebbly sandstone* which indicates north-eastern flow direction. Above the latter, conglomerate and (again) sandstone beds can be seen. Pebbles are made up of *quartzite, metasandstone* and *acidic volcanic rocks* (i.e. dacite) of red or grey colour; grains are cemented together by siliceous-kaolinic cement.

The considerably poor fossil record is represented by petrified tree remains; nevertheless, spores are relatively frequent.

The “new red sandstone” of general areal extent in the area of the one-time Pangea was deposited in semi-arid environment about 250–260 million years ago.

The sandstone of Permian age is the most popular building stone in the vicinity of the Lake Balaton. The soil formed on it yields excellent and characteristic wines.

Balatonfüred, Koloska Valley and Lóczy Cave (G-26)

These formations are among the most popular beauty spots in the vicinity of Balatonfüred. Starting from the Lóczy Cave—which has been made accessible to the public—visitors may get acquainted with these geological values.

The *Koloska Valley* basin of variable width is one of the most beautiful examples of a topography which closely fits the geological build-up. The brook—fed by a *vaucclusian spring* of the valley—cuts through the *Péterbegy* range in a narrow valley. Above the gorge a wide marl basin came into being, in which long, narrow and rocky ridges rise above the surface providing an excellent example of selective erosion. At the Koloska Spring there is a 50-m-high rock wall.

Walking up the valley one can get acquainted with most part of the Middle and Upper Triassic successions of the Balaton Uplands, i.e. from the Anisian dolomite to the *Füred Limestone, Veszprém Marl, Sándorbegy Formation* and the *Main Dolomite*. The geological, botanical and zoological values of the area can be studied along a nature trail.

The *strictly protected Lóczy Cave* (see below) can be found on the outskirts of Balatonfüred which is famous of its spring providing curative acidic water. The 150-m-long, 20-m-deep cave, possessing unique features, has been named after geologist Lajos LÓCZY sen. who was the world-famous researcher of the Lake Balaton in the last century. The cavities—which came into being by the solution effect of thermal water in the well-bedded Füred Limestone (quarried for building stone in the area)—have been made accessible to visitors by a local master joiner already in 1933.



He used his own assets for the purpose. Currently the renovated cave is under the management of the Applicant and is visited by 15 thousand tourists every year. The halls—formed in the tilted limestone beds—, the weathered-out chert nodules, solution pockets, chimneys and the ‘*Lejtős Passage*’ (which was formed in the curved beds of the fold axis), are very spectacular. A nature trail starts from the cave to the lookout tower on the top of the *Tamáshill*.

Bakonyzúcs, Odvas-kő and its caves (G-27)



It is a crag located in one of the tributary valleys of the *Gerence Gorge*, in the foreland of the highest peak (Kóris-hegy, 709 m a.s.l.) of the Bakony. It was named after its caves and caverns. The *Benedictine abbey* of the nearby *Bakonybél* was founded by Saint Stephen the first king of Hungary, in 1037. The earliest reference to a cavernous place in Hungarian language is the name ‘*Oduaskw*’, which can be found in the copy dating from 1230 and providing the description of the property which is included in the deed of gift.

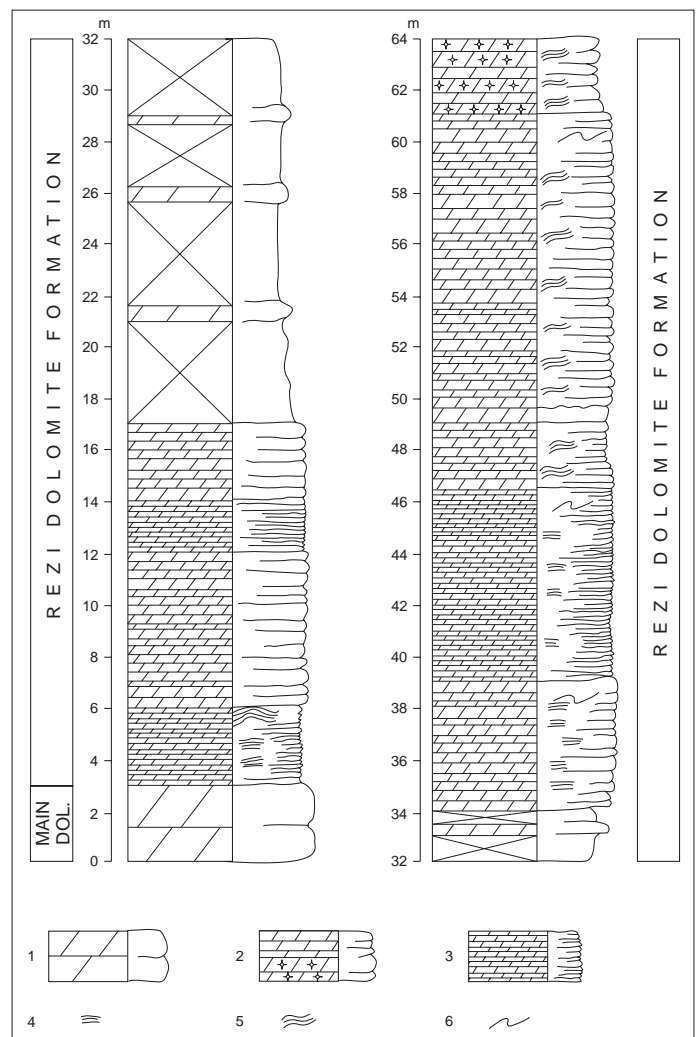
The cliff in the *High Bakony Landscape-Protection Area* is part of a tectonic thrust fault zone; the beds of the Upper Triassic *Main Dolomite* are almost vertical. During the Pleistocene cavities and caves were formed in the rock. The largest among them is the strictly protected *Odvas-kő Cave* (its length is 30 m, see above). *Archaeological excavations* in the cave-filling sediments have been carried out for more than a hundred years: traces of fireplaces, few remains of earthenware pots and a tooth of the cave bear have been found. On the other hand, the nearby *Odvas-kő cavity* yielded a large number of *bear bones*. The third cavern, i.e. the *Odvas-kő rock shelter* was proved to be barren.

