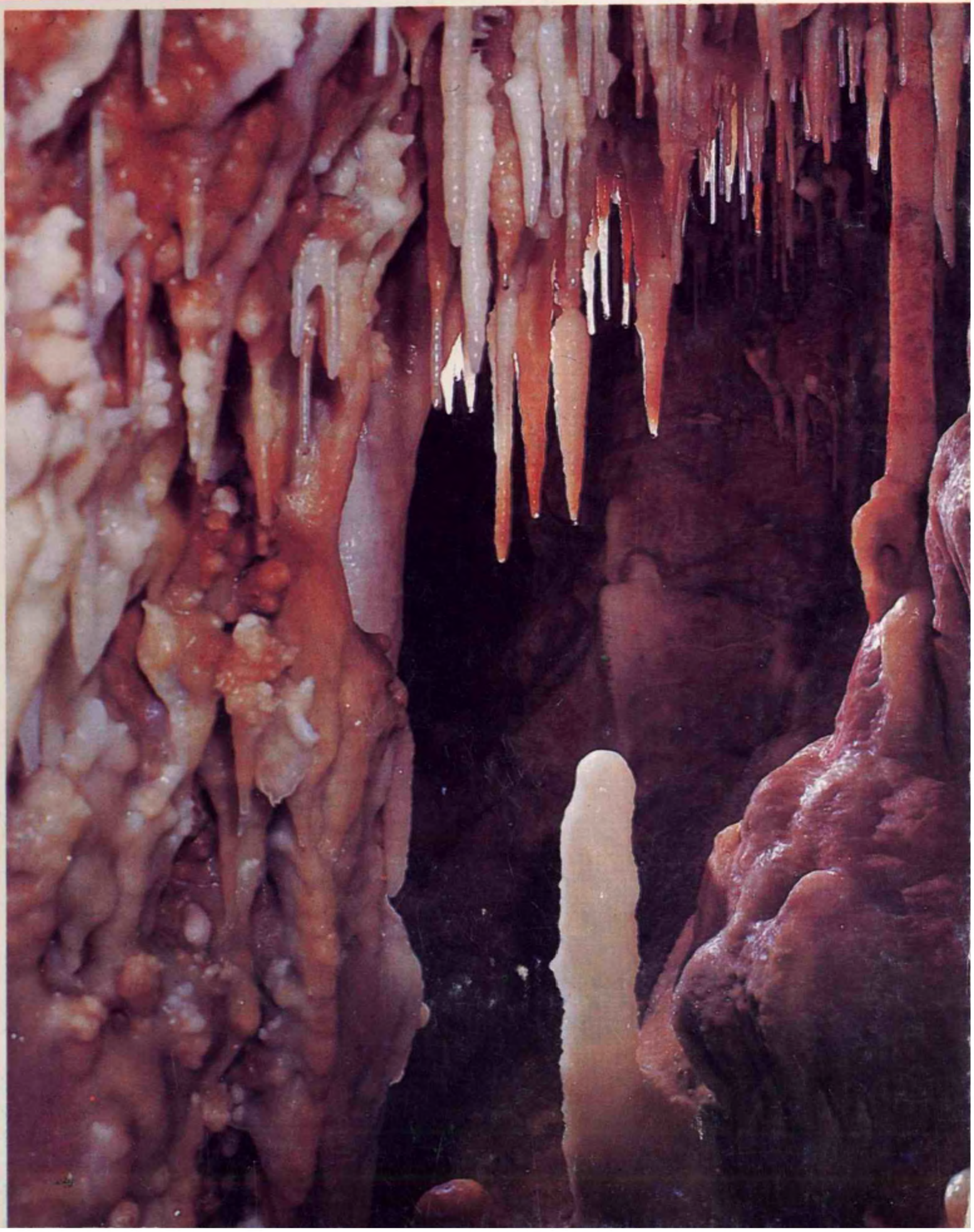
KARSZT és BARLANG

KIADJA A MAGYAR KARSZT- ÉS BARLANGKUTATÓ TÁRSULAT



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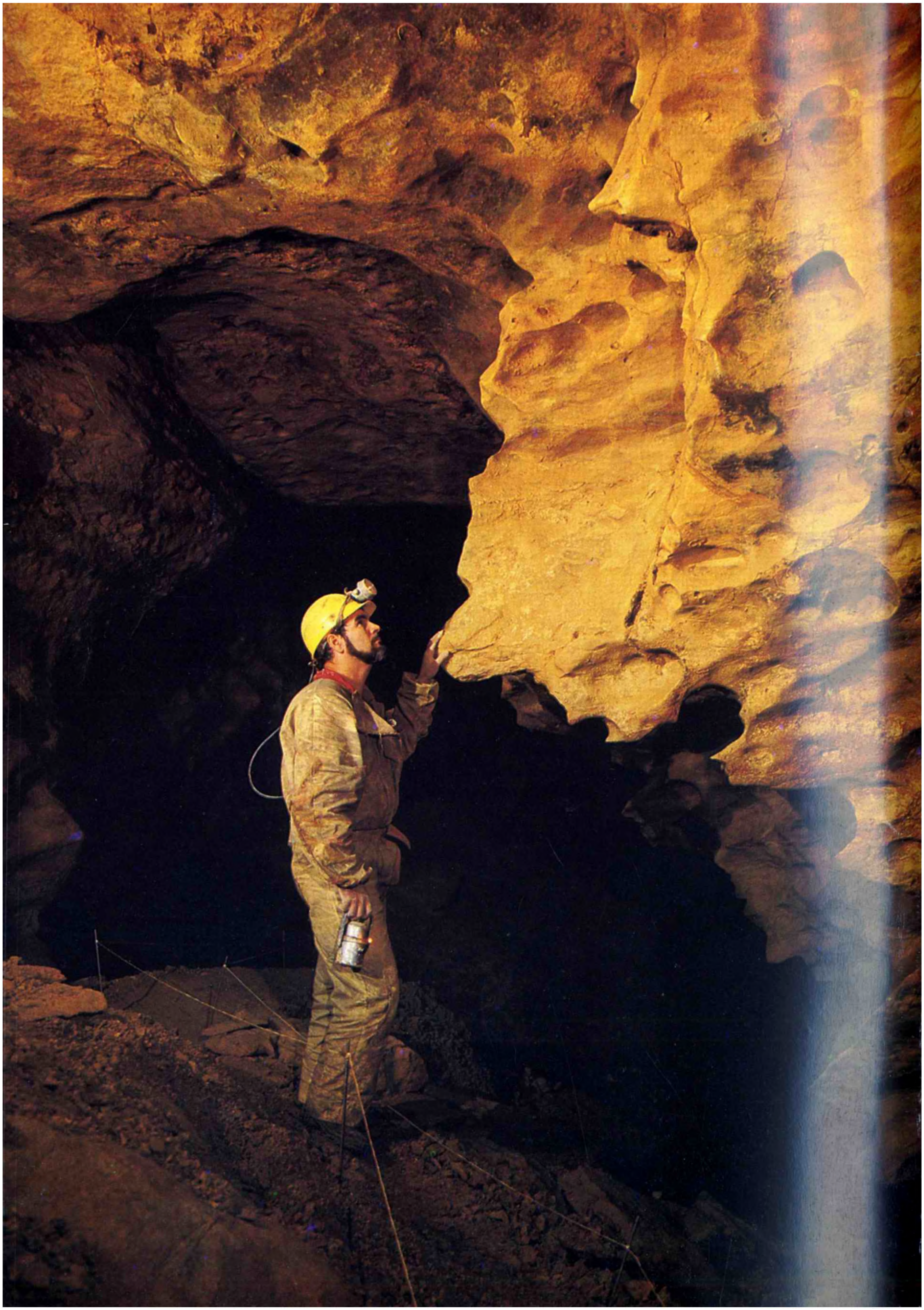

KARST and CAVE

BULLETIN OF THE HUNGARIAN SPELEOLOGICAL SOCIETY

SPECIAL ISSUE

ON THE OCCASION OF 10TH INTERNATIONAL SPELEOLOGICAL CONGRESS HELD IN HUNGARY 1989

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Cover photo: Danca Cave, Aggtelek Karst (by L. Gazdag)
Photo on the left side: solution forms in the Pál-völgy Cave (by P. Borzsák)

INTRODUCTION

The members of the Hungarian Speleological Society, the Hungarian speleologists, welcome the participants of the 10th International Speleological Congress to Hungary. We believe that the historical traditions and scientific results of Hungarian speleology guarantee the high quality of information provided to cave explorers who visit Hungary from all parts of the world.

Speleology has existed for more than two centuries in Hungary. Brought up on this tradition, at the turn of this century numerous outstanding experts undertook research in cave exploration, in archaeological excavations, in geological, geomorphological, karst hydrological and speleoclimatological investigations and in many other disciplines. These activities were greatly influenced by the achievements of speleological research in Europe. As a consequence, scientific speleological research intensified in Hungary, and in 1910 the Speleological Committee and in 1926 the Hungarian Speleological Society were organized for the purpose of coordinating these efforts.

The most important achievements in almost eight decades of institutional cave research in Hungary are presented here. We maintain close links with almost all of the speleological institutions of the world. The big international meeting of speleologists takes place at a date when the flow of information can hardly be followed and therefore the exchange of information is becoming indispensable. Our congresses have to take an increasingly more active part in this process.

Motivated by restructuring in the global economy and by the progress of the sciences in the final decades of the 20th century, the application of scientific results has accelerated enormously. This also applies to the field of karst research and speleology. The world-wide development of tourism now connects continents and the role of karst objects and caves is spectacular in this. Besides the traditional disciplines, interdisciplinary topics are also gaining importance in speleology.

Among others, one such topic is, the problems of the ecological crisis, deeply affecting speleology. The ecological crisis, mainly secondary to environmental pollution, has expanded to a world-wide phenomenon and it does not bypass karst regions. The permanent growth of air pollution and the acidification of rainwater and soils adversely affects karsts and their natural biota. The problem is even more aggravated by the increasing accumulations of various kinds of waste (including toxic waste). In Hungary alone, the annually produced waste amounts to 100 million tons and a considerable part of it is toxic waste. Although a good part of this quantity is detoxified, the amount that reaches the environment is considerable and creates yet another upset to the natural balance. In karst regions the danger is great as the susceptibility of karst to pollution is very high. With water, polution penetrates to great depths very easily, even to the most remote points. At the same time, the process of autopurification is a slow one.

The host country of the Congress provides excellent opportunities to discuss these problems not only on theoretical foundations but also practically, getting acquainted with the processes in Budapest or in the broader environs, in the karst regions of Hungary.

This special issue of our journal "Karszt és Barlang" gives an insight into the results of the research covering the 3,000 caves of the karst areas of our country.

Dr. István FODOR
President

10th INTERNATIONAL CONGRESS OF SPELEOLOGY
BUDAPEST – HUNGARY
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DEVELOPMENT AND EVOLUTION OF KARST REGIONS IN HUNGARY

Dr. Attila Hevesi

I. Location and lithology

Open karst regions only cover 1,350 km² area in Hungary (1.45 per cent of total area). They form a much larger share of the area of low and medium-height mountains (ca 20,000 km² — almost 7 per cent). For this reason and because of their characteristic features and plant associations they strongly influence the landscape of most of our mountains.

Among the limestones the oldest is Carboniferous, while the youngest are of Pannonian (Upper Miocene) age (Fig. 1). The widest spread karst rocks in Hungary are Mesozoic limestones and dolomites, particularly of Triassic and Jurassic age. The most important karst regions are situated-in the NE part of the North Hungarian Mountain Range *(Bükk* and *Aggtelek-Rudabánya Mountains)*, in the *Western Mecsek Mountains* and the *Transdanubian Mountains*, which are also rich in Eocene limestones.

II. Evolution

The karsts of Hungary, irrespective of the rock type, fall into two basic groups according to their features:

1. Aggtelek-type karsts

These are little fractured, extensive *limestone plateaus*. They are equally *rich in surface and subsurface karst features*. The latter mostly include *swallow, spring and through caves* or the remnants of these (shafts, passages and rock arches). Besides gorges and lapiés fields on outcrops, other features such as *solution* and *swallow dolines* and uvalas are found on their surface. A small proportion of dolines are aligned on summits, below summits, and on the floors of shallow to medium deep, dry, limestone valleys. *Rows of dolines along valley floors* are the most marked feature of the Aggtelek-type karsts. The forms of Cretaceous-Paleocene paleokarsts have been almost completely destroyed by now. Hollows created by the solution effect of ascending thermal waters and precipitated travertines only occur along the marginal faults. This type includes the type karsts of the Aggtelek-Rudabánya Mountains, of the Bükk and Mecsek.

2. Bakony-type karsts

These are characterised by rows or groups of mountains, dismembered by rectangular fault systems into numerous, more or less isolated limestone and dolomite blocks elevated or subsided into various elevations. They are poor in surface karst features, usually only lapiés fields, sporadically karst marginal ponors, gorges and rarely dolines or doline-like negative forms. The latter are not aligned along valley floors. They are moderately rich in karst hollows of cold water origin and particularly rich (even in the dolomite and marl mountains) in *karst caverns dissolved or transformed by thermal waters*. Travertine deposits from thermal water are also abundant. They have preserved a good part of their Cretaceous-Paleocene paleokarst features — mostly under Cretaceous-Paleocene bauxitic or Eocene coal-bearing sediments. The group includes the karsts of the Transdanubian Mountains (Bakony, Vértes, Gerecse, Pilis and Buda Mountains), the Western Cserhát and the Villány Mountains.

Both the different and the similar characteristics of the two groups are explained by geologic evolution. The Mesozoic and Paleocene histories were substantially identical. Marine sedimentation in a position at much lower latitude (20—35° N) had stopped by the Mid-Jurassic. The folded and imbricated structures of the Early Kimmeridgian orogeny with local overthrusts uplifted in the middle Jurassic and under the hot humid tropical climate *karstic peneplains* developed on the rocks. Peneplanation, karstification and the formation of laterite and bauxite continued undisturbed until the advent of Austrian orogeny (in the Mid-Cretaceous). When this tectonic activity declined, a second phase of these processes began and lasted to the beginning of the Sub-Hercynian orogenic movements (in the Upper Cretaceous). Since our karst regions were located between 25—30° N in the Paleocene and Eocene, next to seas, climate remained favourable.

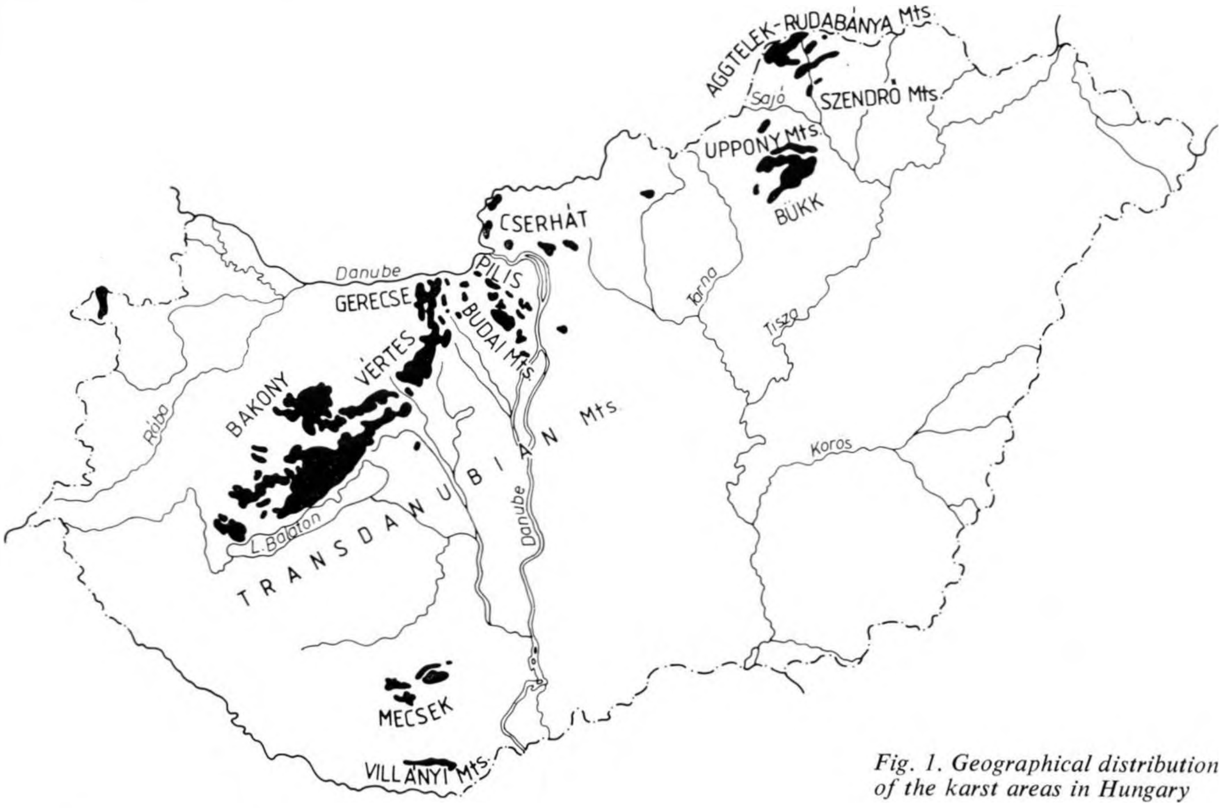


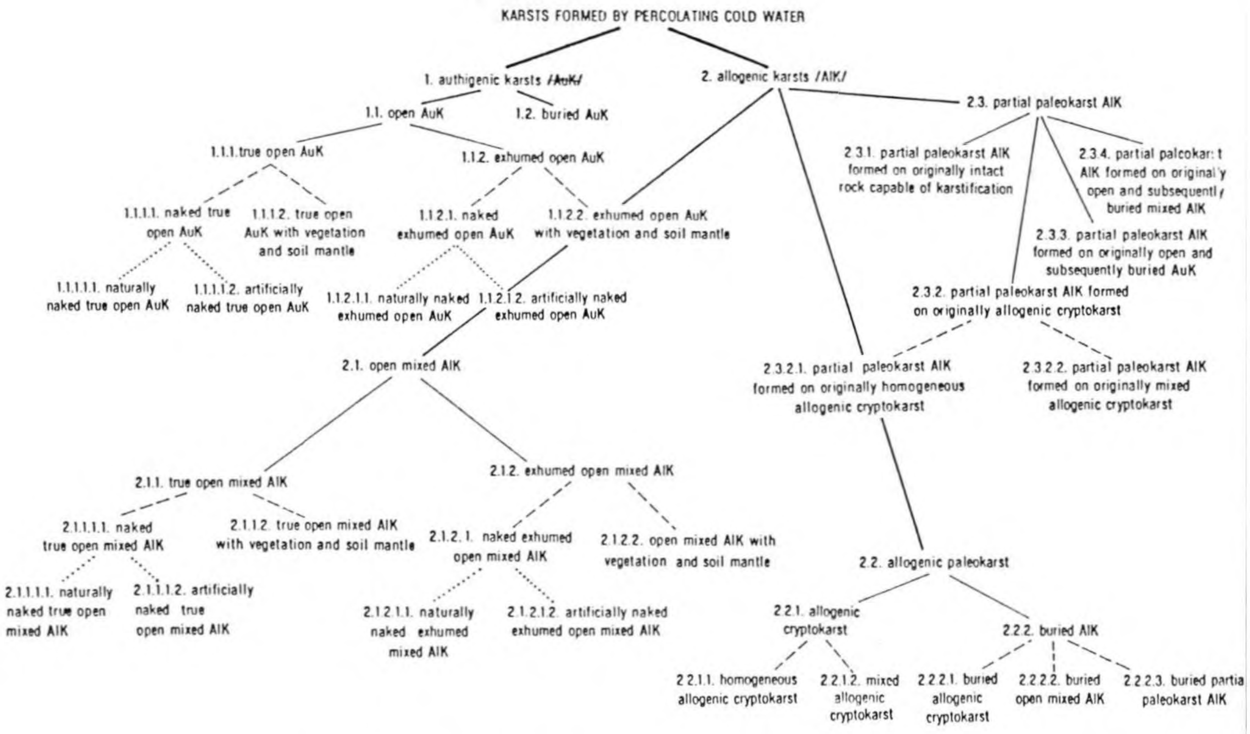
Fig. 1. Geographical distribution of the karst areas in Hungary

Then, however, the processes affected the imbricated and more dissected surfaces left over by Cretaceous tectonic movements.

Cretaceous to Paleocene bauxites have been preserved in the Bakony and Vértes in considerable amounts and smaller patches are also found in the Gerecse, the Buda Mountains, the limestone blocks of the Western Cserhát and the Villány Mountains. Cretaceous kaolinite traces are known from the Keszthely Mountains. The paleokarst features of the open-cast bauxite pits of the Bakony and Vértes Mountains attest to the karst regions being the areas with the most varied topography in the environs of flat planated surfaces in the Cretaceous and Paleocene. The low peneplains were staked by *cockpit and tower karsts* embracing *giant dolines*, intramontane karst levels and coastal karst plains with isolated cones and towers on the margin of peneplains (see Fig. 2). Having close surface and drainage links with their non-karstic neighbourhood, as a whole they must have been *true open mixed karsts* (Table 1, 2.1.1.) with marginal ponors and caves in addition to the mentioned forms. Under the imbrications of thinner, jointed and non-karstic rocks non-independent cryptokarsts formed (Table 1, 2.2.1.), while on top of limestone vaults and imbrications typical open independent karsts (Table 1, 1.1.1.) could form in isolated spots. As deep boreholes have traversed Mesozoic limestones with bauxite and karst hollows in several places, Cretaceous-Paleocene karsts must have occupied much larger areas than remain now.

Since the *Mid-Eocene* the evolution of the two types of karst diverged. Tertiary-Quaternary tectonic movements dismembered the Bakony-type karsts into horsts along an ever denser network of faults, while the Aggtelek-type was much less affected by fractures. The small tectonic units of Bakony-type karsts of chequerboard fault pattern began to move vertically in opposite directions or in the same direction but at different rates beginning in the Mid-Eocene. Consequently, during the marine transgressions from the Mid-Eocene to the late Oligocene, sediments of varying nature and thickness covered the blocks and paleokarsts of the Bakony-type karsts. After regression and uplift the sedimentary cover and the locally exhumed paleokarst were eroded or preserved to various degrees. As a result, the marine transgression from the middle Eocene to the late Oligocene changed the originally typical open mixed non-independent karsts (Table 1, 2.1.1.) into *non-independent karst covered* to various extents (Table 1, 2). After the sea receded, they turned into *partly covered*, locally *exhumde open mixed non-independent karsts* (Table 1, 2.3.).

The less fractured Aggtelek-type karsts were much less affected by sea-level fluctuations. Although it is possible that for a short period of time the whole of the Bükk was submerged under the Upper Eocene sea at its largest extent but it is more probable that it remained land even then. It is a fact, however, that *between the Upper Eocene and Middle Miocene* the Bükk experienced a much



Classification of karsts formed by percolating cold water

longer *land period* and provided a setting for longer denudation than accumulation. There are no traces of early Tertiary sedimentary cover in the Aggtelek-Rudabánya and Mecsek Mountains. Their Cretaceous-Paleocene paleokarsts retained their *typical open mixed non-independent* karst nature all over the Eocene and Oligocene, while karstification went on.

By the late *Upper Oligocene* and *Lower Miocene* both types of karsts had reached their Carpathian locations and integrated into that. Both were *land surfaces* at that time. As a consequence, as attested by borehole data, the area of partly covered and exhumed open mixed non-independent karsts expanded over their present area.

Left without a cover, the bauxite mantle and features of Aggtelek-type tropical karsts have been eroded by the late Oligocene—early Miocene or modified under the influence of climatic change caused by the northward shift. This explains why only traces of bauxite or cockpit or tower karst can be found in the Bükk, Aggtelek-Rudabánya and Mecsek Mountains.

The Ottnangian-Carpathian stages of the Middle Miocene were periods of marine transgression and burial in all Hungarian karst regions. The open mixed non-independent karst of the Bükk, Pilis, Western Cserhát and Aggtelek-Rudabánya Mountains, mostly exhumed in the Lower Miocene, were not only covered by marine sediments but predominantly by Middle and Upper Miocene tuffs and tufites and, in the Aggtelek-Rudabánya Mountains, by alluvial fans. The Miocene subsidence of Aggtelek-type karsts took place without major dismemberment by faults, only marginal faults reactivated and grew in number. The trend of tectonic activity remained the same for Bakony-type karsts also, dismembering continued and covering became uneven again.

By the Badenian burial had slowed down in all Hungarian karst regions and stopped by the Sarmatian. Under the mediterranean climate of the Upper Sarmatian — Lower Pannonian subaerial denudation exhumed small parts of non-independent karsts. Since Lower Pannonian animal bones were recovered from the Esterházy Cave (Vértes) at 204 m altitude and in a doline at 370 m altitude the SE Bükk margin Lower Pannonian marine clay of original bedding was discovered, it seems certain that the rejuvenation of the karsts in Hungary, gave continuous *Tertiary-Quaternary karstification dating back to the Upper Sarmatian.* In that period the present drainage of the low and medium-height mountains and the then mostly covered karst regions began to evolve.

The Pannonian transgression laid deposits over the margins of karst exhumed in the Upper Sarmatian — Lower Pannonian. Ar the same time in the inner parts, due to reduced relief and aridification of climate in the Upper Pannonian, slow exhumation of cryptokarsts and buried karsts went on. When the Pannonian sea contracted into a lake and climate became more humid in the Pliocene, exhumation accelerated everywhere. The forces working against it were only basalt effusions and

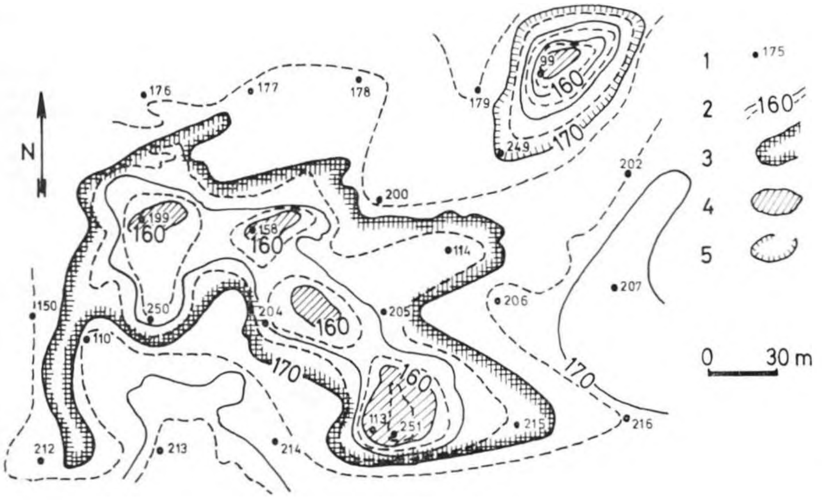


Fig. 2. Karstic surface on dolomite N of Halimba (Bakony Mountains). 1 = no. of borehole, 2 = line of levels (m), 3 = uvala, 4 = deepest part of a doline, 5 = doline

tephra scatters and dust accumulation in the glacials. Since the Upper Pannonian phases of uplift and calm alternated, climate fluctuated and the changes can be detected in the altitude, relative positions, shape and dimensions of karst features, and the sediments and paleontological-archaeological finds in their fills.

Climatic oscillations affected the Aggtelek- and Bakony-type karsts equally. In the late Pliocene and in the Pleistocene interglacials, when temperature, precipitation, soil and vegetation conditions were similar to the present day weathering products and also karstification were governed by rainwater and streams. In colder periods karstification went on at a slower rate, the predominant process of exhumation was frost action and gelisolifluction. The latter played an important role in blocking ponors and dolines, filling them and destroying uplifted caves. Dust accumulation and permafrost efficiently to hindered this slow karstification and elimination of covered karsts.

In the impact of tectonism the differences between the Aggtelek- and Bakony-type karsts still exist. In the Bakony-type karsts — particularly in the Transdanubian Mountains — faults were rejuvenated, new ones added to them and, consequently, ascending thermal waters formed more and more caves, not only in limestone but also in dolomite and marl blocks. The stages of uplift can be reconstructed from spring caves located in levels above each other and terrace-like travertine horizons (Fig. 3).

The unfractured Aggtelek-type karsts show hollows or travertines along their marginal faults. Over their extensive plateaus and broad ridges, the exhumation of covered and partly covered karsts and the formation of Pliocene-Quaternary features were primarily due to the drainage network formed on non-karstic cover rocks. Where streams cut down to the karstifying rocks, depending on the position of the karst water table, they were either superimposed on the karstic rocks or ponors were formed without a previous valley (Fig. 4).

As a result of the rapid drop of karst water levels in stages of uplift, the bathycapture of streams of antecedent valleys, and the headward erosion of the site of bathycapture characteristic swallow doline rows were produced (Fig. 5). The valleys superimposed over exclusively karstic rocks lost their surface catchments (through the erosion of non-karstic cover sediments) and became shallow, or medium deep, dry, low-gradient karst valleys with usually swallow doline rows. As depressions infilled, their deeper soils and richer vegetation remained to be the main lines of karstification and new dolines emerged on their floors, particularly solution dolines while dried-out sinkholes kept on broadening and deepening through solution.

In the Aggtelek-Rudabánya Mountains and the Bükk, dolines are common, both in larger number in antecedent valleys and independent of them. In the Mecsek dolines not associated with valleys are rare, they are 'hanging' over the valley floor doline rows in summit or subsummit positions. They constitute, together with the shafts of summit and dry spring caves opening higher than the floors of valleys with doline rows, the older generation of features in the Aggtelek-type karsts, already existing before the Upper Pliocene.

As exhumation advanced, the surface drainage of covered karsts was also fed by already existing big karst springs. The drainage related to them may have formed by the late Pliocene and inherited over the limestone surfaces in the early Pleistocene. The last date for bathycaptures was the Villányian stage of the Lower Pleistocene.

As the non-karstic cover became dissected and diminished, the catchments of antecedent valleys were reduced in area and they and their doline rows became dry for longer periods. (The only exceptions are those valleys or valley sections which

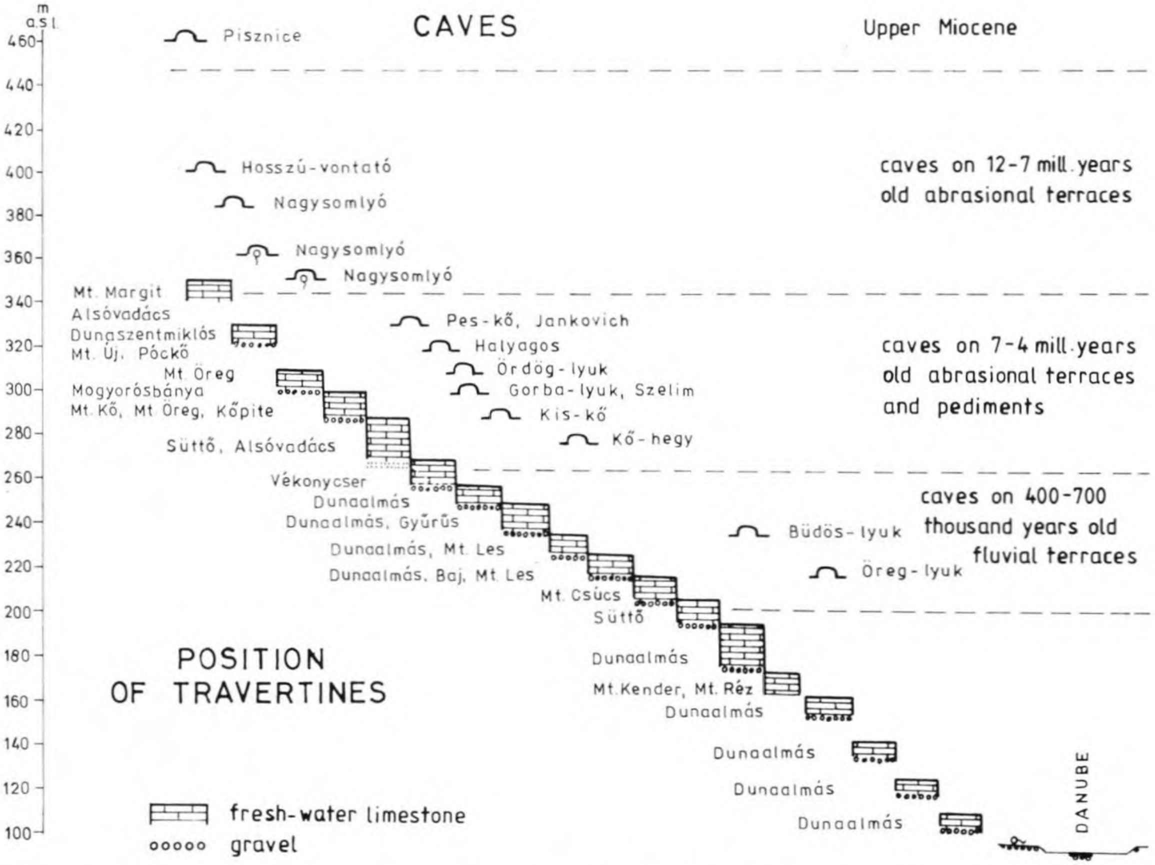


Fig. 3. Connection of the travertines and cave levels in the Gerecse Mountains (after F. Schweitzer)

were superimposed over impermeable non-karstic rock zones.)

During the glacials dust accumulation and permafrost conditions reduced the rate of exhumation and they even gained in area temporarily. With no infiltration, almost all the meltwater and summer precipitation easily found its way from frozen limestone slopes into the valleys and revived the rows of sinkholes there. In winters when strong and prolonged frosts precede the formation of snow cover, a similar effect of frozen soil (only seasonally and for shorter periods) can be observed even today. After thaw the exhumed open karsts became covered ones usually for 4—5 days, but sometimes for one or two weeks. The temporary catchments become functioning ones and snowmelt accumulates in ponds and sinks noisely.

The exhumation of covered and partly covered karsts, governed by surface drainage, is only characteristic of the Aggtelek-type karsts. Over the small limestone and dolomite horsts of Bakony-type karsts large surface drainage networks could not develop even under covered conditions. This is the main reason why there are no karst valleys with doline rows there and the sporadic swallow and solution dolines only occur on the most extensive blocks.

As for the medium-height mountains of Hungary in general, the Plio-Pleistocene uplift of Bakony-type karsts can also be estimated at 250—400 m. Parallel with the multi-stage uplift, relative karst water levels sank and new spring cave levels formed and dry caves began to be destroyed. In the glacials with intensive frost shattering their remuval was particularly rapid, culminating in the last (Würm) glacial.

The recent revival of karstification began in the Atlantic stage of the Holocene (7000 BP). Under somewhat warmer and more humid climate than at present the further exhumation of still covered and partially covered karsts started, blocked ponors opened, infilled dolines cleared of sediment and helped by the CO_2 produced in the brown or locally black rendzinas and red clay paleosols of oakwoods with rich undergrowth, surface and subsurface karst features developed further and became more abundant. These processes, although at a slower rate, are still active today.

III. General description of karst regions, with special regard to their surface features

1. Aggtelek-type karsts

Aggtelek—Rudabánya Mountains

This is the Hungarian portion of the most characteristic and largest karst region of the Carpathian Basin, the Gömör-Torna karst. It is subdivided into the Aggtelek and Szalonna karsts.

The more extensive *Aggtelek karst* is a mostly exhumed, although some remnants are covered, mixed non-independent karst, developed on an originally open and then buried mixed non-independent karst (Table 1, 2.3.4). It is built up mainly of Triassic limestone with some dolomite, shale and sandstone. The S margin is mantled by Upper Pannonian marine sediments.

The larger part, N of the Kecső and Jósva streams, the Haragistya, Nagy-oldal and Alsó-hegy are SE continuations of the Szilice karst in Slovakia. The surface features — because of its more homogeneous lithology — hardly show its nature of mixed karst. There are ridges at 400—600 m altitude with conspicuous lapiés fields, hanging dolines, shafts and some uplifted spring caves. They are divided by broad, dry blind valleys with doline and uvala rows. Coalescing karst valleys often form wider, polje-like sections dotted with a dense network of dolines and uvalas. The most important shafts and swallow caves are found on the Alsó-hegy plateau.

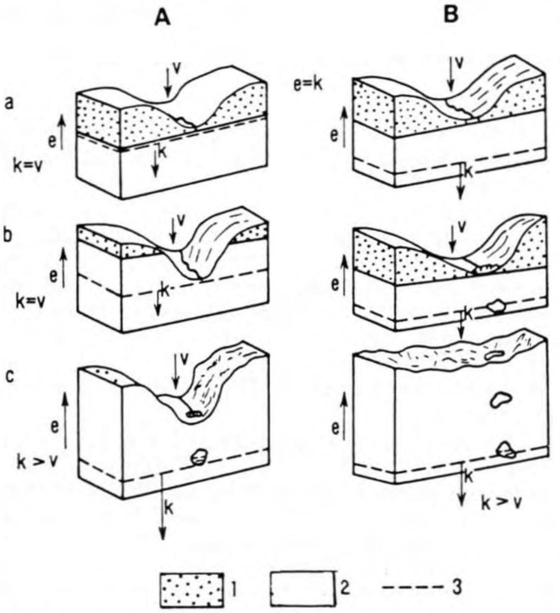


Fig. 4. The ways of inneritance of drainage on non-karstic surface over karstic rock. 1 = non-karstic rock, 2 = limestone, 3 = karst water table; e = uplift, k = sinking karst water table, v = downcutting

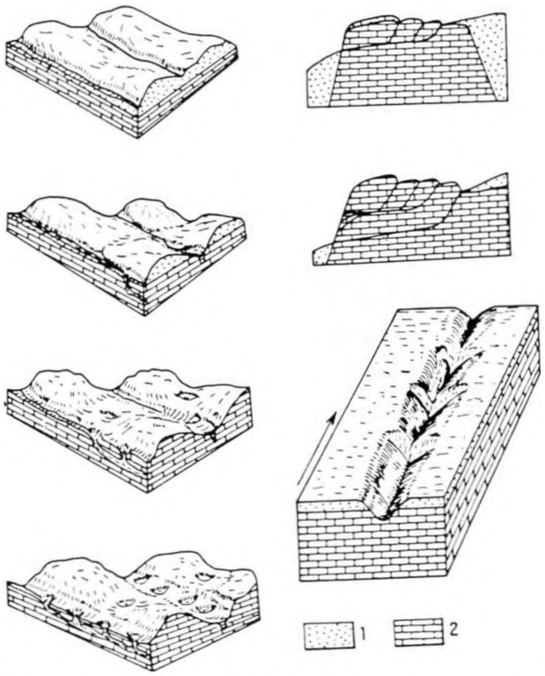


Fig. 5. Valley of epigenetic water course of covered karst transforming into a row of dolines through repeated bathycapture (L. Jakucs 1968. A. Hevesi 1978). 1 = non-karstic rock cover, 2 = limestone

Among the high-yielding karst springs at the southern foot of the Haragistya-Nagy-oldal, the Big and Small Tohonya springs and the Kossuth and Vass Imre caves are worth mentioning. The only permanent water-course of the inner karst area is the Ménes stream. It follows a narrow shale zone within limestone terrain and breaks through a splendid limestone gorge (Vár-völgy) towards the Bódva valley. Its channel is interrupted by fine travertine steps.

The smaller portion of the Aggtelek karst S of the Kecső—Jósva valley is the *Galyaság*, a ridge of 300—480 m altitude. The W half is built up of Triassic limestone and encircled by Upper Pannonian marine deposits on the S and SW and Triassic shale and sandstone terrain on the E and SE. Its karst shows the characteristics of both partially exhumed and open mixed non-independent karsts. Major intermittent and permanent water-courses reach it from the non-karstic neighbourhood and resurgent blind valleys end in typical karst margin ponors (Bába, Ravasz- and Zombor-lyuk, Vizetes ponor). In the past the streams had more abundant water and sediment discharges carved and dissolved the longest through caves with dripstones in Hungary (Baradla, Béke Cave— Fig. 6).

The inner parts of the limestone ridges of the Galyaság are characterised by lapiés fields, shafts and hanging dolines on crests and between the

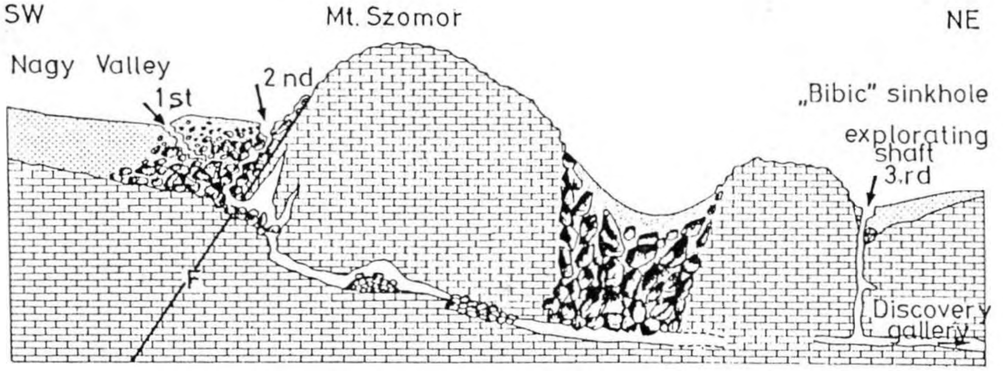


Fig. 6. Natural entrances of the Béke Cave (Aggtelek Karst)

crests karst valleys with doline rows and uvalas. As with all Aggtelek-type karsts the brown and black rendzina soils (accordant with present climate and vegetation) only occurs on the summits.

However it is notable that slopes, karst valley floors, dolines and uvalas are mantled by rendzina with red clay and terra rossa-like paleosols of still debated origin. The swelling red clays are often compacted into impermeable layers and lead to the formation of lakes in sinkholes, the largest of them are the Aggtelek and Vörös Lakes.

A smaller, almost idependent part of the Aggtelek-Rudabánya Mountains lies to the S of the Aggtelek karst, stretching from Rudabánya to Tornaszentandrás, the *Szalonna karst.* It rises to 300—500 m above sea level from its mostly Plio-Pleistocene marine-subaerial sedimentary environs, bordered by fault scarps. Its horst is built up of Triassic limestone, dolomite and shale and the hot and lukewarm springs and travertine precipitations at its foot also make it resemble to the largest Bakony-type karsts.

The tectonically preformed valley of the Bódva divides it into two uneven wings. As a whole, both are mostly exhumed, but with small areas still covered mixed non-independent karst, originally open mixed, then buried under Pannonian sand, Pliocene gravel and Pleistocene loam (Table 1, 2.3.4). Its small area explains why it shows less abundance of surface karst features. On the broad ridges of its wider NE wing some shafts open (Szár-hegy) and karst valleys with dolines along their floors start from among the crests of the Szár-hegy and Dunna-tető area; on reaching the fault scarp margin of the karst they continue with intermittent streams and dry gorges of very high gradient. The dripstone caves below the karst water level in the Esztramos, an isolated hill to the N of the NE flank, have already been destroyed by stone-quarrying.

The narrower SW flank of the Szalonna karst shows even less karst phenomena. The only spectacular feature is the antecedent limestone gorge of the Telekes stream, probably developed from a cave.

The Szendrő Mountains of Devonian-Carboniferous sedimentary and metamorphic rocks in the SE neighbourhood of the Aggtelek-Rudabánya Mountains is now being exhumed from its Pliocene cover by the water system of the Rakaca stream. With the exception of some antecedent gorge section cut into Carboniferous crystalline limestone, which are not true karst features, no other karst phenomena are worth mentioning.

Bükk

On the Carboniferous-Permian-Triassic-Jurassic limestones and dolomites as well as Eocene limestone and calcareous marl, originally open, then buried and now exhuming, only partially covered mixed non-independent karsts are found (Table 1, 2.3.4). Most or its karsts were formed on the exhuming planated surface, originally denuded under the tropical climate of the Cretaceous-Middle Eocene, partly buried and partly further planated in the early Tertiary and substantially modified in the S and N Bükk as well as the E and NE margin of the Bükk Plateau by abrasion. Even today warm and lukewarm karst springs of large discharge issue along the marginal faults and the travertine deposits (at Mónosbél, Eger, Latorút, Diósgyőr, Mályinka and Bélapátfalva) clearly mark the boundaries of the mountains. Travertines deposited from cold water are also numerous, one of them, the Lillafüred accumulation incorporates Europe's second largest hollow system in travertine.

The Bükk is well-studied by archaeologists, paleontologists and sedimentologists. The distinction between the two spring cave and doline generations of Aggtelek-type karsts rests mainly on the results of cave excavations in the Bükk Mountains. They have identified Upper Pliocene spring cave and hanging dolines, at least Lower Pleistocene valley doline rows and Riss spring caves.

Among the parts of the mountains, the Bükk Plateau and the SE-Bükk are true karst regions, while the N- and SW-Bükk are microregions only made more diverse by karsts.

The uplifted *Bükk Plateau* of 22 km length and 0.5—6 km width is the highest lying and largest contiguous karst region (120 km^2 area) of Hungary. Most of the plateau is built up of easily karstifying Triassic-Jurassic limestones. Its Permian bituminous and Triassic cherty limestone and dolomite is of medium to poor susceptibility to karstification. Its mixed karst nature is due to Triassic-Jurassic shales, Triassic porphirites and diabase appearing in long and narrow stripes. It is in two parts, the Great and Little Plateaus, separated by the Garadna valley following Carboniferous-Permian shales and sandstones. These partially covered, non-independent karsts differ in their height and, consequently, in the degree of their exhumation.

The 300—400 m higher *Great Plateau* (at 600—950 m above sea level) was mantled once by Middle to Upper Miocene tuff, tufite and Pleistocene dust, the remnants of which form red and orange clays only preserved in the dolines of karst valleys. It is now mostly exhumed open mixed non-independent karst (Table 1, 2.1.2.). The lower, E part of the *Little Plateau* (350—750 m) is still mantled by 1—3 m clayey weathering material with intermittent water-courses and even permanent small streams. Exhumation, the bathycapture of water-courses and the headward shift of the site of bathycapture can be still detected at some places.

In spite of the differences, the Great and Little Plateaus show some similar features. Antecedent dry karst valleys of low gradient superimposed over the limestone and bathycaptured through sinkhole rows are the most typical landforms. Between them on both plateaus, lapiés fields, hanging dolines, shafts and abandoned spring caves are seen on crests and summits. The characteristic features of the open mixed non-independent karsts (Table 1, 2.1.2.), the blind valleys with resurgent streams on karst margins are only secondary, but not insignificant elements (the Jávorkút, Bolhás and Létrás sinkholes).

Some 'records' from the Bükk Mountains:

1. The deepest cave of the country, the Istvánlápa cave, is found here (—250 m).

2. The highest elevated, now abandoned spring cave (Köris-lyuk, 930 m above sea level), hanging doline (at Istállós-kő, 950 m), shaft entrance (Kis-Kőhát shaft, 920 m) and active swallow cave (Bánkúti-visszafolyó, 870 m) are all on the Bükk Plateau.

3. Due to its uplifted position, the largest number and highest diversity of abandoned caves, hollow remnants (stone arches and passage sections), most numerous on the face of denudation scarps of marginal crests (Tar-, Három-, Tamás-, Magos- and Sólyom-kő).

4. The longest active swallow cave of Hungary, the Létrás water cave and the only true collapse doline, the 15 m deep Udvar-kő are found here.

5. The largest of the karst polje-like features with dolines and uvalas also lie on the plateau (Nagymező, Zsidó-rét, Létrás.

The 450—720 m high *SE-Bükk* is characterised by broad stripes of Triassic-Jurassic limestone, narrow zones of shales and diabase and porphirite of the same age. The water-courses arriving from non-karstic terrain mostly reach its NW half. As a whole it was originally open, then buried, and now largely exhumed, only in small part covered mixed non-independent karst (Table 1, 2.3.4.). The NW half has become almost completely exhumed open mixed non-independent karst (Table 1, 2.1.2.).

The height difference between the floors of stream valleys and the average karst water level did exceed the range of karst water niveau previously and in some cases it is still less. Therefore, the valleys continue their course over limestone. However, some of the streams are bathycaptured on arriving at the valley section in limestone. The latter include the resurgent streams with the highest discharge, the sinkholes are the best-developed karst margin ponors (Pénzpatak and Diós-patak ponors). The streams which reach the limestone terrain at lower altitudes mostly carve gorges, the floors of which do not have permanent swallow dolines because of the range of karst water levels (in the Balla and Pazsag valleys). A outstanding example of karst water range is the Gyertyán valley catavotre, which functions as a sinkhole at medium and low karst water levels, while it is a spring, when karst water rises substantially above the average niveau. This is the only catavotre of the mountains and also of Hungary.

Over the broader limestone zone of the SE part of the SE-Bükk hardly any water-course arrives from non-karstic terrain. Therefore, features here resemble the Bükk Plateau with hanging dolines, shafts on broad flat ridges with dry karst valleys with doline rows and hanging valley torsos between them.

The entire SE-Bükk is rich in caves of various types, abandoned passages and gorges formed from collapsed caves. At its SE foot karst springs mixed with thermal waters recharge a spring cave developed into a broad, health bath (at Miskolctapolca). Along the S margin is the only important Eocene limestone stripe with some dolines and caves.

Although Triassic-Jurassic limestones outcrop only in places in the 400—700 m high SW-Bükk between slates and diabase (basalt) and gabbro masses of similar age, this mountain section is rich in caves and limestone gorges. As a whole it is a non-independent karst buried under shale series of varying thickness and heavily jointed (Table 1, 2.2.1.). In isolation limestone areas rise with karst forms of open mixed non-independent (Table 1, 2.1.1.), partially covered, exhumed or exhuming non-independent (Table 1, 2.3.) and exhuming open independent (Table 1, 1.2.) karsts.

The spectacular limestone gorges and the caves opening on to them have mostly been destroyed by stone-qaurrying. Some evidence however for the origin of the gorges through the collapse of caves still survive. Among the caverns the Hajnóczy cave indludes the oldest paleontological finds of the

Bükk Mountains. The Nádasbérc shaft opening in slate and continuing in limestone provides a perfect demonstration of the cryptokarst nature of the SW-Bükk and the sinking of karst water table in intermittent karst springs (like the Imó, Vöröskő and Feketelen springs). From the partly red-clay mantled ridge of the Berva-Cseres crest, uplifted above a non-karstic environment, blind valleys ending in ponors and valleys with swallow dolines start.

The Carboniferous-Permian-Triassic limestone surface of the *N-Bükk* are of smaller area than those of the SW-Bükk. These karstic areas at 400—600 m altitude are isolated exhumed open independent karsts (Table 1, 1.1.2.) rising as klippen formed by selective erosion above their non-karstic environs (Carboniferous-Permian-Triassic shales, sandstones, Miocene marine sediments and tuffs). Disregarding the two dolines of the Kemesnye-hegy, only some caves and rock niches are known. The most typical karst process today is continuous travertine deposition. A third of the 36 travertine occurrences of the mountains (11) are located here. Deposition takes place from either karst springs or from confined groundwater springs of non-karstic rocks, in communication with karst water. The travertine steps of the Szalajka valley are the finest in Hungary.

The neighbouring *Uppony Mountains* contains smaller Triassic and semicrystalline Carboniferous limestone outcrops. In addition to small caves, the spectacular antecedent gorge of the Csermely stream, carved into Carboniferous limestone is worth mentioning. The Paleozoic rocks are overlain by Middle Miocene (Badenian) marine sediments and Sarmatian andesite agglomerate in the E. Agglomerate blocks of the size of houses have slumped down on sandy-clayey Badenian series and as a result of slumping have produced zig-zag cavity systems closed at the top and dilated at the bottom. The most extensive non-karstic pseudocave of the country developed between the agglomerate blocks of the Damasa gorge of Bánhorváti, as a result of similar slumping only 300 years ago.

Mecsek Mountains

This mountain region lies a long distance away from both the Transdanubian and the North-Hungarian Mountain Range. The karstifying rocks (Middle Triassic, Middle Jurassic and Middle Miocene limestones) only occur in quantities sufficient for the evolution of a major karst region in the W part.

On the Middle Triassic limestone of the W-Mecsek a 38 km² karst area has developed. It continues under Pleistocene loess to the NW and N and under Middle Miocene marine deposits to the NE, while on the STriassic slate and sandstone zone trancates it down. By position it is a two level marginal karst plateau of 300—500 m altitude. The paleokarst features of the Cretaceous-Eocene peneplain, fundamentally reshaped during the Oligocene-Lower Miocene were destroyed by the Middle Miocene marine transgression, which carved a wide abrasional platform into the mountain slopes. After regression, the Triassic limestone body of the W-Mecsek became land as covered karst and was exhuming through the Sarmation down to the Pannonian. In the northern lower part the Pannonian sea abraded a new beach and laiddown deposits where they were missing from the Middle Miocene cover.

The karst region, open from the Jurassic to the mid-Miocene, buried in the Miocene and partially covered today, is a mixed non-independent karst (Table 1, 2.3.1.). It is situated on two raised beaches above each other. Karstification has been continuous on the higher and older level since the Sarmatian and on the lower and younger one since the Pliocene.

The exhumation of the W-Mecsek karst which is much lower than the ones mentioned above, could only have been much less rapid. This explains why the rows of swallow dolines in the antecedent valleys are much younger (although mostly dry for long periods), their slopes are steeper and their diameter is smaller than their counterparts in the Aggtelek karst or Bükk Mountains. The NW and N margin of the W-Mecsek is a typical non-independent cryptokarst (Table 1, 2.2.1.), where the doline like depressions of the loess surface are also present in the Triassic limestone. On the other hand, the S margin of the karst is slowly exhuming, open mixed non-independent (Table 1, 2.1.2.), where minor intermittent and permanent resurgent streams have blind valleys ending in ponors (Büdös-kút and Szuadó valleys). The ponors of the higher-lying S margin and the spring caves of the lower N margin communicate through more-or-less passable passages. Most of them are active through caves.

Lower elevation means that fewer cave levels, multistoreyed caves, abandoned caves, subsummit avens and hanging dolines are found here.

The most picturesque limestone gorge in this karst area is the Nagy-Mély valley and the Melegmány stream flowing through is famous for its travertine steps.

2. Bakony-type karsts

Transdanubian Mountains

Although 65 per cent of the rocks forming this mountain range are non-karstic, 21 per cent are poorly karstifying dolomite, and limestones of all age only make up 9 per cent, all the members of the range are rich in caves. This paradox situation can be explained by the presence of easily karstifying rocks (Dachstein Limestone 5 per cent, with average length of cavities: 25 m/km²; Eocene limestone 4 per cent; 36 m/km²) almost everywhere and the solution capacity of ascending thermal waters.

The karsts are found on the Mesozoic limestones and dolomites of the horsts of the cretaceous-Paleocene peneplain at different elevations and consequently exhumed to various degrees (Fig. 7). A smaller part was formed on late Tertiary-Quaternary raised beaches on these peneplain remnants,

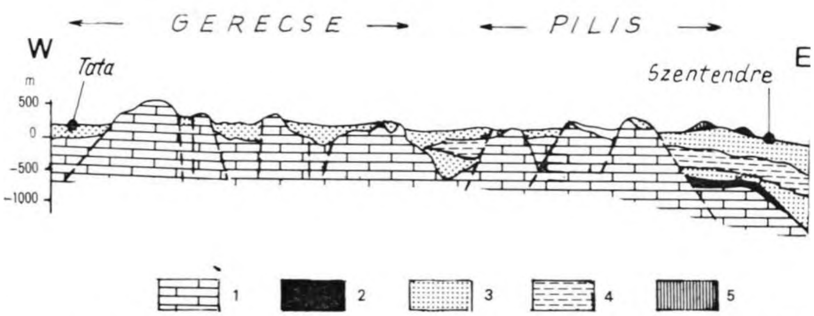


Fig. 7. Geological section of Gerecse and Pilis Mountains (after L. Korpás, 1980). — 1 = Mesozoic and Eocene limestone and dolomite, 2 = Oligocene sandstone, 3 = Oligocene sand with coal desposits, 4 = Oligocene clay, 5 = Neogene rocks

Eocene limestones and marls, Miocene limestone as well as on pediments and river terraces.

Bakony

The 350—700 m high Bakony form the most extensive mountains with one of the most diverse lithologies in Hungary. From Silurian porphiroids and slates to the Holocene, each period (with the exception of the Carboniferous) and from the late Tertiary each epoch are represented by (usually sedimentary) rocks.

Among the three regions the most uniform is the plateau-like *Keszthely Mountains* built up predominantly of Triassic dolomite with Pannonian sand and sandstone cover on its margins. As a consequence of its lithological composition, the mountains is relatively poor in karst phenomena. Some sinkholes and swallow caves (the Szél-lik of Ederics, 50.2 m deep) formed on the Triassic limestone zone above Balatonederics. The short rock niches in dolomite open on the cliffs of narrow gorges (Kígyós, Csider and Szentmiklóssy valleys) or on the steep scarp above the Pannonian raised beach. A true abrasional cave is the Vadlán-lik of Gyenesdiás. Among the thermal solution caves of Upper Pannonian age along the W marginal faults of the mountains the Cserszegtomaj well cave is worth mentioning. The successors of these thermal springs — mixed with lukewarm karst water — issue today much to the S and at lower levels, at Hévíz.

The other two regions of the Bakony, the N- and S-Bakony are much more diverse in lithology and more fractured. The covered and partially exhumed planated horsts make it the microregion richest in paleokarst features in the country and even in the Carpathian Basin. The Cretaceous-Paleocene tropical karst features exposed by open-cast bauxite and manganese mining are equally common in Triassic-Jurassic limestones and Triassic dolomite (Halimba, Nyirád, Szőc, Iharkút and Urkút) (see Fig. 2). The relative uplift of horsts and grabens also produced younger, Oligocene to Miocene dolines. They are filled by red clay mixed with Miocene gravels instead of bauxite.

The conditions of more recent, Upper Miocene-Pliocene-Quaternary karstification and the forms produced in the N- and S-Bakony are not always the same. Most of the caves in the 350—700 m high *N-Bakony* were dissolved by cold waters in Triassic, Jurassic and Eocene limestones and Triassic dolomite. The elevated, totally or almost totally exhumed limestone and dolomite planated horsts contain short abandoned caves and some truncated shafts (Odvas-kő cave, Nagy-Pénz-lik, Hálóvető-völgyi-átjáró, Gombás cave, Likas-kő of Tönkölös and the Kőris-hegy Ördög-lik). Over the mostly covered broader ridges less elevated and mantled by loess and slope loess with red clay intermittent swallow caves have been and are being produced by short intermittent water-courses cutting into the cover layers. The short blind valleys in loess terminating in ponors and the related caves are characteristic of the partially covered plateau blocks encircled by higher horsts of the N-Bakony (the Tés Plateau, Mellás Plateau of Isztimér and Hárskút half-basin). These are also the most extensive karst features of the whole mountains. The 400—450 m surface of the Tés Plateau is densely spotted by ponors (17 in number).

Compared to its richness in caves, disregarding the lapiés fields and ponors, the N-Bakony is poor in surface karst forms. Well-developed dolines are only found on the Jurassic limestone of the Nagy-Som-hegy (650 m) and on the Eocene limestone of the area SE of Bakonybél. The red-clay flats of the Tés Plateau are only shallow embrionic dolines. Spectacular features are the gorge sections, perhaps collapsed caves, of the antecedent valleys cutting through the limestone-dolomite crests. Their steep, locally subvertical cliffs or even overhangs are spotted by a lot of rock niches, shelters, cave and chimney remnants (Cuha, Gaja, Burok, Vár, Sötét-horog valleys, Ördög-árok and Kő-árok). The most abundant marginal karst spring, the Tapolca-fő, once feeding the Tapolca stream of Pápa, mixed with ascending hot waters, supplied Ajka in the late sixties and it dried out when the karst water niveau was reduced for mining.

The 300—600 m high S-Bakony is much poorer in elevated caves, avens and spectacular gorges than the N-Bakony. The dry hollows (the Baglyas-hegy, Biked-tető, Dobogó-tető and Mecsek-hegy caves and the Somos-kő spring cave) are short niches and cave fragments. Only the Eocene limestone outcrop adjoining the Pliocene basalt mantle of the Kab-hegy to the SW between Padrag, Csékút, Ajka and Urkút is a typical karst region. The blind

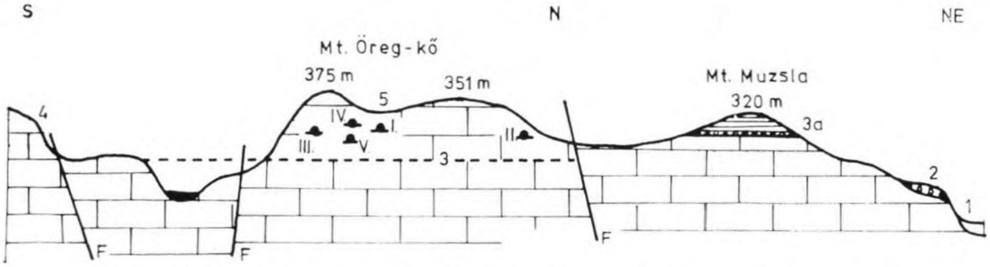


Fig. 8. Geological section of the Mount Öreg-kő (N—Gerecse Mountains)

valleys of the intermittent water-courses coming from the lava terrain and continued in resurgent streams end partly in ponors (Bújó-lik) of open, mixed, non-independent karsts (Table 1, 2.1.) and partly in those (e.g. Macska-lik) beginning in non-karstic rock (here basalt) and continuing in Eocene limestone characteristic of non-independent crypto-karsts (Table 1, 2.2.1.).

The S-Bakony is richer in thermal cavities and those of other extraordinary development. To the S the Balaton Uplands the Lóczy Cave is a system of passages solved by thermal water in folded Triassic limestone, while the largest and most picturesque is the Tapolca lake cave in Sarmatian limestone.

The geysers accompanying Pliocene basalt volcanism and also surviving to the Pleistocene produced several spring hollows (the Forrás cave of Tihany and the Csúcs-hegy spring hollow). Vent chambers of geyserite cones are similar (Aranyház, Cser-hegy and Koloska-völgy geyserite cone hollows).

In other respects Pliocene volcanic activity also contributed to the karst features of the S-Bakony karst: the basalt mantles show doline-like depressions with ponds and irregular passages have formed along the fractures of the lava mantle (Kab-hegy, Loncsos-tető and Fekete-hegy of Monostorapáti and Láz-hegy of Zsid).

Vértes

The 300—480 m high Vértes is the most uniform member of the Transdanubian Mountains. To the extensive Triassic dolomite plates only smaller Triassic limestone areas and insignificant patches of Jurassic, Cretaceous and Eocene limestones are added. Therefore, of the Bakony-type karsts it is the poorest in karst features. Although in the neighbourhood of Gánt Cretaceous-Paleocene paleodolines have been preserved, outcrops with lapiés fields are only common on faulted marginal slopes and gorge walls (Fáni, Kőlik, Ugró and Csákberény Meszes valleys).

The formation of the Csókakő spring vent is due to the action of ascending hot waters and their calcareous silica cemented the material of some of the marginal cliff towers. In the central part of the mountains — disregarding the head-waters of gorges — only minor caves occur (e.g. the Nagy-tiszta swallow cave).

Gerecse

The 300—630 m high, exhumed and partially covered planated horsts are mainly built up of Triassic limestone and dolomite as well as Jurassic and Cretaceous limestones. The partially exhumed limestone blocks are locally covered by Eocene-Oligocene sediments, Pliocene travertines or Pleistocene loesses. The highest elevated and totally exhumed horsts are classified as exhumed open mixed non-independent karsts (Table 1, 2.1.2. or 1.1.2.). As the isolated limestone patches of the latter were also part of the Cretaceous-Paleocene peneplain with much larger open mixed non-independent karsts and then during the exhumation after burial became partially covered non-independent karsts, they are also rich in *swallow and spring caves*.

The most extensive karst plateau fragments after the Bakony are found here. Besides lapiés fields, there are some dolines (Nagy-Gerecse and Lukas-kő) and on the Nagy-Som-hegy even some doline rows. At the terminal point of a small water-course, in a small sinkhole the Arany-lyuk of Szőlős opens. The Vértestolna Basin is a loess-filled graben between planated horst series, resembling a tectonic polje. Towards the N the Bitva stream leaves it through a splendid gorge and and to the S the Tuskó-rét-szurdok stream carved its counterpart.

The Gerecse is also next to the Bakony as regards the abundance of karst cavities in the Transdanubian Mountains. The number of avens and spring caves in summit or subsummit positions is even higher. The precision of cave dating is the highest in the Gerecse as it relies on the paleontological finds of travertines deposited from thermal springs.

Some exhumed horsts are densely spotted by hollows of various dimensions (Fábián-kő, Nagy-Somlyó, Nagy-Pisznice, the Turul-hegy of Alsó-galla, Öreg-kő of Bajót, and others). Among the uplifted spring caves the Pisznice cave and the Szelim and Jankovich caves, famous for their paleontological-archaeological finds, are worth mentioning. Both have huge, caved-in entrance chambers and that of the Szelim Cave now resembles a collapse doline.

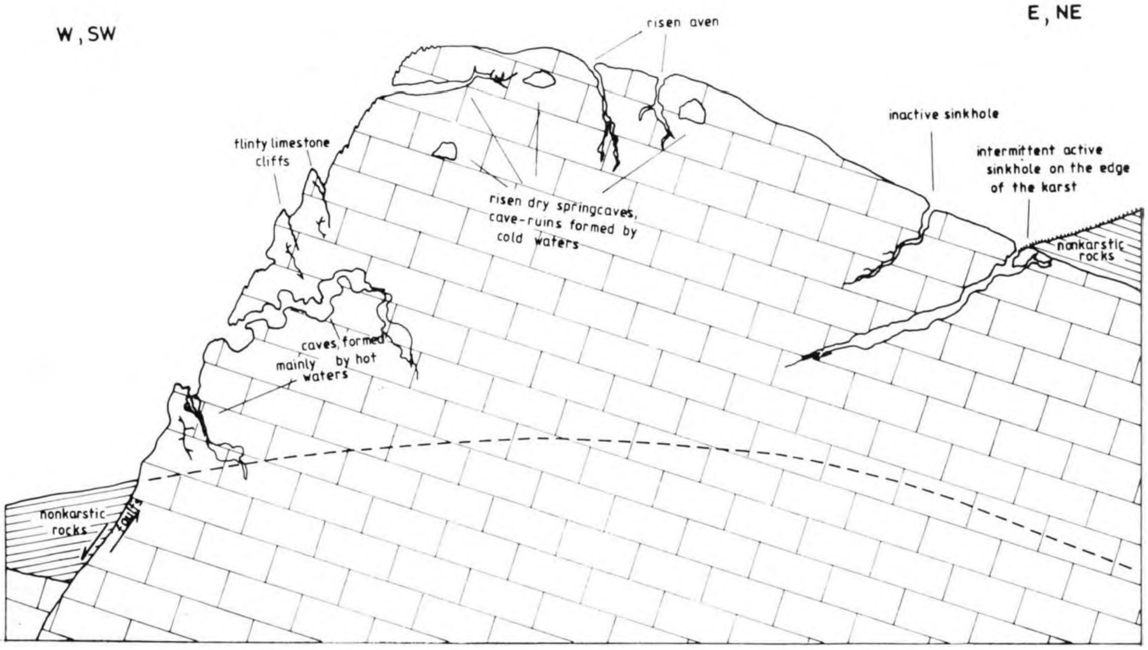


Fig. 9. General distribution of the karst features on the horst of Pilis Mountains

The distribution of intermittent swallow caves, mostly active for only some days, is substantially more sporadic. The deepest is the Nagy-Kaverna Cave of Dorog (Tokod-altáró Cave no 1) of hot water origin.

The successors of the Pliocene-Pleistocene hot springs of the Gerecse, issue mixed with cold karst water in the area of Szomód, Dunaalmás and Tata.

In addition to Mesozoic limestones, some smaller karst features also occur in the travertines and loesses of the Gerecse. A major joint cave deepens into the travertine of the Mogyorós-hegy Kő-hegy and into the loesses of Neszmély, wells and gorges are being cut even today. On the loess surface of the cryptokarst of the Sörház-dülő, Tokod, doline-like negative forms can be detected.

Pilis

A single, 5-tier NW to SE strike horst series with two adjoining N to S blocks at the middle and the SE end. The Triassic limestone and subordinate dolomite tilted planated horsts 230—750 m altitude are elevated above their surroundings by precipitous-fault scarps further emphasised by erosion. The NW margin is less steep, although mostly not gently sloping, and covered by Eocene limestone and marl and Oligocene sandstone. The highest and broadest member, the Fekete-hegy of the Pilis-tető group is divided from its E and NE (Miocene andesite and andesite tuff) neighbourhood by precipices.

The asymmetry of horst ranges is reflected in the spatial distribution of their karst features. The long SW and W edges and N front are ornamented by white lapiés fields on outcrops of beds, cliffs preserved between caved-in chimneys and abandoned through caves and stone arches (Fehér Cliff, Öreg Cliff, Klastrom and Csév Cliffs, Oszoly, Kis- and Nagy-Kevély, Solymár Cliff). Most of the cavities opening at the foot of the SW and S fault scarp are spheroidal caves of thermal or partly thermal origin, adorned with extraordinary minerals and clusters of minerals (Csév, Sátorkő-puszta, Leány, and Legény Caves, Ezüst-hegy Caves; Fig. 9).

Ascending thermal waters were prominent in the formation of the Fekete-hegy of Piliscsaba, the Solymár Cliff and the Teve Cliffs of Pilisborosjenő. The not waters penetrated into the capillary joints of dolomite and decomposed the rock, the walls of their spring vent were made more resistent by depositing calcareous and siliceous cement. Subsequently erosion controlled by to rock quality removed the loose dolomite debris from between the chimneys now solidified into 'towers'.

Since the horst range of the Pilis rises high above its neighbourhood, numerous shafts open on their ridges and many spring caves below their summits and on their walls.

The asymmetry of the tilted horsts and sediment cover on the NE and E, the seasonally active spring caves are concentrated along the NE and E margins (Pilis-nyereg, Pomáz and Harapovács swallow caves and Üröm swallow cave, Arany-lyuk). Also the finest limestone gorges carved by water-courses arriving from non-karstic terrain are located on this margin (the Pilisszentkereszt Szurdok of the Dera stream).

Buda Mountains

These form the *densest fractured, most heavily dismembered* representative of Bakony-type karsts, *richest in caves of hot water origin.* The small Triassic limestone and dolomite karsts at 250—550 m altitude are the best examples of horsts and due to their tilted position their gentler slopes are often mantled by Eocene limestone and marl, Oligocene clay, sandstone and Pliocene-Quaternary travertine or loess.

The majority of caves were dissolved by thermal waters ascending along faults and descending cold waters only played a modifying role. Their plan is zigzag; the spheroidal niches and labyrinths (equally in limestone, dolomite, marl and sandstone are controlled by faults and joints. The overwhelming majority of cavities are enclosed by Eocene limestone.

The four longest cave system of thermal water origin are found here. The Pál-völgy Cave, in Eocene limestone, rich in dripstones, is the third longest cave of the country, while the Szemlő-hegy, Ferenc-hegy and particularly the recently explored József-hegy Caves excel with their rare minerals and clusters of crystals.

The remainder of the hot springs issue along the E marginal fault, parallel with the Danube, some through spacious spring caves. In the passages hot waters mix with descending cold karst waters. Particularly on dolomite crests, the same mechanism of tower formation is also common in the Buda Mountains (Tündér Rock, Kő-hegy of Budaörs, Odvas-hegy).

It is characteristic of the Buda Mountains that most of the caves open in areas not at all resembling a karst. The main reason is the density of buildings. Barren karst terrain only occurs on steep fault scarps. The Nagy-Kopasz group and neighbouring Remete-hegy where large and broad blocks show a karstic face. Dolines of various size have developed on their flat surfaces (Vöröspocsolyás-hát and Remete-hegy) and the gorge of the Ördög-árok stream is a splendid antecedent one between Remete-hegy and Hosszúerdő-hegy. In the walls of the gorge and along its upper edge most of the cavities of cold water origin are found.

W-Cserhát

The Mesozoic limestone blocks of the Transdanubian Mountains reappear in the three horsts (Naszály, Csővár and Romhány Blocks) NE of the Danube in the North-Hungarian Mountains. With the Nézsa bauxite locality, they constitute the only karst region of Bakony-type in the North-Hungarian Mountains.

The most important karst is found on the Naszály plateau (652 m), mostly exhumed from below Oligocene sandstone. Due to its large limestone mass, twelve 2—5 m deep dolines 20—50 m across have formed. Hot waters — as attested by aragonite in the Sárkány-lyuk and the spheroidal niche of the Zsömlye-lyuk — also contirbuted to the formation of shafts double entrance chimneys, swallow and spring caves, rock niches and shelters. The Naszály sinkhole cave of 407 m length and 171 m depth is the fourth deepest in the country. Some small shelters are found in the Csővár-hegy. The Oligocene sandstone cover of the Romhány Block is hardly interrupted.

Villány Mountains

The 442 m high Villány Mountains lies S of the Mecsek, isolated in the SE corner of Transdanubia. Heavily imbricated Triassic limestone and dolomite and Jurassic-Cretaceous limestone (Fig. 1) are separated by sharp faults from their surroundings. The small extent explains why only bright white lapiés fields adorn its surface, but in the inside relatively major cavities mostly of hot water origin have been revealed by stone quarrying. The most famous is the Beremend crystal cave with rich calcite and aragonite formations. The chimneys filled with red clay and truncated hollows are famous for extraordinarily abundant Upper Pliocene — early Pleistocene animal finds.

Dr. Attila HEVESI
geographer
Hungarian Natural History
Museum
Budapest
Kecske utca 22.
H—1034

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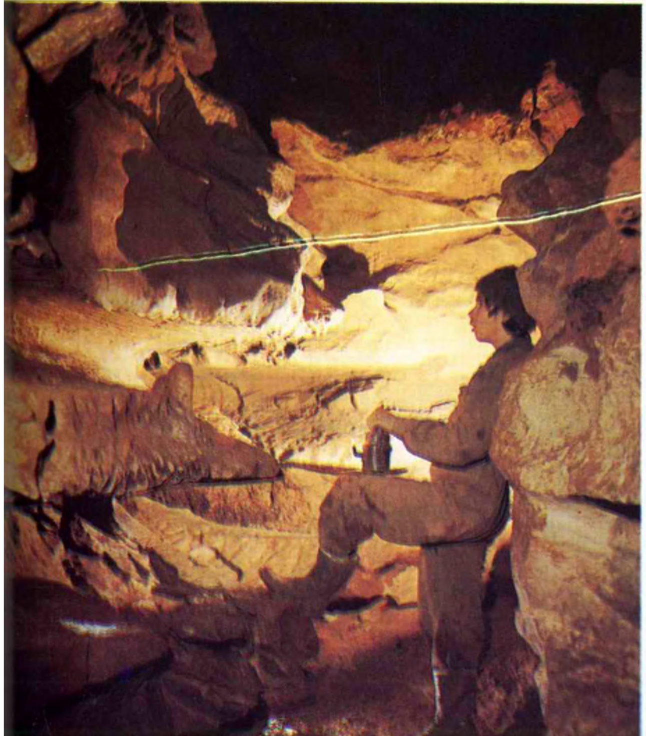
Top: Retek passage in the Baradla Cave (by Pr. Borzsák)

Bottom: Meander (left) and botryoid formations (right) in the Szabadság Cave, Aggtelek Karst (by L. Gazdag)



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THE CAVES OF HUNGARY

Katalin Takács-Bolner — István Eszterhás — Márton Juhász — Sándor Kraus

Young clastic sediments constitute a large share of the geological composition of Hungary; carbonate rocks suitable for karstification only amount to a mere 1.5% of the surface of the country *(Fig. 1)*. Despite the limited expanse of karstic regions, there are more than 2,400 caves registered in Hungary today. Even so, only 77 of them reach 200 m, and a mere 24 stretch to 1 km. Since our karstic regions are mostly of medium height, the vertical extent of the caves is not great: sixty-nine extend to a depth of 50 m, and only 3 are deeper than 200 m.

The number of known caves has increased considerably during the past decade due to systematic field-work and new explorations: compared to the 1,314 known caves in 1977 the present figure is up 85%. The total length of new passages and caves explored during this period exceeds 30 km.

There are many types of caves in Hungary: the number of caves of thermal water origin is significant even by global standards: one-third of our largest caves belongs to this type. The frequency of thermal springs and caves results from the country's geological construction and the above-average geothermic effect: the pressurized karstic waters, stored and warmed in the carbonate masses of the basin floors in the mountain forelands, can only penetrate the surface at the edge of the mountains where the impermeable cover has eroded. The upsurging thermal waters usually mix with the descending karstic waters of the open karstic areas, and the mixing corrosive effect gives rise to the peculiarly formed cave systems.

Due to the most recent rise in elevation of our mountains, the majority of not only caves of warm water origin but also "classic" sinkholes or spring caves of cold water origin have become inactive. Several active water conduit systems are only partially known. Among the cold water caves the value of the small caves formed syngenetically in the travertine deposited by large karst springs is enhanced by their rarity.

Top: Gypsum flowers in the József-hegy Cave, Buda Mts.

Bottom: Red Sea passage in the József-hegy Cave (by I. Czájlik)

The oldest known karstic phenomena in Hungary are the 70—100 million year old karstic surfaces of the Cretaceous period which were exposed during bauxite and manganese mining in the Bakony Mountains. The fossils found in the cave fills prove that our oldest cave was created at the end of the Miocene period; several caves can be dated back to the lower Pleistocene era, while most of our known caves were formed over the past one and a half million years during the middle and upper Pleistocene periods.

Aggtelek Karst

One of the most typical karstic area of Hungary is the Hungarian section of the Gömör—Torna karst region known as the Aggtelek Karst *(Fig. 2)*, found in the Northern Mountain Range, its central mass is constituted of middle-Triassic, so-called wetterstein limestone. In this region some 170 caves are currently known including longest, best known and longest researched cave in the country, the Baradla-Domica Cave System which extends nearly 24 km, 18.8 km of which is in Hungary. It is a "classic" layered water-conducting karstic system with underground streams. It has a catchment basin of some 22 km² whose northern portion is open karst and whose southern part is covered by Pannonian clay and gravel; rainwater enters the system via sinkholes on the border of the karst.

The natural opening of the *Baradla Cave* is near the village of Aggtelek, near the main sinkhole of the Hungarian system; its stream, the Acheron, merges after several hundred meters with the Styx which flows through Domica, originating from the Slovakian part of the catchment basin. The central passage running from Aggtelek to Jósvafő is a rock tunnel about 7 km long, 10 m wide, 7—8 m high, and interrupted in places by monumental halls; currently the cave stream flows along this path only during floods. During the rest of the year the lower cave under Baradla conducts the water to the springs at the mouth of the Jósva Valley. Water tracings in recent years have shown that there exist a so called Long-Lower Cave and a Short-Lower

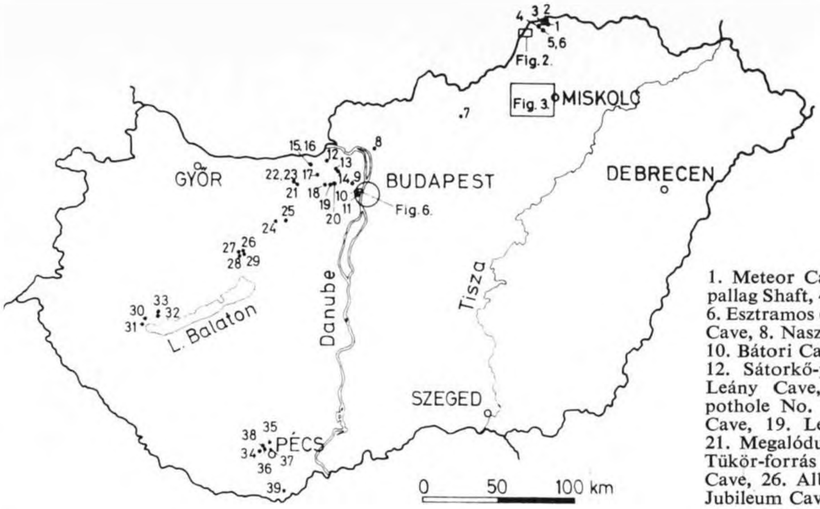


Fig. 1. Geographical distribution of the Hungarian caves mentioned in the text

1. Meteor Cave, 2. Vecsem-bükk Shaft, 3. Szabó-pallag Shaft, 4. Rejtek Shaft, 5. Rákóczi Cave No. 1, 6. Esztramos (Földvári Aladár) Cave, 7. Csörgő-lyuk Cave, 8. Naszály Cave, 9. Solymári-ördöglyuk Cave, 10. Bátori Cave, 11. Budai Vár Cave (Castle Cave), 12. Sátorkő-puszta Cave, 13. Legény Cave, 14. Leány Cave, 15. Jankovich Cave, 16. Öreg-kő pothole No. 1, 17. Pisznice Cave, 18. Szelim-lyuk Cave, 19. Lengyel Cave, 20. Keselő-hegyi Cave, 21. Megalódusz Cave, 22. Angyal-forrás Cave, 23. Tükör-forrás Cave, 24. Gánt Cave, 25. Csákvár Cave, 26. Alba Regia Cave, 27. Csengő Shaft, 28. Jubileum Cave, 29. Három kürtő Cave

Cave, of which the latter has so far been explored to a length of 1 km.

The onset of the formation of the Baradla-Domica Cave System can be dated to the late Pliocene age. Based on separated passage levels and the remains of one-time alluvial fills, several active and accumulative periods can be demonstrated. Corrosion played the central role in the early development of the cave; expert opinions are divided on the role of the corrosive effect of the cave river and the erosive effect of its float in later expansion.

The current natural entrances to the cave have been open since prehistoric times. Archaeological finds reveal that the initial sections at both Aggtelek and Domica were inhabited by neolithic man. Thousands of pottery fragments and bones, remains of dwellings and fireplaces, and dozens of other artifacts attest to the fact that the cave is the major excavation site of the so-called Bükk culture, but numerous finds have been recovered from the early iron Age and the period of the Mongol invasion as well.

The Baradla Cave was first mentioned in writing in 1742, its first map, which shows a 2.2 km wide stretch from the entrance at Aggtelek, was made in 1794. The history of the discovery of the cave goes back to the first part of the 1800s: in 1825 Imre Vass discovered the larger section of the Central passage (some 4.5 km) by breaking through the narrow, waterfilled Vaskapu (Iron Gate). The exploration of the Slovakian Domica Cave in the 1920s is credited to Jan Majko and the two sections were joined in 1932 by linking the water filled passage between them.

In addition to its impressive dimensions, the Baradla-Domica Cave System earned international fame and has appealled to tourists for centuries by virtue of the rich colours and forms of its dripstone formations. These include the rimstone dams of Domica, the forests of stalagmites in the Aggtelek section, the original pure formations in the Jósvafő branch, and the 25 meter giant stalagmite of the Observatory.

The water of the Komlós Spring, wich rises some 400 m from the Jósva Spring, was long thought to originate from the Baradla system since it faithfully reflected the cave floods, much as the Jósva Spring did. However water tracing tests by László Jakucs in 1952 showed conclusively that the spring water originates from another large cave independently of the Baradla. This premis was proved later that year by the discovery of the 8,700 m long *Béke Cave* by the opening of a sinkhole.

Although the genesis of the two neighbouring large caves is nearly identical, differences exist in their character. The Béke Cave has no separate lower cave, the cave river runs through the central passage, completely filling it at places. Its passages are narrower and are more like fissures than tunnels; this is probably due to the smaller size of its catchment basin. Dominant among the dripstone formations are the abundant stalactites and drape-

Baradla Lower Cave (Photo P. Borzsák)

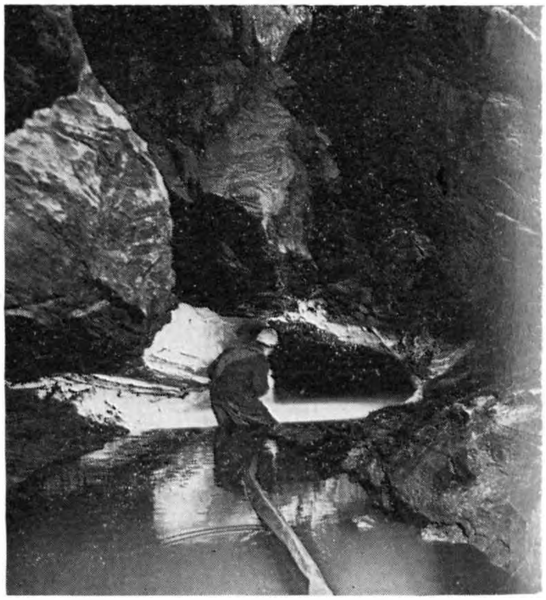


Fig. 2. Surroundings of Aggtelek and Jósvafő with the plans of the six longest caves

ries; the stepwise basins in the river bed created by snowwhite rimstone dams are also fabulous.

The therapeutic effect of the air of the Béke Cave has been proven by extensive investigations. Since the late 1950s its large chambers near the artificial entrance at Jósvafő have been successfully used to cure asthmatic patients.

The third longest system of the Aggtelek Karst is the *Szabadság Cave* near the village of Égerszög. It was discovered in 1954 when its main sinkhole was opened. At present its total length is 2,717 m, its water wells up in the spring belonging to the water-system of the Jósva River, 900 meters away from the known end-point of the cave. The character of the cave changes with the type of rock in which it is embedded. Its limestone first section contains a typical meandering passage-way divided into several levels and decorated with fine stalactites, draperies and spherical precipitations. The segment carved from dolomite is a heavily filled, flat crawlway while its final part in lamellate marly limestone has a keyhole-shaped cross section.

Of the lesser water systems on the southern edge of the karst region which were detected by water tracing, only the *Dance Cava* has been explored, currently to a length of about 1,400 m. Speleologists managed to enter the passages behind the well-known small, intermittently active spring cave through a friable zone in 1981, and in 1983 they reached the sinkhole area of the system by opening a new major tract. The inner segment of the not easily passable, relatively narrow cave carved partly in dolomite is closed off by a siphon of constant water level which protects the enthralling beauty of the dripstone formations inside.

Two other significant stream caves can be found NW of Jósvafő. The intermittently active *Vass Imre Cave* was explored in 1954 through the mouth of the flood waters. The main sinkhole of the cave, detected by water tracing, is the Milada Sinkhole Cave in Slovakia. Of the entire system, presumably stretching to 10 km in length, some 1,000 m is in the Vass Imre Cave, the end of which is blocked by a large breakdown zone. Adorned with finely colored dripstone formations and formations caused by dissolving substances, the cave is the most thoroughly studied karstic phenomenon; it is equipped with a network of telemeters, and there exists a karst hydrological research station nearby.

The underground water passage of the Nagy Tohonya Spring, the *Kossuth Cave*, was also discovered by entering through the mouth of the spring in the breakdown zone in 1956. The bottom of the relatively narrow, fissure-like cave, explored to a length of 800 m, is completely filled by the stream on some places. The end is closed off by an as yet unsurmountable siphon which divers have currently managed to explore to a depth of 30 m. A hydrological peculiarity of the system is that its water is warmer than the surrounding karst springs; this means that the heated waters of the deep karst also mix with it.

There are large karstic springs at the foot of the NE area of the region: the Alsó (Lower) Mountain as well, but researchers have not managed to enter the large cave systems that are assumed to belong to them from either the direction of the springs or that of the sinkholes. The largest known cave of Alsó Mountain is the *Meteor Cave*, currently 650 m long, which was discovered in 1961 when a temporary sinkhole was opened. One of the country's largest cave chambers, the Titans' Hall, can be found at the bottom of the gradually deepening cave. With an approximate area of 90 × 30 m, it is adorned with huge stalagmites, pillars and helictites.

A charakteristic type of cave in the plateau of Alsó Mountain, opening mostly in the side of dolines, is the vertical shaft called here "zsomboly". Due to the friable and loose clay fills in these caves the karst water level has not been reached anywhere yet: therefore, it is still questionable if these caves are linked with the horizontal water-conducting caverns. In the Hungarian part of Alsó Mountain some 50 shafts are known today, nine of them exceeding 50 m in depth.

The deepest known shaft is the *Vecsem-bükk Shaft* found at the border of the country. The shaft, consisting of parallel pits of relatively large cross sectional size, used to be the deepest cave in the

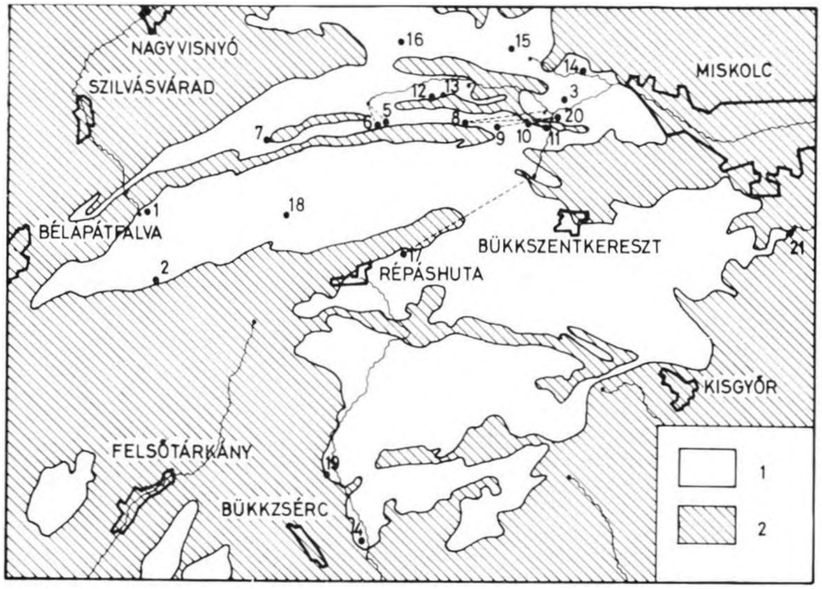


Fig. 3. Bükk Mountains and their important caves. Legend: 1 = karstic surface, 2 = non-karstic area

1. Istállós-kő Cave, 2. Peskő Cave, 3. Szeleta Cave, 4. Suba-lyuk Cave, 5. Bolhás Sinkhole-cave, 6. Jávorkút Sinkhole-cave, 7. Diabáz Cave, 8. Létrási-vizes Cave, 9. Létrás-tető Cave, 10. István-lápa Cave, 11. István Cave, 12. Fekete Cave, 13. Balekina Cave, 14. Kecske-lyuk Cave, 15. Kő-lyuk Cave, 16. Szamentu Cave, 17. Pénz-patak Sinkhole-cave, 18. Kiskőhát Shaft, 19. Hajnóczy Cave, 20. Anna Cave, 21. Miskolctapolcai-tavas Cave.

country measuring 235 m. Its dripstone-decorated middle pit, discovered in 1969, is the largest contiguous pit in the country with its height of 90 m.

The *Szabó-pallag Shaft* situated at a lower level, turned out to be also a system of parallel pits formed along fissures. The explored total length of the pits is 628 m, its known depth is 120 m.

This cave type is less characteristic of the other parts of the Aggtelek Karst. This is why it was such sensational news when the *Baradla-tető Shaft*, at a depth of 89 m, was discovered in 1986, 400 m away from the Baradla Cave.

In the SE forelands of the Aggtelek Karst some cave systems showing signs of thermal water activity can be found. Such activity is evidenced by the abundant mushroom-like or coralloid popcorn-calcites covering the walls of the 74 m deep *Rejtek Shaft* near the village of Bódvaszilas, and by the hydrothermal phenomena in Mt. Esztramos rising on the other side of the Bódva Valley.

In Mt. Esztramos small amounts of high-quality iron ore was mined in the Middle Ages. Now there is a quarry on its peak. The web of mine tunnels and shafts in the limestone mass exposed dozens of small and large cavities, the most important of them being the *Rákóczi Cave no. 1* at the lowest level. The series of chambers carved out along a fissure system reaches a height of 30—40 m and stretches to the same depth under the present level of the karst water. Its walls are decorated with dripstones and popcorn-calcites. The superposition of various types of formations indicates the repeated rise and fall of the karst water level.

Quarrying on top of the mountain also exposed scores of caves including the *Esztramos (Földvári Aladár) Cave*. Among its rich formations, the most beautiful are the accumulations of tiny ponds formed by dripping waters and the dripstones covered by soft white moonmilk. From the red clay fill of small caves destroyed by quarrying, rich fossil finds of small mammals from the Pliocene — Lower Pleistocene were recovered.

Bükk Mountains

The karst region of the country richest in caves is the Bükk Mountains which consist of complex geological construction, mostly of Triassic sedimentary rocks. There are 830 caves recorded here. Most of these are intermittently active or completely inactive sinkhole caves or deteriorating fossil spring caves *(Fig. 3)*.

The excavation of the caves in the Bükk began early this century with the archaeological investigations at the large fossil debourchures. Nearly all these caves with wide entrances and generally one single huge chamber provided some paleolithic finds. The best known are the *Istállós-kő Cave* and *Pes-kő Cave* on the western edge of the Nagy-fennsík, which contains remnants of the Aurignacien culture, the *Szeleta Cave* near Lillafüred whose stone tools belong to the "szeletian" culture which got its name after this cave, and the *Suba-lyuk* near the village of Cserépfalu in the Southern Bükk where some skull fragments were recovered besides the finds of the moustérien culture.

The largest sinkhole caves of the Bükk are related to the Middle Triassic anisusian limestone belt which stretches across the northern part of the Nagy-fennsík and is bounded by porphyrite on the north and argillite and diabase on the south. The western part of the limestone strip conducts water to the springs in Garadna Valley separating the Nagy- and Kis-fennsik, its eastern part directs water to the springs near Lillafüred.

The largest known cave belonging to the system of the Garadna Spring is the *Bolhás Sinkhole-cave.* Speleologists reached its first stretch in 1953. Together with the sections explored in 1977—79, it is now 2,500 m long. The central passage of the cave runs northward and then westward and is interrupted by several gravel and clay siphons and water-filled sections; several narrow side passages heavily filled with deposits join to it at the bottom of the entrance shafts and the currently known endpoint.

The *Jávor-kút Sinkhole-cave,* a mere 400 m away was also discovered in 1953. The 906 m of known cave length shows strong tectonic preformation. The end point of the fissurelike passage network is only 130 m away from the end zone of the previously discussed cave. Further research is hindered by siphons of steady water level at both ends of its active stream section *(Fig. 4)*

The geological interest of the *Diabáz Cave* in Bánkút at the western end of the limestone stretch is that the joining of the limestone and the non-karstifying diabase of volcanic origin is exposed at several points. The 1 km long, 153 m deep cave was discovered in 1975 when a temporary sinkhole was opened and is the fourth deepest cave in the Bükk Mountains. The hydrological peculiarity of the cave is that its lower-level passage conducts the water westward in floods whereas at other times the water flows eastward at a bit deeper level.

Only a few segments of the presumably large cave system in the eastern part of the limestone belt are known. The western member of this system is the *Létrási-vizes Cave* which opens on the border of limestone and argillite. The exploration of the layered labyrinthine sinkhole cave stretching NNE began in the 1950s. At present time its length is about 3 km. Its endpoint is at a depth of 90 m and is filled by a small lake from where the water flows towards the springs in the eastern part of Garadna Valley and the northern part of Szinva Valley.