The group of rocks is valuable in a botanical point of view, too. Despite the cool-wet climate of the mountains, the microclimate of the strongly exposed valley side facing to the South—due to the strong sunlight—is very dry and much warmer than that of the surrounding areas. It is well indicated by the island-like appearance of oak trees in the beech forest. Due to the permanent water shortage, the height of the approximately hundred-year-old trees with thick trunks is only 5 m. Next to the spacious entrance of the *Odvas-kő Cave*—which opens to the NW and descends inward—large icicles and ice columns are formed in winter. The caveman did not settle here permanently—probably due to the unfavourable microclimate. Nevertheless, in the cave-filling sediments of the *Öreg-Szarvadarí Cave*, which is located in the bottom of the valley and is under special protection, a chipped stone tool was found accompanied by the fossil bones of several animals of Pleistocene age.

Key section of the Rezi Dolomite, hydrothermal caves (G-28)

The key section of the Rezi Dolomite is found directly at the foot of the walls of the *Rezi Fortress* which is considered to be a popular beauty spot. The extremely steep path up to the fortress is made up of the series of escarpments of this rock. The *Keszthely Mountains* are built up predominantly of *Upper Triassic rocks*. During the Middle Norian the large carbonate platform of the Tethys Sea was dissected by tectonic movements, and small basins came into being in its area. The *Keszthely Mountains* was part of such a basin.

Three members can be distinguished within the *Rezi Dolomite*. Its lower part is represented by well-bedded, locally brecciated, frequently laminitic, strongly bituminous dolomite. Locally it is dissected by chert laminae. Its exposure in Vállus yielded a monospecific conodont fauna of high specimen number. The middle member is made up of thick-bedded, porous-cavernous, occasionally brecciated, usually bituminous dolomite containing fossil molluscs and dasycladaceans. The upper part



Key-section of the Rezi Dolomite at the Rezi Castle. LEGEND: 1. Thick-bedded to unbedded dolomite, 2. Thin-bedded dolomite, cavernous, cellular dolomite, 3. Laminated dolomite, 4. Lamination, 5. Folded laminites, 6. Slump

is built up of bituminous, laminated and subordinately cherty dolomite; the overlying *Kössen Formation* develops from the latter through a 50-m-thick transitional succession.

The profile beneath the Rezi Fortress exposes the lower section of the Rezi Dolomite. The 60-m-thick succession is made up by dolomite characterised by contorted laminae and slumps. The uppermost few metres are built up of very thick-bedded, porous dolomite which belongs to the middle member.

West of the key section, at the end of the protruding rock (that descends from the fortress) a unique feature of thermal water karstification in the *Keszthely Mountains* can be seen. Due to the solution effect of the warm water—rising up to the surface during the Pleistocene—several caverns and caves came into being in the dolomite; they have been exposed on the surface by the erosion of the hillside. The remnants of linked spherical niches of a diameter of a few metres form a spectacular cave passage near the path. Going further towards the East, the oval-shaped entrance of the *Rezi Cave*, formed by solution processes and situated at the foot of the rock wall, leads into a smaller thermal water labyrinth which comprises several halls. This is the only place which is accessible to tourists to see these peculiar thermal karst forms.

The karst area of the Tés Plateau (G-29)

The central part of the *East Bakony* is made up of a *continuous karst terrain* which is nearly 20 km long and 3–5 km wide, and from the West towards the East its height decreases from 500 m to 300 m a.s.l. Its western half is called *Tés Plateau*, and in the East it is joined by other spectacular karst terrains. The area—which underwent peneplanation—is predominantly made up of Triassic *Main Dolomite* and less *Dachstein Limestone*. These rocks are overlain by the patches of the Oligocene gravel and the Pleistocene loess blankets which represent the relatively thin cover sediments. However, on the north-western part of the area Cretaceous formations crop out at the bottom of the erosional tributary valleys

of the Gaja Brook. The Tés Plateau can be described as follows: it is full of holes, since—according to surveys—*more than 150 sinkholes and dolines* are deepened into the almost flat surface. Beneath most of the karstic hollows – of a predominant size of about 10 m—inflow caves open. Besides this inclined passage network (formed by the dissolution of rock along the bedding planes) locally, more than 100-metre-deep,



vertical shaft caves extend down to the karst water level. The strictly protected *Csengő, Bongó* (see on the left), *Háromkürtő* and *Jubileum avens* possess especially spectacular solution forms. At the same time these are huge, vertical natural exposures. Waters infiltrating the surface of the plateau appear partly in the valley system of the *Gaja Brook* and partly on the southern side of the mountains where they feed the mega springs in the vicinity of *Bánta* and *Inota*. The number of caves listed in the cadastre is of the order of hundreds. Their total length exceeds 5 km.