The next member of the presumably contiguous system is the *Létrás-tető (Szepesi) Cave* whose inactive entrance shafts join a subhorizontal water conduit explored in 1962. Both ends of this level branch are blocked by siphons. The eastern downstream siphon has been explored by divers down to a depth of 166 m from the entrance.

The *István-lápa Cave* was discovered 1 km away from the above discussed cave in 1964 when a temporary sinkhole was opened; it is the longest known cave of the Bükk extending 4,100 m and is the country's deepest at 250 m. Its tiered shafts join the spatious level passage at deeper than 200 m. Its active western water-conducting branch is interrupted by siphons which are filled with water most of the year. Characteristics of its river bed are the fine solution pockets. The known part of its eastern branch is mostly an inactive upper level that joins the river passage with a deep pit.

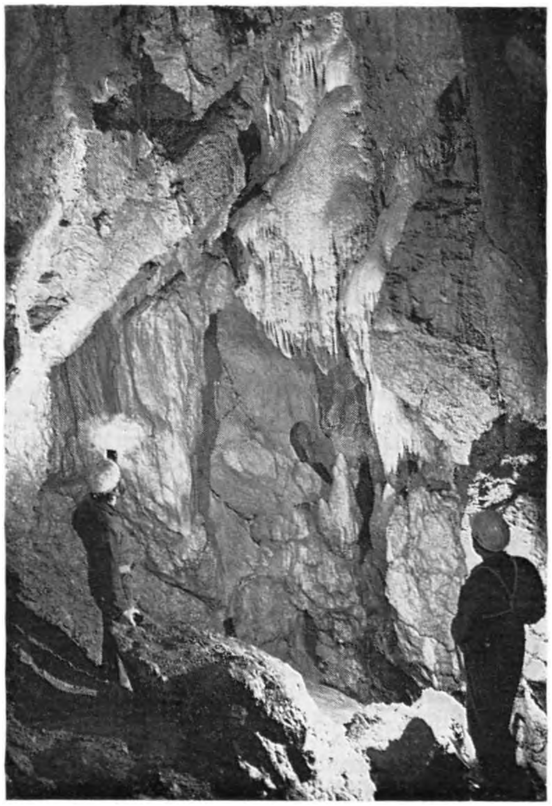
The lowest member of the system is the *István Cave* whose mouth is by the main road in the Szinva Valley. Most of the known passages of the 711 m long cave are also inactive; the developed section is popular among tourists.

Only one significant cave is known in the dolomite strip stretching across the northern border of the Nagy-fennsík. The *Fekete Cave* of Tekenős, found when opening a temporary sinkhole in 1975, is the third deepest cave in the Bükk at a depth of 163 m. The total length of its passages is approximately 1,000 m. The cave provides excellent insight into the geological construction of the region: the rock embedding the shafts is dolomite and Lower Triassic limestone with argillite, the lowest part reaches the Upper Permian limestone, and at some points even the formations of Triassic porphyrite volcanism are exposed.

None of the caves in the limestone mass of the Kis-fennsík on the northern side of the Garadna Valley reaches 1 km in length. The best known of these lesser caves is the intermittent spring cave of the *Kecske-lyuk,* the *Kő-lyuk,* famous for its cave-bear remains, and the *Szamentu Cave* which contains the largest chamber in the Bükk and was explored in 1967.

Part of the water system in the argillite region in the SW foreland of the Nagy-fennsík are drained by the sinkholes of the limestone strip jutting as far

Chamber in the Diabáz Cave, Bükk Mountains (Photo: P. Borzsák—A. Prágai)



as Répáshuta; the water is led to the springs wellings at the southern foot of the mountain. The best known of these sinkholes is the *Pénz-patak Sinkhole-cave* explored in 1953 whose deepest point at 128 m is closed off by a siphon of constant water. Its level may change as much as 42 m a year which indicates that the other water conduits are little developed or heavily blocked.

The names of several sinkhole caves with pits include, quite incorrectly, the word shaft although only a single "classical" shaft is known in the mountain. The *Kis-kőhát Shaft* opening on the southern edge of the Nagy-fennsík is 114 m deep; between the spatious double entrance pits only one of which opens to the surface, and the 50 m shaft with dripstones leading to the lowest point there is a huge hall. The cave opening relatively high above sea level and having an average annual temperature of 4—6 °C, gives winter shelter to thousands of bats.

The largest known cave of the Southern Bükk is the *Hajnóczy Cave* in the side of Mt. Odor on the border of the southwestern argillite and southeastern Triassic — mostly cherty — limestone area. Its initial section was discovered by student speleologists in 1971, and regular research has currently extended its known length to over 2,200 m. The cave has been closed since its discovery and can only be visited with research teams. It is a real gem in the Bükk Mountains because of its interesting corrosive forms, intact dripstone formations, monumental chambers connected by imposing fissure passages, and paleontological finds on the upper level.

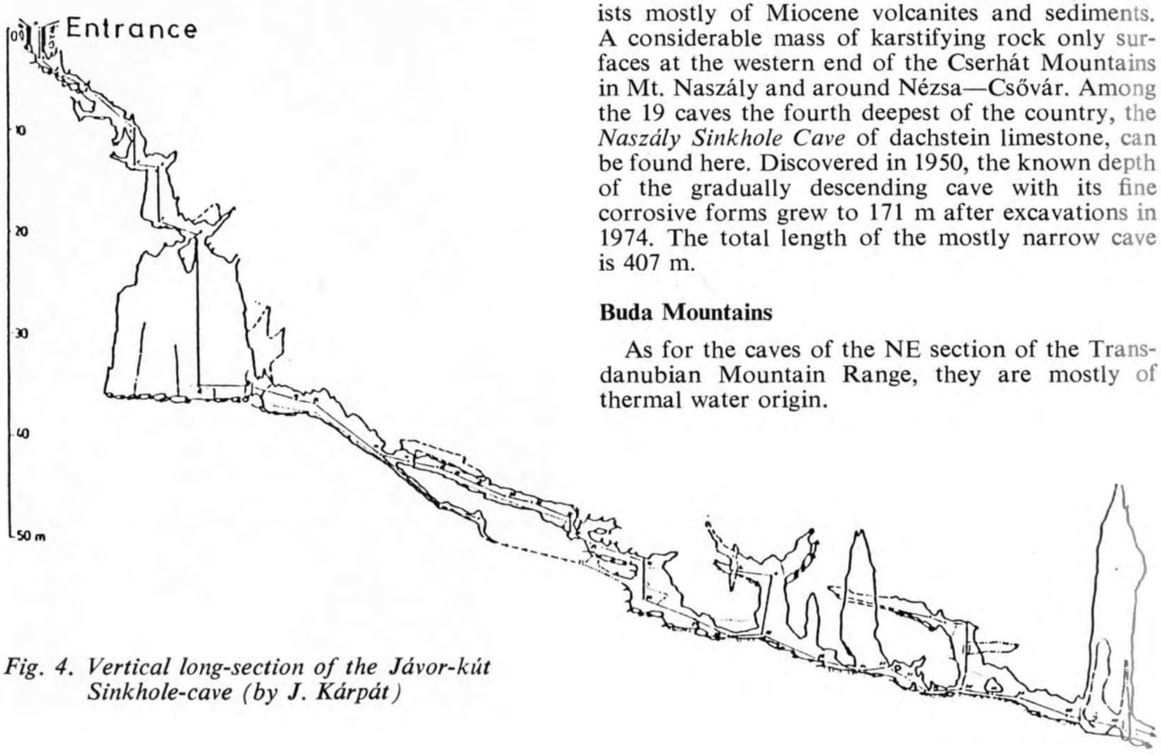


Fig. 4. Vertical long-section of the Jávor-kút Sinkhole-cave (by J. Kárpát)

During the precipitation of the freshwater limestone masses connected to the large karst springs of the mountain-range, they enclosed small cavities, so-called travertine caves. Some can be found in the western and southwestern border of the mountain-range in Mónosbél and Eger, but most of them are located at the NE foot of the Nagy-fennsík, in Lillafüred. Here, in the side of the travertine hill deposited by the waterfall of the Szinva River, there are several smaller cavities, and the caves of the inside of the hill are artificially linked into the contiguous system of the *Anna Cave*. Its first cavities were discovered in 1833 while digging a gallery for water, and it was soon opened to the public. The rooms of the 600 m long labyrinth offer extraordinary natural sights with its travertine walls covered roots and other plant remnants.

In the southeastern foreland of the Bükk Mountains thermal waters have been found by deep borings at several places. The natural tapping point of this thermal karstic water flow system is in Miskolc-Tapolca which got its name from the group of thermal springs at the foot of the mountain. Some of these springs welled up in the *Miskolc-Tapolca Tavas Cave*, already known in the last century. The thermal water lakes filled the bottom of the cave system which opened with tall chimneys to the surface. The cave was converted into a popular cave bath in 1959. Recent expansion work has exposed new parts in the system partly filled with water.

Cserhát Mountains

The rest of the Northern Mountain Range consists mostly of Miocene volcanites and sediments. A considerable mass of karstifying rock only surfaces at the western end of the Cserhát Mountains in Mt. Naszály and around Nézsa—Csővár. Among the 19 caves the fourth deepest of the country, the *Naszály Sinkhole Cave* of dachstein limestone, can be found here. Discovered in 1950, the known depth of the gradually descending cave with its fine corrosive forms grew to 171 m after excavations in 1974. The total length of the mostly narrow cave is 407 m.

Buda Mountains

As for the caves of the NE section of the Transdanubian Mountain Range, they are mostly of thermal water origin.

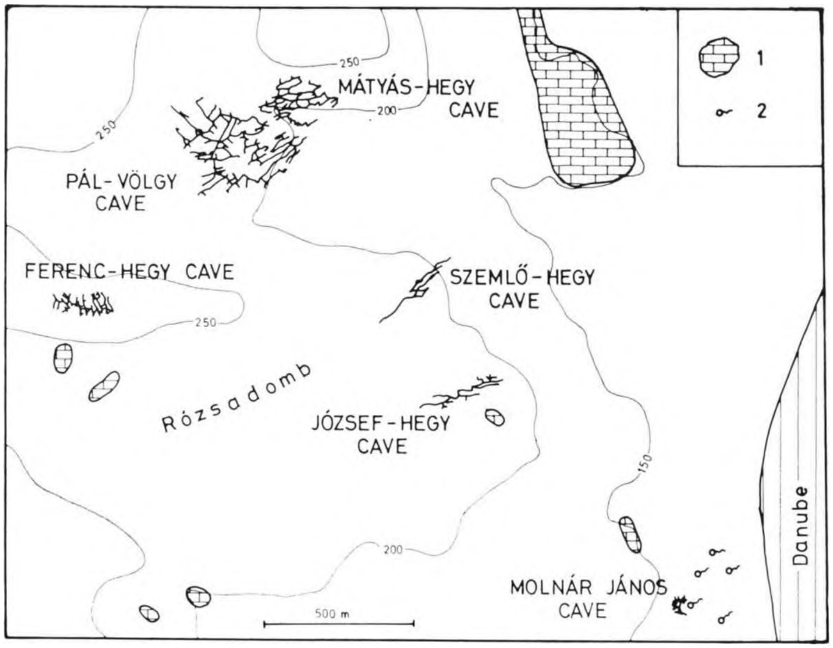


Fig. 5. Geographical location of caves in the Buda Hills. Legend: 1 = travertine, 2 = wram karstic spring

The largest cave systems of thermal water origin in Hungary are in the Buda Mountains surrounding the capital from the NW with an area of 150 km^2 *(Fig. 5)*. Its karstifying rocks include Triassic dolomites and limestones and considerable amount of Eocene limestones and marls. The thermal water effect can be demonstrated for almost all of the currently known 160 caves. The cave systems of the heavily divided mountain range show strong tectonic preformation. Most of the large caves have the plan of a labyrinth. The majority of caves carved out by the mixing corrosion effect of ascending warm waters and descending cold karst waters were explored by quarrying in the first part of this century. The mountain section densest in caves is the Rózsadomb in the capital's second district where the five largest systems can be found within a single km^2.

The largest is the *Pál-völgy Cave* discovered in 1904; its total length nears 7 km after the 1980 excavations which makes it the third longest cave in Hungary. The network passage, covering an area of 500 × 350 m; contains fissure-like, relatively wide passages in Eocene limestone. Its typical formations include walls rich in spherical forms and metamorphosed "silicified" rock zones which stretch along the roof of the passages and shape peculiar cross sections. The largest amount of warm water precipitations are the calcite plates. It contains a relatively large amount of dripstone, unlike the rest of the Buda caves. The entrance section built for tourism has been a favourite destination for outings for decades.

The *Mátyás-hegy Cave* opening in the neighbouring quarry exists a mere 20—30 m away from the northeast termination point of the previously discussed system; the two most probably formed one large system at one time. The spatious ENE-WSW main passages, with the same forms as the previous cave, gradually sink deeper and deeper toward SE in accord with the slant of the rocks. The lowest level of the bare system of nearly 5 km length, lacking warm water precipitations and dripstones, exposes the Triassic cherty limestone base to the Eocene limestone. An intermittent river bed dissolved by the surface waters leads to a lake which marks the karst water level.

The *Szemlő-hegy Cave* was also discovered by quarrying in 1930. It was the first of the Buda caves whose profusion of precipitations in the shape of bunches of grapes and cauliflowers suggested its thermal water origin to specialists. Our typical warm water mineral accumulations such as the popcorn-calcites, cave cauliflower, and calcite plates were first described in this cave. The known length of the system is 2.2.km and constitutes two parallel wide main passages; its most spectacular sections were opened to the public in 1986.

The highest-lying system of Rózsadomb is the *Ferenc-hegy Cave* found while digging canals in 1933. Its maze of passages amounts in length to 4 km and covers a small area of 120 × 250 m. Its passages are fissure-like, relatively narrow, with some large spherical cavities on the upper level. Its walls abound in yellowish white bunches of popcorn-calcites some have been penetrated by later thermal water flows in form of "thermal water pipes".

The Buda cave richest in mineral accumulations is the *József-hegy Cave;* it was only discovered in

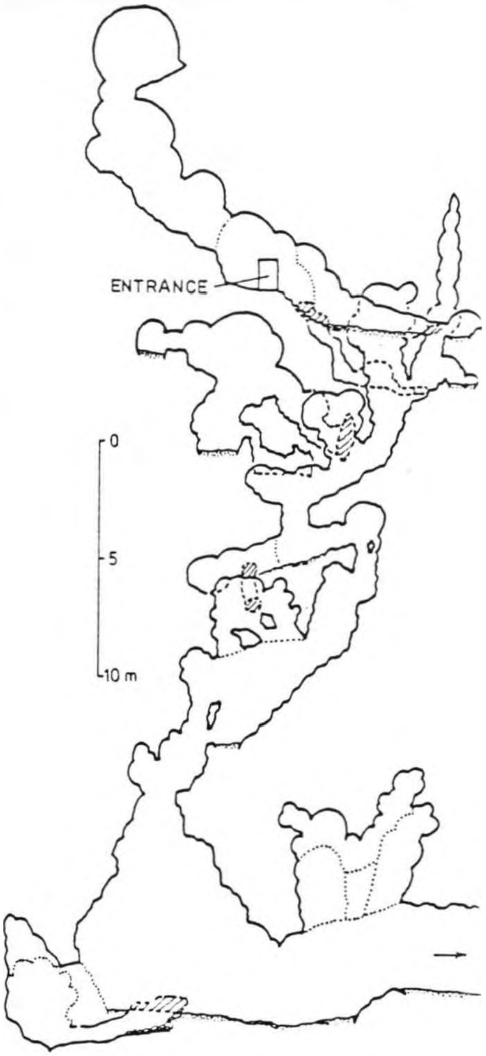


Fig. 6. Long-section of the Sátorkő-puszta Cave (by M. Juhász)

1984. This system consists of wide E-W passages and huge halls, large for caves of thermal water origin; it is 4.3 km long and was discovered during construction works. Its main passage level is some 50 m below the surface and is covered with a wealth of snowwhite gypsum, popcorn-calcites and fragile needle of aragonite; rare large gypsum crystals grow on the ceiling in addition to twining gypsum flowers and hair-thin gypsum threads. In order to protect its formations, the cave can only be researched and visited with special permission.

The only significant active thermal water cave of the mountain range is also in Rózsadomb. The air-filled upper entrance of the *Molnár János Cave* was already known in the last century, and divers explored some 400 m of its underwater stretches. The mixing of components of different temperatures can be demonstrated in the water of the spring cave feeding the Lukács bath.

At the northern edge of the Buda Mountains near Solymár, the *Solymári-ördöglyuk* (Devil's Hole) is the only large cave with a natural entrance. The spatial labyrinth of some 2 km length was carved in Triassic dachstein limestone; its spherical cavities and some areas of popcorn-calcites also indicate its thermal water origin. One of its chimneys was a sinkhole during the Pleistocene as evidenced by fossil bones found in the fill; in its lower rooms a mound of bat guano accumulated several meters high.

Another cave formed in dachstein limestone is the *Bátori Cave* with its opening on top of Mt. Hárs; it was known by neolithic man as demonstrated by the archaeological finds of its entrance hall. This small, 300 m long cave adorned with fine strings of spherical cavities and popcorn-calcites is of special cultural-historical interest. At one time ore mining occurred in some of its passages: in the Middle Ages and later in the 18th—19th centuries veins of high concentration iron and some silver and gold which derived from the dissolution of the ore content in the sandstone of the cover of the limestone were mined.

The genesis of the *Castle Cave* which stretches under the surface of the Castle Hill of Buda is unique: its caverns were carved by a younger generation of thermal springs in the lower level of freshwater limestone deposits of warm water origin. In the Middle Ages the residents of the Castle deepened the small, flat caves for use as cellars, and before World War II a continuous labyrinthine system was formed from them and other artificial cellars for use as air-raid shelters. Its total length is currently 3.3 km.

Pilis Mountains

The Pilis Mountains were built from Triassic carbonates and are attached to the Szentendre—Visegrád andesite mountain in the NE. Within them 150 caves are known today, all of them shorter than 500 m.

The most famous cave of the region is the *Sátorkő-puszta Cave* which opens near the mining town of Dorog. Discovered by quarrying in 1946, it is a typical cave of purely thermal water origin. A bizarre chain of spherical cavities constitutes the 350 m long cave as if we were inside a bunch of grapes. When it was discovered, its walls were covered by a profusion of popcorn-calcites, aragonite needles, and, mainly in the lower great hall, thick gypsum accumulations; unfortunately, by today several lootings have left the cave almost empty *(Fig. 6)*.

The longest known cave in the Pilis is the 403 m long *Legény Cave* opening at the foot of the escarpment of the Csévi cliffs. According to the archaeological finds, its wide entrance gave shelter to several prehistoric groups of people from the Neolithic age. Its chambers are connected by shafts and narrow passages into a maze. Its formations suggests that the original thermal water cave also functioned as a karstic spring cave at a time.

Gerecse Mountains

The karstic central mass of the Gerecse Mountains is made of Triassic carbonate rocks, in the south there is dolomite, giving gradually way to typical thick-layered dachstein limestone toward the north. Smaller areas of Jurrassic limestone and in patches Eocene and Pliocene-Pleistocene limestone can also be found here.

In the heavily broken fault-block mountain divided by basins filled with tertiary sediments no large cave system is known. Except for a few temporary sinkholes the caves are inactive due to the subsequent uplift and the sinking of the erosion base. As both warm and cold waters acted in the region in forming caves, the set of forms of the caves is widely varied. Especially due to research work in the past two decades the number of known caves exceeds 200 now.

Among the caves of thermal water origin in the Öreg-kő of Bajót, an outstanding archaeological site is the *Jankovich Cave* with its impressive entrance hall and wide chimney leading to the surface. Not far is the 40 m deep *Öreg-kő pothole no. 1*, in the lower room of which fine groups of barite crystals with several cm could be studied earlier.

The 500 m long multi-storeyed passage system of the *Pisznice Cave* in the central part of the mountain contains parallel horizontal passages and sizeable cupolas with spherical cavities. Earlier the cave housed a colony of several thousand bats, the guano was excavated in the 1870s.

North of Tatabánya, on the edge of Kő-hegy we find one of the region's archaeologically most intriguing caves, the 40 m long hall of *Szelim-lyuk*. The *Lengyel Cave* of a total length of 550 m and a depth of 73 m opens on the plateau of the mountain. In it the formations created by mixing corrosion can be studied well. The cave is infamous for its extremely high CO_2 content (up to 5.6%).

The deepest cave of the mountains was found in the Keselő-hegy quarry east of Tatabánya in 1976. The *Keselő-hegy Cave* is about 500 m long and 115 m deep. The walls of the fissure-like shafts and halls are at places adorned by fine aragonite crystals.

In the geological conservation area of the Kálvária-domb of Tata, a Mesozoic block rising like a horst from the younger sediments of the Tata—Bicske rift separated from the central mass of the Gerecse, is found the *Megalódusz Cave*. The main spectacle of the 260 m long and 23 m deep cave system, besides the blanket-like calcite coating, is the hundreds of Megalodus-shells petrified finely on the walls.

As coal mining in Tatabánya reduces the karst water level, the *Angyal-forrás Cave* and *Tükör-forrás Cave* in Tata ran dry over the past few decades. The peculiarity of these two spring caves is that most of their passages were carved out in cemented Oligocene gravel.

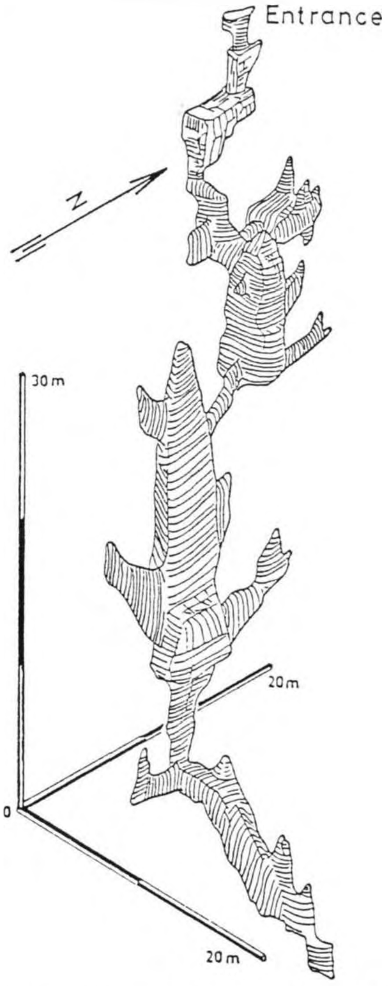


Fig. 7 Three-dimensional map of Csengő Shaft (by J. Kárpát)

Vértes Mountains

In the Vértes Mountains built mostly of Triassic dolomite only few and small caves were formed due to the resistance of the rock to karstification. Of the known 72 caves the largest is the 106 m long multi-levelled *Gánt Cave*. Now inactive, it used to have a spring and now has interesting erosive and corrosive forms. Since the excavations of 1926 in the 90 m long *Csákvár Cave* it is famous for its paleontological finds all over Europe.

Bakony Mountains

The SW unit of the Transdanubian Mountain Range, the Bakony, with the Balaton Highland and the Keszthely Mountains attached to it from S—SW is the second karst region richest in caves. Now 580 caves are known here. Besides the carbonate rocks — Triassic limestones and dolomites as well as Jurrassic, Cretacean and Eocene limestones — the rate of non-karstifying rocks is also high in the geological composition of the mountain range. Most of the caves are small, inactive, slowly accumulating. The majority of the known active systems are sinkhole caves explored over the past 20 years; along the SE periphery inactive and active warm or tepid water caves can also be found.

The largest cave system of the Bakony is the *Alba Regia Cave* in the Tési Plateau covered by a thin layer of loess. Speleologists reached the cave by opening a temporary swallet. As a result of continuous exploratory work, its length is now in excess of 2,500 m, and at —200 m it is the country's third deepest cave. Its main passages with a typical flattened cross section, following the direction of the slanting of the lower Jurrassic limestone, form step-like levels at 10—20 m from each other. The investigation of the lower regions is hindered by the high CO_2 concentration up to 4%.

Several temporary sinkholes of the Tési Plateau continue in sinkhole caves, passable for man. These caves characterized by rows of vertical pits are called also "zsomboly" (shaft) here. So far the *Csengő Shaft* in the vicinity of Kistés has been explored to the greatest depth: its —134 m bottom reached in 1987 is closed off by a syphon of constant water. The typical plum-stone cross-section of the pits and the huge fault plane visible on the lower level suggests the structural preformation of the cave *(Fig. 7)*. Other shafts of the Tési Plateau reach down beyond 100 m: the 121 m deep *Jubileum Shaft* was discovered in 1981, the 105 m deep *Háromkürtő Shaft* in 1975.

The genesis and set of formation of the *Cserszegtomaj Well Cave* opened at a depth of 51 m in 1931 when digging for a well on the SW edge of the Keszthely Mountains go back to one-time hot springs and specific geological conditions. In the Pliocene a thick layer of sand settled on the karstified surface of the Triassic dolomite, which became cemented into impermeable sandstone over the times. The upsurging thermal waters dissolved the upper layer of the dolomite; the 2.3 km long horizontal crawlway maze filled with dolomite powder preserved the negative of the one-time dolomitic surface.

The present-day debourchure of these warm springs is in the *Héviz Spring Cave* opening 38 m below the surface of the Hévíz Lake, an internationally acclaimed spa at the foot of the mountain. Divers explored the spring cave in 1975 by gradually removing the debris accumulated at the bottom of the spring crater and overcoming the powerful current of the debourchure. Both the cold and warm karst springs coming from the dolomite well up on the muddy floor of the nearly spherical spring hall 17 m in diameter in the sandstone. The temperature on the west side is 40° C and on the east side 17° C.

The mixing of the welling-up warm and tepid waters and cold karst waters carved out mostly maze-like horizontal passage networks in the young Sarmatian limestone of the Tapolca Basin wedged amidst three parts of the mountain range. Well-diggers discovered *Tapolcai-tavas Cave* in 1902, which was soon opened to tourism. The exploration of its underwater sections began in 1957. Now the system is known to a length of 1 km. Some 150 m NW of the cave, below the town's municipal hospital, the similar but practically dry *Kórház (Hospital) Cave* has been successfully used to cure asthmatic patients.

The preventive reduction of the karst water level for the sake of bauxite mining some 25 km away has greatly affected the wet caves of the region: in Tapolca the water level sank by 2 m, at Hévíz a significant drop in temperature and yield can be seen.

Mecsek Mountains

In the complex geological composition of the Mecsek Mountains containing volcanic and sedimentary rocks nearly 100 caves are known, some of which are not of karstic origin. Apart from karstic patches, a sizeable karst can be found in the western part of the mountain. This karst region mostly of middle Triassic limestone has intermittently active, shaft-like sinkholes and active spring caves with streams.

The largest and best-known cave of the area, the *Abaliget Cave*, a popular excursion site, is also used for speleotherapy. With a total length of 1,750 m, the active system consisting of a central passage and two side passages has spectacular corrosive and erosive forms, with fine dripstones in the Great Hall. Of its rich fauna, the Stenasellus hungaricus, the blind crab of Abaliget is the most famous.

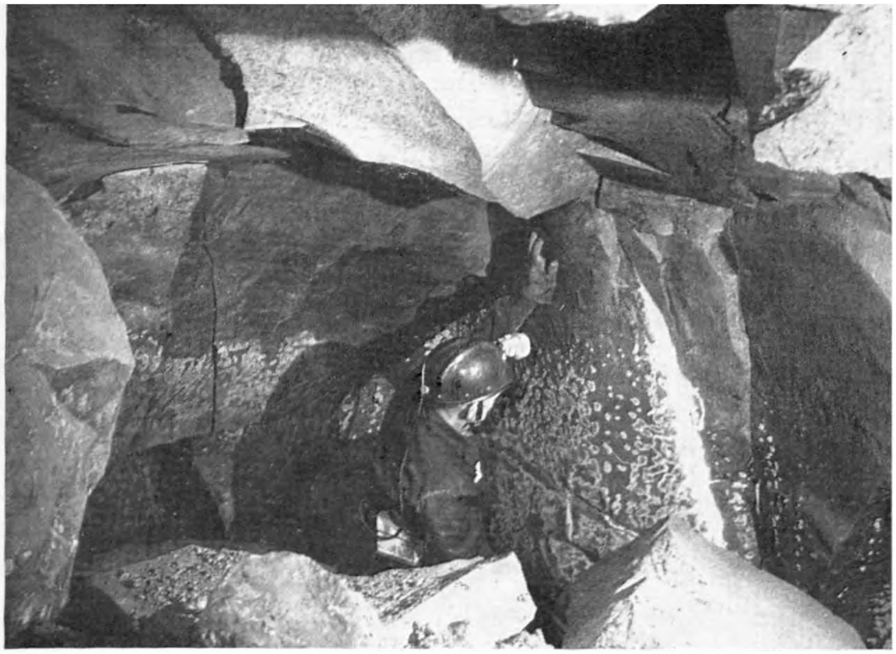
The springs of the 253 m long *Mánfa-kőlyuk* and the 150 m long *Vízfő Cave* of Orfű have been used for water supplies. The *Tettye* travertine cave formed partly naturally and partly artificially is found in freshwater limestone in the area of Pécs. Its voluminous spring is used to contribute to the town's water supplies.

Of the shafts, the *Jószerencsét Shaft* excavated to a depth of 52 m is worthy of note.

Villány Mountains

The southernmost mountain range of the country is the Villány Mountains consisting mostly of Triassic dolomite, Jurrassic and Cretacean limestones. Its most noted caves can be found in the Beremend block in the foreland of the mountain.

Quarrymen found dozens of caverns and pits of thermal water origian partly filled with tepid karst waters even today in the small limestone block rising a mere 50 m above the surrounding plain. The largest of them is the *Beremend Crystal Cave* opened in 1984. The intricate network of caverns stretching 700 m in length is adorned by spherical cavities, snowwhite popcorn-calcites and aragonite needles, and the rare milky white lumps of huntite. The fossil finds of the upper levels suggest that during its development the cave system reached the fill of a one-time open fissure. Similar filled up fissures containing fossils of chronological importance are known at other points of the mountain as well.



Mineral formations on the walls of Pula Basalt Cave (Photo: I. Gönczöl)

Non-karstic caves of Hungary

At present over 200 non-karstic caves are know in Hungary. They occur in almost all mountain regions of the country including mountains of volcanic rocks (basalt, andesite, rhyolite, geysirite, etc.) as well as of sandstone, conglomerate or calceomica. There are especially many in the Bakony (97) and the Mátra (21) Mountains.

Although Hungarian non-karstic caves cannot compete in size with karstic ones, as the largest of them *(Csörgő-lyuk)* is only 230 m in length, the variety of their genesis and of their base rock types makes this group of caves highly interesting.

There are some syngenetic caves in volcanic rocks, although on a small scale. The *Explóziós-üreg* (explosion cavity, 2 m) in the basaltic rock of the Castle-hill of Szigliget on the shore of Lake Balaton, or the *Sámsonházi-hólyagbarlang* (bubble cave of Sámsonháza, 3 m) are simple gas bubbles of regular shape. The underwater *Halász Árpád Cave* (72 m) in Kab Hill, a gas bubble series formed in the interval between two subsequent effusions is a more complex one. Caves formed by gas and steam explosions are also known to exist: the *Gödrös Explosion Cave* on the Tihany Peninsula (16 m), the *Kis-kő Cave* near the town of Salgótarján (30 m), the basalt cavity of *Baglyas-kő* (13 m) and the *Függő-kő Cave* at Mátraszőlős (3 m).

The proportion of postgenetic caves in Hungarian volcanic rocks is much greater. Part of them are linked to the edge of the plateaus formed by basalt on loose rocks and are created by the special denudation of such hills. A shortage of matter, brought about by the pressure of the basalt layer, underground linear erosion, karstification and deflation, results in the gradual collapse of the basalt rim and in the formation of caves. The best examples of these caves are found in the Bakony Mountains: *Remete Cave* (40 m) in Tátika Hill, *Pokol-lik* (51 m) in Bondoró Hill, *Vadlány-lik* (24 m) in Kovácsi Hill, but the only ice cave in Hungary, *Sárkány Cave* in Szentgyörgy Hill also belongs to this group.

Movement along fault lines and incasion created the largest non-karstic caves. *Csörgő-lyuk* (230 m) in the Mátra Mountains was formed in rhyodacite tuff, the *Pula Basalt Cave* (151 m) in the Bakony Mountains and the caves of Szilváskő-Rift in the Medves—Ajnácskő Mountain (with several caves of 20—50 m in a 300 m long, 5—10 m deep open rift) were created in basalt, while the three caves of Vasas cleft (total length: 58 m) in the Pilis Mountains was formed in andesite agglomerate.

Pseudocaves created by boulders falling on each other form only minor cavities in Hungary (in Kovácsi Hill, in Tátika Hill, in Kis-kő Hill, etc.)

Weathering produced only minor caves both in volcanic rocks and in sandstones, conglomerates. *Likas-kő* in the Velence Hills was formed in quartzite (this cave is the oldest recorded non-karstic cave from 1295); *Sziklakonyha* in Somló Hill was formed in basalt; the *caves of Kő-hegy* in the Kál Basin and those of Jakab Hill in the Mecsek Mountains came into being in sandstone, while the caves of Ajka Hill are in conglomerate.

Deflation produces eaves-like caves, like the *Nyereg-hegyi-eresz* on the borderline of basalt tuff and geysirite on the Tihany Peninsula, or the *Kő-lyuk* of Kishartyán formed in sandstone and later expanded by man in the Cserhát Mountains.

Geysirite caves comprise a genetically distinct group. They are partly syngenetic as regards the "lining" of their source pipe or the source cone embracing the central cavity, and partly postgenetic, regarding their dissolved niches and walls. There are over 40 geysirite caves recorded on the Tihany Peninsula. The most important ones are the *Spring Cave* in the centre of the village of Tihany, the spring cave of Csúcs-hegy and the cavities of Aranyház.

Mineral formations primarily occur in caves created in volcanic rocks. They are partly the various crystals of the minerals of the rocks encasing the caves, but partly are precipitations from solutions formerly occupying the caves or from infiltrating waters.

At present, research on non-karstic caves in Hungary is being carried out by a special team, the Volcano-Speleological Group of the Hungarian Speleological Society.

Katalin TAKÁCS-BOLNER
geologist
Institute of Speleology
Budapest
Attila út 111.
H–1012

István ESZTERHÁS
teacher
Isztimér
Köztársaság út 157.
H–8045

Márton JUHÁSZ
technician in geology
Institute of Speleology
Tatabánya
Csokonai út 13.
H–2800

Sándor KRAUS
geologist
Budai XI. Sportegyesület
Budapest
Ságvári Endre út 30.
H–1039

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(For the caves of thermal water origin see p. 38)

THE LONGEST CAVES OF HUNGARY

	Length in meters		*Geographical setting*
	1977.	*1988.*	
1. BARADLA—DOMICA CAVE SYSTEM	25,000	23,916	Aggtelek Karst
2. BÉKE CAVE	8,743	8,743	Aggtelek Karst
3. PÁL-VÖLGY CAVE	1,200	6,753	Buda Mountains
4. MÁTYÁS-HEGY CAVE	4,200	4,770	Buda Mountains
5. JÓZSEF-HEGY CAVE	—	4,300	Buda Mountains
6. ISTVÁN-LÁPA CAVE	2,940	4,100	Bükk Mountains
7. FERENC-HEGY CAVE	4,000	4,000	Buda Mountains
8. LÉTRÁSI-VIZES CAVE	2,200	2,900	Bükk Mountains
9. SZABADSÁG CAVE	2,717	2,717	Aggtelek Karst
10. ALBA REGIA CAVE	925	2,560	Bakony Mountains
11. BOLHÁS SINKHOLE-CAVE	510	2,500	Bükk Mountains
12. CSERSZEGTOMAJ WELL-CAVE	800	2,300	Keszthely Mountains
13. HAJNÓCZY CAVE	1,234	2,250	Bükk Mountains
14. SZEMLŐ-HEGY CAVE	1,962	2,201	Buda Mountains
15. SOLYMÁRI-ÖRDÖGLYUK CAVE	2,000	2,000	Buda Mountains
16. ABALIGET CAVE	991	1,750	Mecsek Mountains
17. LÉTRÁS-TETŐ CAVE	1,660	1,500	Bükk Mountains
18. DANCA CAVE	—	1,390	Aggtelek Karst
19. BORÓKÁS No. 4 SINKHOLE-CAVE	1,000	1,000	Bükk Mountains
20. FEKETE CAVE	1,000	1,000	Bükk Mountains
21. VASS IMRE CAVE	1,000	1,000	Aggtelek Karst
22. BARADLA ALSÓ CAVE	400	1,000	Aggtelek Karst
23. DIABÁZ CAVE	533	1,000	Bükk Mountains
24. TAPOLCAI-TAVAS CAVE	1,000	1,000	Balaton Highland
25. JÁVOR-KÚT SINKHOLE-CAVE	907	906	Bükk Mountains
26. KOSSUTH CAVE	633	800	Aggtelek Karst
27. VIKTÓRIA CAVE	800	800	Bükk Mountains
28. ISTVÁN CAVE	350	711	Bükk Mountains
29. BEREMEND CRYSTAL-CAVE	—	700	Villány Mountains
30. MEXIKÓ-VÖLGY SINKHOLE-CAVE	700	700	Bükk Mountains
31. METEOR CAVE	500	650	Aggtelek Karst
32. KÓRHÁZ CAVE	380	640	Balaton Highland
33. SZABÓ-PALLAG SHAFT	—	628	Aggtelek Karst
34. VÉNUSZ CAVE	600	600	Bükk Mountains
35. LENGYEL CAVE	400	550	Gerecse Mountains
36. KESELŐ-HEGY CAVE	260	500	Gerecse Mountains
37. PISZNICE CAVE	247	500	Gerecse Mountains
38. SZELETA SHAFT	—	500	Bükk Mountains
39. SZIRÉN CAVE	500	500	Bükk Mountains
40. KŐ-LYUK CAVE	350	484	Bükk Mountains
41. HARCSASZÁJÚ CAVE — BAGYURA CAVE	225	440	Buda Mountains
42. MOLNÁR JÁNOS CAVE	351	414	Buda Mountains
43. NASZÁLY SINKHOLE-CAVE	—	407	Cserhát Mountains
44. LEGÉNY CAVE	350	403	Pilis Mountains
45. EZÜST-HEGY No. 3 CAVE	400	400	Pilis Mountains
46. KECSKE-LYUK CAVE	400	400	Bükk Mountains
47. SZAMENTU CAVE	400	400	Bükk Mountains
48. KOPASZGALY-OLDAL No. 2 CAVE	350	350	Aggtelek Karst
49. LÁNER OLIVÉR CAVE	—	350	Bükk Mountains
50. SÁTORKŐ-PUSZTA CAVE	350	350	Pilis Mountains
51. VÁR-TETŐ CAVE	—	350	Bükk Mountains
52. BÁTORI CAVE	300	339	Buda Mountains
53. EDERICS CAVE	—	338	Keszthely Mountains
54. KIS-KŐHÁT SHAFT	—	330	Bükk Mountains
55. RÁKÓCZI CAVE No. 2	200	324	Aggtelek Karst
56. BALEKINA CAVE	—	300	Bükk Mountains
57. PÉNZ-PATAK SINKHOLE-CAVE	221	300	Bükk Mountains
58. SPEIZI CAVE	—	300	Bükk Mountains

THE DEEPEST CAVES OF HUNGARY

	Depth in meters		*Geographical setting*
	1977.	*1988.*	
1. ISTVÁN-LÁPA CAVE	243	250	Bükk Mountains
2. VECSEM-BÜKK SHAFT	245	235	Aggtelek Karst
3. ALBA REGIA CAVE	210	200	Bakony Mountains
4. NASZÁLY SINKHOLE-CAVE	60	171	Cserhát Mountains
5. LÉTRÁS-TETŐ CAVE	166	166	Bükk Mountains
6. FEKETE CAVE	140	163	Bükk Mountains
7. DIABÁZ CAVE	153	153	Bükk Mountains
8. CSENGŐ SHAFT	—	134	Bakony Mountains
9. METEOR CAVE	132	131	Aggtelek Karst
10. BÁNYÁSZ CAVE	130	130	Bükk Mountains
11. PÉNZ-PATAK SINKHOLE-CAVE	128	128	Bükk Mountains
12. BOLHÁS SINKHOLE-CAVE	80	125	Bükk Mountains
13. JUBILEUM SHAFT	—	121	Bakony Mountains
14. SZABÓ-PALLAG SHAFT	130	120	Aggtelek Karst
15. TOKOD-ALTÁRÓ No. 1 CAVE	—	120	Gerecse Mountains
16. HAJNÓCZY CAVE	117	117	Bükk Mountains
17. BARADLA—DOMICA CAVE SYSTEM	116	116	Aggtelek Karst
18. KESELŐ-HEGY CAVE	115	115	Gerecse Mountains
19. KIS-KŐHÁT SHAFT	110	114	Bükk Mountains
20. BORÓKÁS No. 2 SINKHOLE-CAVE	110	110	Bükk Mountains
21. KOPASZGALY-OLDAL No. 2 CAVE	110	110	Aggtelek Karst
22. MÁTYÁS-HEGY CAVE	106	108	Buda Mountains
23. HÁROMKÜRTŐ SHAFT	105	105	Bakony Mountains
24. PÁL-VÖLGY CAVE	—	104	Buda Mountains
25. JÓZSEF-HEGY CAVE	—	103	Buda Mountains
26. BORÓKÁS No. 4 SINKHOLE-CAVE	102	102	Bükk Mountains
27. SPEIZI CAVE	96	96	Bükk Mountains
28. JÁVOR-KÚT SINKHOLE-CAVE	112	94	Bükk Mountains
29. NAGYKŐMÁZSA-VÖLGY SINKHOLE-CAVE	94	94	Bükk Mountains
30. ALMÁSI SHAFT	93	93	Aggtelek Karst
31. LÉTRÁSI-VIZES CAVE	85	90	Bükk Mountains
32. VÁR-TETŐ CAVE	90	90	Bükk Mountains
33. BALEKINA CAVE	—	89	Bükk Mountains
34. BARADLA-TETŐ SHAFT	—	89	Aggtelek Karst
35. SZELETA SHAFT	110	87	Bükk Mountains
36. MEXIKÓ-VÖLGY SINKHOLE-CAVE	80	80	Bükk Mountains
37. RÁKÓCZI CAVE No. 1	87	79	Aggtelek Karst
38. TEKTONIK SHAFT	76	76	Aggtelek Karst
39. REJTEK SHAFT	74	74	Aggtelek Karst
40. LENGYEL CAVE	73	73	Gerecse Mountains
41. TÁBLA-VÖLGY CAVE	78	73	Bakony Mountains
42. CSIPKÉS SHAFT	75	73	Bakony Mountains
43. LÁNER OLIVÉR CAVE	—	72	Bükk Mountains
44. REMÉNY SHAFT	70	70	Mecsek Mountains
45. KESELŐ-HEGY No. 11 CAVE	—	70	Gerecse Mountains
46. LEGÉNY CAVE	—	63	Pilis Mountains
47. HÁRMASKÚT SINKHOLE-CAVE	—	62	Bükk Mountains
48. VÉRTES LÁSZLÓ CAVE	56	62	Gerecse Mountains
49. BORÓKÁS No. 3 SINKHOLE-CAVE	55	60	Bükk Mountains
50. EZÜST-HEGY No. 3 CAVE	60	60	Pilis Mountains
51. ÚTMENTI SINKHOLE-CAVE	60	60	Bükk Mountains

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THE RESULTS OF RESEARCH INTO CAVES OF THERMAL WATER ORIGIN

Katalin Takács-Bolner — Sándor Kraus

Several caves can be found in Hungary whose rich forms and mineral precipitations cannot be attributed to the impact of descending cold karst waters or to the effect of slow subhorizontal streaming of cold waters at the karstic water level. These caves occur at the edge of limestone mountains where uplifted carbonate rock masses in the foothills and intermountainous basins meet with sunken carbonate masses that are covered by thick, water impermeable formations.

The upwellings of our natural thermal springs can also be found in these same regions, but while these were known since prehistoric times, the overwhelming majority of caves were only discovered in our century as a result of some human activity, usually quarrying. Although the genesis of the typical rich forms of certain caves was ascribed by Pávay Vajna (1930) to the work of hot solutions, streams and gases, it was the rather peculiar mineral combination that first convinced specialists that a relationship existed between these caves and the neighboring thermal springs. With the growth in the number of known caves, resulting in expanding investigations and improving hydro-geo-mineralogical research methods more and more details about the genesis and development of the caves became definable.

Hydrothermal caves can be found in greatest number in the Buda, Pilis and Gerecse Mountains, but they also occur in every major karstic region of Hungary: on the SE border of the Aggtelek Karst and Bükk Mountains, in the Keszthely Mountains constituting the SW foreland of the Bakony and in the Beremend section in the S fore land of the Villány Mountains. Quite frequently, these caves are of considerable size: among the 104 longest/deepest caves in Hungary (longer than 200 m and/or deeper than 50 m) 32 belong to this category including the country's third, fourth and fifth longest cave systems.

Some data of discovery of the Hungarian thermal-karstic caves

According to our current knowledge, of all the Hungarian caves formed fully or partly by thermal waters, only some minor caves in the Gerecse and Pilis Mountains, as well as the Castle Cave and the Bátori Cave in Budapest were proved to have been known by prehistoric and medieval man.

The cave opening above Buda's lukewarm Malom lake was first mentioned in 1856 by János Molnár, who explored and surveyed its dry upper section and also carried out hydrochemical examinations there. The first known cave of the Beremend block was a cavity exposed by quarrying in 1863: the fossil bones found there were analyzed by Kubinyi (1863) and Petényi (1864). By the end of the last century, the spatious cavity at the foot of the Bükk Mountains near Miskolc, the Miskolctapolcai Tavas Cave, with its voluminous thermal spring, was also known. The active Tapolcai Tavas Cave in the Balaton Highland filled with lukewarm lakes, was discovered in 1902 during the course of digging wells.

Among the large caves of Buda, the first to be discovered was the Pál-völgy Cave in 1904 during quarrying in the hills of Buda. Cold surface waters were assumed to have played the main role in its formation: thermal waters were felt to be secondary preforming factors via subsequent crystallization (Cholnoky, 1925) or recrystallization (Scharf, 1928).

The nearby Szemlő-hegy Cave was also discovered by quarrying in 1930. By analyzing the abundant, unusual, "popcorn-calcites" covering the walls it was recognized thermal water origin. (Kadic, 1931, 1933, Cholnoky, 1935). While digging a canal, another fissure network covered with "popcorn-calcites" was discovered here in 1933, the Ferenc-hegy Cave.

The largest network of the Keszthely Mountains, the horizontal labyrinth of the Cserszegtomaj Well-Cave, was discovered while digging for a well in 1930, 51 m below the surface.

The Sátorkőpuszta Cave on the NW edge of the Pilis Mountains near Dorog rich in gypsum crystal and aragonite precipitations was explored and examined in 1946. Its peculiar system of spherical niches was regarded as the model of cave formation caused solely by thermal waters origin (Jakucs, 1948). The fissure caves lined with crystalline pre-

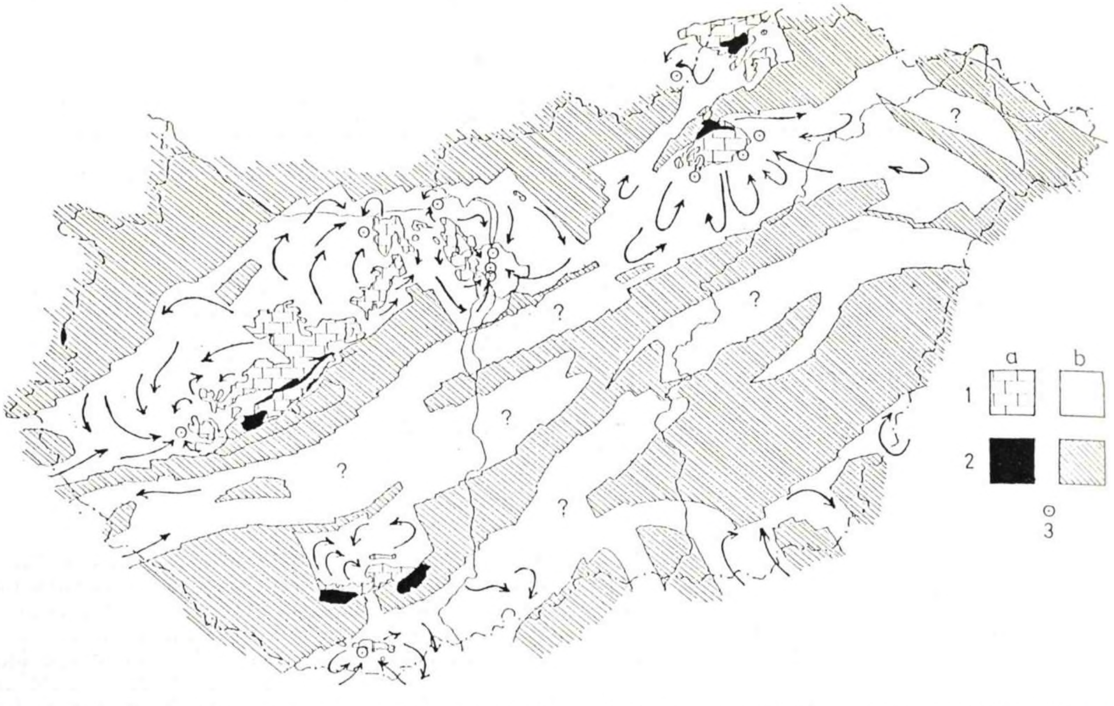


Fig. 1. Directions of the regional karst water circulation in the base-rocks of Hungary (after Alföldi—Böcker—Lorberer). — 1 = karstic base-rocks (mainly mesozoic), 2 = non-karstic base-rocks (mainly paleozoic and pre-cambrian), 3 = bigger thermal spring; a = on surface, b = subsurface

cipitations and crossed by the gangways of the Dorog coal mines were described in 1949 by I. Venkovits.

The exploration of the underwater sections of thermal-karstic caves could began with the spread of cave diving. By 1974 one km of the Tapolca Tavas Cave had been explored; the known length of the Molnár János Cave grew to 400 m in 1977. The country's deepest-lying hot spring cave, the Héviz Spring Cave with its opening 38 m below water level was successfully explored in 1975.

Significant explorations have also occured over the past ten years. Since 1980 the length of the Pál-völgy Cave has increased by over 5 km; in 1984, while laying housing foundations the József-hegy Cave, one of the country's richest caves in crystalline formations, was exposed, followed by the discovery of the Beremend Crystal Cave during quarrying. All this clearly shows that we still do not fully know the number and size of our thermal water caverns.

The system of thermal water flow

In regards to the origin of our thermal springs, Zsigmondy (1878) had already determined that rainwater infiltrating through the surface of the carbonate masses of the Transdanubian Mountain Range warms up while flowing in the basin deposit covered carbonate rocks and reaches the surface again in the form of thermal waters. The first model of this circulation was developed by Schafarzik (1924—26). Vendel and Kisházi (1963—64) described the flow of karstic thermal waters in the middle Mountain Range on the basis of heat and water metabolism calculations. Presently, the most current model of the thoroughly examined Budapest thermal waters was developed by Alföldi et al. (1977).

Structural, geological, hydraulic and thermodynamic factors have all had a share in producing these region-wide flows. The surface outcropping (1350 km^2) of the mesozoic carbonates constituting the great majority of karstifying rocks in Hungary, is a mere 10% of their total area, this means that carbonate rock masses covered with young basin sediments have a significent share in the geological constitution of the country. The considerable warming of waters stored in the cracks and cavities of carbonate rocks partly karstified during the cretaceous period and then submerged is due to the geometric gradient of 5° C/100 m, this is well above the global average, and is caused by the thin crust of the earth in this region.

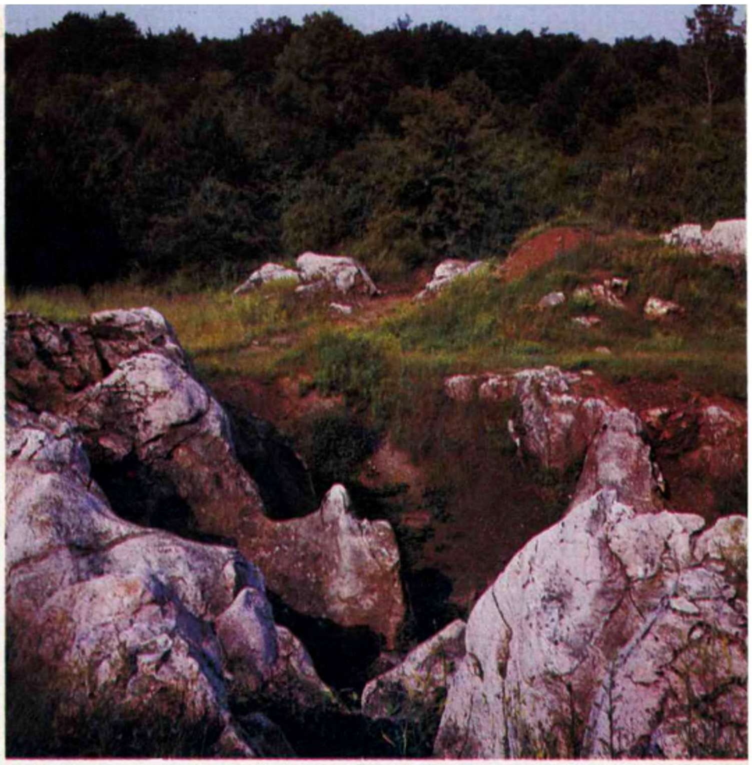
The flow system is kept in motion by the difference in pressure between the free karst water level of the infiltration zones and the tapping points. The pressure difference is caused, on one hand, by the difference in geodetic heights, and on the other, by the difference in specific weights resulting from differing

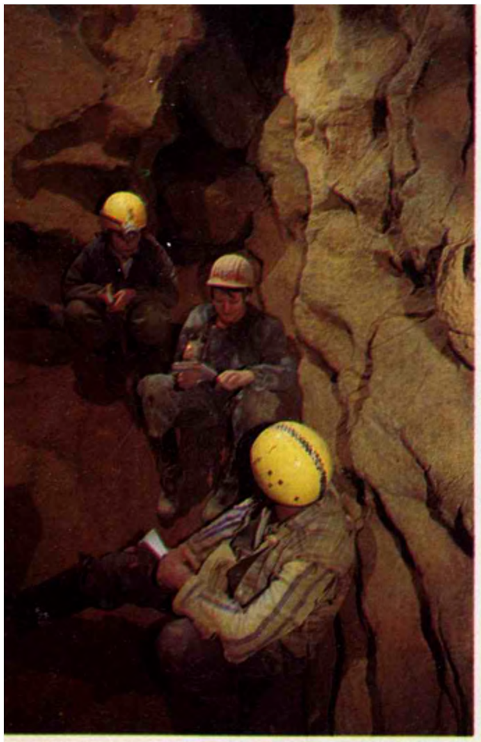
Top left: Hematite and hydrohematite in the Cserszegtomaj Well Cave, Bakony Mts.

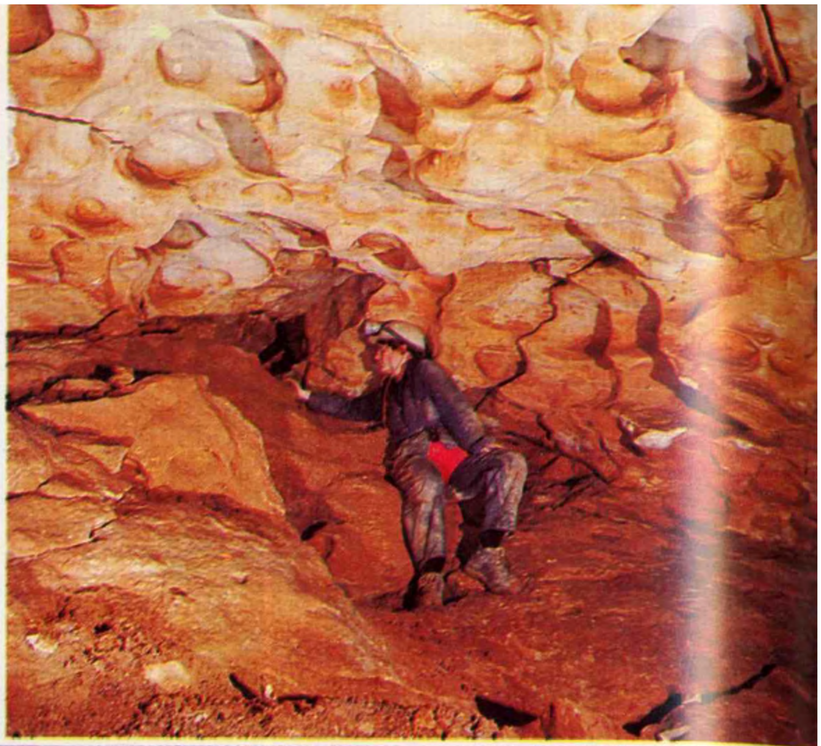
Undernith: Rimstone pool in the Pál-völgy Cave, Buda Mts.

Top right: Exhumed paleokarst of Urkut, Bakony Mts.

Bottom: Remete-völgy Cave, Buda Mts. (by P. Borzsák)







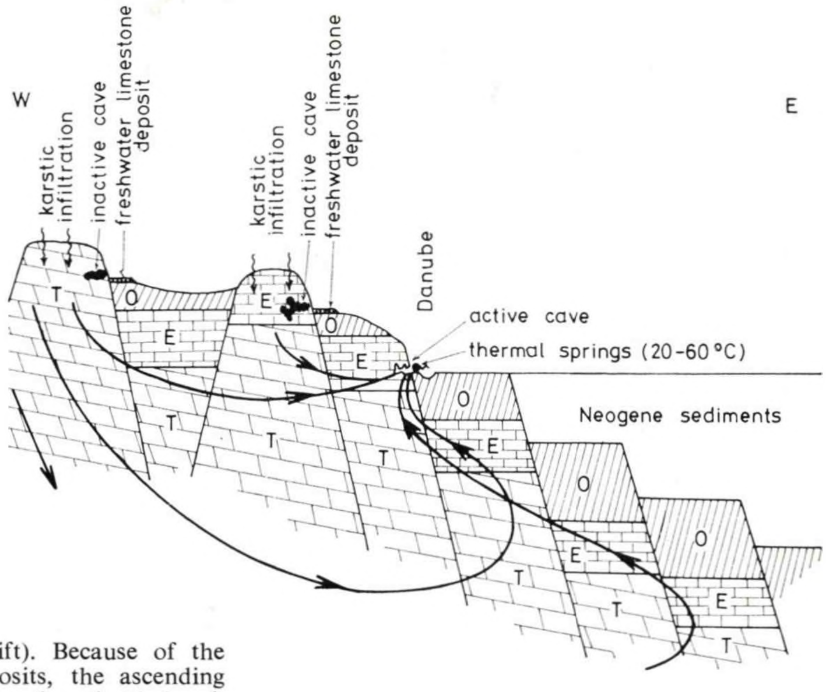


Fig. 2. Scematic profile of the hydrothermal activity of the Buda Hills. — T = Triassic carbonatic formations, E = Eocene carbonatic formations, O = oligocene clay and silts (after Kovács and Müller, 1980)

water temperatures (thermo-lift). Because of the impervious young basin deposits, the ascending thermal waters follow a forced path and only break the surface where the water guiding carbonate masses jut out from the impervious formations at the boundaries of mountain ranges; in other words, this upward flow is conditional upon certain structural zones (Fig. 1).

These structural zones usually coincide with the tapping points of the descending cold waters in a given group of mountains, thus in the spring zones cold and warm components are mixed (Fig. 2). The blending of the two components can be proved by the difference in temperature and tritium-isotope water age between the waters of drilled wells immediately drawing the warm component and the waters of the natural thermal springs (Deák, 1979). It can be observed in our active thermal water caves as well: in the Molnár János Cave water temperatures of 18 and 26° C can be measured (Plózer, 1972), in the Héviz Spring Cave 17 and 40° C waters gush forth a few metres apart (Plózer, 1977). The strong corrosive effect of the mixing of waters of various temperatures and solutions accounts for the karstic networks broadening into cavernous passages in the spring zone (Müller and Sárváry, 1977).

In accordance with the karstic origin of the thermal waters, these caves are not hydrothermal but thermal-karstic systems, since geological terminology ascribes hydrothermal solutions to postvulcanic processes. At the same time, in view of the mixing corrosive factor playing the main role in dissolving most of these caves, these caverns are actually not of thermal water but of warm water origin.

Top left: Teaching in Mátyás-hegy Cave, Buda Mts. (by P. Borzsák)

Top right: Solution forms in Mátyás-hegy Cave (by K. Fehér-Kárpát)

Bottom: Archaeological site in Jankovich Cave, Gerecse Mts. (by P. Borzsák)

On the basis of analyzing freshwater limestones deposited by warm springs in the Buda and Gerecse Mountains (Scheuer and Schweitzer, 1981) as well as paleogeographic investigations it can be assumed with certainty that the above outlined flow systems have been unchanged since the Pliocene and Pleistocene periods. The action of warm water springs over hundreds of thousands of years must have created several levels of freshwater limestones and caves in the gradually rising mountain groups during the Pleistocene era (Fig. 3). The relatively well discernible levels also reflect the climatic fluctuation in the glacial period, greatly affecting the volume of rainwater which provided additional water supplies. These climatic changes can also be monitored by examining vertebrate fossils found in the fills of some caves of thermal water origin (Jánossy, 1979).

Due to heavy water extraction for mining, the karst water level of the Transdanubian Mountain Range has significantly dropped in the past decade. As a result of the altered pressures, lukewarm springs of great yield ran dry in Tata and Tapolca, while in Héviz there has been a considerable decrease in yield and temperature.

The process of cave formation

The spatial pattern of our caves formed by thermal waters (the thick maze of practically equivalent passages condensed on a small area and extending several km in length, the sudden changes in section sizes, the spatious corridors and cavities joined by surprisingly narrow passages) can all be attributed to the mixing corrosive effect in the spring zone. The difference between mixing waters, and hence the corrosive effect, can be enhanced by the hypothetical process of the ascending warm component

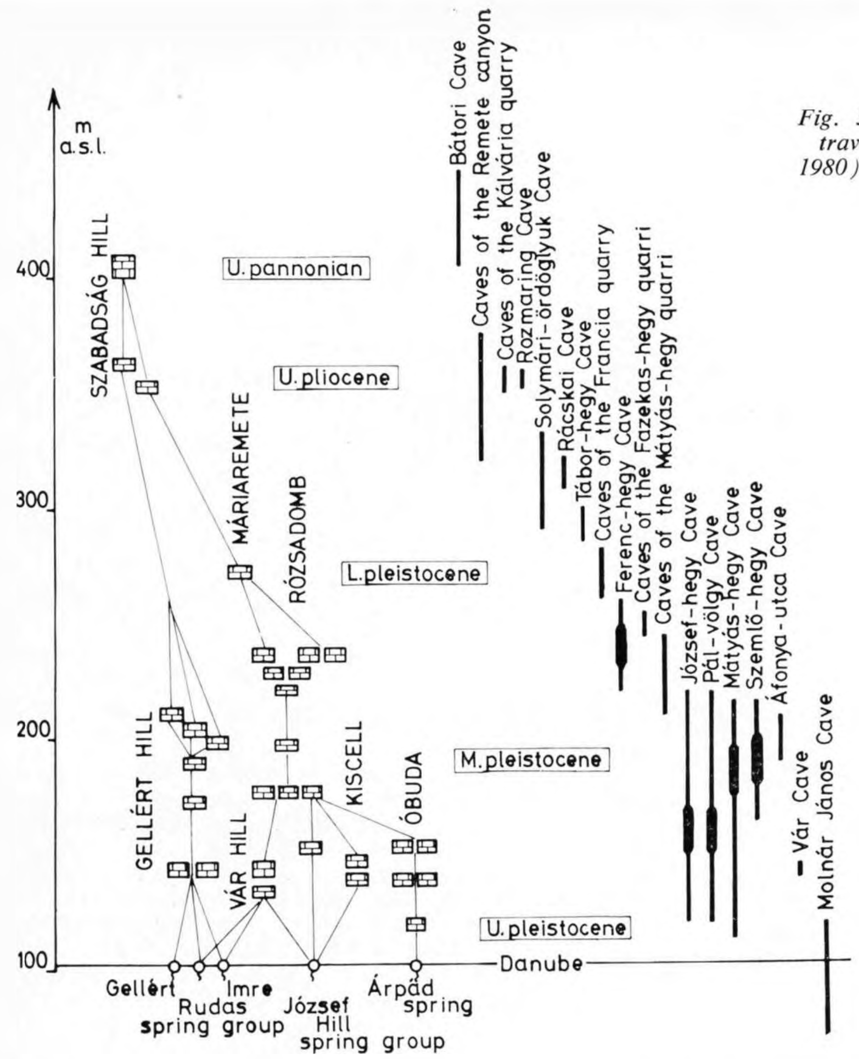


Fig. 3. Vertical locations of the travertine formations (Scheuer, 1980) and the more important caves of Buda Hills

absorbing the CO_2 freed by the metamorphosis taking place in the deeper regions of the sunken carbonate mountains (Müller, 1971).

As the waters mixing in the spring zones move along the network of crevices in the rock mass, normally the most important preforming factor of caves is tectonics. It is most conspicuous in the case of the large grid-like cavity systems in the Buda Mountains (Kraus, 1978), but the effect of tectonic preformation can also be demonstrated by statistical examination of passages directions in intricate spatial mazes like the Beremend Crystal Cave (Mrs. Takács, 1985). In keeping with the strong tectonic preformation, the passages of our thermal-karstic caves are fissure-like, their height far exceeding their width *(Fig. 4)*.

Stratigraphic and petrological preformation also played a significant role in several caves. For instance, in some Buda caves the uppermost level of the main cavity is confined by marl which settled in the cover of the Eocene limestone. This could only be breached by spring vents where more powerful water activity was able to remove the large amount of dissolved remnants in this type of rock (Müller, 1974). The Cserszegtomaj "well-caves", once belonging to the water system of the Héviz lake were carved at the confluence of the Triassic dolomite and the superimposed young impermeable sandstone. There are minor caves of warm water origin in Esztergom that emerged where the Triassic limestone and Oligocene silicious sandstone met.

In some caves in the Buda Mountains a characteristic metamorphosis of rock can be observed to a width of several dm around certain fissures. The yellowish white porous material containing typical Eocene fossils and not soluble in acids was interpreted by Scharf (1928) as rocks recrystallized by hot waters welling up along the crevices; Cramer (1929) showed the presence of 67—90% SiO_2 in it. The process of silicification was first conclusively separated from warm-water activity causing the formation of caves by Kovács and Müller (1980); they argued that these alterations as well as the emergence of certain mineral veins cannot be ascribed to the pressure and temperature relationships in a system of thermal water flow. According

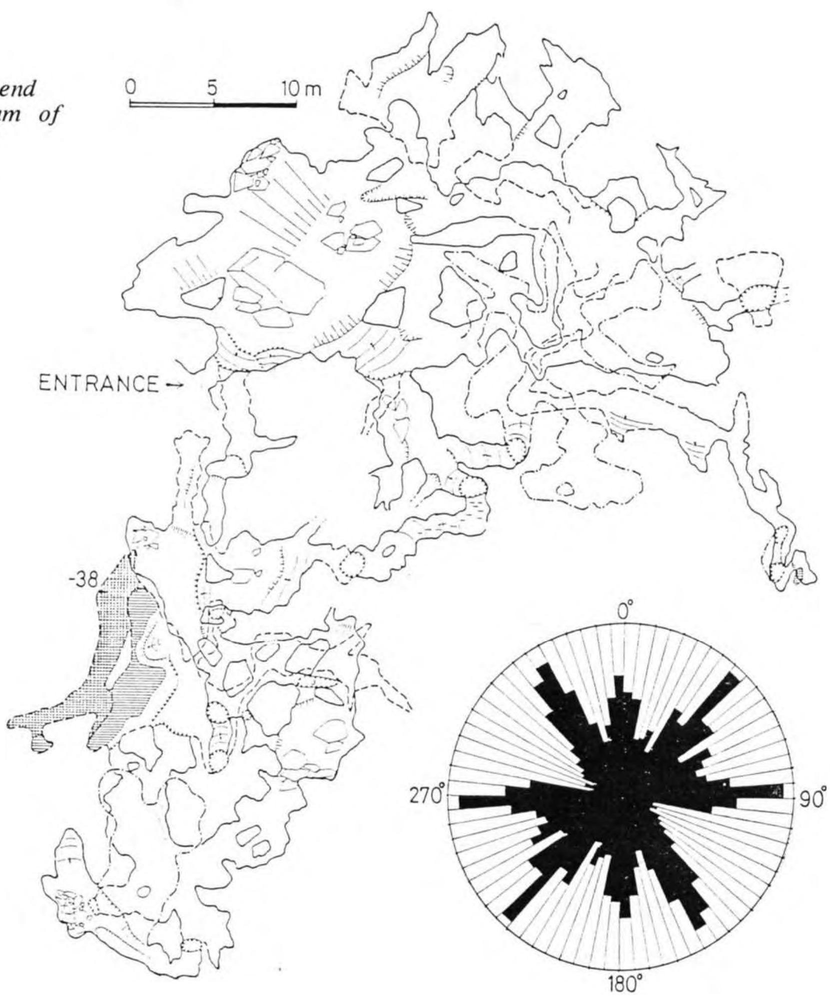


Fig. 4. Plan of the Beremend Crystal Cave and a diagram of their passage-directions

to their two-phase model, the phenomena, which can be studied in surface rock exposures as well are the products of a hydrothermal phase connected to the Miocene andesite volcanism of the Dunazug Mountains, when it took place, the area of the Buda Mountains was still covered by clay several hundred meters deep.

This early phase must have caused some cave formation, but evidence can only be adduced in caverns whose walls are covered by the minerals of this high-temperature phase. The insoluble, silicified rock zones had a preforming effect due to their porous, and thus aquiferous quality, e.g. the wide passages of the Mátyás-hegy Cave and Pál-völgy Cave evolved along such silicious zones (Kárpát 1983, Mrs. Takács 1980). Frequently, only one side of the silicious zones was carved out, producing a typical passage section shaped like the letter 'd' (Kraus 1982).

The most characteristic forms in our thermal-karstic caves are the spherical niches. These nearly regular spherical or hemispherical cavities, several meters in diameter and joined in a head like fashion, are usually found in the upper levels of caves, often as the closing formation. At first Müller (1974) explained their genesis as the result of condensation dripping from the walls of fissures opening above the water surface. This argument, however, failed to account for the fully closed cupolas, and other similar forms which can also be found in cold-water caves, though in far fewer in number. According to the current hypothesis, these forms were created by convection currents in passages filled with water (Müller, 1977, 1983). Both the corrosion model by condensed water (Szunyogh, 1982, 1984) and the model of underwater corrosion (Rudnicki 1978, Dubljansky, 1987) have been proven by theoretical physics. It is noteworthy that the calculations of the time involued in the evolution of these forms also confirm the latter process (Szunyogh, 1987).

The large forms of the passages are enlivened by a variety of minor forms derived partly from selective corrosion, partly from the point-like effect of mixing corrosion, from water current, as well as from the movement of gas bubbles arising from the warm water. The best known minor forms are the hemispherical "kettles", several dm in diameter occurring by the dozen on certain wall sections

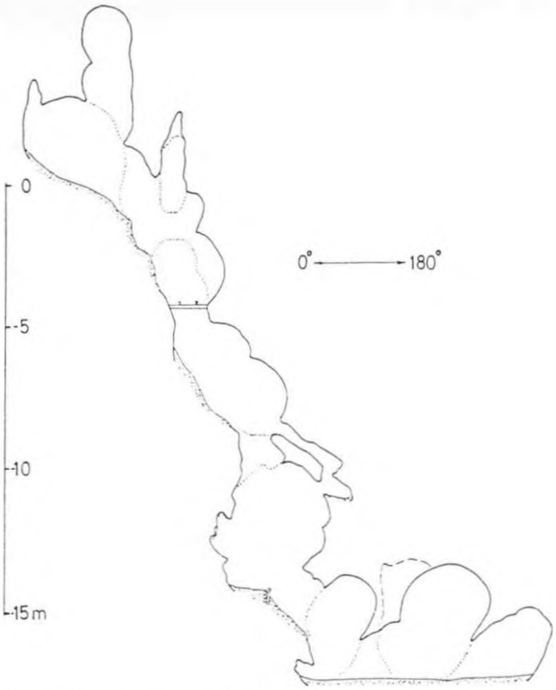


Fig. 5. Long section of the Bátori Cave with the line of spherical niches (by P. Borka and J. Kárpát)

(earlier attributed to vortices) as well as the ceiling canals and narrow bubble tubes in the roofs of passages or overhanging wall surfaces.

It can be demonstrated in several caves of thermal water origin that the extent of water coverage periodically changed during their evolution. This can be attributed to the combined effect of the climatic fluctuations during the Pleistocene era and the gradual rise of our mountains. During the glacial, dry periods of the Pleistocene era the decreased quantity of precipitation diminished the yields of springs, probably causing some to go completely dry. In the carved out system of caves the decreased water level produced practically stagnant lakes in contact with the air-space, and from these characteristic minerals settled on the walls and floors of the caves.

In areas where the rise of massifs opened up new tapping points, there was a relocation in the area of spring activity in the forthcoming milder, wetter period and the formation of caves continued in new spring zones. The stations of this process can be retraced by examining the caves and freshwater limestone deposits at different levels (Scheuer and Schweitzer, 1981). Where no considerable shift was possible, the warm water refilled the former passages or a part of them when thermal water activity resumed. It can be observed in some thermal karstic caves of the Buda Mountains that the renewed water movement broke through the accumulations and thus produced characteristic "thermal spring tubes" (Kessler, 1961); elsewhere hemispheric "kettles" were carved into the precipitations and some precipitations partly dissolved again, then continued to grow (Kraus, 1982).

In the Pál-völgy Cave, however it can be proved that some of its thermal karstic mineral precipitations settled on a previously sere base (Kiss—Mrs. Takács, 1987), the remains of this earlier filling level is sometimes several meters higher than the present floor. That is, there occured at least three water filled periods. In some caves in the Beremend block, of the Pilis Mountains and in the Esztramos Hill, dripstone formations started in the periods between thermal karstic activity, and returning ascending warm waters then dissolved their surfaces and subsequently covered them with precipitations. The stalactites found deep under the present water level in our active warm water caves reflect the karst water level changes in the recent past history of the Earth.

The further expansion of completely dried out caves by the gradual rise of the massifs was only caused by collapses and the slow draining of the silicious zones, though in the case of some caves of thermal water origin the passages opening on the surface came to act as swallets later. This is attested by the paleontological finds of the Solymári Ördöglyuk Cave (Vértes, 1950), the cold-water corrosion created forms known as the Stream Passage in the Mátyás-hegy Cave (Kárpát, 1983) or the remains of carbonized plants in the sediment fill of the Pál-völgy Cave.

Mineral precipitations

Minerals of the high-temperature phase preceding the dissolution of caves, precipitations of warm waters filling the caves, and dripstone formations o cold waters oozing in the dried systems may all be found among the varied mineral associations of our caves formed by warm waters.

Minerals linked to high-temperature solutions are obviously not limited to the caves; they can be located in rock outcropings on the surface and on the walls of quarries and mine shafts. Cave passages merely expose these minerals, much as they do the paleontological remains of the bedrock or its limonitized pyrite concretions.

Among the minerals formed at high temperatures, calcite is the most widespread; its massive loads sometimes appear in meter-wide veins, while its "dogtooth spar" crystals of a few cm, line the walls of open fissures and crystal cavities (geodes). Barite veins consisting of tabular crystals are also common in the Buda Hills and the Gerecse and Pilis Mountains.

Because the mineral veins were barely soluble due to their material and the large specific surface area of their crystals, they were a hindrance to the subsequent formation of caves; thus, they appear deeply jutting into the passages on the walls and ceiling. Partly due to this fact and partly because the crystalline forms were indicative of high temperatures came the recognition that prior to the thermal-karstic activity that created these caves they evolved through "closed cell" redeposition in the rock mass buried beneath a thick clay cover (Kovács and Müller, 1980).

Recent mineralogical researches has confirmed the above hypothesis. The examination of the fluid inclusions in the vein and "dog tooth" calcites (Gatter, 1984) proved their separation the 135—200° C waters of the confined karst. Based on the composition of the enclosed solutions, the samples from the Buda Mountains suggested volcanic activity as the origin of the thermal effect, while those from the Bakony and Bükk Mountains indicated geothermal heating. According to U/Th dating and ^{13}C—^{18}O isotope tests to which the samples from the Buda Mountains were subjected, by Ford these minerals differed sharply from mineral precipitations caused by warm waters (personal communication, 1985).

In the Buda Mountains we can find several generations of calcites and barites characterized by different crystalline forms (Schafarzik, 1928), and in some places alternate calcite and barite formations (Koch, 1966). This indicates that the closed-cell redeposition of material was intermittent, renewing several times. These phenomena can be observed in caves as well. The warm waters that carved the caves dissolved a part of the older calcite crystals e.g. in Beremend the surface of the thick calcite veins falls into match stick thin calcite chips, and at several places on the surface or tip of the "dog tooth" calcites deep grooves can be seen.

In contrast to the previous genetic group of mineral formations, those of warm water origin generally do not appear outside of the caves except as occasional precipitations near the surface of drilled thermal well sites. Their concentration at certain levels inside caves suggests that they were deposited during the invervals between thermal karstic activity through the precipitation of dissolved materials in lakes of partly air-filled caves due to the gradual rise of the massifs (Kraus, 1982). Mineralogically, most of these deposits are calcite.

The most frequent form that warm water precipitations assume is the "popcorn-calcite", white or yellowish-white stratified pellets which cover cave walls like bunches of grapes clustered along thin stalks. Originally this formation, first found on a mass scale in the Szemlő-hegy Cave was thought to be aragonite and led to the recognition of the thermal water origin of the cave. Modern research techniques proved them to be of calcite, probably the result of subsequent recrystallization.

In some caves one can find formations similar to "popcorn-calcites", consisting of spar-shaped units, but each unit consits of a selfcontained crystalline structure. These were probably calcitic from their conception (Kiss—Mrs. Takács, 1987). The "cauliflowers", more densely clustered than the "popcorn-calcites" lacking a stratified structure (Kraus, 1982), probably evolved in areas sealed from streaming.

Another typical formation is the calcite platelets containing calcite sheets a millimeters to centimeters thick. These evolved from thin calcareous films which separated from surface of cave lakes. As these broke apart and sank to the bottom, they acted as crystal niduses, thus thickening and adhering together (Kraus, 1978). Due to redeposition in the original fill the remains of these often occur several meters above today's walkways; at their bottom edge pieces of debris from the one-time fill can also occasionally be recognized. In some passages horizontal ribs can be observed indicating the gradual lowering of the water level in these caves.

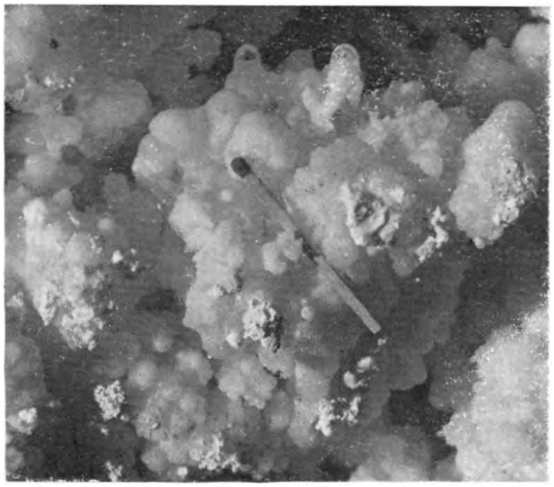
"Christmas trees" are a rare formation. The 30—200 cm tall, 20—50 cm wide, "popcorn-calcites" covered conic columns found in the Szemlő-hegy Cave were supposed to have been warm water geysers (Panos, 1960) or inundated stalagmites, but samples cut during the development of the cave and those found in the József-hegy Cave demonstrate that they were formed by local accumulation of calcite platelets.

The crystalline variant of calcium carbonate which is unstable below 29° C, the needle aragonite, only appears in a few caves, but their mass concentration turns the József-hegy Cave and the Beremend Crystal Cave into the most spectacular of our caves of thermal water origin.

In some of our caves there are gypsum formations as well. Their genesis probably is connected to the pyrite content of the bed rock. By the effect of the thermal waters this is oxidized into limonite and the sulphur content of the pyrite is released. Gypsum occurs either as this scales or as densely plated fiber: in some places the gypsum creates "flowers" and "corkscrews" as it pushes through the pores of the rock. Rarities of the József-hegy Cave include the "gypsum daggers" of several decimeter length and the tenth of a millimeter wide "hairs" which can stretch to 1 m in length (Adamkó—Leél Össy, 1984).

It can also be attributed to petrological relations that marcasite blocks of several kg each can be observed at the bottom of the Héviz Spring Cave formed in sandstone (Plózer, 1977).

Huntites in the Beremend Crystal Cave (Photo T. Hazslinszky)



Among the special minerals of Hungarian caves is the milk-white, soft knobs or creamy grains of huntite ($CaMg_2/CO_3/_4$), which in Hungary occur only in three caves of thermal water origin. (Ozoray, 1961, Mrs. Takács, 1985).

Fluid inclusion tests on warm-water precipitations have only been carried out in the Pál-völgy Cave. The findings revealed that the temperature, density and chemical composition of solutions creating the mineral formations were very similar to the present-day warm water springs in Buda (Gatter, 1984).

The dripstone formations of thermal karstic caves differ only in size and quantity from those of other karstic caves. As there are often slightly permeable rocks above the caves, dripstone formations are confined to certain areas, thus generally these caves are poor in dripstones. Because of the accumulated loose fill at the bottom of the caves stalagmites often assume a subordinate position instead, extensive saturations and incrustations occur on the floor. In the Acheron Well Cave the rare stalactites of limonite can be seen at the boundary between dolomite and sandstone these occur due to the leaching of iron from the sandstone cover (Kárpát, 1983).

Various mineral formations are documents of the different stages of evolution of our caves of thermal water origin. Thus further research into the age of these formations and the physico-chemical properties of the medium from which they separated can greatly aid in the investigation of the origin and in understanding the differences in the morphology and mineral associations of these caves.

Katalin TAKÁCS-BOLNER
geologist
Institute of Speleology
Budapest
Attila út 111.
H–1012

Sándor KRAUS
geologist
Budai XI. Sportegyesület
Budapest
Ságvári Endre út 30.
H–1039

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KARST WATER RESOURCES RESEARCH IN HUNGARY AND ITS SIGNIFICANCE

László Maucha

1. Importance of karst water resources

Karst water is of great practical importance in Hungary. Cold and thermal springs, the water of spas and mineral-medicinal waters are all to a considerable extent of karstic origin. The activity of these groundwater systems has resulted in the formation of many caves of cold or thermal-water origin.

Hungary is located in the central, subsiding part of the Carpathian Basin; thus, heatflux here is higher than the average elsewhere in the world. Under most of the mountain areas of the country there are carbonate rocks of the Palaeozoic (Devonian and Carboniferous), or Mesozoic (mainly Middle and Upper Triassic — but also lesser areas of Jurassic and Cretaceous) and Cainozoic (i.e. Eocene, Miocene, Pliocene). In sum, almost one fourth of the basement formations are karstic, totalling 25,000 km² *(Fig. 1)*. These carbonate formations are from nine different geological epochs.

Within the near-surface karstic areas of the country a total of 2,700 km² of so-called "unconfined" karst highlands are known. They include ca 1,800 km² of exposed recharge or direct infiltration area. The remainder of the karstic areas are covered by thick Cainozoic sediments and function as deep-karst aquifers under pressure (artesian conditions). Karst aquifers that are deeply subsided and several thousand metres thick locally, originally recharged many natural karst springs. Some of these have already dried out as a result of human influence, but there are still several thermal and medicinal springs active in Hungary today.

Karst areas that are unconfined or partly covered by younger rocks (Jurassic, Cretaceous, Eocene, Miocene, Pliocene or Pleistocene) still feed springs whose water can be obtained by gravity or by pumps to serve local domestic water-supply systems. These waters are of excellent quality. In the karst areas the proportion of mean annual precipitation that infiltrates and provides water suitable for drinking is much greater than surface runoff will yield in equally mountainous but non-karstic parts of the country. This phenomenon can be explained by the fact that in karst terrains precipitation in-

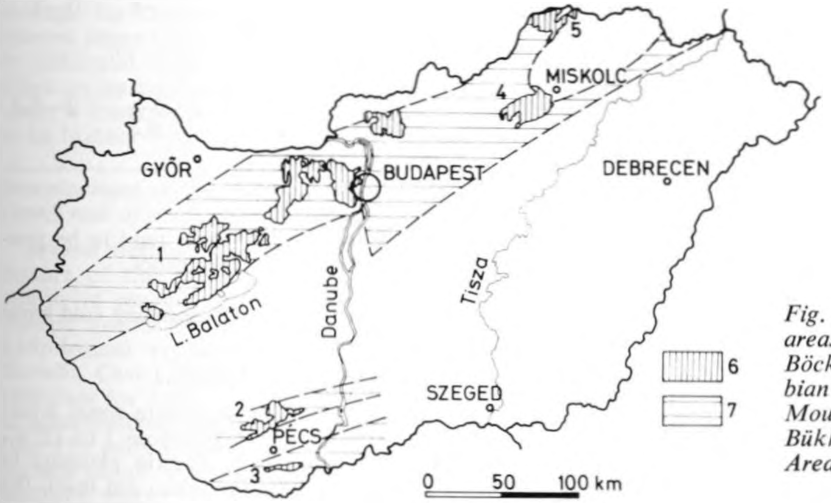


Fig. 1. Surface and covered karst areas of Hungary (after T. Böcker). Legends: 1. Transdanubian Mountain Ranges, 2. Mecsek Mountains, 3. Villány Hills, 4. Bükk Mountains, 5. Gömör Karst Area, 6. Outcropping karstic rocks, 7. Covered karst

Table I.

Karst areas of Hungary characteristic extreme values of all water types in the water budget

Type of water	*pH*	*Electric conductivity* $\mu s\ cm^{-1}$	*Total hardness nk°*	Ca^{++}	Mg^{++}	HCO_3^-	Cl^-	SO_4^-	NO_3^-	NH_4^+
							mg/l			
Precipitation	4—8	10—670	0.1—10	1—50	0.1—15	6—100	0.2—24	0—150	0.5—50	0.2—16
Surface runoff at the karst-lysimeter	7—8	25—200	2—3	10—70	4—7	6—10	5—2	2—30	2—10	1—3
Surface runoff at the swallow-holes	6—8	60—670	1—6.5	8—50	1—9	1—100	1—24	6—150	1—190	0.1—16
Subsurface runoff in soil	8—10	200—1.600	1—20	8—30	1—10	130—470	0.3—4	4—40	0.5—50	0.1—1
Infiltration in karstic rock	8—9	130—780	3—25	15—100	4—50	70—620	0.3—2	8—50	0.2—40	0.1—1
Dripping waters in caves	7.5—7.8	620—790	14—25	90—160	0.5—19	200—480	3—30	25—60	0.5—90	0—0.8
Waters of cave streams	7—8	150—850	3—27	18—140	2—16	60—430	6—105	6—125	6—40	0—2
Waters of cold springs	6.7—8.1	340—860	5—27	30—220	0.7—37	85—490	1.7—40	6—150	0.8—50	0—0.9
Waters of thermal springs	6.5—7.8	480—900	16—27	76—125	29—54	360—510	20—45	10—110	0—6	0—1
Waters of thermal wells	6.7—7.0	850—1,200	27—40	90—250	25—70	490—800	90—150	100—290	0—0.4	0—1.2

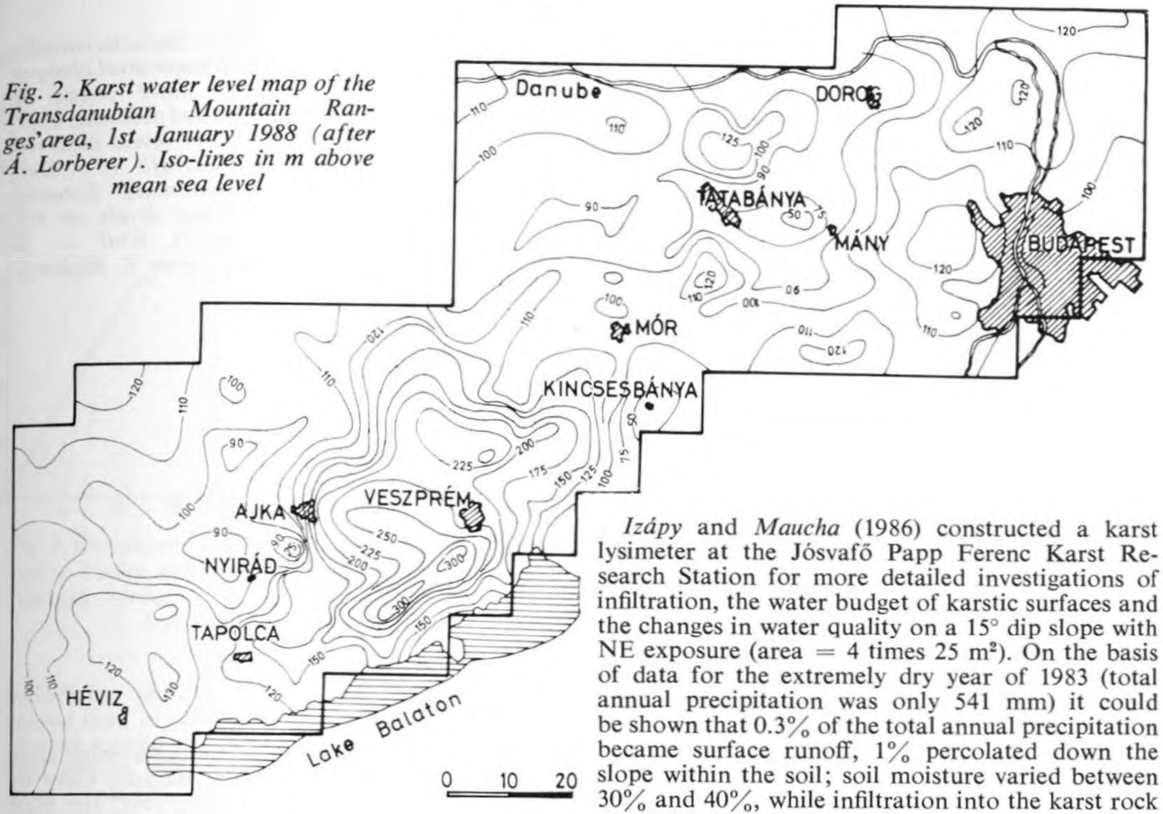
filtrates rapidly and, once underground, it is less subject to evaporation. In the most extensive mountains, the Transdanubian Ranges, because of coal- and bauxite-mining, "active": karst water protection has become a necessity. Water pumped from the mines has recently surpassed the natural recharge (460 m^3/min.). The operation of deep mines, the environmental impact studies for dewatering of mines and the need for domestic water supplies have resulted in the multipurpose development of the theory and practice of karst hydrology. The costs of specific hydrogeological projects tend to be proportional to their economic significance.

2. Results of investigations of descending cold karst water resources

Characteristic precipitation conditions

Hungary is located in the temperate zone. Average annual air temperature ranges from 7 to 12° C. The average elevation of the karstic plateaus in Hungary is about 500 m above mean sea level, the

Fig. 2. Karst water level map of the Transdanubian Mountain Ranges'area, 1st January 1988 (after Á. Lorberer). Iso-lines in m above mean sea level



highest being in the Bükk Mountains (900 m amsl) and the lowest in the Villány Mountains (350 m amsl). The mean annual precipitation ranges accordingly from 500 to 900 mm; it increases with elevation and towards the West.

The chemical composition of rainwaters was studied in detail by *Izápy* and *Maucha* (1987) in three karst regions. Characteristic results are presented in *Table 1*. It is a remarkable feature that in forested areas under natural conditions the ammonia ion concentration in rainwater is double the average for the country. The reason this is the intense degradation of forest soils (2 to 4 mg/l). In industrial areas and the surroundings of large cities on the contrary, the ammonia content of rain water is lower, while Ca and Mg ion contents prove to be higher.

Investigations of the infiltration and the subsurface runoff rate of precipitation

Several attempts have been made to form a clear picture of the changes of the water budget and quality of precipitation water as it enters the karst masses. *Kessler* (1954) was the first to investigate the hydrological properties of the swallow holes of Baradla Cave. *Böcker* (1986) showed from runoff plot data for 1978 to 82 (five year interval) that on a grass-covered slope on dolomite near Jósvafő (dip 15°, with an area of 1,834 m^2) the amount of surface runoff was only 2% of the mean precipitation of 5 years.

Izápy and *Maucha* (1986) constructed a karst lysimeter at the Jósvafő Papp Ferenc Karst Research Station for more detailed investigations of infiltration, the water budget of karstic surfaces and the changes in water quality on a 15° dip slope with NE exposure (area = 4 times 25 m^2). On the basis of data for the extremely dry year of 1983 (total annual precipitation was only 541 mm) it could be shown that 0.3% of the total annual precipitation became surface runoff, 1% percolated down the slope within the soil; soil moisture varied between 30% and 40%, while infiltration into the karst rock was 12%. Changes in quality of the water are shown in *Table 1*. It is clearly seen that the pH of the precipitation increases by about 2.0 after percolating through the thin (30 cm) soil layer and its hardness grows threefold in these slightly basic soils. On the other hand, nitrogen contamination drops to one fourth or one sixth of that in the rain. *Zámbó's* (1986) investigations added new date to the lysimeter measurements because he studied in detail the changes — over time and space — of the CO_2 content of rain water filtering into doline fills. Amongst other results he claimed that the dissolved CO_2 content and aggressivity of the ground water rises in proportion to the increase of soil thickness.

Investigations of the water quality in Baradla Cave showed that surface runoff can be enormously contaminated because of improper use of chemicals over neighbouring agricultural areas. This is indicated by the extremely high ammonia and nitrate content of waters running into karst swallow holes.