Monoszló, the volcanic neck of the Hegyestű, geological exhibition site (G-30)

For the moment, the abandoned basalt quarry of the Hegyestű, which is located only a few kilometres from the Lake Balaton, is *one of the most important geological exhibition sites* of the proposed Bakony–Balaton Geopark (see at the bottom of the page). The mining area—developed on the hilltop—is the memory of an *early success of the Hungarian nature conservation*, as the quarry was not opened on the side that is facing the Lake Balaton; therefore the hill—watching from the lake shore—has retained its original, natural shape.

The 336 m peak of the *Hegyestű* rises more than 200 m high above the shore of the Lake Balaton. The *basalt peak* steeply rises above the approximately 300-m-high Triassic surface. In the course of quarrying the peak was almost cut in half, thus the internal structure became visible. The nearly 30-m-high wall of the disused quarry is entirely made up of basalt (more precisely *basanite*) characterised by *columnar jointing*, and this is *one of the most beautiful and spectacular occurrences in Hungary*. Based on the latest $^{40}\text{Ar}/^{39}\text{Ar}$ dating measurements the melt got cooled on the surface 7.94 million years ago, that is to say not more than 20 thousand years after the first explosions of the intercontinental basalt volcanism in Tihany. The diameter of the vertical columns is 10–45 cm. The upper section of the basalt is characterised by a *vesicular structure* which indicates a *wet environment* during the explosion. The Hegyestű's neck has been formed from the melt that had filled up the vent and crater of the strongly-eroded volcano. On the lower, northern side of the quarry basalt clasts of a vesicular texture can be seen in a *strongly palagonitized*

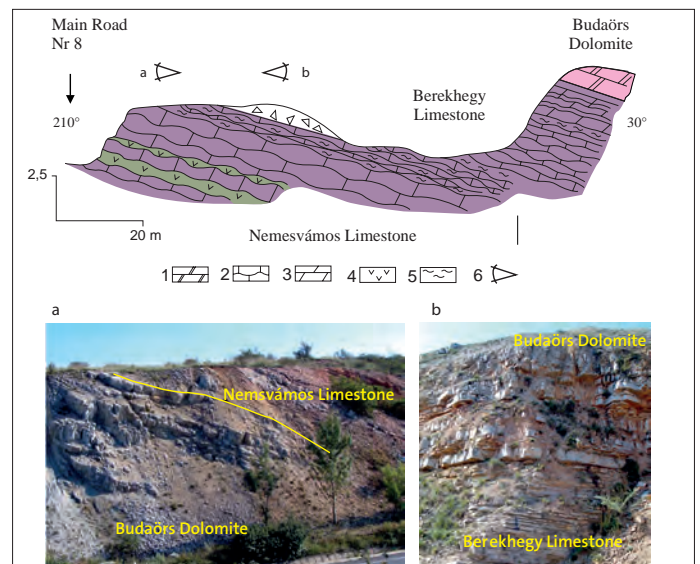
matrix. This *tuff breccia* may have been formed in a high-temperature environment abounding in water, within the surrounding basalt body that is characteristic of the entire quarry.

From the top of the Hegyestű visitors can have a 360-degree panoramic view; the ‘Somogy’ (Sothern) side of the Lake Balaton, the Balaton Uplands, the Bakony and the Keszthely Mountains are visible from here.

Not only the geological build-up and geological history of the Balaton Uplands, but the flora and fauna and the memories of the former quarrying are illustrated by a small exhibition on the exhibition site, as well. Outdoors, visitors may get acquainted with the *most typical rocks of the Transdanubian area* in the form of multi-ton boulders. At the same time, the Hegyestű may offer space for the *prospective visitor centre of the Bakony–Balaton Geopark*.



Hajmáskér, Berek-hegy Limestone near Main Road No. 8 (G-31)



Geological cross section of the Berek-hegy (Berek Hill) between the Main Road No. 8 and the quarry (after BUDAI 2006). LEGEND: 1. thick-bedded dolomite (platform carbonate); 2. nodular limestone (basin facies); 3. dolomitized limestone; 4. volcanic tuff, tuffite; 5. marl; 6. observation point

The *Veszprém Plateau* represents the interfingering area of the pelagic basinal sediments characteristic of the south-western part of the Bakony (Balaton Uplands), and the Middle Triassic shallow-marine sediments of the north-eastern part of the Transdanubian Range. Its most spectacular exposures are found in the road-cuts of the Main Road No. 8. The most detailed-studied profile is the *Berek Hill* road-cut near Hajmáskér and the quarry which is located above it in a stratigraphic point of view.



The succession of the exposure on the southern side of the main road starts with the Upper Anisian *Vászoly beds*. Their nodular limestone of basin facies is overlain by the lower part of the shallow-marine platform carbonates of the *Budaörs Dolomite*. The well-stratified, thick-bedded dolomite is overlain by tuff with a greenish tint. It underwent slight clayification. Upwards red, clayey, nodular limestone beds (*Nemesvámos Limestone*) can be seen, which belong to a younger, i.e. the Ladinian stage of the Middle Triassic. Pelagic bivalves (*Daonella*) and ammonites (*Eoprotrachyceras*, *Protrachyceras*, *Arcestes*) are relatively frequent in this succession which was deposited in a several-hundred-metre-deep pelagic basin.