Hydrology of cave waters

The water infiltrating below the surface will appear on the ceilings of caves in the form of dripping water. The amount and quality of such waters has been studied in Vass Imre Cave in Jósvafő, Szent István Cave and Létrási-vizes Cave in the Bükk Mountains, in the thermal water caves of Budapest and Alba Regia Cave in the Bakony Mountains. *Gádoros* (1961), *Czájlik* and *Fejérdy* (1960—61), *Böcker* (1975), *Lénárt* (1978), *Zentay* (1986) and *Takácsné Bolner* (1987) have all made important studies in this field. According to *Izápy*

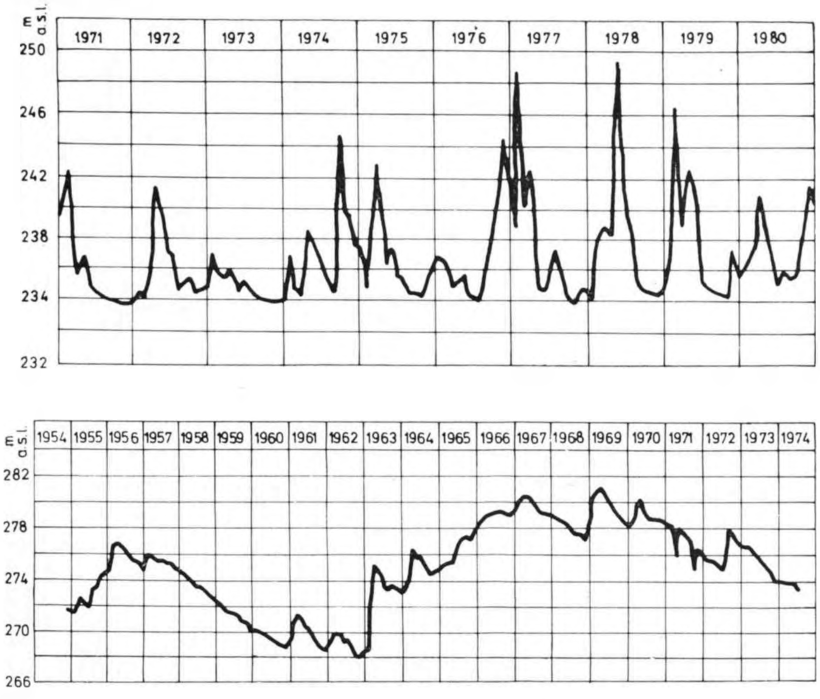


Fig. 3. The characteristically differing water level changes of karst water stored in limestone and dolomite. Top: Karst water levels observed in the Jósvafő N°1 Well — in limestone. Bottom: Karst water levels in the Nemesvámos Well — in dolomite (after T. Böcker)

and *Maucha* (1980) the yield of drip sites ranges from 0 to 7 l/day; at seven stations in Vass Imre Cave the annual average was 230 l/year. Kessler, Böcker, Lénárt and Maucha also used the data for infiltration calculations and for estimating vertical filtration velocity. The average catchment area of a drip measurement site in Vass Imre Cave is 1.3 m^2 according to the water budget investigations in the Jósvafő area, based on specific yield. Over a ten year study period mean annual precipitation was 666 mm and the mean yield for a 1 m^2 area was 177 l/year, a value which is 27% of the total (mean) precipitation.

The quality of dripping waters was first analyzed by *Maucha* (1929) in Baradla Cave, and again by *Czájlik* and *Fejérdy* (1959). On the basis of the study of 50 drip sites it can be stated that waters from within stalactites have an average hardness of 25° (Germ.) while waters outside have only 15° (Germ.) The hardness of dripping waters is maximum during the vegetation growth period and drops to a minimum in winter — because soil plays a decisive role in the karstification processes. Later, systematic investigations proved that the chemical composition of drip waters is very similar to that of local spring waters, but the concentrations of individaul constituents are more constant. Water quality changes are primarily indicating the increase of environmental contamination in the study area. Recently *Jakucs* and *Kevei* (1986) have made a number of drip water analyses in order to discover whether there is dripstone degradation, as they had assumed.

Quantitative and qualitative investigations of streams in caves were begun by *Kessler* (1954) in Baradla Cave; later, *Czájlik* and *Fejérdy* (1960) carried on the work in Béke Cave. Our most recent investigations showed that the annual average contaminant transport flux through Baradla Cave in the period, 1982 to 87, was 115 kg/year; the Styx stream (from the Domica-section in Czechoslovakia) supplies 17% of the total. *Gádoros* (1966) showed that in Kossuth Cave pressure-waves pass through at 1,000 m/hour and a wave of indicator dye at appr. 100 m/hour. Extreme values of our analyses are displayed in *Table 1.*

Karst water level studies

Beginning 1954 in the Transdanubian Mountain Range at the initiative of Kessler, karst water observation wells were drilled to collect data on changes of water levels. *Fig. 2* shows that on the basis of the data from about 150 observation wells a map can be constructed annually to display the karst water levels on the Transdanubian Mts. It has become possible to monitor human impact. Of great importance are the first, experimental, maps of karst water levels by *Szádeczky* (1948) and *Mike* (1963), and afterwards the wellconstruction activities of *Sárváry*, *Müller* and *Böcker* (1965—76) and *Lorberer* (1977—88) which are summarized in the annual karst water level maps. The systematic observation of changes of stored water resources by *Lorberer* has extended the area depicted in the karst water maps beyond the unconfined into the confined zones, by calculating the different levels according to pressure gradients.

The multi-annual record of karst water level changes shows that, in response to precipitation, in limestone aquifers the water level returns every year to an almost identical base level while in dolomitic aquifers water levels follow the multi-year

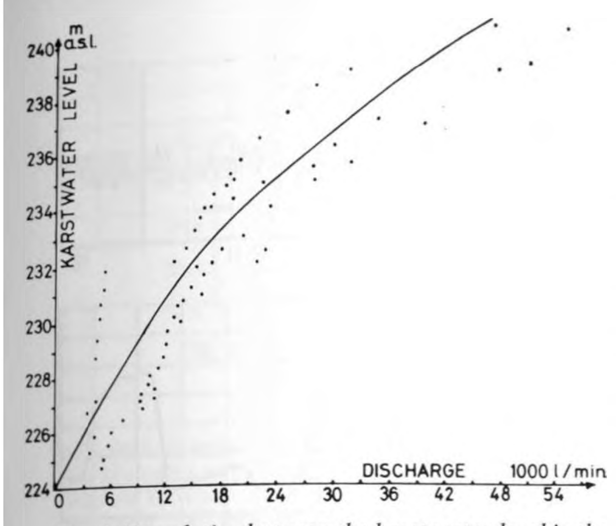


Fig. 4. Correlation between the karst water level in the Szelce Valley well and the discharges of the Nagy Tohonya Spring — in a period of increasing water level (daily data of 1977)

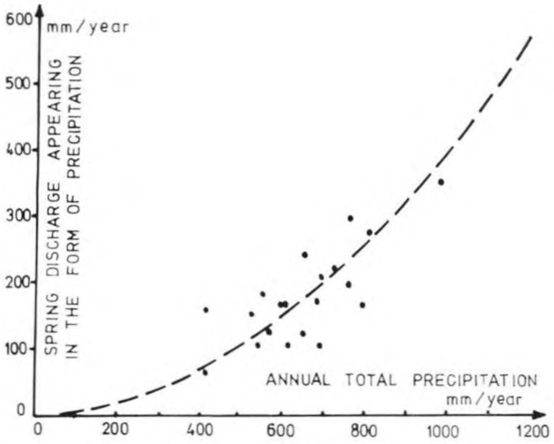


Fig. 5. Parabolic correlation of precipitation and discharge — Jósvafő Nagy Tohonya Spring — 1964 to 1983 years

periodicity of the precipitation. *Gerber* (1965) proved that, in observation wells drilled into partly covered karstic aquifers, atmospheric pressure and tidal effects will also influence the behaviour of water levels *(Fig. 3)*.

From data on level changes in the Nagy-Tohonya spring catchment ("Szelce-völgy drilled well") *Maucha* showed that spring discharges correlated with increasing water levels. He stated that changes of the karst water level (H) are proportional to the three-fourth power of the spring discharge (Q).

$\Delta H = n.Q^{3/4}$ [m]

The changes are governed by the above relationship *(Fig. 4)*, in which $\Delta H = H - H_{min}$: n = a physical constant whose value approximates 1, and dimension is [min/m^2] if the dimension of Q is [m^3/min].

Comprehensive research on springs

Papp (1940—50), *Kessler* (1952—65), *Szabó Pál* (1953), *Rádai* (1954—88), *Jakucs* (1960), *Venkovits* (1960), *Balázs* (1954—64), *Böcker, Müller* and *Sárváry* (1965—75), *Hazslinszky* (1964), *Gádoros* (1971), *Aujeszky* and *Scheuer* (1972), *Juhász* (1973), *Tóth* (1973), *Rónaki* (1975), *Szalontay* (1965—75), *Dénes* and *Deák* (1977), *Lénárt* (1977), *Lorberer* (1975—88) and *Sásdi* and *Szilágyi* (1985) have pusblihed spring and water quality research works of fundamental importance in the exploration of the karstic springs of Hungary.

Between 1952 and 1965 and within the framework of VITUKI, *Kessler* with the assistance of *Rádai*, developed a National Register of Springs of Hungary. This was further expanded by *Böcker, Müller* and *Sárváry* (1965—85). About 2000 springs were measured during 10 to 25 years of work.

During investigations of 15 large karst springs, 15 to 25 years of continuous instrumental recording have been obtained and a wealth of knowledge accumulated. The Lófej, Nagy-Tohonya, Kis-Tohonya and Vecsem Springs prove that at least the following factors have to be taken into account:

The effect of precipitation

From 20 years of continous recording of precipitation and discharge at Nagy Tohonya Spring, *Maucha* (1988) stated that the correlation of total precipitation (C) and annual spring discharge (Q) is well defined by the parabolic function:

$Q = c^2/2{,}500$ [mm/year]

At the same time this correlation represents the relationship between annual infiltration and annual total precipitation by an approximate (not corrected) function *(Fig. 5)*.

Siphon effects at the springs

At both the Lófej and the Nagy Tohonya Springs karst siphons are able to produce non-climatic discharge fluctuations (outbursts) equal to several multiples of base flow. At Lófej Spring laboratory experiments and models indicate that two large siphons and one small siphon, connected in sequence and in parallel respectively, produce outbursts of 20 to 500 m^3 yield *(Maucha 1966)*. A 5,000 m^3 outburst at Nagy Tohonya Spring was first detected by *Kessler* (1965). This is produced by a side passage siphon because the discharge does not decrease between the outbursts. *Gádoros* (1966) showed that about 1.5 to 2.0 hours after each outburst there is slight increase of water temperature; it is concluded that the water recharging the main gallery is not as cold as the side passage stream feeding the siphon.

At Sárkány-kút Spring in the Mecsek Mountains *Rónaki* (1988) has observed a maximum of 21 siphon outbursts a day.

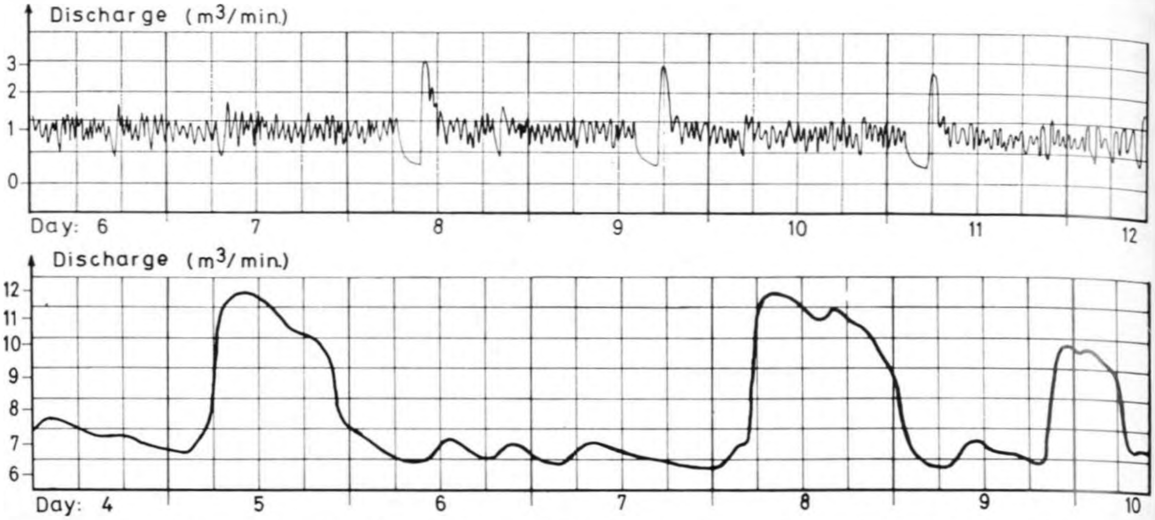


Fig. 6. Records of the Jósvafő siphonic springs. The triple siphon system of the Lófej Spring is in the main corridor leading to the spring. At the Nagy Tohonya Spring a single side-corridor siphon is producing the outbursts. Onto this discharge time-series is superimposed the series of pulsations generated by the Lófej Spring. Top: the discharges of the Lófej Spring in May 1980. Bottom: the discharges of the Nagy Tohonya Spring in May 1976

The effect of a more distant siphon is also apparent in changes of yield that occur at Nagy Tohonya Spring. The water produced by the siphon outbursts of Lófej Spring enter the water system of Nagy Tohonya via swallow holes at a distance of 3 km. According to observations by *Szilvay* (1966), the outburst pressure waves (in the form of discharge pulsations) are delayed by about 4 hours in their arrival at Nagy Tohonya Spring. The average duration of discharge pulsations is 18 hours *(Fig. 6)*.

Tidal effects

The statistics of these siphon outbursts show that they occur with 30% probability close to 6, 12, 18 and 24 hours *(Fig. 7)*. It can further be proved that their frequency increases at the new moon and the full moon. *Maucha* (1965) supposed that the effect s produced by lunisolar fluctuation of vertical karst oints and demonstrated this in Vass Imre Cave, with the cooperation of *Gádoros* and *Sárváry*, in 1965. *Gádoros* (1964) had already observed discharge oscillations at Kis-Tohonya Spring which were later found to be caused also by tidal effects. *Gerber* (1965) and *Csaba* (1974) found evidence of tidal effects in karst water observation wells *(Fig. 8)*.

Air temperature effects

At the Jósvafő Research Station it was observed that during the period of snowmelt, fluctuations of air temperature and insolation cause periodic melts which in turn result in discharge oscillations *(Fig. 9)*. Other relationships for discharge measurement data will be presented in Chapters 4 and 5.

Correlations of discharge and water quality

The fundamental researches were carried out by *Kessler* (1954), *Jakucs* (1960) and *Balázs* (1964). The saturation state of spring waters, the changes

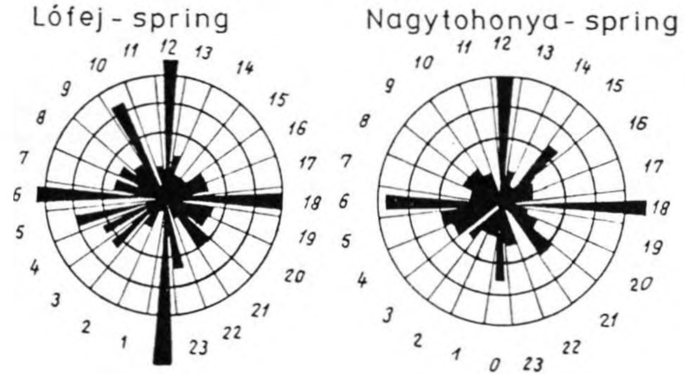


Fig. 7. Hourly distribution of the times of siphonal activity in the Lófej and Nagy Tohonya Springs (based on the statistical processing of 175 resp. 128 eruptions)

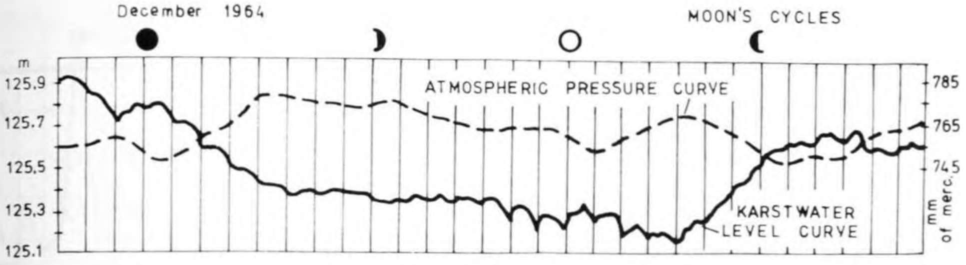


Fig. 8. The karst water levels recorded in the Tatabánya 1 Well — changes related to the periodicity of athmospheric pressure and tidal forces (after P. Gerber)

of solute composition in time and problems of the Ca/Mg ratio were studied in detail at the Research Station by *Cser*. Correlations between changes in discharge and water quality were established at several springs using weekly chemical analyses by *Izápy* (1983) in a joint work with *Maucha* within the framework of the VITUKI programme. It turned out that during floods the really significant effect is the change of Ca ion content in parallel with discharge and the inverse change of the Mg ion *(Fig. 10)*. The causes may be best understood by taking into consideration flow system data in the last column of *Table 2*. In the piezometric system not only the cold but also the warm components of the water will increase in response to a rise of the karst water level *(Gádoros 1966)*. Waters ascending from the zone below the level of the spring (stagnant and thus warmer) have higher Ca concentrations and in Jósvafő these ascend from a zone with less dolomite than in the zone of descending waters. Existence of this warm water component is supported by the fact that the average water temperatures occurring near base flow are higher than those of the multi-year mean temperature of the region.

Correlations of spring discharge and water quality were first investigated properly by *Gádoros* (1961), who found an inverse relation at Nagy-Tohonya Spring.

3. Results of research on ascending thermal karst waters

Investigation of thermal springs

The thermal springs in the country originate from the deep karst masses buried under thick cover formations, as mentioned in the Introduction.

Before 1950 recharge of these thermal water resources was attributed to so-called "juvenile water" *(Pávay—Vajna 1950)*. Other important researchers on the thermal water springs *(Vendl* and *Papp, 1928—1962)* dealt with their hydrogeological characteristics in several papers. *Vendel* and *Kisházi* (1963) were the first to develop a theory of "underflow" based on the heat lift effect, explaining that the ascending karstic spring waters were being heated by the interior heat of the Earth. *Kessler* (1968) gave the first evidence to show that the thermal waters of Budapest originated from atmospheric precipitation.

Böcker, *Müller*, *Horváth* and *Sárváry* (1968) demonstrated hydraulic links between thermal springs and wells in Budapest by mutual effect experiments. At the same time *Szalontai* (1965—1975) proved by detailed water quality studies that the waters of the Budapest thermal water system belong to three main types, i.e. they originate from different source regions, partly outside of the Buda Mts. (the Pilis Mts. and Romhányi Karst area). He was the first to find correlation between discharge and water quality in this area.

The real functioning mechanism of the thermal springs was subsequently revealed by the research of *Alföldi*, *Erdélyi*, *Gálfi*, *Korim*, *Liebe* and *Lorberer*

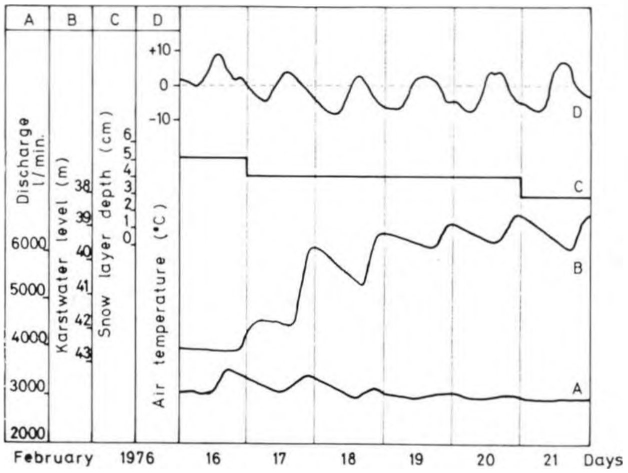


Fig. 9. The changes of the daily air-temperature and isolation causing periodical changes in snow-melt, infiltration, karst water level and discharge of the Nagy Tohonya Spring. A = discharges — Nagy Tohonya Spring (l/min), B = Szelce Valley karst water observation well — water level (m) under the orifice of the casing, C = decrease of the thickness of snow spots (cm) at the Jósvafő Research Station, D = air temperature (°C) at the Jósvafő Research Station

Table II.

Characteristic hydraulic parameters of non-confined karst areas of Hungary

Channels				*Average of breadth of passage (m)*	*Mean flow velocity (m/hour)*	*Time constant of deplenishment (decrease of storage volume 1/10th) (day)*	*Fictive Darcy's flow-factor (m/day)*	*Transmissivity (for 50 m thick rock layer) (m^2/day)*	*Rock type and porosity*		*Three different types of water in two hydraulic systems*	
Direction of flow	Vertical	0	Vertical infiltration in 2—3 channels	10^{-3}— —10^{-1}	10^{-1}— —10^{1}	$1.7 \cdot 10^{2}$— —10^{1}	10^{-2}— —2.10^{0}	10^{0}— —10^{2}				
	Horizontal	1	Microjoints of elementary rock blocks	10^{-4}— —10^{-3}	10^{-2} —10^{-1}	$1{,}7 \cdot 10^{2}$— —$3.8 \cdot 10^{2}$	10^{-3}— —10^{-2}	10^{-1}— —10^{0}	Triassic limestone 0.4—1.0%	Triassic dolomite 1.0—3.5%	Piesemometric cold and warm α-karstic waters	hydraulical-system
		2	Secondary rifts systems of elementary rock blocks	10^{-3}— —10^{-2}	10^{-1}— —10^{0}	2.10^{1}— —$1.7 \cdot 10^{2}$	10^{-2}— —10^{-1}	10^{0}— —10^{1}				
		3	Main rifts systems with karstic channels	10^{-2}— —10^{-1}	10^{0}— —10^{1}	10^{1}— —2.10^{1}	10^{-1}— —2.10^{0}	10^{1}— —10^{2}				
		4	Secondary corridor of cave with swallowhole	10^{-1} —10^{0}	10^{1}— —5.10^{1}	5.10^{0}— —10^{1}	2.10^{0}— —2.10^{1}	10^{2}— —10^{3}			"Short circuit" swallowhole β-karstic waters	
		5	Main corridor of cave with swallowhole	10^{0}— 10^{1}—	5.10^{1}— —10^{2}	10^{0}— —5.10^{0}	2.10^{1}— —2.10^{2}	10^{3}— —10^{4}				

(1976—77). The essence of their "hydraulically controlled geothermal flow systems of water", is as follows: — a proportion of the water infiltrating from the recharge mountain surface will pass (flow) along deeply curved stream tubes passing through a large heat accumulation area. The velocity of this slow flow is in the order of dm/year *(Deák 1984)* and thus the water will be heated by its environment. The heated water reaches the surface again at the tops of buried domes, where it mixes with local cold waters. Thus, thermal water issues as mixed water at the surface; consequently most of our "thermal-water" springs are actually lukewarm (tepid) springs, their temperatures being below 35° C. An exception is the Héviz Lake Spring. The chemical composition of the thermal spring waters is close to that of cold karst water but contains more dissolved solids, including more trace elements. In thermal water wells (drilled wells) yet warmer and high concentrations are typical *(Fig. 11)*.

The heat output of the springs of the Transdanubian Mountain Range was investigated by *Gölz* (1982). He found that the heat capacity of approximately 90 springs warmer than 15 °C is approx. 320 MW.

4. Karst water flow — results of investigations

Tracer experiments

Research on characteristics of the subsurface flow of karst water has provided considerable know-

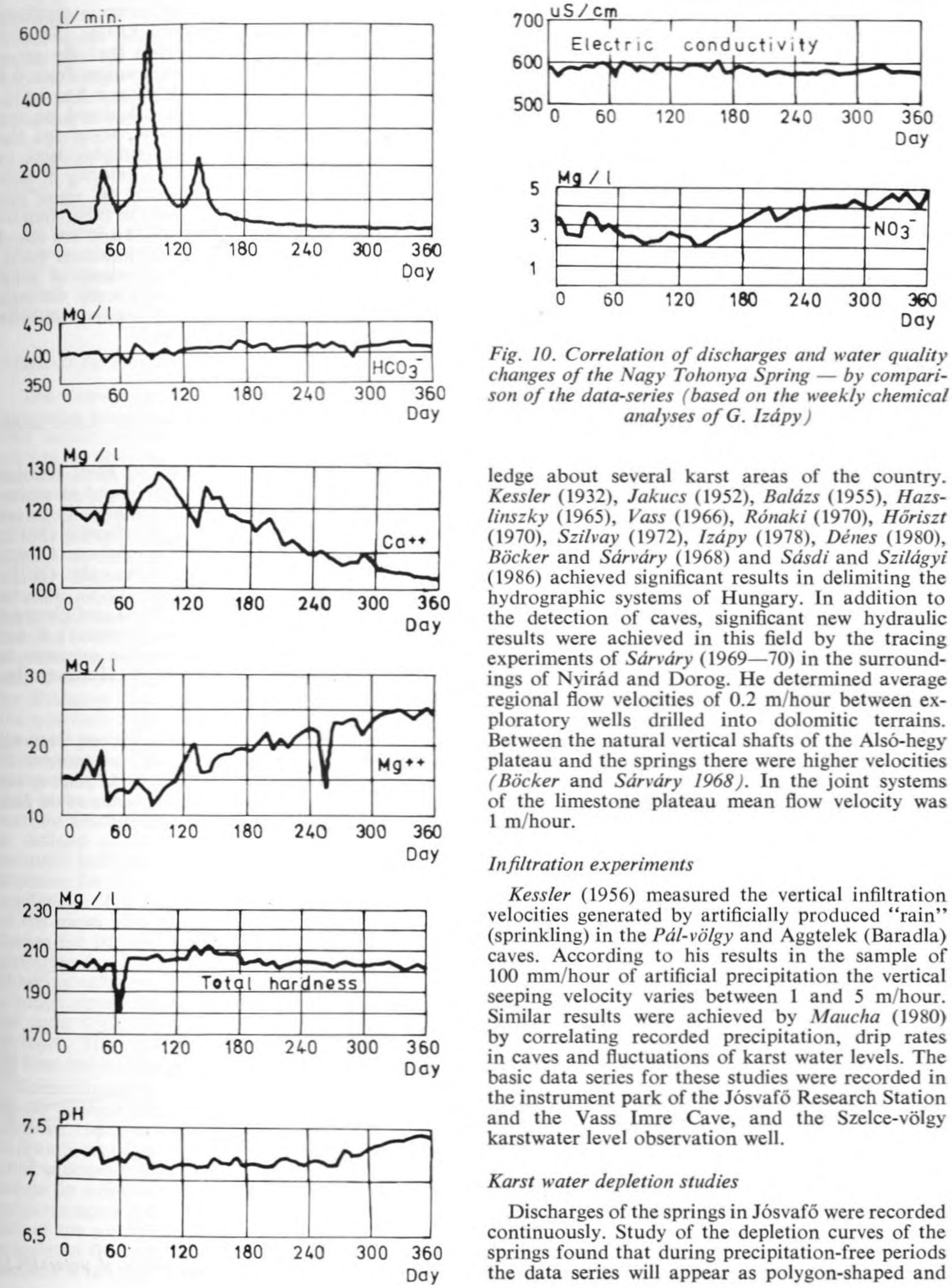


Fig. 10. Correlation of discharges and water quality changes of the Nagy Tohonya Spring — by comparison of the data-series (based on the weekly chemical analyses of G. Izápy)

ledge about several karst areas of the country. *Kessler* (1932), *Jakucs* (1952), *Balázs* (1955), *Hazslinszky* (1965), *Vass* (1966), *Rónaki* (1970), *Hőriszt* (1970), *Szilvay* (1972), *Izápy* (1978), *Dénes* (1980), *Böcker* and *Sárváry* (1968) and *Sásdi* and *Szilágyi* (1986) achieved significant results in delimiting the hydrographic systems of Hungary. In addition to the detection of caves, significant new hydraulic results were achieved in this field by the tracing experiments of *Sárváry* (1969—70) in the surroundings of Nyirád and Dorog. He determined average regional flow velocities of 0.2 m/hour between exploratory wells drilled into dolomitic terrains. Between the natural vertical shafts of the Alsó-hegy plateau and the springs there were higher velocities (*Böcker* and *Sárváry 1968*). In the joint systems of the limestone plateau mean flow velocity was 1 m/hour.

Infiltration experiments

Kessler (1956) measured the vertical infiltration velocities generated by artificially produced "rain" (sprinkling) in the *Pál-völgy* and Aggtelek (Baradla) caves. According to his results in the sample of 100 mm/hour of artificial precipitation the vertical seeping velocity varies between 1 and 5 m/hour. Similar results were achieved by *Maucha* (1980) by correlating recorded precipitation, drip rates in caves and fluctuations of karst water levels. The basic data series for these studies were recorded in the instrument park of the Jósvafő Research Station and the Vass Imre Cave, and the Szelce-völgy karstwater level observation well.

Karst water depletion studies

Discharges of the springs in Jósvafő were recorded continuously. Study of the depletion curves of the springs found that during precipitation-free periods the data series will appear as polygon-shaped and at least five sides of the polygon can be identified. This means the decreasing discharges over time can be described as the consequence of the continuously decreasing time-constant of $y = e^x$. This phenomenon was observed for the first time by *Ferenc Cser (1978)* and he used it to estimate stored water resources. According to *Maucha* (1978) the phenomenon is to be explained by the block-like structure of Jósvafő limestone karst systems. Ground plots of the caves show that the karst rock masses are dissected into 50×50 m blocks by subvertical main joint systems. From the data in Table 2 and from the depletion investigations, it can be presumed that vertical infiltration waters descend to the karst water level through the main rifts and the secondary joints within the blocks. Water then flows horizontally through the main rifts and the side and main galleries of the caves to the springs. In sequence the water content of the main galleries, the side galleries, the main rift-system, the joints within the blocks and the microfissures will be drained, one after the other. At any given instant the cavity that is draining will block flow from the smaller diameter voids that are subsidiary to it. During very dry periods the base flow will be produced by the depletion of the micro-fissures.

Space image interpretation (and use of other remote sensing methods also) was initiated and practised in karstic areas by *Rádai (*1969).

Representative hydraulic parameters

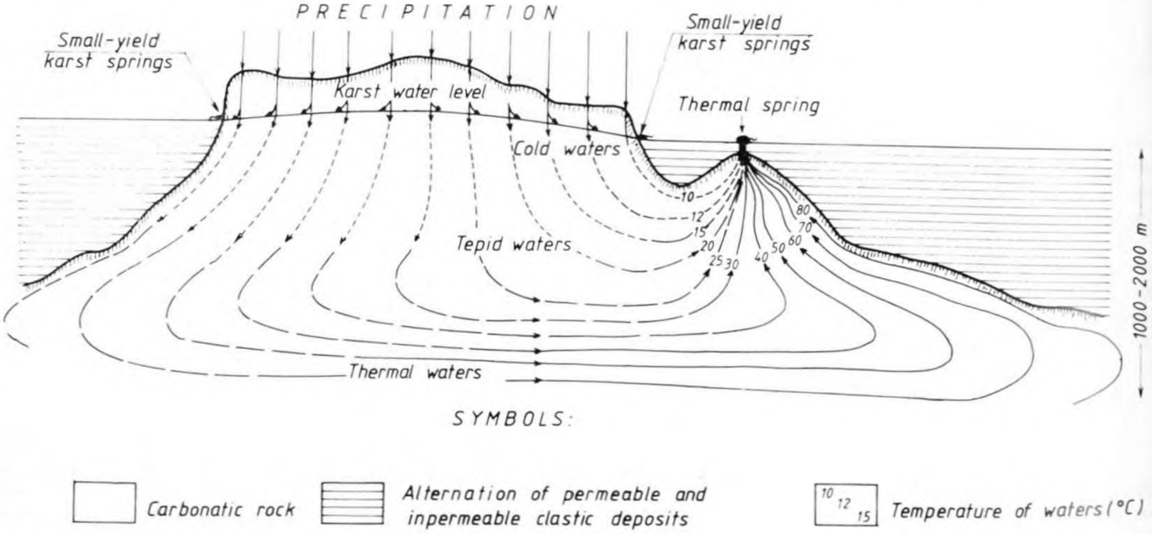
Research on the laws of karst water movement have resulted in the determination of the most important hydraulic parameters in our country. *Öllős* (1965), *Böcker* (1976), *Schmieder* (1976), *Sárváry* (1969) and *Maucha* (1980) showed that the gross porosity of the Triassic limestones ranges from 0.4 to 1%, while that of Triassic dolomites is 1 to 3.5%. The values for limestones were calculated on the basis of depletion of rock volume, those for the dolomites were computed from pumping tests in water level observation wells. The velocity of flow of thermal waters are derived from ^{14}C water age determinations *(Deák 1984)*. All the other important factors are presented in Table 2 and are based on the block-structure model of limestone karst *Böcker* (1976) discovered the importance of joint and fault systems (which vary in scale through several orders of magnitudes) in our karsts and has obtained a number of new results.

5. Water budget investigations

Water resources and balance of the karst areas of Hungary

The water balances of individual karst terrains were obtained using spring discharge and precipitation data coupled with different methods to calculate the amount of infiltration, by *Kessler* (1954), *Szabó Pál* (1955), *Láng* (1972), *Jakucs* (1960), *Balázs* (1964), *Rónaki* (1976), *Szlabóczky* (1978), *Dénes* (1983), *Tóth* (1983), *Böcker* (1975), *Maucha* (1980), *Ráday* (1986), *Lorberer* (1986) and *Csepregi* (1988). After corrections (where necessary) it can be stated that the mean precipitation amounts to 650 mm/year in the karst areas of Hungary. In-

Fig 11. Theoretical hydrogeological profile of the thermal karstic system. Subsurface flow is not only occuring in the plane of the profile, but there is an arch-shaped flow out to the outmost borders of the carbonatic rock-base. Cold spring waters did originally pour large discharges at the foot of the mountains. At the peak of the karstic dome — after the breaking-through of the impermeable layers because of the transformation of the base of erosion in the depth, a stronger than the former intense deep-flow has started



filtration is 27% (180 mm/year). In the unconfined karst areas with their total infiltration area of 1,800 km² the total dynamic karst water resources can be estimated to average about 10 m³/sec. The multi-year mean karst water balance is obtained by iteration of the equation

$P = I+E+R$

that is $650 = 180+450+20$ [mm/year]

where P = precipitation I = infiltration E = evapotranspiration, R = surface runoff.

In recent years the karst water balance of the Transdanubian Mountain Range has been calculated annually by *Böcker* and *Lorberer* in order to protect the Hévíz Lake Spring and the thermal springs of Budapest.

Methods for computing infiltration

The ever-increasing exploitation of karst water resources has made it necessary to develop new and better methods for the calculation or forecasting of amounts of infiltration. All the methods mentioned define the annual infiltration as a total of the spring discharges in a given catchment area, including the actual base flow. The values calculated here relate to the limestone karst areas; on dolomite karsts only multi-annual averages will give a correct answer. *Kessler's* method (1954) for the calculation of the representative infiltration percentages started from the rate of precipitation for the first four months of the year and that for the whole year. He corrected to allow for remaining moisture at the end of the previous year and calibrated the method by discharge time series. *Böcker* (1965) substracts the quarterly evapotranspiration runoff losses from the total precipitation received during each quarter of the year to obtain total annual infiltration. Evapotranspiration and runoff are computed from drip measurements in the Bükk Mountains. In one method used by *Maucha* (1987) annual infiltration is defined as the total of monthly infiltration, monthly infiltration being the product of the infiltration for the month and a monthly infiltration coefficient. The infiltration coefficient is the ratio of the mean monthly discharges of Nagy Tohonya Spring for 20 years and the some figure of the precipitation for Jósvafő catchment. The monthly infiltration value produced this way represents only a rough approximation of annual infiltration, like the ratio $C^2/2{,}500$ (the base quantity of the other method). The multi-year rough value is actualised by four water budget corrections.

Corrections are calculated by both of the methods, applying the monthly data of precipitation and air temperature. *Csepregi* (1988) adopted Morton's method for karsts. From the monthly total precipitation and the total of soil moisture values he subtracts the total of the monthly mean evapotranspiration and the maximum water capacity of the soil. The monthly infiltration values are calculated from the sums of monthly values. The method is not yet calibrated for karst terrains.

6. Chemical transport investigations

Denudation and environment pollution of karst areas in Hungary

In 1983—1984 VITUKI carried out investigations in three representative water quality areas in order to find characteristic water quality constituents representative for all kinds of karst water types in the country *(Table 1)*. In the Jósvafő area *Izápy* made the analyses and in the other two areas the Waterwork Labs did the work.

Izápy and *Maucha* (1986) evaluated all the data from the Aggtelek, Bükk and Bakony representative areas. Because discharges were also known the data could be compared by calculating the average specific ion transport in kg/year/km². The areas of the three representative catchments are 80, 110 and 200 km² respectively. From the differences between the solute loadings of the infiltrating precipitation and those of the springs it was found that Ca, Mg and HCO_3 ions are dominant; Na, K, Cl, SO_4 ions contribute a total of 6 to 8% of the load. 20% of dissolution occurs below soil depth according to the estimate of *Balázs* (1964). The extremes of denudation rates calculated in this manner ranged between 58 and 71 tonnes/year/km² in the three areas. Nitrate compounds (major environmental pollutants) show a mean specific range of 0.9 to 3.0 tonnes/year/km². The denudation rate obtained in the Aggtelek area is twice as great as *Balázs* calculated in 1964. Since *Balázs*' work multi-year records of reliable discharge and water quality data have been collected in the framework of the activities of the measuring network of the Jósvafő Research Station and, in addition, results of other more recent researchers could be considered. The denudation values transformed into m³ are between 22 to 26 m³/year/km². The specific surface denudation is 0,032 to 0.041 mm/year for a mean precipitation of 1,000 mm/year.

László MAUCHA
hydrogeologist
Research Centre for Water
Resources Development
Budapest
Szigeti József utca 7.
H—1041

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THE ROLE OF CAVE SITES AND THEIR CHRONOSTRATIGRAPHY IN THE RESEARCH OF THE PALEOLITHIC OF HUNGARY

Dr. Árpád Ringer

Cave sites have played a particular role in the history of research on the Paleolithic in Hungary and the archaeo-, bio- and lithostratigraphical-chronological data of Upper Pleistocene sediments studied in them were also used in equally interesting ways.

This particular role may be illustrated by the fact that between 1906 and 1938 Hungarian Paleolithic research concentrated — with some exceptions — almost exclusively on cave excavations. The balance was slowly regained between 1938 and 1959 and over the period from 1959 to the present day the situation is the very opposite of the first stage: open-air sites are much better studied than those in caves.

The original archaeostratigraphy of the cave deposits of Hungary was based upon the French typochronology early this century and in general it is still correct.

The French school is still followed in many respects, but the name of cultures is rightfully no longer exclusive. Our Paleolithic research has become 'Central European' over the decades and recognises its own range of issues. At the same time, it has retained and even developed further the links with international investigations first established in 1907 (for instance, GÁBORI, 1976; GÁBORI—CSÁNK, 1968, 1986; RINGER, 1983; T. DOBOSI, 1983; VÉRTES, 1964).

In biostratigraphy the faunal phases described by M. Kretzoi (KRETZOI—VÉRTES, 1965) and D. Jánossy (JÁNOSSY, 1979), primarily built on small mammal successions or — using J. Chalin's terminology — climatozones are important elements in the divisions of the Upper Pleistocene in Hungary and in European distant correlations. The results of Hungarian Quaternary research are internationally known and respected.

The same does not apply to the lithostratigraphical-chronological divisions of cave deposits. In Hungary, the investigations of loesses and other subaerial sediments have a long history and the results are internationally acknowledged (PÉCSI ed. 1985), however, the study of cave deposits was given less importance in Quaternary research.

But, as the history of Paleolithic excavations in caves suggest, as early as the period between 1906 and 1938 the base profiles from caves were known and studied in an interdisciplinary approach (as we would say now) and the same profiles could be the references for a cave chronostratigraphy through modern interpretation, oxygen isotopic dating (KORDOS—RINGER, 1986) and correlations with Hungarian loesses (PÉCSI—RINGER, 1987; RINGER, 1987).

In the 1950s and even up to the second half of the 1960s the results achieved were promising (VÉRTES, 1959, 1965).

Regrettably, since the late 1960s, when Western European polyphase Upper Pleistocene chronology had just been established (LABEYRIE, 1984), the data collected about cave deposits before that time has remained without further research and virtually unutilised.

Today with the spreading paleoecological approach in the ever widening Paleolithic research, the historical study of the relationships between prehistoric man and the paleoenvironment has become the leading consideration, and the mentioned archaeo-, bio- and lithostratigraphy of the Hungarian Pleistocene needs ever closer correlation, refinement and detailed paleoecological investigations with international comparisons.

In the present paper, written on the 50th anniversary of the end of the first stage in cave excavations in Hungary, the changes of the complex Upper Pleistocene chronology of cave deposits and its contribution to the modern, paleohumanecological trend of Hungarian prehistoric research are described.

In the light of the complex nature of this topic, only the benchmark achievements and historical science issues which pointed towards the present polyphasal division of the Upper Pleistocene are dealt with in the following.

Fig. 1. Geographical location of caves investigated from archaeological point of view. BÜKK MOUNTAINS: 1. Subalyuk Cave, 2. Büdöspest Cave, 3. Szeleta Cave, 4. Lambrecht Cave, 5. Háromkúti Cave, 6. Herman Cave, 7. Istállóskő Cave, 8. Peskő Cave. TRANSDANUBIA: 9. Jankovich Cave, 10. Szelim Cave, 11. Pilisszántó Rock Shelter No. 1., 12. Bivac Cave, 13. Remete Cave, 14. Remete-Felső Cave. (Gábori, 1977).

Landmarks in the research of cave Paleolithic and sediments in Hungary 1906–1938

Regular Paleolithic research in Hungary began in 1906 with excavations in the caves of the Bükk Mountains. Some years later work started in the caves of the Transdanubian (Buda, Pilis and Gerecse) Mountains *(Fig. 1)*.

The work done before 1938 was impressive, excavations were carried out in the fill of almost all the important caves of the country.

The leaders of the excavations were originally geologists, paleontologists and anthropologists. In their activities they followed the French Paleolithic research system and for chronology they initially held equivocally monoglacial views.

Archaeostratigraphy. In the old cave excavations the majority of finds consisted of leaf tools, considered uniform by researchers and dated after the French model to Solutréen. Its evolution was subdivided into four phases (HILLEBRAND, 1935; KADIĆ, 1934).

This complex of finds is subdivided into two cultures today, primarily by eponym localities: the Bükk-Szeletian and the Jankovichian of Transdanubia (Fig. 1 — localities 3 and 9 — GÁBORI, 1977, 1984; GÁBORI—CSÁNK, 1973, 1983, 1986; RINGER, 1987, 1988).

With in the leaf-tool complex, often from the same layers finds classified as Aurignacian were recovered, primarily from the Istállóskő and Peskő Caves of the Bükk Mountains (Fig. 2 — localities 7 and 8 — HILLEBRAND, 1935; KADIĆ, 1934). Naturally, over the years, the interpretation of the Aurignacien of Hungary has changed several times (VÉRTES, 1965; GÁBORI, 1977, 1984). This assemblage of remains was the first dated by C^{14} method at 30,000 to 40,000 years BP (VÉRTES, 1965).

The remnants of the cultures older than the Aurignacien, the Moustérien, and the younger Magdalénien were first found in the Kiskevély and Szelim caves of the Transdanubian Range, which are more diverse in Paleolithic cultures than the Bükk, and from the classic Pilisszántó rock shelter (Fig. 1 — localities 10 and 11 — HILLEBRAND, 1935; KADIĆ, 1934). In the present evaluation of these cultures there are also many new aspects (GÁBORI, 1984; T. DOBOSI et al. 1983).

These results allowed the adaptation of the Western European Moustérien-Aurignacien-Solutréen-Magdalénien typochronology to Hungary and to build upon it a comparative complex bio- and lithostratigraphy.

Until 1932 a problem was presented in the systematisation and dating of Paleolithic cave cultures: the poverty of Moustérien caves compared to their abundance in Western Europe. In 1932, however, in superposition in the Subalyuk cave of the Bükk Mountains (Fig. 1 — locality 1) the long missing 'warm' and 'cold' Moustérien were found — in not less than 14 layers in continuous sequence. The first was dated to the last interglacial, while the latter to around the cold maximum of the last glacial (BARTUCZ et al. 1938).

Thus, the cave deposit sequence of the Upper Pleistocene (as interpreted today: Emiliani stages 5e to 2) became more diverse and lent itself for finer subdivisions.

Biostratigraphy. In vertebrate paleontology the most outstanding figure of this period was M. Mottl. A paleontologist and archeologist, who published in the Subalyuk monograph a table of the systhesis of chronostratigraphy for the subdivision of the Hungarian Pleistocene as known in her day, using the paleobotanical data by F. Hollendonner (MOTTL, 1938).

Then Mottl approached the polyglacial concept. She placed the 'Pleistocene stage' after the Preglacial of mediterranean climate and subdivided it into four substages.

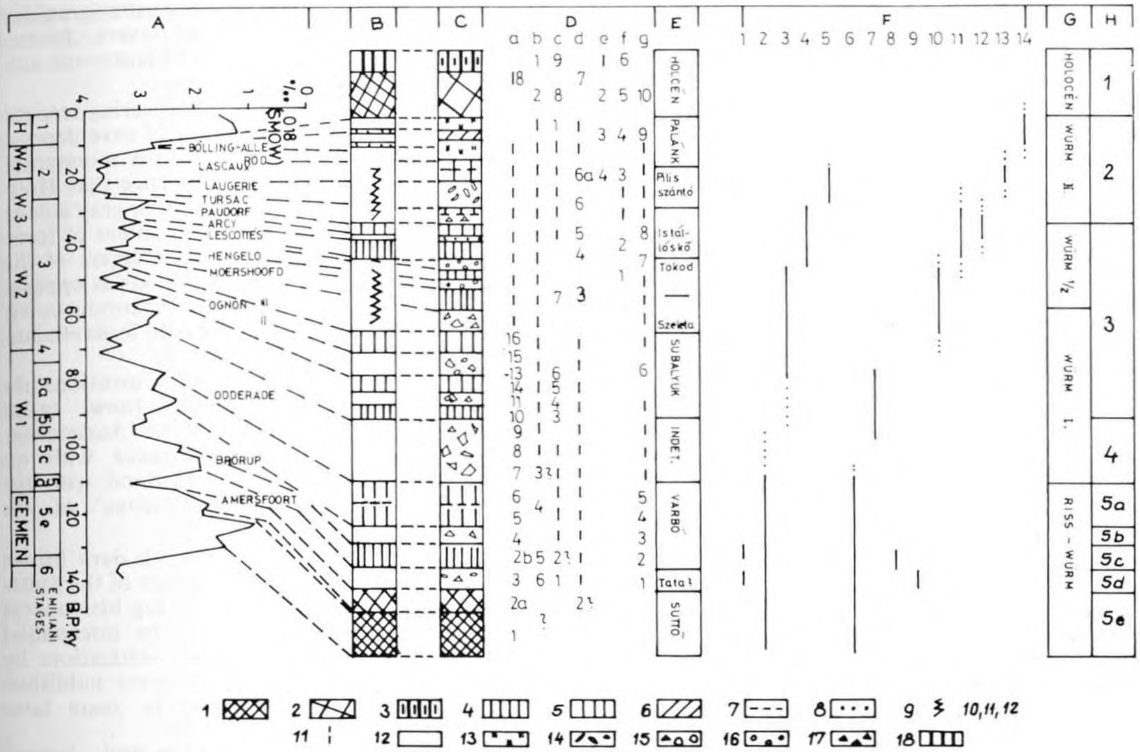


Fig. 2. Chronostratigraphy of the Upper Pleistocene of Northeastern Hungary.

I. Units of the table. A. Paleoclimatic curve for the last 140.000 years by J. Labeyrie (LABEYRIE, 1984); B. Stratigraphy for subaerial loesses; C. Cave stratigraphy; D. Cave deposits: a) Subalyuk Cave, b) Lambrecht Cave, c) Büdöspest Cave, d) Szeleta Cave, e) Puskaporos Rock Shelter, f) Peskő Cave, g) sequence of the Diósgyőr-Tapolca Cave foreland; E. fauna stages and climatozones by M. Kretzoi and D. Jánossy (modified after JÁNOSSY, 1979); F. Paleolithic cultures: 1. Bábonyian in cave, 2. Bábonyian, open-air, 3. Early Szeletian, 4. Developed Szeletian, 5. Szeletian-solutroïde, 6. Central European typical Moustérien, levallois débitage, rich in scrapers, 7. Bükk Charentien, 8. Bükk Taubachien in cave, 9. Bükk Taubachien open-air, 10. Bükk Aurignacien I, 11. Bükk Aurignacien II, 12. Aurignaco-Gravettien of Bodrogkeresztúr type, 13. Gravettien, 14. Pilisszántóian; G. The classic chronological subdivision of the Upper Pleistocene in Hungary (after KADIĆ and MOTTL, 1938); H. Emiliani's stages.

II. Legend to the table. 1 = brown forest soil and its sediment in caves, 2 = brown rendzina, 3 = black rendzina, 4 = paleosol or soil sediment of interstadial character, well developed, 5 = the same, poorly developed, 6 = paleosols or soil sediments of Late Weichselien moderate oscillations, 7 = double paleosols or soil sediments, 8 = travertine precipitation, 9 = unknown series, 10 = number of layers, 11 — unconformity, 12 = subaerial loess, 13 = cave loess, 14 = limestone bed cryofraction in cave loess, 15 = limestone blocks and debris in cave loess, 16 = limestone gravels in cave loess, 17 = small limestone debris in cave loess, 18 = Holocene chernozem soil.

In her opinion the Early Glacial substage ends with the Riss-Würm interglacial, represented by the layers of lower 'Hochmoustérien' (layers 1 to 3) and part of the upper 'Spätmoustérien' (layers 7 to 10). The fauna and flora consist of forest species, among them mediterranean elements.

At the end of the substage a temporary cold spell was identified on the basis of layers 11 to 14 in the 'Spätmoustérien' of the Subalyuk cave. In this fauna steppe species also occur and broadleaved trees are replaced by conifers in the forest vegetation. The Pleniglacial substage with Aurignacien and Solutréen cultures, after the Early Glacial substage correlated with the Moustérien, is characterised by typical glacial fauna and flora. The coldest glacial, with arctic fauna (lemmings) and the dominance of Pinus montana, however, is only represented by the next, Late Glacial substage with Magdalénien I culture. Finally, the first half of the Postglacial substage has Magdalénien II culture.

Mottl also attempted to adapt Alpine chronology. After Penck and Brückner, she assumed a bipartite

Würm after the Riss-Würm interglacial and subdivided the former by the Würm I—Würm II interstadial, associated with the Aurignac culture.

Mottl's paleoclimatological-paleoecological Upper Pleistocene periodisation is only based on the study of macroscopic finds, collected without washing. Therefore, she could not follow the changes from layer to layer. Her works indicate that the Upper Pleistocene as we understand it today would be undividable except by the Riss-Würm optimum, the first and the last cold minimum of the Würm and the interstadial between them.

Her influencial mistake was the extension of the last interglacial at the expense of the Würm. Thus the Hungarian Würm 1/2 interstadial took the place of the Würm 2/3 interstadial of the classic Western European Upper Pleistocene chronology.

Lithostratigraphy. The recognition of stratigraphical divisions in the Upper Pleistocene cave sediment sequences of Hungary was untertaken by the geologist-archaeologist O. Kadić (KADIĆ, 1915, 1934, 1938). Kadić's system was completed by the publication of the monograph on the Subalyuk locality.

I. Riss-Würm interglacial, Early Glacial fauna horizon. Its deposits are red or brown plastic cave clays with little limestone debris. The stratotype is layers 1—6 in the Subalyuk cave, i.e. the last interglacial in the broader sense (KORDOS—RINGER, 1986) or Emiliani's stage 5e to 5a (Fig. 2 C, D, G and H).

II. Pleniglacial fauna horizon. Cave clays of various colour (light or dark brown, dark gray, greenish gray etc.), with limestone debris, blocks or gravels are typical. This stage coincides today with Emiliani's stages 4 and 3 (Fig. 2 C, G and H).

III—IV. Late Glacial and Postglacial fauna horizon. Both are characterised by fills oflithostratigraphically analogous character: "yellow loess-like layer, partly pure, partly mixed with limestone debris" (KADIĆ, 1934. p. 20). Their age corresponds to Emiliani's stage 2 (Fig. 2 C, G and H).

For the further subdivisions within the three major lithostratigraphical units, Kadić collected large amounts of well-interpretable data.

His observations are especially valuable related to phase II concerning the colour of the layers, the amount and nature of the incorporated limestone debris, the wearing of bones found in the layers, the dip of strata and other factor allowing distinction and description.

Kadić's name is also associated with the initiation of the geochemical analyses of cave sediments (BARTUCZ et al. 1938. pp. 31—34). This method only became general in international practice in the 1960s and 1970s.

Kadić and Mottl virtually agreed in the subdivision of the Upper Pleistocene in its broader sense and for the major units — with the exception of the upper boundary of the Riss-Würm. However, Mottl was forced to draw layers together because of her fauna collection without washing, whilst Kadić, with meticulous documentation, lithostratigraphical identification and typification of layers, pointed to the modern polyphasal Upper Pleistocene subdivision and supperted it with date.

Here we have to mention the pioneering recognition by J. Hillebrand of the colour of cave deposits (HILLEBRAND, 1935. p. 39). In his monograph Hillebrand started from the experience that Holocene cave deposits are of dark brown or gray colour, which he explained by the humus content of forest soils. In his opinion the Pleistocene layers of this colour are associated with warm periods as opposed to the light brown layers of the 'Spätmoustérien' or the yellow ones, formed under cold loess climate, of the Magdalénien.

As with Mottl, Hillebrand only mentions the Aurignacien and 'proto-Solutréen' (now: called Early Szeletian) layers related to the 'Aurignacien interstadial' which are in accordance with his assumption and made them correspond with the so-called 'Göttweiger Verlehmungszone' of the interstadial.

Unfortunately, for instance, the 5th dark brown and the 10th and 12th dark gray layers of the Subalyuk cave escaped his attention. Using his concept these would also have proved to be interstadial formations, as the anthracotomic investigations by F. Hollendonner confirmed. These were published in the Suba-lyuk monograph three years later (HOLLENDONNER, 1938).

Hollendonner found charcoals of Tilia, a thermophilous tree, in the 10th dark gray layer of the Subalyuk cave, as opposed to the Pinus cembra finds in the 11th, light brown layer, indicating a cold climate. This way, for the first time in Hungary he linked the paleoecological conditions of cave lithostratigraphical types with paleobotanical data. His pioneering results in the progress towards a polyphasal Upper Pleistocene subdivision were developed further only after almost twenty years (STIEBER, 1957).

After the break of 1939—1945, a new group of researchers resumed Paleolithic research.

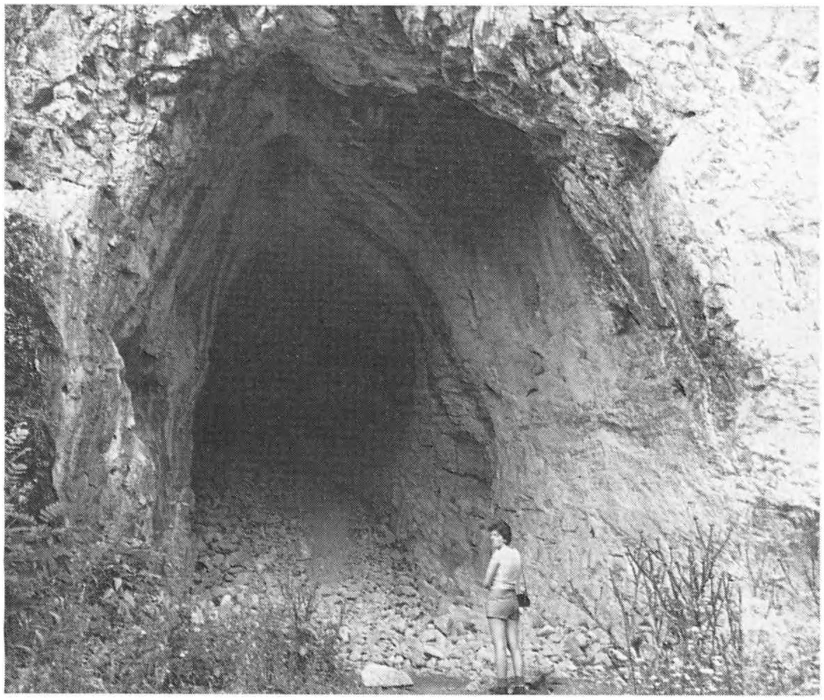
The excavations of the Istállóskő and Lambrecht Kálmán Caves, Petényi Salamon Rock Shelter and then the repeated one in the Peskő Cave, Bükk Mountains were conducted by the archaeologist L. Vértes and the paleontologist D. Jánossy (Fig. 1 — localities 4, 7, 8). The sequence of several Transdanubian caves was settled under the guidance of M. Gábori, D. Jánossy and L. Vértes.

A particularly important excavation of a cave unstudied at the time took place in the Bivak Cave (Fig. 1 — locality 12). The achievements for the history of science can be summarized as follows:

Archaeostratigraphy. The small material of Archaic quartzite from the Lambrecht Cave, Bükk Mountains, was dated Premoustérien by Vértes and last interglacial on faunistic stratigraphical basis (VÉRTES, 1965).

In the 1950s the revision of the 'Szeleta culture' began and it still represents the typological and

Entrance of the famous Subalyuk Cave in Bükk Mountains



chronological revealuation of one of the most important Paleolithic cave finds complex.

In his paper published in 1953, M. Gábori uses the name Solutréen after previous authors, but also emphasises the differences between the Transdanubian and the Bükk finds. He sought the origin in the industry now called Central European Micoquien, more precisely in the archaeological finds of the Kleine Offnet Höhle (GÁBORI, 1953).

The use of the term Szeletian began to spread in 1955. Hungarian researchers wanted to emphasise that this industry is, in every aspect, independent from the Solutréen (VÉRTES, 1965. p. 136).

Vértes correlated the Early Szeletian of the Bükk Mountains with the recently explored Bükk Aurignacien I and the developed Szeletian with the Aurignacien II, placing it in the Würm 1/2 interstadial (VÉRTES, 1955). In 1959 C^{14} date was obtained for the upper, Aurignacien II culture of the Istállóskő Cave (30,900 ±600 years BP).

During the revising excavations of the Pilisszántó rock shelter, M. Gábori underlined the oriental origin of the finds, opposed to earlier authors. In general, the whole assemblage of finds dated Magdalénien earlier was identified as Eastern Gravettien (GÁBORI, 1962; VÉRTES, 1965).

Biostratigraphy. The most important new results of the period occurred after the introduction of the washing technology. New prospects opened up of layer-by-layer paleoecological research through the study of small mammal finds (JÁNOSSY, 1979). By the sixties the synthesis of the new results had become possible.

In paleobotany J. Stieber continued the layer-by-layer charcoal analyses of old and recent excavations and made paleoecological evaluations (STIEBER, 1957).

Lithostratigraphy. In this period of the discipline the archaeologist L. Vértes studied cave deposits in Hungary, relying on the results of R. Lais and E. Schmid and also raising new issues. He published his achievements in German in 1959 (VÉRTES, 1959). Vértes developed the geochemical analysis proposed by Kadić and supplemented it with mineralogical investigations. For his synthesis where he finally identified 15 climatic phases in the Upper Pleistocene, he applied vertebrate paleontology and anthracotomic findings. Although he insisted on the Alpine chronology, Vértes was flexible enough to adapt the Western European polyphasal Upper Pleistocene chronology and its terminology. Among others, he introduced the term Arcy-Paudorf interstadial, for which the C^{14} date of 30,600 ±900 years BP was first available.

He obviously recognised that cave sediments in Hungary are much more subdivided than they should be and forced them into the Alpine scheme. The advance towards modern Upper Pleistocene subdivision is unambiguous.

1958 — Present day

It is not easy to summarise the achievements of the last thirty years, even if — as was mentioned in the introduction — cave excavations were of much lesser importance in this period.

Major complex Quaternary geological excavations were only performed in the Remete Upper Cave, Transdanubia (GÁBORI—CSÁNK, 1983), in the Szeleta Cave, Bükk Mountains (VÉRTES, L.), at the entrance of the Diósgyőr—Tapolca Cave (HELLEBRANDT et al. 1976) and in the front of this cave (RINGER et al. under preparation) (Fig. 1 — locality 3).

The researchers viewed the archaeological finds at new sites in an increasingly European perspective and published voluminous monographs of interdisciplinary approach, usually in foreign language (GÁBORI, 1964; GÁBORI—CSÁNK, 1968; VÉRTES, 1964, 1965). M. Gábori's impressive monograph on the Middle Paleolithic of Central and Eastern Europe has particularly attracted great international attention (GÁBORI, 1976).

Archaeostratigraphy. Especially since the 1970s, with the growing number of publications abroad on this topic, the reevaluation of early Paleolithic finds has been continuing in Hungary.

In 1973 V. Gábory—Csánk distinguished the Transdanubian Szeletian (as Jankovichian) from the Bükk Szeletian (GÁBORI—CSÁNK, 1976). By 1986 she had revealed its origin and relations as well as the paleoecological, paleoethnographical and archaeozoological implications of this culture (GÁBORI—CSÁNK, 1986). This Middle Paleolithic leaf-tool industry may be related to the Central European Micoquien of the Upper Danubian region. It was dated 50,000 to 35,000 years BP, between the recently described Bábonyian of Micoquien analogies, Bükk Mountains (RINGER, 1983), and the Early Szeletian.

The origin of the Bükk Szeletian is thought by Á. Ringer, — in agreement with M. Gábori (GÁBORI, 1984), to be in the Bábonyian (KORDOS, RINGER, 1986; RINGER, 1988), criticising Vértes' hypothesis, which places it locally, in the Bükk Moustérien (VÉRTES, 1958). In his papers, Ringer describes the true Moustérien industry of the Subalyuk Cave in the Bükk Mountains as "Moustérien typique riche en racloirs de débitage levallois" and suggests the term 'Charentien de Bükk' (KORDOS—RINGER, 1986; RINGER, 1987, 1988).

At the Paleolithic Colloquium in Nemours, 1988, he suggested the classification of the Late Szeletian finds of the Herman and Puskaporos rock shelters, Bükk Mountains, as a separate phase of evolution under the term 'Szélétien solutroïde' (RINGER, 1988).

After his excavations in 1988, he referred the oldest Middle Paleolithic finds of the Diósgyőr—Tapolca Cave into the Taubachian culture.

In the repeated re-evaluation of the 'Cave Gravettien' or Pilisszántóian culture, Gábori attaches equal significance to Gravettien and Magdalénien cultures and envisages the origin of the Gravettien culture in Hungary within Central Europe (GÁBORI, 1984).

Biostratigraphy. The upper Pleistocene vertebrate paleontological information, rapidly expanding in the wake of the washing technology introduced in the fifties, was classified by M. Kretzoi (KRETZOI—VÉRTES, 1965) and D. Jánossy (JÁNOSSY, 1979) into the Süttő—Varbó—Szeleta—Tokod—Istállóskő—Palánk fauna stage or climatozone. Finally abandoning the Alpine chronology he presented the paleoecological changes reflected in the Upper Pleistocene faunae of Hungary from the last interglacial to the Holocene in an independent local subdivision.

Recently L. Kordos attempted to correlate the small mammal successions of these fauna stages with the oxigen isotopic climatic curve by J. Labeyrie (LABEYRIE, 1984) back to 140,000 years (KORDOS—RINGER, 1986).

In Fig. 2 the time sequence of fauna stages is indicated according to this correlation. The Subalyuk fauna stage is parallelised with the fauna in the layers 10—16 of the cave after which it is named (JÁNOSSY, 1979. p. 130) and intercalated between it and the older Varbó stage, a still unknown fauna stage is shown. This cold period, represented by layers 7—9 in the sequence of the Subalyuk Cave, may correspond to Emiliani's stage 4 and, according to L. Kordos, is contemporaneous with the first Upper Pleistocene occurrence of Dicrostonyx torquatus in Hungary (KORDOS—RINGER, 1986).

Lithostratigraphy. The author, an archaeologist-geomorphologist, began to study the correlations between loesses and cave deposits in the Geographical Research Institute of the Hungarian Academy of Sciences in 1981. He attampted to draw correlations between the Upper Pleistocene loesses and cave deposits of Hungary in his papers published in 1986 and 1987 (PÉCSI—RINGER, 1987; RINGER, 1987).

On this topic Fig. 2 demonstrates the opportunities of correlations between young loesses and cave fills is one of the focal areas of Hungarian Paleolithic and Quaternary research, the Bükk and Northeastern Hungary (Fig. 2 — B, C) in relation to the Paleolithic industries of the region (F) as well as the paleoclimatic (A) and paleoecological (E) conditions.

For this chronostratigraphy, J. Labeyrie's oxigen isotopic climatic curve, which also incorporates the parallelization of Emiliani's stages and the classic French prehistoric subdivisions (LABEYRIE, 1984), was applied.

The table also shows the old Hungarian chronology elaborated by Mottl and Kadić, in the above system (KADIĆ—MOTTL, 1938).

In the climatozones of Süttő and Varbó, corresponding to Emiliani's stages 5e—5a, the climate of the Bükk Mountains and its environs ranged from warm temperate with submediterranean influence to cool temperate. In the area, the Bábonyian, the typical Moustérien of the Subalyuk Cave and the Bükk Taubachien lived side by side.

It seems that in the cold spell of Emiliani's stage 4 the evolution of these cultures stopped or — in the case of the Bábonyien — took a new trend. At any rate, in this stage the Subalyuk-type Charentien appears and during Emiliani's stage 3 the cave bear hunter Bükk Szeletian and the Aurignacien I and II emerge. In the cold spells coniferous forests were characteristic of the mountains, while in the interstadials forests mixed with deciduous tree species grew. This is the time of the Subalyuk and the Tokod—Szeleta—Istállóskő climatozones, respectively. In the latter periods the climate was occasionally very moist and cold.

During the climatozones of Pilisszántó and Palánk, corresponding to Emiliani's stage 2 the mountains were covered by sparse Pinus cembra and Larix—Picea coniferous forests.

The number of Ursus spelaeus showed a major decline at that time. Its hunting experienced an ecological crisis. Contemporaneous with the last phase of the Bükk Szeletien, the horse and reindeer hunting people of the culture, called Gravettien and then Pilisszántóian culture lived occasionally in the caves of the mountains.

In later periods the subarctic nature of climate gradually shifted towards cool temperate.

Dr. Árpád RINGER
archaeologist
Herman Ottó Museum
Miskolc
Felszabadítók útja 28.
H–3525

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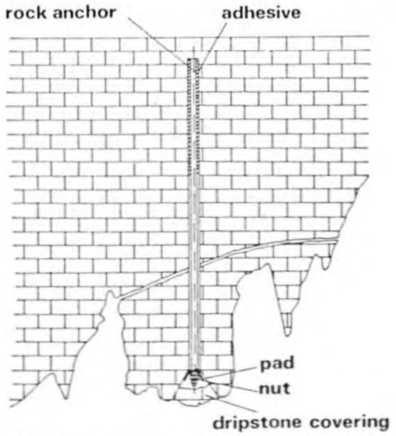
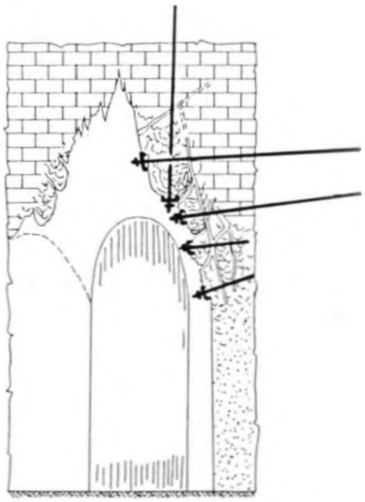


Dripstone group (scheme)



LILLAFÜRED. ANNA CAVE (instance)

Karszt és Barlang, Special Issue 1989. p. 59—64. Budapest

RESULTS OF PALEONTOLOGICAL INVESTIGATIONS IN THE CAVES OF HUNGARY — WITH SPECIAL REFERENCE TO THE LAST DECADE

Dr. János Hir — Dr. Dénes Jánossy

The beginnings of the scientific vertebrate paleontological excavations in the caves of Hungary can be said to have started with the activity of S.J. PETÉNYI (1864) and later with the compilation of a list of vertebrate paleontological finds in Hungary, mostly originating from caves, by A. KOCH (1900). Systematic excavations achieving both paleontological and archaeological results began with the work of O. KADIĆ in the Eastern Bükk Mountains (Szeleta Cave, 1906).

A series of excavations made before the First World War and in the twenties and thirties brought paleontological as well as archaeological results (O. KADIĆ—M. KRETZOI 1930, M. MOTTL 1940). At that time the most important locality was the Subalyuk Cave, Southern Bükk Mountains, not only because of its remnants of Neandertal Man and rich Paleolithic material, but also because of major vertebrate paleontological finds. This cave later became the type locality of the Subalyuk Phase, the so-called 'Old Würm' of the Upper Pleistocene in Hungary.

The results of paleontological excavations in the caves of Hungary up to 1976 were summarized by D. JÁNOSSY (1977, 1986).

More recently further excavations for paleontological purposes in a series of caves and karst hollows have parallelled the investigations and revision of previously collected material. Several comprehensive papers have been written about the cave faunae of Hungary, relying partly or totally on the above studies.

Below the achievements of the last decade are described in a geological order.

1. Neogene

In the karst areas of Hungary deposits with older than Lower Pleistocene fauna are rather infrequent. Therefore it is fortunate that three such faunae have been found recently. One was gathered by D. JÁNOSSY from the red limestone quarry of Tardosbánya, Gerecse Mountains, in 1975. From the group of localities in the Polgárdi limestone quarry which have been known from early this century, L. KORDOS and co-researchers have recently

The most important localities of the vertebrate paleontological finds in Hungary between 1977—1988. A = Neogene, B = Lower Pleistocene, C = Middle Pleistocene, D = Upper Pleistocene, Holocene collected D. JÁNOSSY (1988) and L. KORDOS (1985b, 1987b, 1987c) have published partial results.

M. KRETZOI (1985a) described the fauna of the Sümeg stone quarry and constructed a biostratigraphical unit, the Sümegium. He published widely his synthesis on evolution and fauna history (KRETZOI, M. 1985a, b; 1987; M. KRETZOI—M. PÉCSI 1979, 1982a, b), in which he summarized the history of Upper Neogene to Quaternary events, primarily relying on cave and open surface vertebrate faunae.

2. Lower Pleistocene

In the classic Villány—Beremend region which has been studied for more than a hundred years, localities exceptionally rich in finds have been discovered recently. Most of them were examined by D. JÁNOSSY.

During stone quarrying, in 1981 a Lowermost Pleistocene locality, Beremend 15, was exposed. It provided five species of bats (TOPÁL, GY. 1985) and 53 other vertebrate species (JÁNOSSY, D. 1987).

From localities nos 16 and 17 in the Beremend crystal cave, discovered in 1984, a late Lower Pleistocene 'Allophaiomys fauna' was recovered with interesting large mammals (antelopes and sabre-teeth tiger). The small mammal fauna is equally rich and allows precise dating (TAKÁCS-BOLNER, K. 1985).

On the Somssich hill, Villány Mountains, D. JÁNOSSY conducted excavations between 1975 and 1986. The locality Somssich hill 2 is of special importance. Like the other localities in the Villány Mountains, it is a karst hollow fill, but it was not opened by stone quarrying, extraction proceeded from the surface downwards in 20—30 cm deep layers. The uppermost five metres were constituted of loessy sand, then, after a calcitic intercalation, beginning from sample no 28, reddish-brownish clay followed. D. JÁNOSSY (1983) published the list of species recovered from the upper 36 layers and a vole species diagram. By the end of the excavation the total number of samples reached 50. This is a locality of incomparable abundance of species and the expected total specimen number is several hundred thousand. The fauna can be dated as Nagyharsány Phase (late Lower Pleistocene). It includes the first lemming occurrence in the Villány Mountains. The processing of the material from these three sites will probably take several years.

A typical 'Allophaiomys fauna' was also recovered from the stone quarry of the Ujlaki-hegy, Buda, in 1981, from a cave formed in Eocene Nummulitic limestone (JÁNOSSY, D.—TOPÁL, GY. 1989).

In the Hajnóczy cave, Bükk Mountains, L. KORDOS and J. HIR collected finds on several occasions between 1975 and 1982. The fauna presently under study is probably also of the late Lower Pleistocene (Templomhegy fauna phase — HIR, J. 1982, 1985).

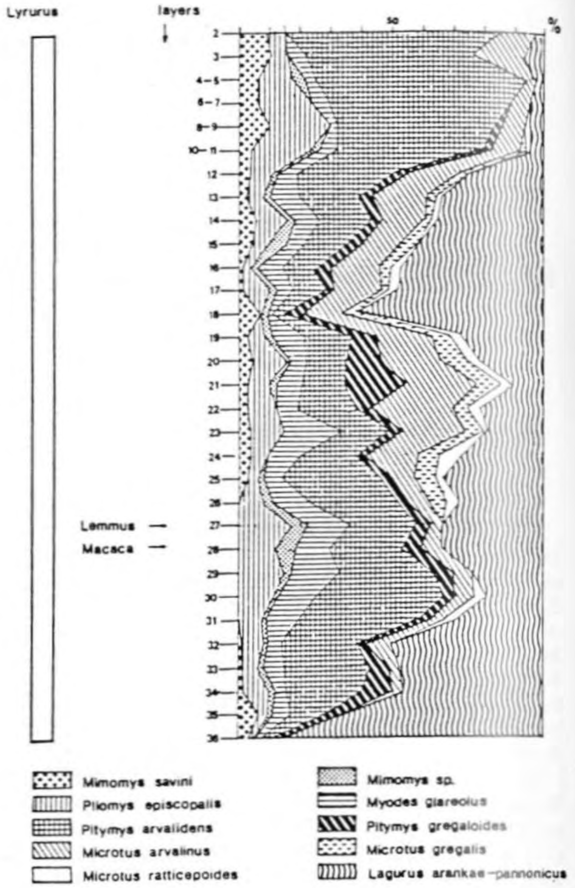


Diagram illustrating changes in relative frequency of different vole species in profile of locality Somssich Hill 2. Occurence of black grouse, lemming and ape on the left side.

The first faunistic and morphological overview of the Osztramos localities, found in the early seventies, was published by D. JÁNOSSY and L. KORDOS (1977).

D. JÁNOSSY published a monograph of great importance first in Hungarian (1979) and then in English (1986) on the vertebrate faunae of the Pleistocene in Hungary including numerous cave faunae and its biochronological importance.

3. Middle Pleistocene

The first works in this section are the revisions of previously collected faunae using a novel approach and stratigraphical re-evaluations, concerning the Hór valley cave, Bükk Mountains, and the Vár-hegy, Hotel Hilton, Buda Mountains, localities. The latter supplied the material for D. JÁNOSSY's identification of the Castellum horizon (1978, 1979, 1986) as a new stratigraphical unit. Investigating the metric features of the species in this horizon, statistical deviations were found in comparison to both the Lower and the Upper Pleistocene related species. Also detailed statistical analyses motivated the re-evaluation of the fauna of Szuhogy—Csorbakő (JÁNOSSY, D.—VÖRÖS, I. 1985) and the Hungária-hegy of Dorog (JÁNOSSY, D.—VÖRÖS, I. 1987), previously regarded Würm, and their reclassification as Middle Pleistocene. It is also important that I. VÖRÖS (1985) studied the Alces brevirostris finds recovered from the Ördög-lyuk of Solymár in 1943.

A recent Middle Pleistocene vertebrate fauna was recovered from the Pongor-lyuk of Répáshuta. This small cave lies only 30 m from the locality 'Kövesvárad' described by D. JÁNOSSY (1979, 1986). The Würm is totally absent from its profile. The Holocene layers are immediately underlain by Middle Pleistocene sediments, the lower 60 cm of which provided 725 specimens of 56 species. Most of the fauna consists of characteristically late Middle Pleistocene elements. Subordinately, however, some typical forms from the older phase of the Middle Pleistocene also occur (HIR, J. 1984, 1986, 1987).

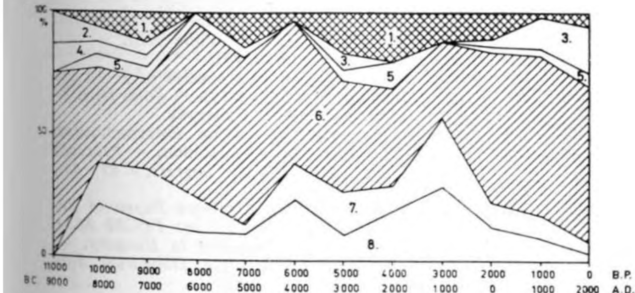
4. Upper Pleistocene — Holocene

The small ruin cave, Horváti-lik, is located on the N side of the Uppony gorge which also exposes several other caverns. The excavations here were conducted by L. FÜKÖH and L. KORDOS (1977, 1980). The 4 m profile can be subdivided into two main complexes: the stratigraphic position of the lower can be placed in the Varbó Phase (sensu lato — 'Riss-Würm') ,while the upper complex is of Holocene age.

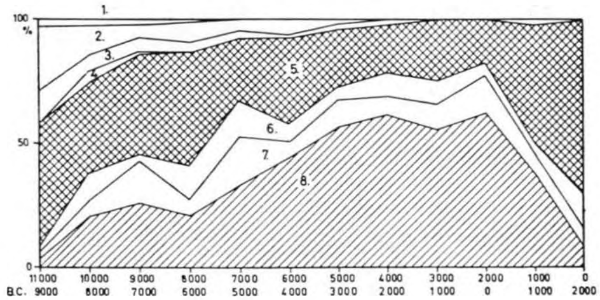
The profile of Pongor-lyuk excavations. Holocene: 1 = grey debris, 2 = rendzina with debris, 3 = grey debris, 4 = brown debris; Middle Pleistocene: 5 = yellow debris, 6 = brown debris, 7 = ochre clay with calcareous debris

In 1976 two hollows were opened up in the travertine under the Dobó ramparts of the Eger Castle. The rich mollusc and small vertebrate fauna recovered from the fill was analysed by L. KORDOS and E. KROLOPP (1980). A faunistical curiosity is the first occurrence of Hygromia transylvanica in the Hungarian Pleistocene. The vertebrate fauna of 29 taxa shows affinity to layers 5—8 at the locality 6 of Süttő (JÁNOSSY, D. 1979, 1984).

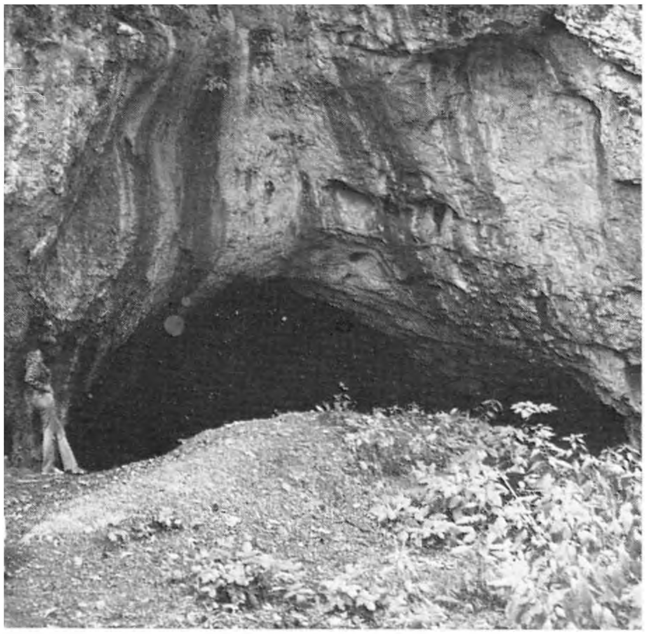
At the localities Giants' Hall 1 and Big Hall 2 in the Hajnóczy cave J. HIR (1982, 1985) also collected 'Riss-Würm' faunae. They, however, showed clear signs of climatic deterioration. A common feature of the materials from all the four localities is that they are slightly different



Frequency of the rodent faunae in the Hungarian Central Mountain Range. 1 = Sciurus, 2 = Citellus citelloides, 3 = Citellus citellus, 4 = Castor, 5 = Eliomys, 6 = Glis, 7 = Dryomys, 8 = Muscardinus



Changes in frequency of different vole species in the Holocene ground faunae in Hungary. 1 = Microtus nivalis, 2 = Microtus gregalis, 3 = Microtus occonomus, 4 = Microtus agrestis, 5 = Microtus arvalis, 6 = Pitymus subterraneus, 7 = Arvicola terrestris, 8 = Myodes glareolus



Entrance to the Kőlyuk Cave

from the typical animal communities described for the last interglacial in Hungary (Suba-lyuk and Varbó — JÁNOSSY, D. 1979, 1984). In summary it can be claimed that the systematization and stratigraphic evaluation of the fanuae of the minimum 50,000 years between the 'Riss-Würm' warm peak and the 'Würm 1' pleniglacial is still partly a task of the future.

The importance of the Függő-kő cave primarily lies in its geographical position, since it was formed in andesite in the eastern Cserhát Mountains. Until recently the volcanic area between the Transdanubian and the NE-Hungarian karst regions has been regarded a 'terra incognita' from Quaternary paleontological aspect. The fauna of the rock niche was studied by D. JÁNOSSY, L. KORDOS and E. KROLOPP (1983).

The first phase of its fill represents the Subboreal and early Subatlantic Phases of the Holocene. The vertebrate material of the lower horizons characteristically reflects an Upper Pleistocene cold climate. Also at this site a small part of the mollusc fauna consists of cold indicators or eurytherm species.

In the Bükk Mountains, in the Csunya valley, SE of Répáshuta, the excavations by L. FÜKÖH and E. KROLOPP (1983, 1986) began in 1980. From the two profiles of the Muflon cave a total of 5935 specimens of 50 mollusc species were found. The profiles cover most of the period from the late Pleistocene to the present. A faunistical curiosity is the new species described from this locality: Daudebardia helenae (FÜKÖH, L. 1985).

L. FÜKÖH performed the malacofaunistical analysis of some previously collected material: from the Kis-kőhát aven (1981), Rejtek I rock niche and Petény cave (1987b). L. FÜKÖH and E. KROLOPP (1985) processed the mollusc fauna of the Kőlyuk II. cave, Bükk Mountains. This profile includes the Boreal and Atlantic Phases of the Holocene (FÜKÖH, L. 1979, 1986) and as a whole reflects the process of forest spreading only interrupted by the clearances of the Neolithic cultures.

Generalizing the results from these excavations, L. FÜKÖH (1979, 1983 and 1987a) has also set up a malacostratigraphical system for the Holocene.

It was also in the last decade that L. KORDOS published the results of his excavations made in the seventies in the Hosszú-hegy aven (1983), Kis-Kőhát aven (1980) and the Rigó-lyuk of Bodajk (1984).

Based on 62 investigated layers of 12 caves in the Hungarian Mountains, L. KORDOS elaborated a complex stratigraphic, climatic and fauna evolution synthesis for the Holocene (1978a, b, 1981, 1982, 1984b, 1985a, 1987a).

Dr. János HÍR
paleontologist
Local-history Museum
Pásztó
Postafiók 15.
H–3060

Dr. Dénes JÁNOSSY
paleontologist
Hungarian Natural History
Museum
Budapest
Torockó utca 10.
H–1026

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AN OVERVIEW OF RESEARCH ON CAVE BATS IN HUNGARY

Dr. György Topál

Caves form part of the natural habitat for all but three of the 24 bat species of Hungary. Those species which utilize caves — at least the entrance chambers — spend much of the winter there. This group also includes species which use caves in summer for reproducing. Speleobiologically bats are troglophilous animals. The first impression of cave visitors in many places is that bats are the sole representatives of cave fauna. However, the excrements of bats provide ample food for part of the true speleofauna.

The information accumulated up to the turn of the century was summarized by *L. Méhely (1900)* in a splendid monograph. He collected data from the literature of the previous century and a half of from his own observations made at the Zoological Department of the National Museum. In the five decades following the publication of this monograph *Schwalm (1904)*, *Éhik (1924, 1941)*, *Kubacska (1926—1927)*, *Dudich (1930, 1932)*, *Gebhardt (1933)*, and *Vásárhelyi (1939, 1942)* made new contributions, most of which were additional data on cave bats.

This author started his investigations of bats in 1950, first as an outside collaborator of the Natural History Museum, with the support of the Museum, and since 1955 as a museologist. In addition to morphological, systematic and paleontological investigations and investigations concerned with tropical bats (not covered here), he studied the distribution of bats *(Topál, 1954c, 1959, 1976)*, their ecology and ethology *(Topál, 1962b, 1966)*. On the advice of professor *E. Dudich*, he also introduced the first banding of bats in Hungary in 1951, following the example of the Germans. The results of the ringing have only partially been made public *(Topál, 1954a, 1954b, 1956, 1962, 1963)*. Between 1951 and 1965 the number of bats banded exceeded 24,800. This method helped researchers collect much new data on the occurrence and extension of the animals and also on the quantitative aspects, structure, and seasonal changes of their populations. Numerous data has been collected on the wanderings of various bat species, their life-span, and behaviour.

After 1965 the rate of ringing investigations was greatly reduced, and only 940 specimens have been marked in the last twenty years. It was recognized internationally that disturbing hibernating bats for examination and tagging upset their intimate metabolism and thus reduced their chance for successful hibernation, forcing them to leave their safe shelter. In addition, some species also reacted more sensitively to the mere presence of the ring. At the same time a large-scale decline of the European bat population began. This was explained in many places by the wide-spread use of chemical insecticides (DDT et al.) and other toxic chemicals.

The requirements of nature conservation, stricter since the early 1980s, have called for new investigations, primarily in cave habitats. Commissioned by the Speleological Institute, the Hungarian Speleological Society selected 20 caves in 1985 in which to count bats, once each winter and once each summer every year.

Until 1988 out of the 20 selected caves the following were studied: the Baradla and Béke Caves *(Dobrosi, 1986, 1987, 1988)*, the Három-kút Cave, the István-lápa Cave, the Kecske-lyuk and Kőlyuk *(Kováts, 1986, Lénárt, 1986, 1988b)*, the Létrási-vizes Cave *(Kováts, 1986, 1987, Lénárt, 1986, 1988a)*, the Pál-völgy Cave *(Takács—Bolner, 1985, 1986, 1988)*, the Solymár Ördöglyuk *(Rajczy, 1987, 1988)*, the Szoplaki Ördöglyuk *(Dobrosi, 1986, 1987, 1988)*, the Leány Cave *(Dobrosi, 1988)*, the Legény Cave *(Dobrosi, 1986, 1988)*, the Pilis Cave and the Abaliget Cave *(Dobrosi, 1987, 1988)* and finally in the Pisznice Cave and Shaft No. 1 of the Öreg-kő *(Juhász, 1986, 1988)*.

In addition the Marcel Loubens Caving Group published data on bats from 17 other caves *(Lénárt, 1985, 1986, 1987)*. The Vértes László Group of Tatabánya and the Gerecse Cave Exploration Association *(Juhász, 1986, 1988)* found bats in 18 other caves. *Dobrosi (1987, 1988)* counted bats in the Kossuth Cave and some caves of the Mecsek Mountains.

It is worthwhile to compare, where data are available, the present conditions with those of 35, 25 and 15 years ago. The extensive Baradla Cave with its high chambers has been a den for bats for several centuries. Bats live in Baradla not only during the winter but also during periods in the summer. While earlier investigations in the first part of this century *(Dudich, 1930, 1932)* only studied the species *Rhinolophus ferrumequinum* and *Rh. hipposideros*, in late October, 1955, the author *(Topál, 1962b, 1966)* also found *Rh. euryale*. He counted the flights of the individuals of this species out of the cave in the evening and estimated the summer population at a minimum of 700 in late June, 1956. In June, 1965, however, he did not find a single bat in the cave. The information from *I. Szenthe* and *D. Dobrosi* (personal communication) point to the resettlement of *Rhinolophus euryale*. In January, 1983, author observed sixty *Rh. ferrumequinum* and twenty *Rh. hipposideros* in the cave. *D. Dobrosi* counted 91, 90 and 119 *Rh. ferrumequinum* and 19, 32 and 5 *Rh. hipposideros* along the Aggtelek section in February 1986, 1987 and 1988, respectively.

Besides the sporadic appearance of other bat species, in the 1950s the Pál-völgy Cave was the permanent hibernation place of small populations of *Myotis blythi oxygnathus* and *Rhinolophus hipposideros*. According to the recent detailed observations of the Bekey Cave Exploration Group *(Takács—Bolner, op. cit.)*, although the known length of the cave has grown multifold in 30 years, the number of *Myotis* has decreased a catastrophic extent. Recently only 13 and 10 hibernating specimens were found in two countings, while from 1951 to the spring of 1955 (during four winters) altogether 680 specimens were banded there *(Topál, op. cit.)*. Between 1955 and 1972 they only numbered between 7 to 19 during single day observations. The number of *Rhinolophus hipposideros* hibernating there during the winters of 1951—52 and 1952—53 was altogether 59, and in the winters of 1953—54 and 1954—55 103 (comprising 16 and 15 days of survey, respectively, *Topál, op. cit.)*. Most recently, very detailed investigations in the second half of February, 1986, counted 113 individuals and in late February, 1988, 107 individuals. This by no means represents a decline compared with the population 30 years ago, and even some growth is noticed. It is worthwhile to note that in Western Europe this was the very species which suffered the greatest loss during the last several decades.

The Szoplaki Ördöglyuk was an important winter den of several species of bats in the 1950s and 1960s. When intensive ringing began, the population was estimated to be between eight and ten thousand. Later there was some decline and the number fluctuated seasonally between 3000 and 6000. The higher number of individual bats was invariably observed in January—February *(Topál, op. cit.)*. Some years later, in January, 1983, the number of hibernating animals was around 300. The majority were *Myotis blythi oxygnathus* mixed with a smaller number of *Myotis myotis*. *Miniopterus schreibersi*, the second commonest species 30 years ago, had totally disappeared from the cave. According to *I. Szenthe* (personal communication), in 1985 he counted about 1700 hibernating animals and in early March of 1986, the population consisted of 700 bats. In early February, 1988, *D. Dobrosi (op. cit.)* observed about 650 bats (most of them *Myotis blythi)* in the cave. It is hoped that if they are not disturbed frequently during the winter, their population will remain permanently at this level in this once so important hibernating place.

The Pisznice Cave, Gerecse Mountains, was an important bat den in the 1950s. At the time this was the third known breeding place of *Rh. euryale* (along with the Baradla and Miskolc-tapolca Caves, *Topál, 1962a, 1962b, 1963)*. In late July to early August, 1957, this species comprised about a quarter of the total population (more than 800 out of 3,300 individual bats, counted during their evening flight). In addition, *Myotis myotis* and (in smaller numbers) *Miniopterus schreibersi* also mated here. It was then demonstrated that by the end of August 200 individuals of the total population had left the cave in the evenings, and not returned. Thus, by September, only a few *Miniopterus* remained there. In November hardly any bat hibernated in the cave. In mid-June, 1971 (before the young were born), the number of adults reached a thousand, but in late July, 1973 (calculating most of the young into the population), the counting at the evening flight yielded a maximum of 750 individuals, only a third of the number recorded 17 years ago. In the summer of 1976, 20 to 30 bats of the *Rh. euryale* species could be seen in the cave. *Juhász (1986, 1988)* and the members of the Gerecse Cave Exploration Association of Tatabánya noted 54 and 8 bats in January, 1986, and February, 1988, respectively. No bats were seen, however, in the September, 1988 counting. In 1986 the survey of the above mentioned speleologists was extended to 190 caves in the Gerecse Mountains, but the results were equally poor. The counts in the winter and summer of 1988 found bats in only four other caves.

In the 1950s it was proved *(Topál, 1956, 1962a, 1962b, 1966)* that the Abaliget Cave was an important den for Transdanubian *Myotis blythi oxygnathus* (1,500—2,000 individuals hibernated there anually), for *Miniopterus schreibersi* (in late May, 1954, they had a nursery colony of 600), and also for *Rhinolophus ferrumequinum* (150 hibernating individuals). The most common species at the time, *Myotis blythi oxygnathus*, has virtually disappeared from this cave, and *Miniopterus schreibersi*, the second most frequent species, no longer is represented. These facts are shown by *D. Dobrosi (1987, 1988)*. At the same time there has been no decrease in the number of *Rhinolophus ferrumequinum* compared with the 1954 population of 150 specimens. However, compared to the figure of March, 1987, the survey of March, 1988, showed decline.

There was no comparative data available for the cave selected for investigation and mentioned below. In the Három-kút Cave, as indicated by the observations of *Kováts (op. cit.)*, *Lénárt (op. cit)* and this author, several hundreds or even thousands of bats spend the summer there. Beside *Myotis myotis* and *Myotis blythi oxygnathus*, several hundreds of *Miniopterus* were known to live there. The latter species seems to be disappearing from all of Hungary although, still relying on the data of the mentioned observers, the Kecske-lyuk still functions as a summer den of this species.

In some respect, these investigations need some supplementary work. However, the opportunity for making regular countings, allowing the estimation of hibernating and the summer populations, should be taken advantage of in many different areas of the country. Thus, there would be a data-base for noting prior differences and future changes. In addition to the caves mentioned in the study, it would be useful to include the previously neglected Kács, Alba Regia, and perhaps the Mátyás-hegy and Ferenc-hegy Caves along with the major caves used for hibernation.

Dr. György TOPÁL
zoologist
Department of Zoology
Hungarian Natural History
Museum
Budapest
Baross utca 13.
H–1088

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THE FLORA OF HUNGARIAN CAVES

Dr. Miklós Rajczy

It is twelve years since paper on Hungarian cave botany (Hajdú 1977) was published under the same title on the occasion of the 7th Congress. This paper provides an account of the new results covering cave-dwelling green plants in Hungary.

Entrance flora

The vegetation of cave entrances consists of plant species adapted to the special ecological conditions (reduced light, more constant temperature, higher air humidity). These plants, mostly lower plants, i.e. algae, bryophytes and ferns can be found not only in caves but in other wet and dark habitats such as in crevices, on shady wet rocks in woods, in deep narrow valleys, etc. A valuable collection of data on entrance flora is that of Á. Boros who collected very frequently in caves. In 1985 H.-Kovács produced a guide and a card file to these data by means of his itineraries covering 175 plant species in 213 Hungarian caves.

During the past 12 years 6 caves have been studied, one shaft (Komáromy 1977 — only algae), three thermal caves (Buczkó & Rajczy 1986) and two caves of archaeological importance (Rajczy & al. 1986).

Darkness flora

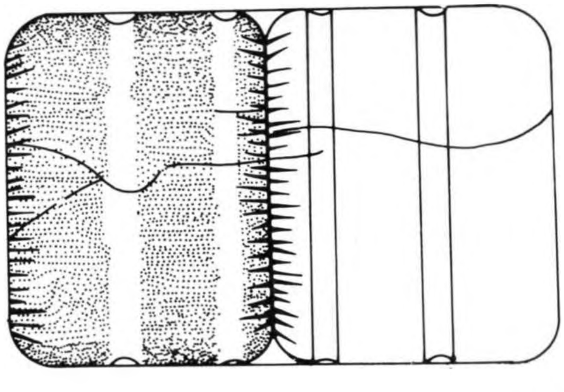
This ecological group of the vegetation of the caves is that which exists in total darkness. Though the algae of this flora have been studied in detail, nowadays this field is neglected. It is surprising that a comparison of the well-known darkness flora of the Baradla Cave at Aggtelek and its lamp flora sevealed no similarity in the two (Hajdu—Orbán 1981). The reason might be the inadequate conditions while cultivating the samples in the laboratory (lower air humidity, higher temperature), or that the propagating bodies are so few in the innermost part of the cave, that they cannot win in the competition with those ones introduced by the number of visitors (cf. Padisák & al. 1985).