The succession that overlies the Nemesvámos Limestone and is built up of the cyclic alternation of well-stratified, thin-bedded, light beige limestone and marl is exposed in a small quarry of the Berek Hill. The limestone layers are made up of carbonate debris showing an upward-fining trend within the layers; in the lower part of the beds clasts of a size of 1–2 cm can be observed. This characteristic oriented sorting (gradation) and the fossil assemblages of the carbonate grains indicate that the material of the individual limestone beds is derived from a shallower environment and it was transported into a deeper sea basin. On the limestone bedding-planes tortuous sedimentary structures—indicating wormholes—and scattered ammonite impressions (*Celtites*) can be observed. Beds of the overlying Budaörs Dolomite indicate that at the end of the Middle Triassic carbonate platforms prograded towards the increasingly shallower sea basins; this was resulted by the global sea-level drop.

The detailed palaeontological and sedimentological studies on the succession of the quarry yielded significant data for the international research on the boundary between the Middle and Upper Triassic and for the development of Triassic sequence stratigraphy in Hungary. The quarry was shown in several *international field conferences*.

Csesznek, Fortress Hill (G-32)



The *medieval fortress*, which attracts several tens of thousands of visitors every year, has been built on the E–W-oriented blade of a *large-scale tectonic overthrust* of Miocene age. On the wall of the gate-bastion (carved into the bedrock) the fault-striated surface of the Middle Eocene limestone and the Upper Triassic *Dachstein Limestone*—which have become “smeared” onto each other—is clearly visible. The combination of the overthrust and the right-lateral strike-slip fault resulted in

the formation of the 50-m-long and 10–15-m-high rock wall of the ridge that is located W of the fortress.

Several *caves*, *solution cavities* and decaying, tube-like *passage-remains* can also be seen in the wall. Their palaeokarstic origin is proved by conglomerate fillings in them.

The *Kőmosó Gorge* (see above), which cuts through the ridge, has been deepened by the brook as a result of *tectonic uplift*. Movements are still going on, and the watercourse flows down over several-metre-high rock steps into the hollowed rock pools forming waterfalls. The gorge is only 200 m long but its depth is 50 m. With its precipitous, rocky walls and bedrock-paved stream-bed it is a spectacular morphologic feature. Caves open on its both sides; one of them has yielded archaeological finds.

Another geological curiosity is the disused quarry designated for parking; its *Eocene limestone* wall reveals an overturned fold.

The strong microclimatic effect of the Castle Hill’s sharp crest is well-indicated by its vegetation. Its shaded, cool northern side is covered with beech trees, whereas 20 m away, the treeless rocky grassland of the sunny, southern side is flanked by a Mediterranean-like karst shrubfor-

est. The several-km-long gorges of the *Kő-árok* and the *Ördög-árok* are two popular hiking destinations in the vicinity of Csesznek.

Bakonyszücs–Fenyőfő, Százhalom: mound graves, sinkhole, brook meanders (G-33)



The central mass of the Bakony (*Kőrös Hill*) is surrounded by the 5-km-long, epigenetic, strongly meandering valley of the *Száraz-Gerence* (“*Dry Gerence*”), which is worthy of its name; the lower section of the valley is almost always dry; water rapidly seeps away into the karstified limestone bed. Water is carried by the *Ördög-séd* only after thaw or heavy rains. The *Száraz-Gerence Cave* (also known as *Pörgöl Cave*) opens in the middle section of the valley, above the vertical rock walls on the right-hand side. Traces indicating temporary human presence have been revealed by the repeated excavations. The uppermost section of the *Ördög-séd* has been formed on the impermeable succession of the Miocene clayey gravel field. The brook which rises at the *Tekeres-kút* has formed very spectacular meanders along its 50-metre wide, terraced valley floor.

The intermittently active *Meander Sinkhole* (see above) can be seen in the East neighbourhood of the watercourse. Holes had developed in the impermeable cover above the locally uplifted limestone basement; therefore a young sinkhole cave was formed.

The Bakony’s largest *mound-grave field*, consisting of about 220 mounds, is located on the western side of the brook. The name (*Százhalom = Hundred Mounds*) refers to the area. There are usually 1–2-metre-high mounds, of a diameter of 5–10 metres beneath the old beech trees; there are only a few larger ones among them. On the basis of archaeological investigations the graves with cremation urns—belonging to *Bronze Age people*—can be found in the gently-sloping area. The Road of the Monks passes along the mounds; the monks of the Bakonybél Benedictine Abbey walked along this road to *Pannonbalma* in the Middle Ages.

Úrkút Palaeokarst Nature Conservation Area (G-34)

One of the most famous geological exhibition sites in Hungary can be found in the inner area of *Úrkút* village. Since *it has been declared protected in 1951*, millions of people visited this geological curiosity, which has been made accessible by stairs and provided with nature trail information tables. It can be found along the route of the ‘*National Blue Trail*’, which crosses Hungary in an E–W direction. The demonstration of the geological formation and the better understanding of the processes that acted to create it are supported by an *information booklet*.