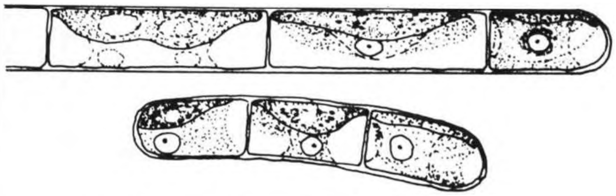
Lamp flora

This flora — the green plants living in show caves around electrical lamps — was studied in detail in the period under consideration. These green coatings do not belong to the caves, moreover they hide their original beauties, the dripstone formations, helictites, crystals and other decorations. The green color itself is rather strange in this place. However, the danger is not only in the loss of aesthetic value of the decorations but in the disturbance of the cave-dwelling animal community. One of the main characteristics of the cave ecosystem is the low level of nutrient resources, i.e. these animals are living under the conditions of starvation. The fact that this habitat is poor in energy, results in few species in limited numbers living very disproportionately in the cave. A large influx of energy (i.e. nutrients) may introduce new species which have not been adapted to the special cavern conditions.

Lamp floras consists of lower plants, i.e. algae, bryophytes and ferns. One should expect similarities in species composition of lamp floras and darkness flora or lamp floras and entrance floras respectively. The "predictive value" of the darkness flora proved to be an inadequate supposition as I mentioned before. The other assumption, that the lamp flora originates mainly from the entrance flora can only be inadequately documented. Regarding the algae we can find only a few common species: the special

A special diatom species in cave entrances, Melosira roeseana Rabh.

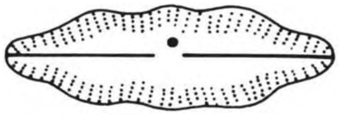




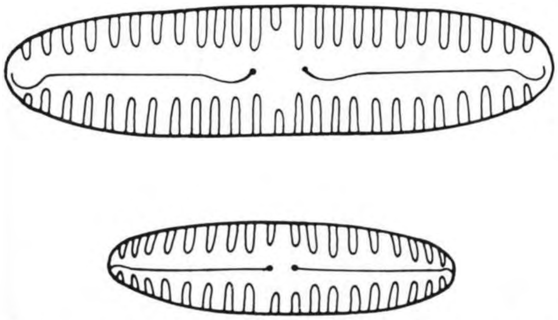
Characteristic species in the lamp-lit areas, Chlorhormidium flaccidum (Kütz.) Fott

Diatom species living in caves, Hantzschia amphioxys (Ehr.) Grun.

Diatom species living in caves, Fragilaria brevistriata Grun.



Diatom species living in caves, Navicula mutica var. nivalis (Ehr.) Hust.



Diatom species living in caves, Pinnularia borealis Ehr.

species very characteristic of the entrances are completely lacking in lamp floras. The typical participants of lamp floras originate from the soil and rock surfaces outside the caves. Lichens could not be found in Hungarian lamp floras though there is a very common genus living in almost every cave entrance. Regarding hepatics we find the same situation — no hepatic was found in Hungarian caves though they are not rare in cave entrances. Among mosses there are some species which can be typical either of cave entrances or of lamp floras. There are many moss species, of course, which originate from other habitats. Even photophylous plants are living in the lamp floras (Hajdu & Orbán 1981, P.-Komáromy & al. 1985, Végh 1985). The reason for this interesting phenomenon is, that the limiting factor at cave entrances is low light intensity, only sciadophylous plants can survive there. On the contrary, the surfaces around the electric lamps are mostly well illuminated.

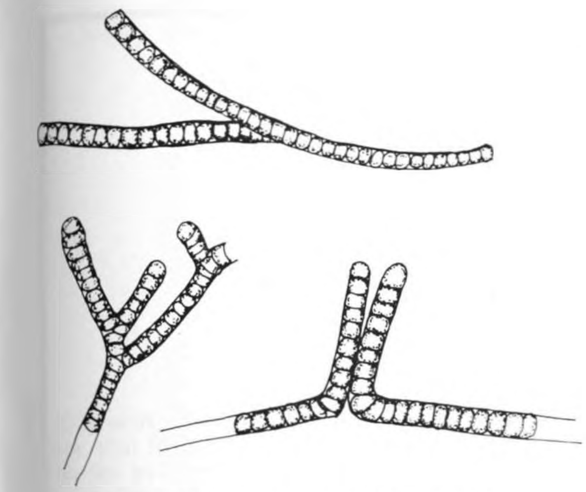
Analysis of the floristic composition of the lamp floras and the study of the dynamism of early succession led to the conclusion that the species of the lamp flora originate from the wider vicinity of the cave entrance, the most common, good propagating species have the highest possibility of inhabiting the cave interior (P.-Komáromy & al. 1985).

How to protect caves from green plants?

Padisák & al. (1985) described the endangering factors in detail. Besides the well-known factors of light intensity, length of illumination (Hazslinszky 1975) and the water supply of the surface the importance of several new ones can be proved. The most significant among these circumstances is the introducing (infection) probability. As the cave air contains extremely few propagating bodies and the dripping, seeping waters are very well filtered, the main introducing power is man (visitors, cavers, technicians). Another important factor is the role of the substrate. The softer and more divers the surface the faster is the development. The clay deposits or muddy floors are among the first places where lamp floras appear.

In my opinion the strategy of the war against the "green enemy" consists of the following parts:

1. The reduction of light intensity and the time of illumination — Use pressure-operated buttons and as short sections in the illumination system as possible.
2. Better choice of illuminated surfaces and lamp types — Avoid illuminating wet or soft surfaces. The vicinity of the lamp must remain in darkness (do not put security lamps in natural or artificial cavities). High pressure mercury lamps and sodium bulbs and spot-like light sources recommended.
3. The reduction of infection probability — Illuminated surfaces must not be available to the visitors, cavers may use only dark paths, techni-



Characteristic species in the lamp-lit areas, Plectonema schmidlei Limanowska

cians should not touch bright places during work if possible. The possible foci of infection — the developing lamp floras must be sterilized as soon as possible.

It is evident that effective protection depends on the illuminating system itself. It seems to be very important to take this strategy into account while planning the system. It is cheaper to modify existing systems than to remove the green coatings each year. The modification of systems often results in savings of a considerable amount of electricity! Such a modification (not radical at all) in the Szemlő-hegyi-barlang resulted the disappearance of many dangerous infection foci which could not be sterilized (Buczkó & Rajczy 1987, 1988). An important part of this suggested strategy is the removal of lamp floras in their initial stage. A developed lamp flora can spread rapidly from lamp to lamp as the propagation depends mostly on the distance under cave conditions. You can use less chemicals when sterilizing small spots. This way it will be cheaper and will endanger cave-dwelling animals less. The last is very important for the protection of the rare and unique fauna of the caves. The removal of existing green coatings by brushers and water is not only very expensive but very dangerous: this way we ourselves disperse the propagating bodies over large surfaces. The result will be a rapid and extensive growth.

Dr. Miklós RAJCZY
bryologist
Department of Botany
Hungarian Natural History
Museum
Budapest
Postafiók 222.
H–1476

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SPELEOTHERAPY IN HUNGARY TODAY

Dr. Tibor Horváth

It is written in the ancient Indian epic, the Ramayana, that Rama — deadly fatigued from the chase after the kidnappers of his wife, Sita, in the forests of the Vindhya Range — took refuge in a cave. Breathing in the balsamic cave air and gulping the crystal clear stream water, he and his companions regenerated very quickly and could soon resume their chase, successful in the end.

This is perhaps the earliest evidence that man recognised and utilized the beneficial and curing effects of cave microclimate even in ancient times.

From medieval Hungary we also have written documents testifying to the relationship between caves and the treatment of illnesses. They inform us about the wide-spread application of bone remnants in cave fills, powdered dripstones, cave waters and the climate of certain caves for medical purposes. The 'sweating' cave of Szkleno or the Büdösbarlang (Stinking Cave) of Torja became popular places of pilgrimage not only for people of the area suffering from diseases, but their medicinal influence was also known all over Europe (Tardy, 1984).

While in caves with sulphuric emanations and radioactive influence the treatment of chronic locomotional, dermatic and neurological diseases looks back for centuries, World War II represents a turning-point, in the medical utilization of caves with comfort or cooling sensation. In post-war years systematic climatological and medical observations began initially in the Klutert Cave, Ennepetal, West-Germany, in order to confirm the common experience that the condition of people suffering from asthma, bronchitis or whooping cough tends to improve after some time spent in caves.

The news about promising results and reliable statistics had reached Hungary by the late fifties and gave impetus to the experiments which started at the beginning of the decade.

The Béke Cave of Jósvafő was discovered by *Jakucs* in 1952. The climatological measurements, conducted by him, *BIRÓ* and *FÁZOLD*, proved that climate here was very similar to that in the Klutert Cave, already a basis for reference. *JAKUCS* called the attention of physicians to the fact that more and more asthmatic patients visited the cave, in spite of the inconvenience and risks, and they insisted that their complaints had reduced here. The obvious demand, the enthusiasm of fanatic people and the practical help from the Borsod Collieries Trust led to the introduction of speleotherapy in Jósvafő and, thus, in Hungary.

Experimental treatments began in 1959. The leading figure of these attempts was *Kirchknopf*, who involved *Varjas* and *Kraszkó*, relying on the technological background of the nearby hospitals, into the medical research. *Kirchknopf* persuaded the Borsod Collierie to provide the necessary conditions (developing the cave to accommodate patients and building overnight facilities) and, with *Szoboszlay* and then *Adorján*, undertook the selection of patients (Kirchknoph, 1985). Since 1965 organised treatments have taken place and the results have been analysed scientifically (Kraszkó—Jónás—Szoboszlay, 1973). The chemical and bacteriological investigations conducted for many years by Takács (1982) and his coworkers, which supplied the basis for curing diseases, are also to be emphasized. The Ministry of Health declared the cave a medicinal one in 1969 and this marked the acceptance of speleotherapy officially as a way of medical treatment — unprecedented in the whole world.

The cave is still run by the Borsod Collieries. The patients are mostly miners, who are accommodated in a seasonal resort for 46 persons. There are six sessions a year and permanent medical supervision, previously a major deficiency, seems to have been ensured recently.

Between 1969 and 1988 a total of 8232 patients received a three-week treatment (four hours daily); half of them were manual workers, the other half consisted of intellectuals, pensioners or children. The latter have formed one group each year since 1981 and are recruited from the patients of Centre for Child Hygiene in Miskolc. Most of them suffer from chronic bronchitis and bronchial asthma. By subjective judgement, patients reported considerable improvement and for a high percentage the medicine demand was reduced. This positive trend could be supported by objective parameters (breathing function tests). The observations on the rehabilitating value of repeated cures are important as they attest to a deceleration of disablement (Adorján, 1988).

The activity going on at Jósvafő is a pioneering venture. This is the place where speleotherapy was first put into practice in Hungary and thanks to it speleotherapy was officially accepted by health authorities. The methods for the scientific evaluation of results were also elaborated here. The investigation which proved that the pathological hipersensitivity of bronchia decreases in the cave environment (Kraszkó, 1983) is still unique in the world. Their contribution to the international respect enjoyed by Hungarian speleotherapy is great.

A negative phenomenon is the only seasonal use, the lack of a hospital background, narrowing down both supervision and the complexity of medical supply.

In the second half of the sixties speleotherapeutical activities began in two additional localities, at Abaliget and Tapolca.

The curing effect of the Abaliget dripstone cave was known in the circles of the local population suffering from respiratory diseases since the forties or fifties. The detailed climatic mapping of the cave is the work of *Urbán*, *Páter*, *Szabó* and, most of all, *Fodor* (1969, 1977). Under the professional supervision of the Pulmonological Institute of the Baranya County Hospital and sponsored by the Pécs Ore Mines, organised treatment here began in 1971. Groups of 20 people spend two hours daily in the cave for four weeks and hygienical gymnastics is also part of their treatment. The procedure is preceded by detailed examination in the pulmonological institute and the curing is accompanied by continuous medical supervision.

Since 1980 2,000 patients have been treated, including those suffering from silicosis. Subjective improvement is observed for a considerable percentage of patients and for half of them the reduction of the amount of medicine demanded also supported this feeling (Kövesdi—Háber—Borsiczky, 1976; Schreiner, 1988).

In some respects the activities at Abaliget are also pioneering. Partly the intention to provide a satisfactory professional background and correct preliminary examination and partly the initiative that hygienical gymnastics should be included into speleotherapy.

The difficulties partly arise from the large distance between the background institution and the cave and partly from the narrow cave space available and, in addition, the latter is shared with tourism.

In 1969, relying on *Kessler*'s (1972) climatological measurements, experimental treatments began at Tapolca, in the Lake Cave. After the first successful years a decision was made to organise this activity on a regular and broader basis. For this purpose the dry cave under the hospital was developed. It had excellent climatic potential and allowed the establishment of an organic link between a cave and a hospital. Thus, under satisfactory professional supervision, the conditions for the regular and scientific evaluation of results were created. Here cave climate is a useful component of a complex respiratory rehabilitation activity and also an optimal setting for this activity. Speleotherapy has been integrated into the complex medical treatment in the hospital. Since 1973 curing is regular (lasting for three weeks with four hours daily) with 24 patients taking part. In 1976 an independent hospital department was set up with its main profile being speleotherapy. The development of the cave and the outfitting of the hospital department were subsidized by the Bakony Bauxite Mines Company, the Hungarian Aluminium Industry Trust and chemical industry. Most of the patients are employed in these branches of industry. At Tapolca speleotherapy is a complex activity with breathing exercises, autogenic training, psycho- and musicotherapy in the cave and other, nonspecific ways of treatment, such as electro- and phototherapy, vertebral exercises, inhalation, outside the cave assist the improvement of patients' health, supplemented by medicines. An enthusiastic group of specialists forms the staff. At the start the merits of *Somogyi* were great and since 1976 the department has worked under the guidance of *Horváth*.

Over the last 15 years about 6,000 patients have been treated and a considerable percentage return regularly. The overwhelming majority of patients shows prolonged improvement, their demands for medicine, sickness benefit and hospitalisation are reduced and their respiratory function improved. The rehabilitation value of regular medical care could be validated through the delaying of the inability to work. It could also be confirmed that the complex respiratory rehabilitation under cave conditions had numerous advantages against passive climatic therapy or conventional hospitalisation (Horváth—Somogyi—Mészáros, 1979, Horváth, 1980, 1981, 1984, 1986).

In recent years the activity of the hospital was broadened to include the continuous care of local children suffering from asthma. The psychical and physical practices learned and regularly repeated in the climate of the cave are of utmost importance. The results are very promising and this activity is becoming a national service and the social and professional responses are favourable.

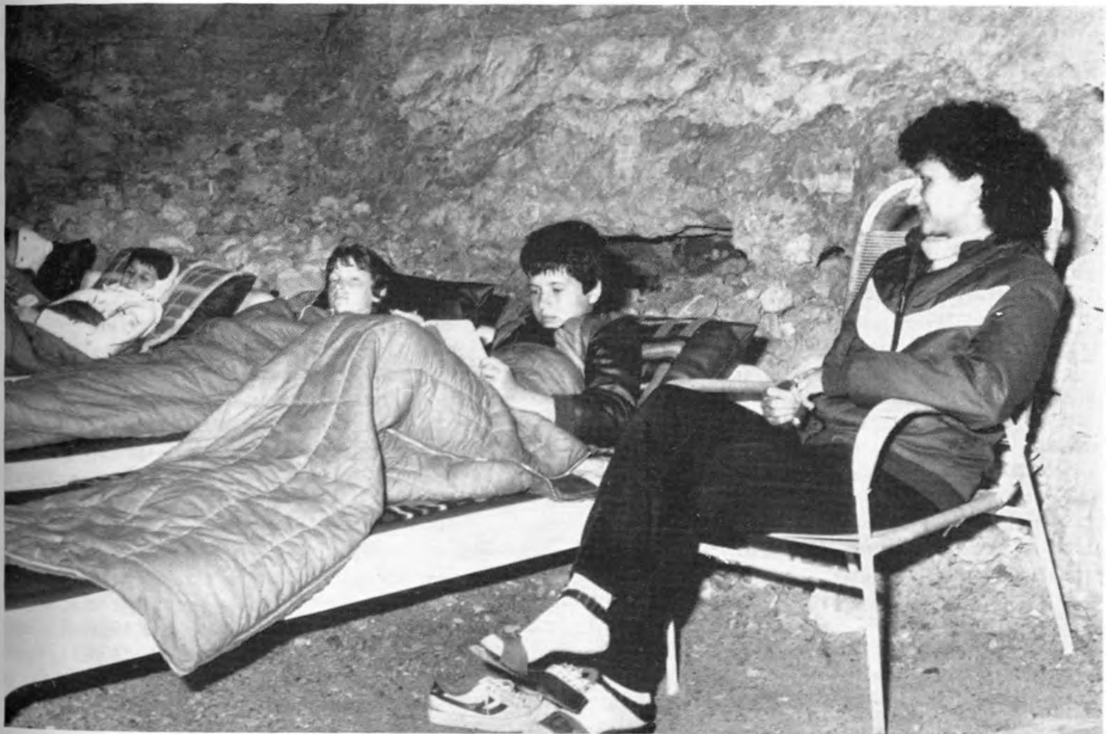
The work going on in Tapolca presents a model in several respects. This is the only independent institution in Hungary where speleotherapy is the main profile. This is the only cave-hospital complex, where professional background, comprehensive care and the monitoring and evaluation of results are accompanied by a comfortable sanatorium life and resort setting. Speleotherapy introduced a series of related activities (care of children, medicinal tourism), which are profitable, in addition to the treatment itself, for both the town and the country. The department did much for the acceptance of this way of treatment by the professional public in Hungary. It is primarily due to the results achieved here that speleotherapy is accepted in the Hungarian and international medical forums. There are great merits in the international respect for Hungarian speleotherapy. Since 1986 *Horváth* is the president of the UIS Committee on Speleotherapy. If we are not so modest we may say that all other activities around the world are measured to the Tapolca example.

Besides the three currently active cave there have been other plans and attempts to this activity and to begin speleotherapy at other localities. For a quarter of a century *Kessler* (1982) has been making efforts to use the Molnár János cave and the drift in the Gellért hill for medical purposes. *Osváth* gathered favourable experience concerning the curing of asthmatic children in the Pálvölgyi Cave. *Mucsi* (1987) examined the microclimate of the Hajnóczy Cave and found a positive influence on the respiratory functions of healthy people. There have also been attempts to utilize the Szemlő-hegy Cave for health tourism. Although these ideas, have not yet been realized, the blame cannot be totally put on the lack of fundamental climatological research aimed at the prospects of the utilization of these caves for therapeutical purposes. The researches by *Fodor* (1981) and *Gádoros* (1988) are of great importance. The recent investigations by *Tardy* and his coworkers concerning the climatology and bacteriology of caves help to define the term 'medicinal cave' and may mean a revolution in the theory and practice of speleotherapy (Bolner—Tardy, 1988, Tardy, 1987, 1988). However, it must be considered whether the restricted resources available for health service, including speleotherapy, should optimally be concentrated on the support, maintenance and development of the now active localities or be used to broaden our activities to cover new facilities.

Speleotherapy as a kind of medical treatment is now judged in Hungary in a rather ambivalent manner. Patients demand it and the opinion of the medical profession ranges from full approval to total rejection. The same applies to financial subsidies and technical equipment. Manifold dependency has both positive and negative effects, as speleotherapy belongs equally to the Hungarian Speleological Society, the Ministry of Environmental Protection and Water Management as well as to the Ministry of Health and Social Affairs, but work at given localities directly affects settlements and industries and even tourism in certain places. This circumstance may multiply opportunities and may also open a way to shift responsibility and tasks.

Hungarian speleotherapy is respected internationally. During recent years more than 60 publications have appeared on this topic written by Hungarian authors, in Hungarian and foreign languages. The number of lectures by Hungarians in speleotherapy at conferences at home and abroad surpasses a hundred. Hungarian experts take part at all international conferences on speleotherapy

Patients in the Tapolca Hospital Cave (Photo: Z. Sándor)



and their contributions are significant. Since its formation the UIS Committee on Speleotherapy has had a Hungarian secretary general *(Kessler)* and, as has been mentioned, a Hungarian president for two years.

Nature provides good opportunities for the rehabilitation of respiratory diseases, increasing in number in Hungary. There are still many unused potentials in our medicinal caves and the related medical facilities. The exploitation of this potential in health tourism may open up new perspectives and the income could be used to develop new caves for the service of medical treatment.

Dr. Tibor HORVÁTH
pulmonolgist
Municipal Hospital
Department of Speleotherapy
Tapolca
Ady Endre út 1.
H–8301

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Karszt és Barlang, Special Issue 1989. p. 77—80. Budapest

A HISTORY OF HUNGARIAN SPELEOCLIMATOLOGY

Miklós Gádoros

The origins of Hungarian speleoclimatology date back to the early 19th century. By his measurements in 1826, *I. Vass (1831)* basically correctly claimed that the Baradla Cave of Aggtelek has an almost stable, 10 °C temperature. He recognized and confirmed by measurements that meltwater has a cooling effect on caves. It is worth mentioning that he also thought it necessary to record outside temperatures.

After I. Vass, others also published climatic data *(Fényes, 1851; Schmidl, 1856)*. Nevertheless, for dripstone caves in the 19th century, only sporadic data were collected before 1870. Today they have only historical value.

Research was given a new impetus by the exploration of the Dobsina Ice Cave (1870). The cave was a curiosity at the time, and its interior temperature was investigated by several researchers with increasing temporal and spatial detail *(Fehér, 1872; Krenner, 1874; Pelech, 1884* — data by the latter was first published by *Krieg* in *1883)*. Between 1882 and 1888 *E. Hanvay* measured, along with recording supplementary weather data, almost 2,000 points on the interior surface and 4 to 5 non-surface interior points in the cave. Unfortunately, only the calculated means of his data were published *(Fischer, 1888; Hanvay, 1900)*; the original record was recently found in a manuscript *(Dénes, 1970)*.

For a long time the peak of measurements in Dobsina was represented by the work of *Steiner (1922)*. From 1911 to the end of World War I he measured, besides air temperature, the temperature of the rock wall at various depths, with the precision and regularity of a meteorologist. (After the Trianon Peace Treaty Dobsina was annexed from Hungary and its research history by Hungarians was interrupted.)

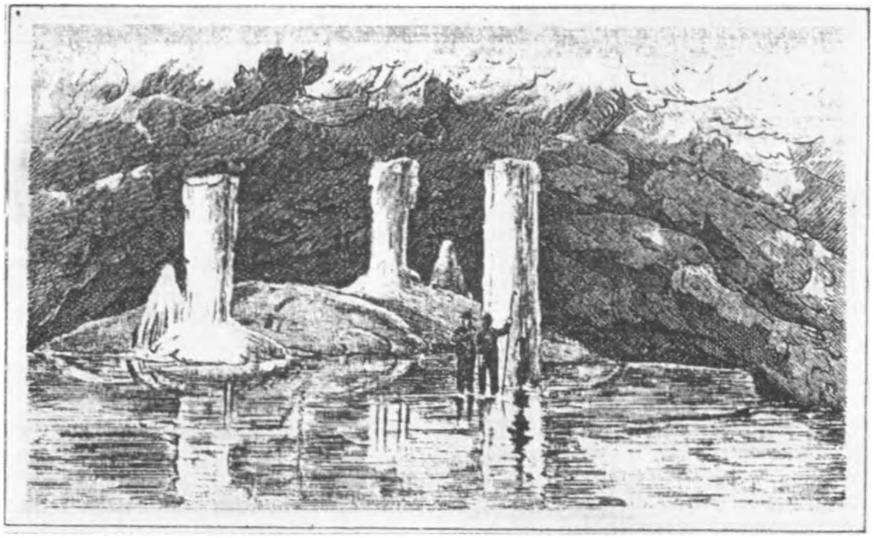
Climatological investigations in dripstone caves only intensified, after the initial steps, in this century. The work was begun by biologists who wanted to discover the physical conditions of cave habitats. The Abaliget Cave near Pécs was studied by *Gebhardt (1934)* and the Baradla Cave of Aggtelek by *Dudich (1932)*. In addition to the description of almost 300 animal species in each cave, they both stated that the annual range of air temperature is moderate in the caves studied and cave air is saturated with vapour most of the time and in most places.

In the last major publication in the first half of the century, *Béll (1945)* points toward a period of new attitudes. He investigated cave ventilation and in his evaluation compared the ventilation of mines and caves. The importance of his work lies in the analysis of ventilation.

The economic and political consequences following World War II brought about a decline in the research on cave climate for a long interval. It was not until 10 years after the war that the first publication appeared. *Dudich (1955)* disclosed that in Central Europe the climates of moist karst caves in low and mediumheight mountains are approximately the same and consequently the curative effect observed in the Klutert Cave must be characteristic of other caves too. Shortly after this recognition, *Markó* and *Jakucs (1956)*, studying air currents in the Béke Cave of Aggtelek, found that, related to the difference between outside and inside cave temperature, the role of air pressure, previously regarded predominant, was generally inconsequential.

The climate of the Béke Cave of Jósvafő was first studied by *Jakucs (1959)*. Workers of the Public Hygiene and Epidemics Station of Borsod-Abaúj-Zemplén county investigated temperature, moisture, CO_2 concentration, ventilation and the calcium content of aerosol, in 1959, 1960, 1961 and in 1965 *(Kerényi—Bíró—Kirchknopf, no date)*. In 1963 or 1964 *Szabó* and others conducted similar investigations, and *Urbán* carried out a general climatological survey in the Abaliget Cave, Mecsek Mountains in 1964. A similar general climatological investigation took place in the Baradla Cave *(Berényi—Justyák, 1960)* showing air current, temperature and air moisture differences along the same cross-sections. Parallel studies went on in the Béke and Baradla Caves *(Csomor—Zalavári, 1964)*, while *Gy. Szabó* conducted climatic measurements in the caves of Lillafüred.

At the Jósvafő research station measurement techniques were further developed *(Gádoros, 1966)* and the relationship between aerosol and helictits formation was studied *(Cser—Maucha, 1964)*



Dobsina Ice Cave, where the first detailed climatological investigation was taken in the 1870s

in the Vass Imre Cave, which belonged to the station.

In the same period, *I. Fodor* began speleoclimatological investigations in the Baradla Cave in 1959—63 and in the Abaliget Cave between 1966 and 1975. In the meantime he also made numerous measurements in the two caves of Tapolca. Besides temperature, air moisture and air current velocity measurements, he also conducted CO_2 measurements, aerosol analyses and bacteria countings. He wrote a lage-scale treatise based on more than 11,500 (!) temperature measurements, more than 10,000 air moisture measurements and other data (of unknown number) and provided a statistical analysis of the averages and fluctuations of various climatic elements in various caves. He analyzed the vertical gradients of temperature and moisture, introduced a new bioclimatological classification, and extended Gressel's climatological classification with a 'quasi-dynamic' type. For his work he was awarded a scientific degree by the Hungarian Academy of Sciences *(Fodor, 1981)*.

In order to study radioactivity, large-scale serial measurements began at the Jósvafő research station in 1966. During 10 years time, more than 30 caves were surveyed *(Gádoros, 1986b)*. At the end of the decade *Rónaki (1973)* investigated the radioactivity of the air and stream of the Abaliget Cave.

The next step was the aerial extension of the investigation. *Walkovszky (1970)* studies the Vecsembükk Shaft (Alsó-hegy) and *Lénárt (1975)* the Létrási-vizes Cave (Bükk Plateau) while *Kordos (1975)* analyzed the intricate climatic conditions of the entrance parts of caves. *Miklós (1978)* described the climatic conditions of the Hajnóczy Cave and then conducted detailed measurements in the Remény Shaft, Mecsek Mountains *(Miklós, 1980)*. The research of the Béke Cave continued, and aerosol samples were taken using modern technology. This allowed the precise determination of the calcium content of the cave air *(Takács et al. 1984)*.

The year 1978 saw a turn in the investigation of cave radioactivity. Trace detector measurements began in the Hajnóczy Cave, Bükk Mountains *(Somogyi et al., 1983)*, and after a short time a survey of 10 caves was under way by this method (partly unpublished results; *Somogyi—Lénárt, 1986)*.

A new advance in speleoclimatology was realized by regular ionization measurements, initiated long ago by *H. Kessler*. In 1985, under the guidance of *J. Tardy (1987)* this type of investigation began in the Szemlő-hegy Cave of Budapest as part of abroad research project which was directed at the specification of the impact of urban development on the underlying caves *(Bolner—Tardy, 1988; Tardy, 1988.)*

For lack of publication we cannot say much about the most recent activities. What is known, however, is that ionization measurements have been extended to four caves, radioactivity determination by the trace detector method is going on, and regular CO_2 measurements are being conducted in the Baradla and Alba Regia Caves (Tés Plateau), and, naturally, the extended conventional climatological measurements are continuing.

This brief summary indicates that Hungarian speleoclimatology, relying on a century of traditions, developed in three main directions during the past decades:

1. Aerial extension of the study of traditional climatic elements, reducing the time intervals of measurements and increasing measurement sensitivity;

2. Introduction of the analyses of more and more, previously unstudied climatic components (e. g. radioactivity, aerosols and ionization);

3. Disclosing physical foundations and interactions on the basis of accumulating measured data and making advances towards the synthesis of these elements of cave climate into a complex physical system.

The latter purpose is efficiently promoted by progress in related disciplines. For instance, the karst corrosion studies by *Zámbó (1986)* supplied valuable data for the evaluation of the CO_2 content of the involved caves.

All these are 'only' fundamental research, but indirectly, or even directly, they promote the development of applied fields, such as speleotherapy.

Miklós GÁDOROS
electrical engineer
Budapest
Kapi út
H–1025

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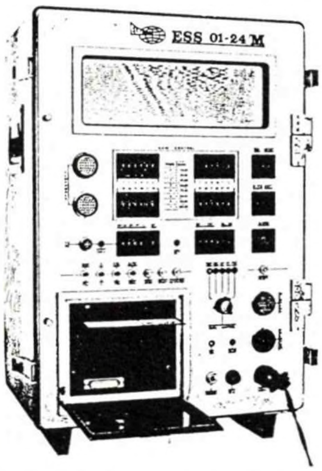
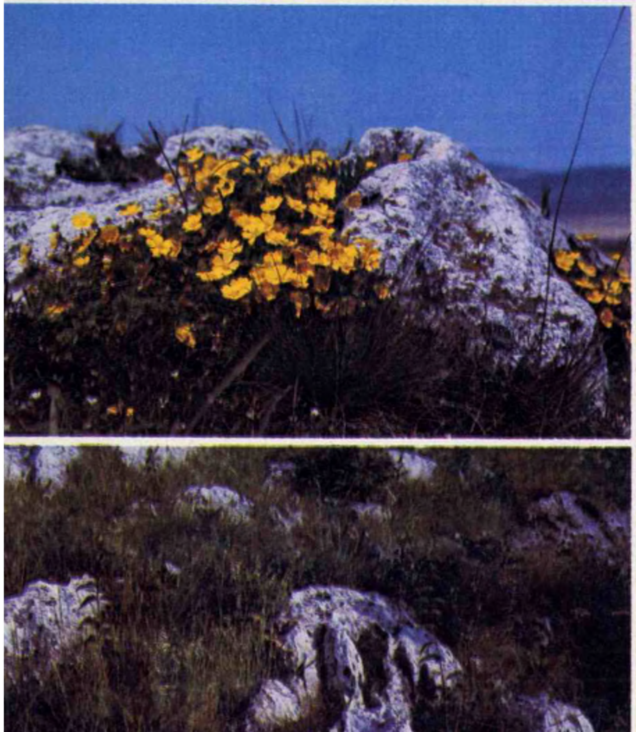
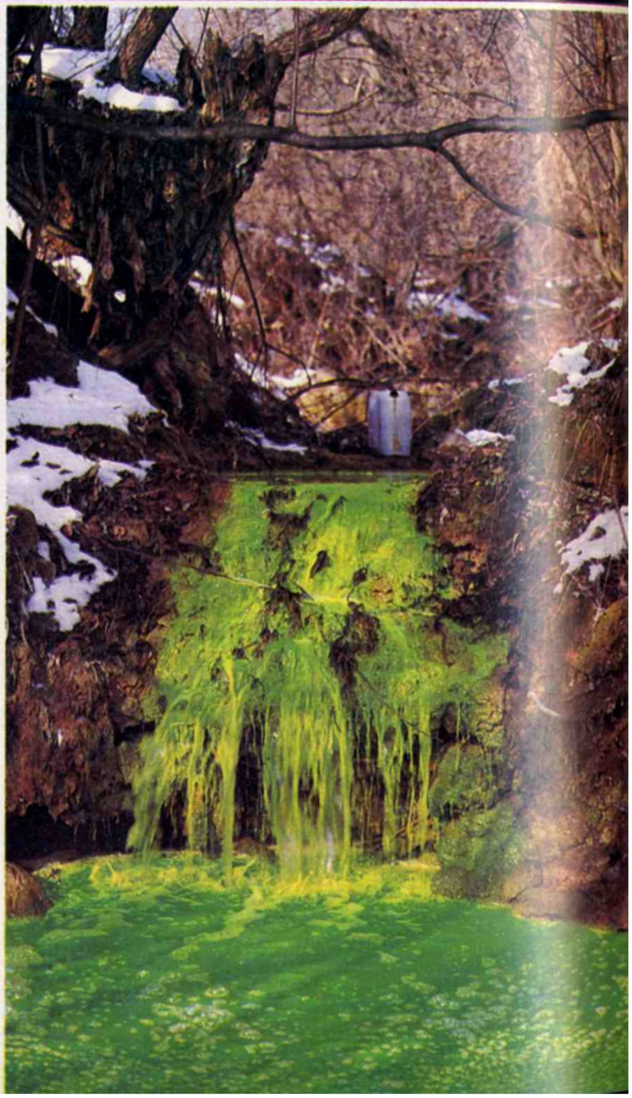


Top: Mineral formations in the Beremend Crystal Cave, Villány Mts. (by T. Hazslinszky)

Bottom: Sátorkő-puszta Cave, Pilis Mts. (by P. Borzsák)





Karszt és Barlang, Special Issue 1989. p. 81—86. Budapest

PROMINENT ACHIEVEMENTS IN CAVE STUDIES IN HUNGARY

Dr. Gábor Szunyogh

The papers in the present number of Karszt és Barlang (Karst and Cave) provide, in thematic groupings, the activities of Hungarian speleologists and their most important results. The reviews show that the development of speleology — as of any other science — progresses through continous and meticulous foundation work and just occasional discoveries of great importance. For this reason, the final output is equally dependent upon the many, many speleologists in the background as well as the gifted or lucky researcher who finally compiles the sensational new theory. More than a thousand reports and studies have been published by our cave exploration groups to supply evidence to the importance of that background work. The present paper, however, emphasises the other side of cave exploration; it provides a summary of the prominent achievements which fundamentally influenced the development of the individual branches of speleology or received international attention because of their particularly interesting nature. This article summarises just the Hungarian results.

I would like to underline that it is a subjective judgement to decide that something is prominent and in this case I made the judgements. The list is naturally incomplete and rather a selection of extracts. I apologise to those whose important discoveries are not included in this paper. Certainly the description of the activities of some scientists means repetition of parts of other articles, but the reader is kindly asked to pardon this, as the viewpoint from which they are cited here is different.

The karstification process

The role of climate and vegetation in karstification by cold waters

In the late 1950s the accumulation of information on the evolution of tropical karst features called attention to the contradictions in views on the rate of karst denudation. Previously (in the first place according to Corbel's school) the opinion was widely held that karstification is faster in a cold climate, since the aggressivity of water containing carbonic acid is inversely proportional to temperature. The concept seemed to be supported by measurements: rivers under cold climates transported ten times more dissolved $CaCO_3$ that those in warm belts. Why is it then that karst features are better developed in the tropics than under cold conditions?

The contributions of László Jakucs (1971, 1977) and Dénes Balázs (1964, 1965, 1969, 1971) to the settlement of this issue are of great significance. They revealed the fundamental role which the vegetation on the limestone surface plays in controlling the rate of karst denudation. While the free atmosphere contains only 0.03 per cent carbon dioxide, soils — as a result of their dense vegetation — commonly have CO_2 contents of 1 to 10 per cent. The amount of soil CO_2 depends on the activity of biological processes in the soil mantle, which makes infiltrating rainwater much more aggressive under the abundant vegetation of the tropics than in the temperate or polar belts. This is the reason why the dissolution of limestone is quicker under a soil cover. D. Balázs (1969) conducted laboratory experiments and L. Jakucs (1971, 1977) made field measurements to test the above statement.

L. Jakucs and D. Balázs also contributed to solving the contradiction mentioned in this introduction. The poverty of tropical rivers in dissolved $CaCO_3$ is explained by the fact that only the amount of $Ca(HCO_3)_2$ in equilibrium with the atmospheric carbon dioxide at that temperature can be retained in water, and the excess of $CaCO_3$ dissolved in karst groundwater is precipitated in caves or at springs. This precipitation is limited in the case of polar karsts.

The rate of denudation is also influenced by the amount of precipitation, which is greatest in the tropical belt. Consequently — although the $CaCO_3$ contents of rivers are lower — the amount of $CaCO_3$ transported during unit time is larger.

Top: A bat-mother with her baby (by Cs. Forrásy)

Bottom left: Lapiés near Aggtelek (by P. Borzsák)

Above it: Typical plant of the lapiés: Potentilla arenaria (by E. Siklósi)

Bottom right: Karst water tracing, Aggtelek Karst (by G. Salamon)

Recognising the role of vegetation in karstification, Jakucs arrived at a novel and surprising statement: forest clearance and the destruction of vegetation cover (involving sooner or later the erosion of the soil mantle) do not promote, but instead reduce, the rate of karstification. (It should be noted that this observation was made as early as the fifties by H. Kessler in connection with the investigation of karst waters in Albania and his report attracted much attention in professional circles.)

The selective karst corrosion of dolomite

Much of the dolomite which occurs in Hungary — particularly along structural lines — is heavily disintegrated and altered to dolomite flour. This weathering cannot be explained by sub-aerial mechanical processes, since the disintegrated rock remained in situ and preserved its original stratification and bedding. The phenomenon is due to the impact of hot waters ascending along faults *(Pálffy M. 1920; Scherf E. 1922; Brugger F. 1940; Jakucs L. 1950)* and depositing aragonite (or anhydrite) in the pores of the dolomite. During the cooling of the rock this transformed into calcite (or gypsum) and the increase in volume disintegrated the dolomite into debris.

Jakucs (1971, 1977) also pointed out the process of selective cold water karstification contributing to the weathering of dolomite. His starting point was that dolomitic rocks usually have a surplus amount of $CaCO_3$ compared with the Ca content of chemically pure dolomite. This surplus Ca takes the form of calcite and cements the rhombohedral crystals of mineral dolomite ($CaMg[CO_3]_2$) in the texture of the dolomite rock. During the karstification of this rock the dolomite crystals and the cementing calcite dissolve simultaneously *(Markó, 1961)*, but the degree of solubility is lower for the latter than for the former. This finally leads to mineralogical separation and further to loosening the bonds between the dolomite grains, and the rock weathers in situ. With this concept, *Jakucs* also explained why the usual karst features are not characteristic of impure dolomites: selective karst corrosion is predominant and dolines and lapiés fields only develop in compact, chemically pure dolomites, where the dissolution of dolomite crystals is not preceeded by the selective dissolution of calcite.

The karst corrosion effect of carbon dioxide of metamorphic origin

The chemical analysis of the Buda thermal springs revealed a strange contradiction. The dissolved carbon dioxide content of spring waters was found to be proportional to the temperature of thermal waters. On the other hand — according to now accepted views — ascending hot spring waters originate from the deep circulation and hence warming of cold karst water, which descends in the mountains and flows in convection currents under the Great Hungarian Plain *(Vendel M. and Kisházi P. 1964)*. We would expect the concentration of dissolved CO_2 in the ascending waters to be almost equal or — because of dripstone formation — less than that of infiltrating waters. However, infiltrating waters at 10 °C contain 198 mg per litre CO_2, while in waters at 20 °C, 264 mg per litre is found and in those at 60 °C 466 mg per litre. This paradoxical situation was solved by *P. Müller (1971)*.

The carbonaceous rocks of the Great Plain basement, buried and metamorphosed at depth, release (by the estimation of *P. Müller, 1971)* at least 1 ton CO_2 annually from every square km, and this is dissolved in the water flowing over the basement. The actual amount of CO_2 dissolved depends on the time the waters spend underground. (By C^{14} dating, it is known that the Buda hot springs waters infiltrated into the rock ca 15,000 years B.P. It is to be noted that the C^{14} dating of 15,000 years ago is only correct if the water has not been mixed with other.) But the warming of water is also proportional to the time spent underground, and this explains the ratio of CO_2 contents and temperatures. The basic conclusion on karst corrosion drawn from Müller's argumentation is that limestone solution does not only take place from descending waters near the surface, but may also be by thermal waters of metamorphic origin, which ascend from great depths and become aggressive with CO_2 acquired at depths of over a thousand metres.

As the metamorphism of carbonaceous rocks also takes place in orogenic belts and along the margin of subductive oceanic plates, this process may also be characteristic of other karst regions. This could explain the formation of giant caves (e.g. Hölloch and Dachstein) below the karst water table (in the saturation zone).

Origin of caves

Mixing corrosion theory of cave formation by hot springs

The morphological features of caves in the Buda (and partly in the Pilis) Mountains are fundamentally different from those in sinkhole caves with stream; they have horizontal and vertical labyrinths, blind chimneys reaching up in a dendritic fashion, spherical niches, no net flow direction and a relatively regular trellis pattern of equal-rank passages. The idea of an origin by hot water, to explain some of these features (blind chimneys and spherical niches) originated long ago *(Pávay-Vajna F. 1930; Kessler H. 1936; Jakucs L. 1948)*, but several important properties were not explained (for instance, why ascending thermal waters did not become aggressive). A unified theory for the reason of all cave features was missing for the Buda Mountains. *P. Müller* (1974) undertook to create one.

The CO_2-bearing thermal water flows through densely jointed and faulted dolomite (with a rectangular fissure system) and then emerges through limestones and marl along the Danube bank, at the foot of the Buda Mountains. The narrow fractures of the dolomite only allow percolation flow. The flow extends over a large area, but the resulting depression in the permeable rock directs it towards springs. Thus, in the vicinity of springs (from the fractures in the limestone overlying the dolomite) waters converge from various sources, with various temperatures and chemical compositions (CO^{2} contents). It has been proved that through the mixing of such solutions the water becomes aggressive (or more aggressive if unsaturated waters mix). Since a karstified rock is highly permeable, the cold karst water percolating downwards from the surface may reach great depths, and mixing with warm water may occur in an extended vertical zone. Consequently, thermal spring caves form through temperature mixing and concentration mixing corrosion along the tectonic fissures.

The theory explains why thermal caves are associated with recent or fossil springs and why they have large vertical extent. The model also accounts for the other morphological features in the thermal caves of Hungary *(Müller P. 1974)*. Müller's theory was supported by measurements in a presently developing underwater spring cave labyrinth, the Molnár János Cave.

A model of shaft or pothole formation purely by corrosion

Karstic shafts, as studied in Hungary, show certain distinctive characteristics, but their explanation in a single comprehensive theory has been lacking for long and even today there is no universally accepted answer to many questions. Shaft or potholes (term used in England) are vertical caves, but most of them are independent of passable horizontal stream caves, according to the examples of Alsó-hegy (North Hungary). At present they do not function as ponors and their positions do not indicate earlier ponor or sinkhole functions. They reach down to several hundred metres' depths, and they consist of a chain of offset shafts connected by narrow passages and broadening downwards. Their entrance is mostly found in a ponor, but in the side and not on the bottom of the doline.

Previous theories say that shafts (potholes) are secondary karst features and their origin was ascribed to upward extension from the ceiling of horizontal caves *(Cholnoky J. 1916; Kessler H. 1933)*. These models, however, only explained the downward widening of shafts, but did not account for their other properties. Although *Jakucs (1971, 1977)* first raised the idea of shaft (pothole) formation as an independent, primary karst corrosion phenomenon, the first unified theory without contradictions and considering all the features of shafts is associated with *I. Sárváry* and *P. Müller (1970)*. They supplied evidence that shafts form simultaneously with dolines and make genetic units with them. Their theory identifies the following stages in shaft development *(Fig. 1)*.

1. Karstification begins over the exposed limestone surface, and embrionic dolines emerge. The solution of rock is confined to a shallow zone some metres below the surface, since waters become saturated at greater depths.

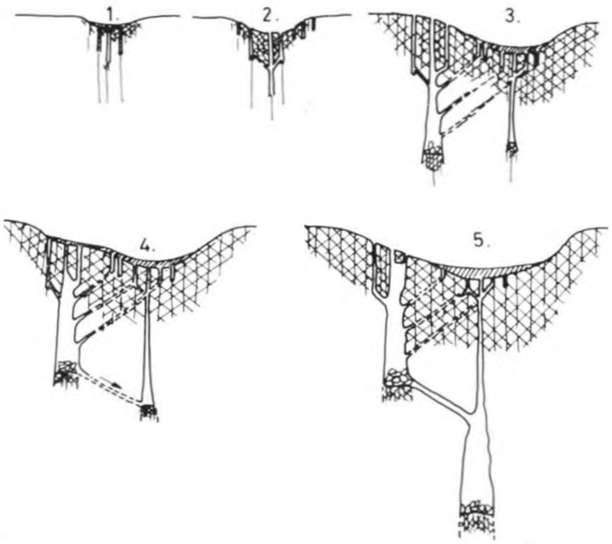


Fig. 1 Stages in shaft formation by Sárváry (1970)

At places where there are fractures at least a millimetre wide in the rock, water sinks rapidly (without causing solution) and the corrosion effect is located at the bottom of the crack. The fissure with low hydraulic resistance produces a hydraulic cone of depression around itself, and drains the percolation water in the nearby capillary fractures into the larger fissure. Water flow in the fissure, therefore, increases and the mixing of waters of various concentration makes it more aggressive. As a consequence the solution zone is lowered in the area around the fissure.

2. This process starts at several points in the doline and the fissures deepen at various rates. At any one time, the deepest fissure drains, through the depression created, the other downward reaching openings. Thus the mixing-corrosion mechanism outlined under 1. and the increases in flow go on at an ever increasing speed.

The rate of shaft widening suddenly increases when the depth limit is reached at which ascending air cannot warm up the rock and melt the snow of the shaft. This way the amount of water necessary for corrosion is available all through the year.

3. Since the hydraulic cone of depression of the embrionic shaft exerts a draining effect in its surroundings, the deepening of the doline slows down at this point. As a consequence, the deepest point of the doline shifts away from the shaft. At the new deepest point a new shaft begins to form.

The new shaft will naturally be narrower than the previously developed, but it deepens at a greater rate, since the bottom of the doline receives more water than the old channels now in the side of the doline. On the other hand a similar amount of solution causes larger growth at depth.

4. The base of the new shaft sooner or later becomes deeper than the old one, and creates a cone of depression that drains its water. At this point the

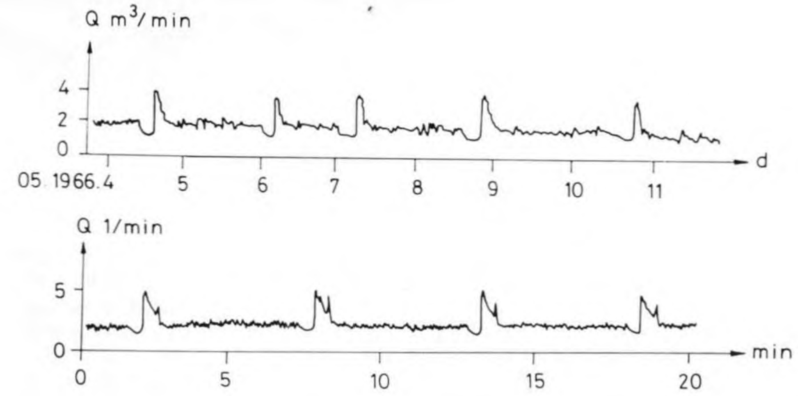


Fig. 2 Original hydrograph for the Lófej Spring of Jósvafő and the changes of flow recorded in the hydraulic pipe model

further deepening of the original shaft slows down and then stops, and its water contributes to the widening of the young shaft. The increased flow of water, and renewed aggressivity by mixing, leads to the formation of a wider and more rapidly deepening shaft.