The unique, 70-million-year-old natural value owes its existence to the fact that the overlying Eocene limestone has protected it from erosion and at the beginning of the last century the accumulated manganese ore was extracted by hand tools. Therefore, the mineral ore-bearing palaeokarstic land-

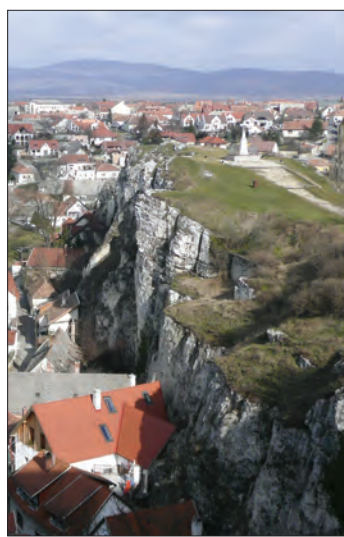


forms have been perfectly preserved. In an area of an extent of a few hundreds of metres series of vertical-walled, cauldron-like *dolines* have been dissolved in the *Lower Jurassic limestone*. They are of a diameter of 30 m and of the same depth. The surface of thresholds and highs between the karstic depressions underwent considerable karrenification. All these took place under the end-Cretaceous tropical climate—similarly to the formation of the footwall of karst bauxites in Hungary. The difference between them is that in Úrkút Jurassic limestone is the rock that underwent karstification and forms were filled with oxidic manganese ore—this gives its uniqueness. The long-term preservation of finer morphologic features (i.e. half-chimneys, solution pockets and shafts and rill channels) exposed on the surface is due to the stability of rock. In other parts of the protected area other geological curiosities can also be found: e.g. one-time submarine fissure-fillings, striae of strike-slip faults, caverns cut in half by faults and a small *cave*.

Besides geological knowledge dissemination, the very spectacular and unique area well serves education as a location of school excursions and university field exercises. Research on the formation of manganese ore (which has not fully understood yet) attracts a lot of scientific experts to Úrkút.

Veszprém: meandering gorge in the town (G-35)

The administrative centre of Veszprém County (wearing the same name) has been made famous by *Queen Gizella*, the wife of Hungary's first king, since it was the centre of her estates. The monuments of the medieval castle, comprising palaces, commercial houses and churches, provide a picturesque view. The thick walls have been erected on a cliff which rises above the Séd Brook. The long and narrow strath terrace of the *Benedek Hill* (see on the right) protrudes from this cliff. One can look far over the ranges and internal basins of the Bakony from here. This unique view is due to the fact that the ancestor of the *Séd Brook* has incised a 50-m-deep valley into the eroded Triassic dolomite of the Veszprém Plateau. Its bed formed several-metre-wide bends on the former surface (covered with pebbly-clayey sediments). Near the present-day Veszprém such a double S-bend was superimposed on the uplifting dolomite bedrock. During the Pleistocene it deepened its valley in these incised meanders. A few-km-long foot path leads through its gorge-like valley, where water mills used to work.



A further beautiful example of tectonic movements is the road-cut behind the viaduct that bridges the valley, where the overthrust of the Veszprém Marl upon the Main Dolomite can be seen. The steep valley-incisions of the adjacent grassy hillside also indicate fault lines.

Jenő CHOLNOKY (1870–1950) the native of the town was a world-famous geographer and a participant in the research on the Lake Balaton. Geologist and museum founder monk Dezső LACZKÓ taught and worked in Veszprém through nearly half a century since 1888. He has found the fossil skull and skeleton remains of *Placobelys placodonta* (flat-plate turtle, see on the left) of Late Triassic age in the quarry of the town.



Darvas-tó Exploited Bauxite Lens Nature Conservation Area (G-36)



Bauxite occurrences in the Transdanubian Range were exploited partly in open-pit mines. Such a *disused bauxite pit* can be found East of Sümeg which is famous of its medieval fortress; later it was *declared a nature conservation area*. The *palaeokarst features* of the underlying Triassic *Main Dolomite* have remained almost intact during the exploitation. Along the bottom of the 500-metre-long open-pit mine the series of large *dolines* and the 10–20-m-high *karstic elevations* and *crests* show the end-Cretaceous morphology. The value of the site is increased by the exposure of the Eocene succession (which directly overlies the bauxite) in the wall of the former mine.

The continental conditions in the Bakony, which started at the end of the Cretaceous Period, lasted for more than 20 million years. It resulted in the denudation of Cretaceous and Jurassic sediments over a large part of the area. Due to the tropical, subtropical climate the exposed Triassic *Main Dolomite* underwent considerable karstification. Several-metre-deep dolines, of a diameter of sometimes a hundred metres, came into being; they became connected to each other and have formed series of dolines.

45 million years ago, during the Lutetian Age transgression occurred. The palaeoenvironmental changes are indicated by the transgression deposits which overlie the bauxite. The organic-rich, clayey sediments of the lagoon are overlain by a fauna-rich, more calcareous bed and upwards by a shallow-marine, Alveolina-bearing limestone and Miliolina-bearing calcareous marl. The succession is topped by the lower, nodular limestone of the *Szóc Limestone Formation*.

The protected area is *regularly visited for educational purposes by students of higher education institutes* who deal with earth sciences and by excursion groups of other schools.

Dörgicse, Kő Hill (G-37)

The Kő Hill—which is located between *Felsődörgicse* and *Kisdörgicse*, SSE of the high road—is made up of a characteristic formation of the Balaton Uplands, i.e. the Upper Triassic (Carnian) *Füred Limestone*. The path leading to the hill starts at a *Baroque stone bridge* and reaches the marked tourist path after 200 m. The latter leads to the upper yard of the abandoned quarry. In this horizon of the quarry the lower, thick-bedded section of the *Füred Limestone* was excavated for building stone and for decorative stone. In a south-south-easterly direction the wall of the disused quarry continues in a cliff above which the most beautiful *karrenfeld* (limestone pavement) can be found in an area of a diameter of some hundred metres. The development of the sometimes half-metre-deep grikes—which densely intersect each other—is associated with the tectonic fracture network.



The upper yard of the quarry exposes the upper section of the *Füred Limestone* which is dissected by marl intercalations and characterised by tabular bedding. Borehole Dörgicse Drt-1 was drilled in this yard in

1985; it penetrated through the succession of the Kő Hill from the Füred Limestone down to the base of the *Tagyon Limestone*.

The hiking trail mark leads from the stone bridge southwards to the some hundred-metre-long antecedent gorge. On the uphill side of the *Kő Valley* (see the photo of the previous page) the Füred Limestone forms a 10–15-metre-high, near-vertical wall showing the alternation of 1–1.5-metre-thick beds and the well-bedded sections—made up of thinner layers—in the succession of the Füred Limestone. In the slope of the gorge there are about a dozen smaller caves indicating the one-time subsurface karstification.

Among the fossils of the Füred Limestone *protozoans* (foraminifers and radiolarians) are frequent. Thin-shelled bivalves also occur, ammonites are sparse.

Fonyód, Fortress Hill (G-38)



The most prominent peak in the southern, flat shoreline of the Lake Balaton rises opposite of Badacsony (233 m). Similarly to the *volcanic remnant hills* in the Tapolca Basin it is—together with the neighbouring *Boglár Hill* on the East—of the same origin (erosional volcanic remnants). Based on radiometric dating on basalt blocks which crop out of the soil that covers the hilltop, *the lava solidified 3.5 million years ago*. However, the origin of this basalt is still not clearly understood: according to some opinions, similarly to the other volcanic remnant hills, it was a single eruption centre. Others

say that the small amount of lava rocks and the lack of pyroclastics rather refer to the remnant of a lava flow. On the basis of petrographic similarities lava may have come even from the Badacsony.

However, this small basalt cap was enough to protect the underlying Pannonian succession from the erosion (see above). The spectacular clay stringers of the abandoned sand pit in the southern part of the town were deposited in the Lake Pannon. Nevertheless, the real geological (and geomorphologic) peculiarity is the vertical collapse on the northern side of the hill. The wave activity of the Lake Balaton eroded the loose sand beds even 150 years ago; situation has changed only after the construction of the railway line. The sometimes still moving, almost 50-metre-high wall of the coast—which stretches over several hundred metres—exposes the beds of the Tihany Formation. The lower part of the profile exposes coarse-grained, cross-bedded fluvial sand with reworked mollusc shells and clay clasts in it. It is overlain by a succession of cyclic structure made up of beds of coastal facies which are dissected by paludal horizons.

A walkway has been built along the coastal edge of the bluff top. The panorama from here provides probably the most spectacular view of the Lake Balaton. Opposite to this place almost all volcanic remnant hills of the Tapolca Basin can be seen. The Keszthely Mountains rises in the north-west, whereas north-eastwards our gaze wanders even beyond the Tihany Peninsula. One of the historic buildings of the landscaped walkway houses the permanent exhibition which shows the Lake Balaton and its vicinity. The natural history material illustrated with plentiful photos and figures makes visitors acquainted with a great variety of aquatic and terrestrial habitats. Fossils, maps and the rocks in a sand table provide insight into the geological history of the area.

Pénzesgyőr, Kerteskő Gorge (G-39)

The *Gerence Brook*—which flows westwards from the *Pénzesgyőr Basin*—cuts through a few-hundred-metre-long but rather spectacular gorge towards *Bakonybél*. In times past the ancestor of this brook flowed through the Miocene gravel blanket, which overlies the Mesozoic rocks of the area. Due to the Quaternary uplift of the area the bed of the brook was superimposed onto the underlying Cretaceous limestone and meandered its way through this rock, cutting deep into it. The valley is located in the *High Bakony Landscape Protection Area*. It is surrounded by



vertical cliffs of a height of several tens of metres. The well-bedded *Lower Cretaceous limestone* is dissected by numerous faults indicating strong tectonic effects. Erosion has widened the vertical cracks into crevices; characteristic rock ribs can be seen on the walls.

The rocks of the southern side of the gorge were uplifted by these tectonic movements, which resulted in the formation of a perched karst water table. The water of the Judit Spring rises up to the surface at the contact of the impermeable Cretaceous clay with the overlying *Zirc Limestone*.

Carbonate precipitation from the karst water resulted in the formation of a series of small *flowstone terraces* along the steep slope; small waterfalls make beautiful additions to the valley-side above the Gerence.

According to tradition, the rock pinnacle of semi-cylindrical shape of the neighbouring *Oltár-kő*—as its name suggests—was a place of sacrifice of the conquering pagan Hungarians.

The *Szömörke Valley* with a special atmosphere represents the lower continuation of the gorge. It leads tourists to Bakonybél. Here goes the tourist path named after a 19th-century famous Hungarian naturalist of the Bakony area (i.e. Flóris RÓMER).

„Basalt street”, Kovácsi Hills (G-40)



This geosite can be found near *Vindornyaszőlős*, on the western margin of the basalt hills that form the northern part of the *Keszthely Mountains*, in the area of the Balaton Uplands National Park. The alkaline basalt volcanism of the *Kovácsi Hills* is different from the processes common in the area of the Transdanubian Range and in the Little Plain. Most of the 3.4–2.7-million-year-old volcanic bodies have been trapped beneath the surface in a small depth and could not penetrate the entire succession which had been deposited in the Lake Pannon. Basalt became exposed on the surface after the denudation of the Pannonian sequence (which is made up of loose sediments) and in several quarries the network of sills and dykes can still be studied; its best exposure is in the abandoned quarry in Sümegprága.

The exceptionally spectacular Basalt street was formed during the Quaternary in connection with processes that led to the *erosion of the Pannonian succession*. The basalt—overlying the loose Pannonian deposits frequently dissected by impermeable clay layers—is more resistant to all exogenic processes of weathering than the neighbouring beds, therefore it rises above the surrounding area with steep slopes. The slopes are frequently affected by *landslides* occurring along the clayey Pannonian beds; both the sedimentary succession and the basalt are represented in these processes.

The Basalt street represents the largest, long-stretching form of such a type of mass wasting. It borders the edge of the Kovácsi Hills on the West about along a half-a kilometre-long curve. A ditch-like form—which is

wider than 10 m and locally is of a similar depth—came into being due to the displacement of rock masses. It is lined with houses and resembles a street. Its uneven surface is hardly passable due to the huge collapsed and displaced boulders. Displacement resulted in the formation of hardly-accessible crevices in the basalt. Such a pseudo-tectonic cave is the *Vadlány-lik* in Vindornyaszfőlős. The unique natural assets are well represented by the *nature trail* that starts in *Vindornyaszfőlős*.

Pécseley, quarries on the Meggy Hill (G-41)



The *Meggy Hill*—which is made up of the Upper Triassic (Lower Carnian) *Füred Limestone*—rises in the centre of the *Pécseley Basin*. The crest of the Dobogó Hill of the Middle Carnian *Nosztor Limestone* stretches North of it. The Pécseley Basin is located between the ridges and was formed on the soft layers of the *Veszprém Marl*. The southern rim of the basin is bordered by the Middle Triassic range of the *Ágas-magas*. This “wavy” surface is an excellent example of the impacts of selective erosion.

The disused quarries of the Meggy Hill can be reached from the main road. The most spectacular wall exposing the upper section of the *Füred Limestone* can be found at the eastern end of the series of pits. The north-eastward-dipping succession is made up of the rhythmic alternation of 1–2-dm-thick limestone beds and the intercalating thin marl layers. Due to this tabular bedding the rock can be easily quarried, therefore the *Füred limestone* is one of the most popular pedestals and curb stones in the Balaton Uplands. The light grey limestone is dissected by strips and elongated nodules of dark grey chert. Fine striae can be observed on the limestone escarpments, which indicate horizontal displacement of the beds which had been broken due to tectonic effects. Finding fossil costate bivalves (*Halobia*) and ammonites (*Trachyceras aon*, *Dittmarites rueppeli*) on the nodular bedding-planes involves luck. Detailed palaeontological investigations (on radiolarians and conodonts) have proved that the *Füred Limestone* belongs to the Lower Carnian and its age is about 228 million years old.

Ajka, Padrag cliffs (G-42)



Padragkút is a district of the town Ajka which is known for its former coal mining. The considerably spectacular cliff formation rises above both sides of the dry bed of the nearby ephemeral watercourse. Because of its geomorphologic value, the formation—favoured by the tourists—has received local protection.

It is made up of the well-bedded, Middle Eocene *Szőc Limestone*. It contains the fossils of gigantic protozoans, i.e. nummulites. The most well-known among them is the lentil-like *N. perforatus* and the flat disc-shaped *N. millicaput*. The colloquial name for the latter—due to its coin-like shape—is *Saint Ladislaus's coin*; moreover, a folk legend is attached to it. Besides these fossils, numerous—mostly microscopic—extinct, calcareous unicel-

lular organisms represent the diverse palaeobiota that inhabited the subtropical shallow-marine environment 50 million years ago. Bivalves, gastropods and echinoids belong to the larger fossils; therefore they are less frequent here.

The *Padragi-víz creek* deepened a short, antecedent valley section into the rocks during the Pleistocene. The north-eastern side of the rock mass forms a rock ledge which steeply bends downwards. Above it, the surface water—filtering into it along the bedding planes and fissures—formed some-dm-large cavities and short cave passages by the dissolution of the limestone. The path which leads up to the cliff continues along the forest edge; the panorama from here provides a spectacular view over the plain of the Bakonyalja and the solitary volcanic remnant hill of the Somló. The southern group of the Padrag cliffs rises above the surface on the other side of the valley, forming a vertical rock pillar. The huge rock walls with their weathered, smooth surfaces make interesting impressions. The rock mass with an almost vertical wall on one side is penetrated by several faults, along which narrow fissures have been incised into it. A boulder protruding several metres from the top of the wall is especially spectacular. The surrounding rock mass has already collapsed forming huge stone crests, set on their edge, on the hillside.

Bakonynána, Roman Bath: gorge with waterfall, cave, geological key section (G-43)



The formation of a peculiar name is not related to the Romans; however, archaeologists have found brick remains of this age near the neighbouring village of *Bakonynána*. The most significant watercourse of the East Bakony, i.e. the *Gaja Brook* has formed a 2-km-long, meandering *epigenetic gorge*. The brook, cutting a 50-m-deep valley into the *Cretaceous limestone*, is flanked by rocky sections. Its wildest part is called ‘*Roman bath*’; it is characterised by small waterfalls in the potholes of the rock steps, but during floods awesome swirling water is found here. A graphic description of the cauldron was published in a popular science book already in 1860.

A further natural curiosity is the cave that opens 10 m high above the brook in a well-stratified, thick-bedded limestone. According to the legend, the 12-metre-long hollow was the hiding place of Jóska SOBRI, one of the famous outlaws in the Bakony. It is hardly accessible on a narrow rock ledge.

In the romantic part under the waterfall near the *Vadalmás spring*, a small rest area has been established for tourists who often arrive here while hiking along the route of the ‘*National Blue Trail*’.

In a road-cut on the way to the parking place above the gorge a geological key section has been established. The rock wall exposes the transition of the Cretaceous *Zirc Limestone Formation* to the overlying *Pénzeskút Marl*, which were formed in near-shore environments. The lower succession is made up of greenish-grey, glauconitic, fine-sandy beds containing coalified plant remains, echinoid fragments and worm-tube fillings. The boundary between the two formations has been drawn on the basis of foraminifer investigations. Some of the marly-clayey beds in the upper, few-metre-thick section contain rich macrofauna (*Ammonites*, *Belemnites*, *Echinoidea*). *Ammonites* derived from the vicinity of Bakonynána have already mentioned in HAUER’s 1861 dissertation.

The Vadlány-lik cave in Gyenesdiás, key section of the Diás Formation (G-44)



The small cave—located on the top of the steep, western slope of the hill that rises directly in the outskirts of Gyenesdiás—drew the attention of geoscientists (who worked in the area) already long ago. The hill is situated on the southern edge of the Keszthely Mountains. Everywhere in its background the Upper Triassic dolomite crops out to the surface; however, the hill itself is built up of conglomerate beds which are made up of dolomite breccia and dolomite pebbles. The cave was formed in this succession.

The succession which builds up the hill was deposited along the shore of the Lake Pannon during the Late Miocene. Its material is derived from the dolomite debris that had been transported into the lake shore-zone from the marginal slope of the Keszthely Mountains which stood out like an island from the Lake Pannon. The debris has been partly reworked by the wave activity; clasts became medium- to well-rounded pebbles, and were formed into sorted beds. However only a part of the debris could have been reworked by wave action, therefore gravel beds are found only above a few debris beds. In the area of the Transdanubian Range, the name “Diás Gravel”, referring to the abrasional gravel, breccia and conglomerate beds of the shore-zone of the Lake Pannon, comes from this locality; this exposure is the key section.

Detailed examinations on the origin of the small cave—located on the hillside, directly beneath the hilltop—have not been carried out, yet. Bulla (1928) mentioned it in his work as an abrasional cave that had been formed on the shore of the Lake Pannon. However, this would mean that an 8-million-year-old surface form has been preserved almost intact, moreover, in a slightly-cemented rock. The path leading to the cave reveals such conglomerate beds which are cemented by sparry calcite. The latter and the harder “rock cap” of the hilltop indicate ascending warm water. Hence, this suggests that the formation of the cave is due to subsequent processes related to ascending warm water.

“Cockpit karst” near Zirc (G-45)



Tourist may find unique, cone-shaped rock features nearly 1 km to the NW of the so-called ‘Aklí’ district of Zirc. Walking through the small forest patch of the Köves Hill, it is prominent that there are two, approximately 1-kilometre-long, parallel limestone outcrops. The distance between them is 50 to 100 metres. Isolated cones and rock crests rise from

the almost flat surface. The ground-plan of the limestone protrusions, lining up one after the other, is more or less an elongated ellipse of a diameter of 10–50 m and of a height ranging from 5 to 20 m. Mound-like, elongated forms are seen between the isolated cones. On their steep hillsides, frequently with boulders staggered on them, locally several-metre-high, vertical (subordinately concave) surfaces also occur. Locally they are thick-bedded (0.5–1.5 m), however, the chaotic appearance is more typical; it is interspersed with slip planes (of a size of a few square metres) characterised by striae, reverse fault planes and fault lines. Old linden-trees can often be found on them, enhancing the dark green colour of mosses which cover the light grey rocks.

The material of the cones belongs to the Lower Cretaceous Zirc Limestone Formation; it is indicated by the thick-shelled bivalve shells which have been weathered out on the dissolved surfaces. Formerly the rock was named after them: “Requienia-bearing limestone”. It is prominent that—with few exceptions—these strange landscape features are predominantly characteristic of this rock type. Similar features can be found only in three sites in the surroundings (i.e. South of Pálibálás, on the Ibaros-tető in Pénezgyőr and on the Mester-Hajag in Hárskút). Such forms are unknown in other karst areas of the country.

The development of the strange rock features have not clearly explained, yet. They may have been formed due to the exhumation and further recent karstification of palaeokarst terrains. The underlying clayey succession (Tés Clay Marl Formation)—being impermeable, loose sediment—and tectonic processes (manifested in striae and brecciated-crushed zones) probably played an important role in their formation. Karst water lenses “leaning” on the clayey aquiclude are tapped by small, intermittent karst springs at the foot of the limestone outcrops. Precipitation of calcareous tufa from the water of the small brooks occurs, coating the pieces of wood lying in the bed. Such a precipitation can be seen at the western end of the area, where a periodic waterfall has developed, which flow down over a few-metre-high scarp.