5. At the bottom of the old shaft, now inactive, with respect to corrosion, debris can accumulate and block access between the shafts for people, but it presents no obstacle to water flow. (The more complex explored shafts are characterised by narrow passages connecting the shafts, and this supports the theory.)

Sárváry and *Müller* have confirmed their theory with examples taken from reality, and also with numerical estimation of the rate of corrosion.

Hydrological processes effecting caves

Experimental simulation of karstic sinks

In the vicinity of Jósvafő there are numerous extraordinary karst springs (with caves), some of which show regular fluctuations of flow independent of precipitation *(Fig. 2)*. This fluctuation (often known as ebb-and-flow) is most striking at the Lófej Spring, where minimum flows (during drought) are 50 litres per minute, but during surges rise to 5,000 litres per minute. (The surges of the nearby Nagytohonya Spring also have outputs up to 5,000 litres per minute.) It is also characteristic of the Lófej Spring that between surges, occurring very often at 12, 24 and 48 hour intervals, a flow pulsing of 150 litres per minute and 0.5—2.0 hour period is observed, and its period is reduced before surges. The surge is immediately preceeded by a state of constant water flow, without pulsing, lasting for 5 to 6 hours *(Fig. 2)*.

The reason for this unusual regime was revealed by *L. Maucha (1967)*, who assumed that this fluctuation in flow is related to the activity of a complex system of sinks. (The idea of the existence of karstic sinks was first raised by *Anker (1962)*, the first evidence was provided by the investigations of *Maucha.)*

Maucha used an electric analogue to show that the system of Lófej Spring consists of two large sinks (A and B) and a small sink connected in parallel (C) *(Fig. 3)*.

Fig. 3 shows that the overflow level of A lies higher than that of B. Sink C connects with sink A through a narrow section and its overflow level is somewhat below that of sink A.

The activity of the triple sink system can be summarised as follows. The water-course feeding the system recharges simultaneously sinks C and A. When water level reaches the overflow height of C, the downsurging water in the descending branch of the sink creates a vacuum in C and drains its total water content (about 30 m³). This water induces some pulsing in the spring flow (the small amplitude section in *Fig. 2)*.

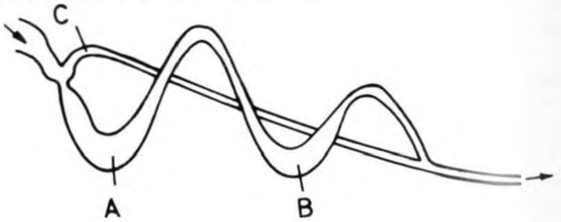
When sink A is full the water overflows into sink B (about 300 m³); in the meantime pulsing stops as the suction effect emerges at the bottom of sink C. During this period there is only base-flow from the spring, since the flow is consumed to recharge reservoir B (about 270 m³ — see the minimum section before surges in *Fig. 2)*. When B is being emptied about 500 m³ water leaves through the spring and this represents the surge itself (surge section in *Fig. 2)*.

Then the process begins again from the initial stage. This intricate hydraulic mechanism was simulated in the laboratory by Maucha and the correspondence with the hydrograph of the spring was good *(Fig. 2)*.

Fluctuation in joints and the tidal oscillation of karst water table

The periodicity of both the Lófej and Nagytohonya Spring surges shows a similarity to the tidal motion of the seas. It seems that the surplus water which overflowed sink A (and triggered the surge) is related to the tidal fluctuations of the gravity field

Fig. 3 A theoretical sketch of the sink system of the Lófej Spring (Maucha, 1976)



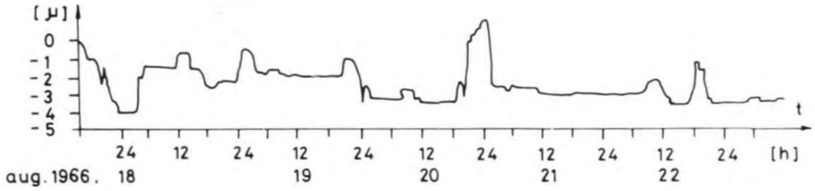


Fig. 4 Tidal changes in the size of a fissure in the Vass Imre Cave

of the Earth induced by the Moon and the Sun. To settle this problem, *Maucha*, with the assistance of *Gádoros* and *Sárváry (1966, 1968, 1971)* conducted precise measurements in the Vass Imre Cave.

The results showed that the rise of the Earth surface during terrestrial high tide (involving growth of this section of the Earth's perimeter) induces horizontal stretch tension in the crust. This results in the considerable widening of vertical north-south joints (the average expansion is 0.5×10^{-3} mm, but in extreme cases the figure may reach $2—5\times10^{-3}$ mm); during low tide, joints rebound into their narrow positions *(Fig. 4)*.

Since karst water is located in the fissures and the caves of the limestone, the periodical changes of the fissure volume necessarily involve the rising and lowering of the karst water table. The average range of fluctuation is 10 cm (exceptionally around half a metre) and this induces minor floods on cave streams. This small flood wave can be observed on the hydrograph of the Little Tohonya Spring which has no feeder sinks. On the other hand, this fluctuation may trigger changes in the sink systems, and so induce surges of several hundreds of cubic metres.

Maucha proved that the extreme values of tidal rock motion coincide with earthquakes and with large-scale and rapid changes in atmospheric pressure, when permanent deformations of 10^{-3} mm dimension are generated in the rock.

Cave formations

Dripstone discoloration and surface morphology

In the Baradla Cave and particularly in the Béke Cave, which is free from sooting by old lamps, researchers observed that the distribution of dripstones of various colour is uneven along the passages. In order to determine any regularity of this distribution *L. Jakucs (1961)* analysed 14,335 dripstones and found that the nature of discoloration is closely related to the surface morphology and the vegetation above the cave.

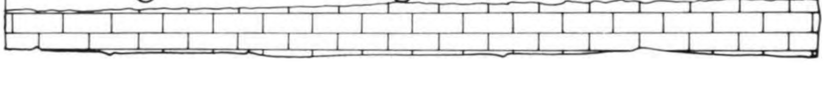
His observations indicate that in cave sections where the overlying terrain is of low relief (and parallel with the horizontal cave with stream) dripstones develop slowly to relatively small size, with uniform colour, and with only slightly contaminated material. Contrasted with these, there are sections where the cave runs under the sides of a doline, and large, inhomogeneously coloured and chemically heavily contaminated dripstones are found. In these latter dripstones, zones of various colour alternate in a concentric pattern. This phenomenon can only be observed under doline sides with less than 8—10 degrees slope. Underground with steeper gradients the amount of inhomogeneous dripstone does not increase within the cave. Under the central parts of dolines, however, dripstones are fewer and smaller, and, in parallel, the proportion of red dripstones increases greatly *(Fig. 5)*

This relationship between surface morphology and dripstone colour is explained by differences in jointing. Under dolines the rock is more densley jointed than below flat terrains which are less affected by superficial karstification. On the sides of dolines the soil mantle is also shallower, or entirely missing. For these reasons, infiltration is faster over these spots and — lacking the filtering effect of soils — the chemical composition of the water reaching the cave shows more serious contamination. The final consequence is the faster growth of more colourful dripstones.

Doline floors are usually sealed by red clay (terra rossa), which hinders infiltration. Therefore, in cave passages below dolines dripstones develop in smaller numbers and to smaller size. At the same time the terra rossa functions as a filter, removing contamination (colouring materials) from rainwater, but — due to its own iron content — stalactites are stained red.

Jakucs (1971, 1977) recognised that in areas where forest clearances took place within the last hundred years (the longest period for which data are available) or where the vegetation was removed from the surface, dripstone formation came to a halt and stalactites received a red coating. After the reintroduction of vegetation, dripstones began to develop pure layers again, devoid of chemical contamination. Consequently the changes in the colour of consecutive concentric layers of dripstones provide evidence for landscape changes above the cave — even back over several millennia.

Fig. 5 Colour and size of dripstone deposits and the relationship with surface morphology above the cave. I: flat terrain; II: doline side; III: doline floor; 1: pure and homogeneous dripstone; 2: inhomogeneous, large dripstone; 3: red dripstone



Theory for the origin of certain types of helictite

Previously they were thought to be rare, but subsequently clustered or isolated helictites have been found in many caves. Their peculiar forms and crystal structures attracted the attention of mineralogists, and various hypotheses were set up to explain the mechanism of their formation. *F. Cser (1967)* and *L. Maucha (1968)* evaluated the proposed explanations, and made mathematical and physical calculations to test them, and arrived at the conclusion that most of the models are burdened with contradictions. They also indicated that study on the minerals in caves could be worthwhile. In particular, their theory on crystals precipitating from the cave air is a novel one.

As shown by the physical-chemical investigations of *Cser*, helictite formation depends on drops of water containing dissolved $Ca(HCO_3)_2$ falling from the cave ceiling. They splash as they impact on the floor or on a stalagmite and the resulting microscopic droplets — due to their small size and friction with the air as described in Stokes' law — remain suspended in the air for a long time as an aerosol. Meanwhile, the water of the droplets partly evaporates, since relative humidity in the cave is always less than 100 per cent. Evaporation results in loss of volume and increased concentration of $Ca(HCO_3)_2$. According to the law of reducing tensions, increased concentration makes the vapour pressure, corresponding to the state of saturation, decrease, and consequently the evaporation of the water (as the solvent) stops, even at a relative humidity less than 100 per cent (the same physico-chemical effect is responsible for the rise of boiling-point in solutions). Consequently drops of water of 10^{-2} to 10^{-4} mm diameter, supersaturated with dissolved calcium bicarbonate and incapable of evaporation are suspended in the cave air.

If such a drop hits the cave wall, crystallisation from the supersaturated solution immediately begins. However, attention should be paid to the situations where splashing droplets are charged with electricity (as proved in the Millikan experiment). If a charged droplet passes a pointed formation, the electric peak effect produces opposite charges on the drop, and the formation attracts the water droplet to itself. As a consequence, the surplus calcium carbonate of the supersaturated water droplet precipitates on the pointed protrusion of the cave wall. The apex of the rhombohedron of the new calcite crystal would trigger further crystallisation.

This theory (also confirmed from the results of experiments) explain the observation that pointed helictites are single calcite (or twinned crystals) and that there is no relationship between their crystallographic axes and the shape of helictites.

In a very demonstative way, *Cser* drew parallel between ice and calcite crystals. Dripstones form in a manner similar to icicles, while helictite formation is analogous to hoar-frost accumulation.

Dr. Gábor SZUNYOGH
mining engineer
Central Institute
for Mining Development
Beloiannisz utca 9.
H–1054

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BRIEF INFORMATIONS

CAVE CONSERVATION IN HUNGARY

Kinga Székely

Introduction

The problem of the protection of cave formations has been occurring ever more frequently since early last century. However, the demand for the legislative settlement of cave protection only became articulated with the advent of regular cave exploration and research in this century.

The first draft for a cave protection act was outlined by the Hungarian Speleological Society, under the guidance of Ottokár Kadić in 1929 and introduced to the then authority, the Ministry of Land Cultivation. The draft consisted of 5 chapters and 20 sections with provisions on the (state) ownership, research (restricted to the Speleological Institute and its comissionees), guarding, utilization, management and protection (only for caves of particular value) of caves, the punishment of violations of the act, and on the establishment of a Speleological Institute. It is regrettable that the draft was lost in the maze of ministerial bureaucracy and never came into force.

Another great initiator of cave protection was Károly Kaán, father of Hungarian nature conservancy. Commissioned by the Hungarian Academy of Sciences he prepared a treatise entitled 'Nature conservancy and natural monuments' in which he presented the natural monuments worth protection and proposed a nature conservation act. Of the more than 300-page volume, published in 1931, 42 pages are devoted to the description of the 32 major caves known at that time.

The first decree on cave protection was the Forest Act of 1935, which included nature conservation tasks under heading six. It states that caves of unique character and scientific value as well as their surface catchments, if the need arises, can be put under protection; the exploration of a cave must be reported to the Ministry of Land Cultivation and for cave exploration permission is needed from the Ministry.

The first cave (the Baradla-Domica) was declared protected in 1940. Up to 1961 21 decrees were made to extend protection to 34 caves.

The first independent nature conservation act came into force in 1961 and its novelty lay in the fact that it stated that all caves were under protection in Hungary.

Valid legislation on nature conservation

The tasks and activities concerning caves are regulated by the nature conservation law decree of 4/1982 and the government decrees nos 8/1982 and 58/1986 and the statutes issued by the Minister of the Environment and Water Management.

A cave is legally defined as 'a natural cave in the rocks of the Earth's crust which has a longitudinal

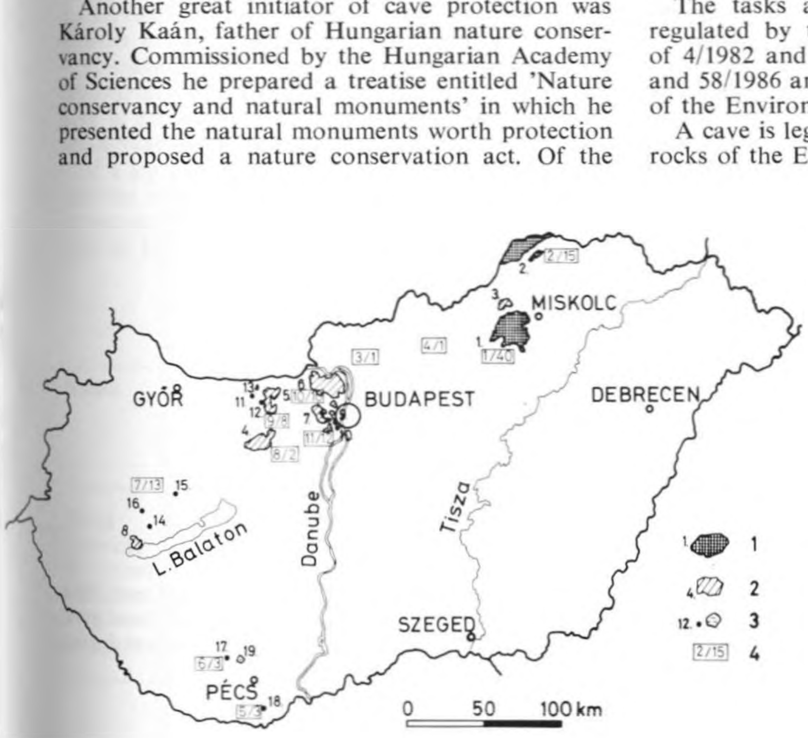

Fig. 1. Protected karst areas and increased protected caves in Hungary

1. National Park: 1. Bükk, 2. Aggtelek
2. Landscape Protection Area: 3. Lázbérc, 4. Vértes, 5. Gerecse, 6. Pilis, 7. Buda, 8. Keszthely
3. Nature Conservation Area: 9. Surface of Pál-völgy Cave 10. Surface of Szemlőhegy Cave, 11. Tata, Kálvária Hill, 12. Vértesszőlős, settling of prehistoric man, 13. Dunaalmás quarries, 14. Surface of Tapolcai-tavas Cave, 15. Úrkút paleokarst, 16. Darvas Lake (Nyirád paleokarst), 17. Surface of Abaliget Cave, 18. Szársomlyó Hill, 19. Melegmány Valley
4. Increased protected Cave (mountain/cave's number) 1/40 = Bükk, 2/15 = Aggtelek, 3/1 = Cserhát, 4/1 = Mátra, 5/3 = Villány, 6/3 = Mecsek, 7/13 = Bakony, 8/2 = Vértes, 9/8 = Gerecse, 10/10 = Pilis, 11/12 = Buda

axis exceeding 2 m and whose dimensions allow human entry. All caves are of national value, if it is necessary, the surface area of the cave can also be declared protected; by its scientific value, economic importance or endangered position a cave and its surface area can be placed under strict protection by the Minister of Environmen and Water Management. (In Hungary there are 108 caves under protection at present).

If the maintenance of protection is not in the interest of nature conservation or conflicts with an economic interest, this (strict) protection can be lifted by the Minister. The discovery of a new cave or the exploration of a new cave section must be reported to the nature conservation authority within eight days. A cave can be declared a medicinal cave jointly by the Minister of Health and the Minister of the Environment and Water Management. A permit from the area nature conservation authority is necessary for research, experimentation, collection, diving in caves and for visits to caves not open to the public (that is a non-touristic or closed cave, or a cave in a closed protectiv zone where entrance is prohibited by sign). Those having permission to explore caves have to report their activities annually. Permission from the Ministry is necessary for closing, developing, utilizing caves, removing, utilizing, evaluating and exporting cave formations.

Organisation of nature conservation

The protection, management, utilization and other tasks prescribed in the Act are the responsibility of two national parks, the Aggtelek and the Bükk National Parks, to the east of the Danube and five Environmental Protection and Water Management authorities (seated in Budapest, Győr, Szombathely, Székesfehérvár and Pécs) west of the Danube.

The professional management and control of the national parks and the tasks of the second-rank authority, in addition to those included in the decrees, are performed by the Ministry or its Speleological Institute.

Other regulation

Cave protection is also promoted by a series of other legal documents. The Water Management Act regulates water colouring, diversion, sampling and abstraction. The act on the protection of museum finds states that when (paleontological or archaeological) finds are recovered work in the cave must be stopped and the finds given over to the museum.

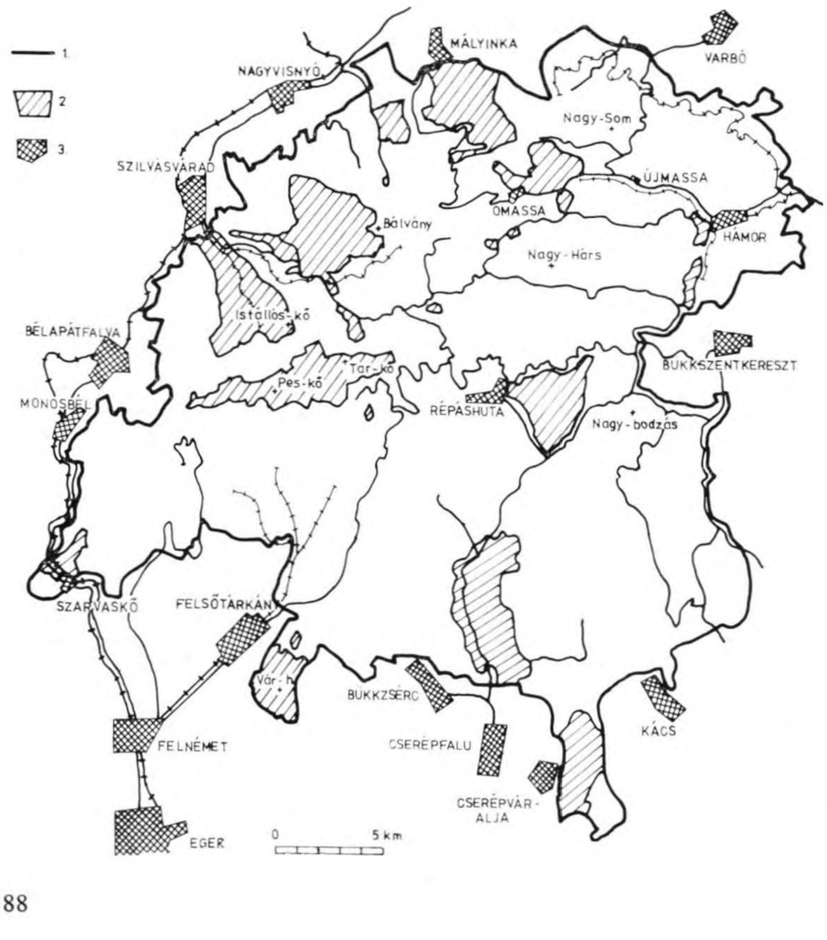

Fig. 2. Bükk National Park.
1. Boundary of national park,
2. Increased protected area,
3. Settlement

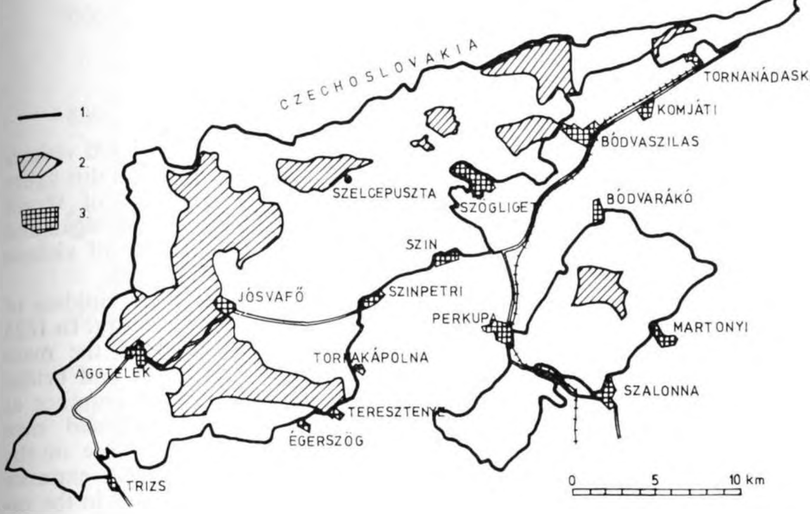

Fig. 3. Aggtelek National Park, 1. Boundary of national park. 2. Increased protected area 3. Settlement

The work can only be resumed with the permission of the museum.

Cave protection is promoted indirectly by the declaration of certain animal species (strictly) protected. All bat species enjoy protection in Hungary and their theoretical value ranges from 1,000 to 3,000 forint. Their disturbance, capture or destruction is punished by law.

Sanctions in nature conservation

Exploration, utilization and transformation of caves without permission, the neglect of the duty to report, and destroying cave formations are an offence and involve fines of up to 10,000 forint.

If these activities lead to large-scale demage or destruction of the cave, then the action is a crime and is punishable by a prison sentance of one to three years duration.

If a legal entity or an organisation carries out an activity in a cave which leads to damage, a nature conservation fine has to be paid with a maximum rate of 100,000 forint per 100 m^2 affected.

Landscape Protections Areas including karstic surfaces

Name	*Year of foundation*	*Area (hectare)*	*Strictly protected area (hectare)*
Buda	1978	10,234.0	1674.5
Gerecse	1977	8,617.4	417.2
Keszthely	84	2,711.0	—
Lázbérc	1975, 1986	3,634.0	—
Pilis	1978	23,322.8	6183.3
Vértes	1976	13,722.6	1035.9

Nature Conservation Areas on karstic surfaces

Name	*Year of foundation*	*Area (hectare)*
Dunaalmás quarries	1977	230.1
Surface of Abaliget Cave	1941	1.0
Darvas Lake (Nyirád paleokarst)	1971	34.0
Melegmány Valley	1957	709.0
Surface of Pál-völgy Cave	1944	1.0
Sas Hill	1958	30.0
Vértesszőlős, settling of prehistoric mean	1976	38.4
Tata, Kálvária Hill	1958	26.0
Szársomlyó Hill	1944	125.0
Surface of Szemlő-hegy Cave	1957	0.5
Surface of Tapolcai-tavas Cave	1942	3.0
Úrkút paleokarst	1951	6.0

Kinga SZÉKELY
geographer
Institute of Speleology
Budapest
Füst Milán út 12.
H—1039

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CAVE TOURISM IN HUNGARY

Tamás Hazslinszky

On the territory of pre-Trianon Hungary (before 1920) therewere known only two caves visited regularly since the 18th century. This cannot be called tourism in the present sense of the word, but the services of local guides were offered.

One of them, the *Deményfalva Cave* (today: Demänovská l'adová jaskyňa) was primarily visited for the abundant bear bones, regarded to have medicinal power ('dragon bones'). The so-called 'Visitors' book', a wall section with dense inscriptions, attests to frequent visits. The long section of this cave was mapped, first among the caves of Hungary, by György Buchholtz jun. in 1719. Visiting became organised in the 1880s using oil lamps.

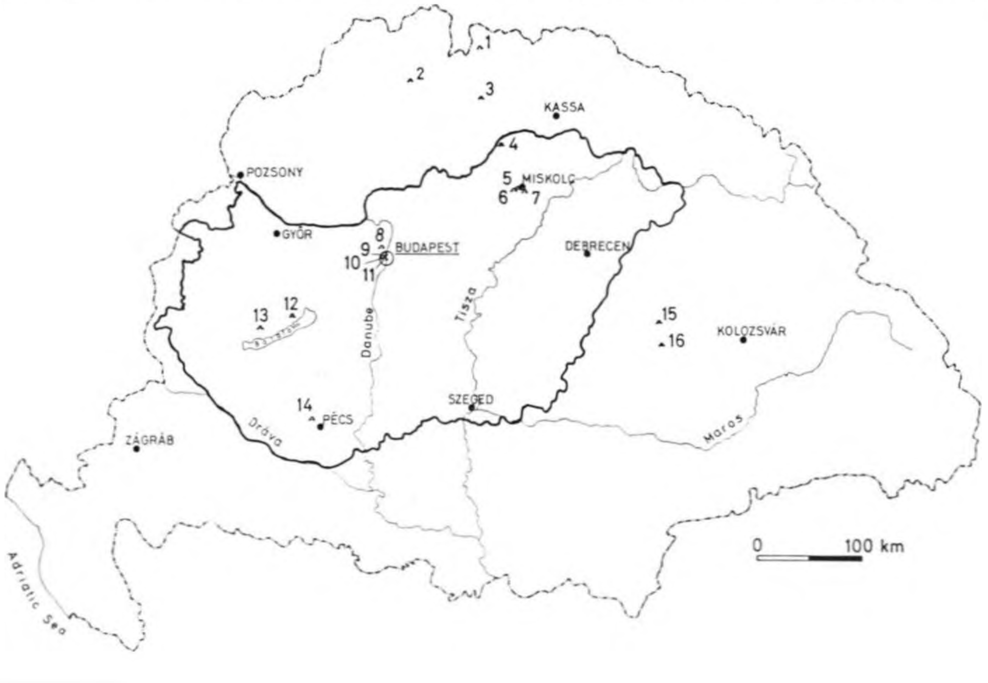
Visits to the *Baradla Cave* can also be reconstructed from wall and ceiling inscriptions at the old terminal points. The first written document on the commercialisation of the dates to 1806: before the visit of Palatine Joseph "the cave was enlarged at the entrance and along its whole length illuminated by candles...".

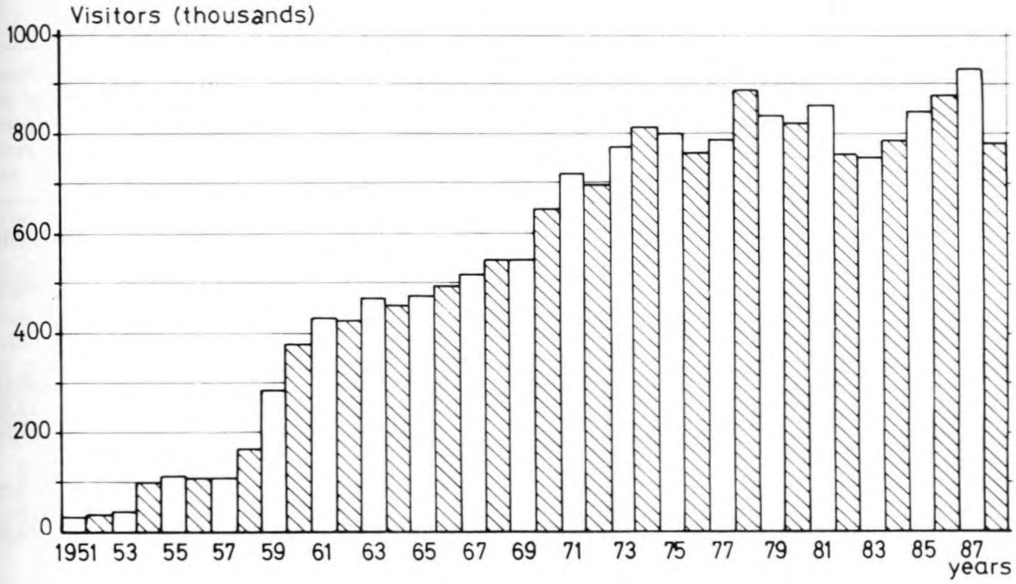
The most valuable documents from the last century concerning cave visits are the two preserved visitors' books (1835—1897). The first rules for cave conservation and visiting, with entrance fees, were listed in the visitors' book dated 1839. At that time the annual number of visitors was 200 on average. Numbers rose slowly to 500—700 people by the end of the century and to 1,300—1,400 visitors early this century. With some fluctuation this figure reached 6,000 people by the outbreak of World War II. In post-war years a major boom began and during the last 40 years the number of visitors amounted to 200 to 240 thousand people.

The exploration of the cave and the building of facilities also dates back to the last century. In 1825 Imre Vass discovered a large part of the main branch. Between 1880 and 1890 path and bridge construction took place, the artificial entrance at Vörös Lake was built and this allowed cave touring without following the same route on the way back. In 1927 the Jóafősv artificial entrance was built and ui 1935 reflectors were lit in the cave. After World War II modernisation work was untertaken on several occasions and a new exit was built at Aggtelek allowing a circular tour of the cave-

The first natural caverns of the Lillafüred *Anna Cave* were discovered in 1833, when a 94 m long horizontal drift was made into the tufa hill accumulated by the Szinva and Garadna streams. No document was preserved about cave facilities, but it is probable that soon afterwards visits to the 'cave of dripping stones' began. In a preserved diary a cave visit planned for July 5th, 1839, is mentioned, but it was not implemented because of high water.

Geographical distributions of the tourist caves in the pre-Trianon Hungary and on the present territory of country. 1 = Béla Cave (Belanská jaskyňa), 2 = Deményfalvi Cave (Demänovská l'adová jaskyňa), 3 = Dobsina Ice Cave (Dobsinska l'adová jaskyňa), 4 = Baradla Cave, 5 = Anna Cave, 6 = Szent István (Saint Stephen) Cave, 7 = Miskolctapolca Cave, 8 = Solymári-ördöglyuk Cave, 9 = Szemlő-hegy Cave, 10 = Pál-völgy Cave, 11 = Budai Vár (Castle Hill) Cave, 12 = Lóczy Cave, 13 = Tapolcai-tavas Cave, 14 = Abaliget Cave, 15 = Zichy Cave (Peştera de la Vadu Crişului), 16 = Meziád Cave (Peştera Meziad)





Attendance at the Hungarian tourist caves in the past four decades

The great Hungarian poet, Sándor Petőfi, on the occasion of his visit to the cave on July 8th, 1847, wrote: "...Nature also placed a cave into the valley, a dripping cave. It may be trivial compared with the Aggtelek one, but — as people walk in it with candles only instead of torches — it is much clearer and brighter than the Aggtelek Cave and this way splendour is somehow made up for." In the 1890s the cave was already forgotten and only sporadically mentioned in literature. Only in the 1920s, when the construction of the Hotel Palace began did the cave come again into the fore, new cave chambers were explored, the present passages were opened and the cave was supplied with electric illumination. Except for interruptions after the war and during restoration works, the cave has been continually visited ever since.

The *Dobsina ice cave* (today: Dobšinska l'adová jaskyňa) was discovered by Jenő Ruffinyi and his companions in 1870. It was opened to visitors as early as 1878 and soon gained fame in Europe as indicated by the 2,500—3,500 visitors, who came to see it in one year, as well as having the largest number published cave postcards, including colour ones, prior to World War I.

The *Béla Cave* (today: Belanská jaskyňa) was probably known by prospectors, who left their names on the walls of the cave, in the 18th century. The forgotten cavern was rediscovered in 1881. Soon visiting began and in 1883 a detailed guide was published about the cave. In the last century — when touring the cave took a whole day — visitors numbered 1,000 to 1,500 annually. Around 1910 the currently used 1,800 m circular path was built and the tour along it took two hours then.

As early as 1768 local people had descended the whole length of the *Abaliget Cave*, but as it had a narrow entrance only rarely ventured to enter it. In 1820 Bailiff Vince Kölesi described it in detail and published a map of it. Financed by public donation, at the initiation of Reverend János Chalupni, the cave entrance was broadened, paths, steps and bridges were built and visits began. The cave was left without an owner after World War II. Modern facilities, including electric lighting, were installed in 1957.

Among the numerous caves of the karst region of the Transylvanian Mountains, the impressive entrance of the *Meziád Cave* (today: Peştera Meziad) had been open since time immemorial. It was first explored by Adolf Schmidl of Vienna for 1,150 m in 1859—60 and he provided a description and sketch map of this section. Between 1880 and 1890 Gyula Czárán, the great explorer of the Bihar Mountains, began to develop the cave, levelling the surface and removing large boulders, before he presented the cave in his tourist guide published in 1903. Because of poor accessibility, visitors came only in limited numbers.

The spring mouth of the *Zichy Cave* (today: Peştera de la Vadu Crişului), reaching the Rapid Körös through a waterfall was opened by explosives. Gyula Czárán together with Károly Handl and István Veress explored the first sections, but then primarily Handl advanced to the first syphon lake. The local landowner, Count Ödön Zichy, also supported the cause and built a tourist cottage next to the entrance at his own expense. In 1905 the cave was made passable and opened for tourism. In the same year Czárán published a brochure presenting

Show caves of the recent Hungarian area

Name of the cave	*Year(s) of the discoveries*	*Year of the opening for tourism and moderniza-tion*	*Year of the electrical installation*	*Commercial operation*	*Length of touristic way*	*Duration of touristic visit*	*Number of visitors (present) person/year*
Abaliget	1768	1884, 1957	1957	1884—1944, 1957	500	1 hr.	100,000
Anna	1833, 1927	ca. 1834, 1926—27, 1985	1927	ca. 1834,— ca. 1890, 1929—	200	30 min.	40,000
Baradla							
Aggtelek tour	?		1935	ca. 1806—	2,000	1.5 hrs.	190,000
Jósvafő tour	1922	1927	1935	1928—	1,500	1 hr.	13,000
Vöröstó tour	1825	1966	1966	1890—1928, 1966	2,000	1.5 hrs.	37,000
long tour[1]	1825, 1922		—	1927	7,000	5 hrs.	700
special tour[1]	1932		—	19	9,000	8 hrs.	
Buda Castle	?	1935, 1938, 1961, 1984	1935	1935—44, 1961—75 1984—	350	30 min.	90,000
Diósgyőr-tapolca[2]	?	1974	1974	1974—	—	—	5,000
Lóczy	1882	1934	1969	1934—45, 1969—	120	20 min.	12,000
Mátyás-hegy[1]	1948	—	—	1987—		ca 3 hrs.	200
Miskolctapolca-Lake[3]	?	1959, 1969—70	1959	1959—	80	max. 2 hrs.	230,000
Pál-völgy special tour[1]	1904, 1980—87	1919, 1964	1927	1919—1944, 1960—1987	400	45 min. ca. 3 hrs.	40,000 200
Solymár[1]	?	1931	—	1931—1944			—
Szemlő-hegy	1930	1974—86	1975, 1986	1986—	300	35 min.	40,000
St. István	~1910, 1927	1931, 1955, 1988	1931, 1955	1931—45, 1954—	300	30 min.	100,000
Tapolcai-tavas	1902, 1961, 1974	1913, 1938	1928	1913—1945, 1950—	340	30 min.	50,000

Remark

[1] with caving equipment
[2] sauna, cold-water basin
[3] cave-bath

the cave. A new stop was established for the cave along the Nagyvárad—Kolozsvár railway.

In 1920, with the territories disannexed by the Treaty of Trianon, Slovakia received the Demény-falva Cave, the Dobsina Ice Cave and the Béla Cave and Rumania the Meziád and the Zichy Caves.

The other tourist caves of Hungary were commercialised after World War I. They include caves such as the Solymár Ördög-lyuk, which for an entrance fee provided minimum facilities and allowed touring in overalls with a guide. This was stopped after World War II. Some years ago, however, this kind of cave touring again came to the fore and overall tours with several hundred participants a year are regular — after previous announcement — along the undeveloped sections of the Pál-völgy Cave in Budapest and in the nearby Mátyás-hegy Cave.

Tamás HAZSLINSZKY
engineer
Institute of Speleology
Budapest
Törökőr utca 68.
H–1145

DATE RECORD ON THE HISTORY OF HUNGARIAN SPELEOLOGICAL RESEARCH

Kinga Székely

In the 1977 Special Issue of "Karszt és Barlang" in the English language, *Dr Károly Bertalan* published a compilation of the important dates of cave exploration including altogether 55 events of international significance. The Hungarian version was extended by the author to 93 events.

The present compilation is based on Bertalan's Hungarian version. The dates of the eminent cave explorers' death and other events which are only interesting to Hungarians were left out. However, some additional data which promote the better understanding of the history of cave exploration in Hungary were included. In the references, Hungary invariably means the territory of the given date.

1037 Date of issue of St. Stephen's donation document for the Benedictine monastery of Bakonybél. It includes the name of Odvaskő, the first Hungarian toponym of speleological implication ever recorded.

1355 Mention of Likaskő in a document. The name refers to the mountain of Kis-Kevély whose cave was inhabited by early man.

1549 Several Hungarian caves are mentioned in G. Werner's 'De admirandis Hungariae aquis hypomonemation' (Basel). The first record of the Aggtelek Cave, although it is incorrectly refered to as Fülek Cave. The mistake was pointed out by Matthias Belius, and in his book published in 1742 the right name appears.

1558 In his work "Epitome Rerum Hungariae" (whose manuscript was written between 1489 and 1491) Ransanus mentions the Drevnyik Ice Cave.

1692 To serve the military operations against the Ottomans, a map is drawn showing the exact location of the Veterani Cave.

1719 At the request of Matthias Belius, György Buchholtz prepares a longitudinal section of the Deményfalva Cave. (According to out current knowledge, it is the first cave profile in Hungary.)

1723—1742 In his Latin works Matthias Belius mentions several caves in the territory of Hungary.

1725 F.E. Brückmann publishes a report on the "Dragon caves" of Liptó county. (The alleged dragon bones found in them were later identified as cave bear remnants.)

1768 József Mattenheim, a miller, discovers today's Abaliget Cave, while penetrating into a spring in the Mecsek Mountains.

1774 Relying on his own experience, Elek Nedetzky describes the Funaca Cave in Transylvania.

1788 A 17 page situations plan is made about the environs of the Veterani Cave, including cave plan, profiles and views.

1793 Robert Townson visits the Baradla Cave. He identifies the remnants recovered from the Deményfalva Cave as bones of Ursus spelaeus. His work was printed in London in 1797.

1794 János Farkas and József Sartory, mining-engineers, explore part of the Baradla Cave. Sartory surveys the cave and makes the first planimetric plan of it, while Farkas prepares its first description in Hungarian. (A copy of the map has survived, but the description manuscript in form is lost.)

1799 Stanislaw Stasić, the father of Polish geology, visits the Baradla Cave and describes it in detail in his book published in Warsaw in 1815. On the appendix geological map the location of the cave is shown.

1801 Keresztély Raisz, an engineer, surveys the Baradla Cave and makes its layout, plan and logitudinal profile together with a German description. The map had several editions, but is was not issued with the text until 1807.

1801 László Bartholomaeidesz explores the Baradla and Büdös-tó (currently: Domica) caves. In his printed work he shows the plans of the two caves in one figure with detailed descriptions and conjectures about their probable connection.

1808 Glinka, a Russian tzarist officer, explores the Baradla Cave and reports on his observations in his book published in Moscow in 1815. The Russian version of Raisz' map is attached.

1819 Vince Kölesy explores, surveys and describes in detail the Abaliget Cave. His work is published the following year in the Tudományos Gyűjtemény (Scientific Collection).

1821—1825 In the company of Imre Vass, Károly Markó, Sr. paints some characteristic details of the Baradla Cave.

1825 Imre Vass, an engineer of Gömör county, discovers the part of the Baradla Cave beyond the Vaskapu (Iron Gate) to the Szinpad (Stage). He resurveys the extended cave and provides a monograph printed in Hungarian and German which includes a cave plan, longitudinal section, and layout map in 1831.

1833 When extending a shaft in Hámor, natural calcareous tufa hollows were exposed and their artificial connection resulted in the present Anna Cave.

1835 George Hering English painter makes pictures in the Baradla

1835 István Fekete, an engineer, explores, surveys, and provides a detailed description of the Homoródalmás Cave. His work is published in Kolozsvár in 1836.

1843 In the preface to the Archives of Vereins für Siebenbürgische Landeskunde the first call for collecting all types of data on Hungarian caves appears.

1846 The first cave animal is caught in the Baradla.

1846 The first scientific presentation of the Tufna Bone Cave is published by Pál Almási Balogh.

1846 János Petényi Salamon conducts excavations in the hollows of the Beremend stone quarry and this marks the beginning of the paleontological research of Hungarian caves.

1854 János Petényi Salamon and János Kovács explore the caves in the Bihar Mountains between the Rapid and Black Körös rivers. This is the first occasion when efforts are made to explore the caves of a large area and to study them in detail.

1856 Adolf Schmidl investigates the Baradla. His description is published in 1857.

1857 Relying on his own exploration experience and available data, Antal Kiss describes the Jászó Cave.

1863 Adolf Schmidl's monograph on the Bihar Mountains and his description of the Abaliget Cave appear in print.

1864 On the basis of his investigations, János Frivaldszky publishes a treatise on the fauna of Hungarian caves.

1868 Flóris Rómer's "Inhabited caves in Hungary" marks the beginning of historical research in to Hungarian caves.

1869 The geologist József Szabó carries out research in the Ágasvár Cave of the Mátra Mountains of non-karstic origin.

1876 Jenő Nyáry undertakes large-scale archaeological excavations in the Baradla Cave. The results are published in an abundantly illustrated book in 1881. Its importance is underlined by the fact that it encouraged Lajos Kossuth to make detailed comments.

1881 Gyula Husz and János Blitz discover the Béla Cave.

1882 In Balatonfüred, during the course of quarrying at the foot of Tamás Hill a cave, which is now named after Lajos Lóczy is discovered.

1884 J. Chalupny, parson of Abaliget, explores the Abaliget Cave and makes it suitable for being visited by tourists.

1886 Searching for a new entrance, Kálmán Münnich resurveys the Baradla Cave and designs the present Vörös-tó entrance to be opened in 1890.

1890 Károly Divald publishes a photoablum of 32 of his photographs taken in the Baradla Cave.

1891 In Miskolc, during house foundation works, stone tools are found and identified by Ottó Herman as belonging to Ice Age man. To settle the resulting debate, Herman proposes excavation in the caves of the Bükk Mountains.

1900 Antal Koch publishes a review on Hungary's fossil vertebrate remnants and localities, including hosts of famous caves.

1900 A monograph on the bats of Hungary is published by Lajos Méhely.

1902 In Tapolca, when digging a well, an entrance to a cave is found and the first chambers of the present Tavas-barlang (Cave with a Lake) are explored.

1904 Pál Kornél Scholtz and János Bagyura reach the Pál-völgy Cave through a hollow in the Pál-völgy quarry and explore the cave to the Theatre Hall.

1906 As proposed by Ottó Herman, Ottokár Kadić begins his largescale excavations in the Szeleta Cave.

1910 At the meeting of the Board of Selected Officers of the Hungarian Geological Society, Lajos Lóczy submits a proposal on the formation of a Commission on Speleology. The Commission first meets on 28th January, under the chairmanship of Károly Siegmeth.

1911 Károly Jordán organised an expedition to explore the shafts of the Alsó-hegy for the Commission of Speleology.

1911 At the International Archaeological Congress in Tübingen Ottokár Kadić convinces the specialists that the Paleolithic artefacts found in the Szeleta Cave are authentic.

1913 The Commission on Speleology of the Hungarian Geological Society becomes an independent section and launches the publication of "Barlangkutatás — Höhlenforschung", a bilingual periodical of its own edited by Ottokár Kadić.

1913 Ottokár Kadić explores a hollow in the wall of the Szent István doline, Bükk Mountains, which is the first section of the István Cave.

1914 Making use of the legacy of Károly Siegmeth, a bibliography of Hungarian caves compiled by Henrik Horusitzky is published. This is the first systemized bibliography of this kind.

1919 The Pál-völgy Cave is made accessible and opened to the public.

1926 Date of founding of an independent Hungarian Speleological Society which includes the members of the Commission on Speleology of the Hungarian Geological Society, cave-exploring tourists and all interested people at large. Besides "Barlangkutatás", the Society institutes a new journal, called "Barlangvilág" (Cave World). (Both periodicals ceased to be published in 1944.)

1926 As part of the building of the Lillafüred Hotel Palace the travertine cave under the hanging gardens is supplied with electric lighting and opened to the public (Anna Cave).

1927 An international meeting of German and Hungarian speleologists is held in Hungary, where renowned Austrian experts also participate. Electricity illuminates the Pál-völgy Cave and the deepest shafts of Alsó-hegy are penetrated.

1929 The Jósvafő exit from the Baradla Cave is completed on the basis of measurements and plan by chief engineer Péter Kaffka. Thus the cave can be traversed over its total length without need of returning to its entrance at Aggtelek.

1930 In the course of levelling the ground on Szemlő Hill in Buda, a cavern, the first section of the present Szemlő-hegy Cave, is found.

1931 Ferenc Pávay-Vajna publishes an article about the caveforming role of hot vapour and gases in the journal "Hidrológiai Közlöny" (Hydrological Bulletin), giving the foundations of the theory of cave origin by thermal water activity.

1932 Hubert Kessler and József Sandrik penetrate from the Aggtelek Cave via the streambed of the underground river Styx. They provide evidence of the existence of passable communication between the two caves.

1932 In Vienna the pioneering monograph by Endre Dudich on the biological investigations in the Aggtelek Cave is published in German.

1932 When building the sewage system along Törökvészi út on the Ferenc Hill, Buda, a cave-in is found and through it the Ferenc-hegy Cave explored.

1935 Part of the "cellar cave" under the Buda Castle (Vár-barlang) and the Cave Museum in the upper cellars are opened to public.

1935 Electric lighting is installed in the Baradla Cave.

1940 The Kecső Cave (i.e. the Baradla-Domica Cave system) and its 10 ha surface area is placed under protection. It is the first protected cave in Hungary.

1944 War damage is inflicted on the office of the Hungarian Speleological Society. Almost all documentation and the library is destroyed.

1946 István Venkovits and László Jakucs discover a cave of thermal origin with gypsum ornamentation at Sátorkőpuszta.

1948 Cave explorers of the BETE sport club explore the Centenary section of the Mátyás-hegy Cave.

1952 László Jakucs and his associates reach the Explorers' branch of the Béke Cave.

1954 Led by László Maucha, the cavers of the Budapest Technical University penetrate into the first section of the Vass Imre Cave and by the use of explosives, open the main passage of the cave on 18th August, 1955.

1954 Dénes Balázs and his associates penetrate into the Szabadság (Liberty) Cave of Égerszög.

1956 The exploratory audit, driven by the staff of the Research Institute of Water Resources Development, reaches the hypothetic system of caverns, subsequently named Kossuth Cave.

1957 Upon the initiative and under the direction of Professor Ferenc Papp a research station is established at Jósvafő, close to the Vass Imre Cave.

1958 The Hungarian Speleological Society, the social base of cave exploration in Hungary, is re-founded.

1959 The periodical "Karszt- és Barlangkutatás" (Karst and Speleological Research) is launched to publish outstanding results from Hungary, mainly in foreign languages.

1959 A cave-bath is opened in the Tavas-barlang of Miskolctapolca.

1959 A sanatorium for the treatment of people suffering from illnesses of respiratory organs is instituted in the Béke Cave of Jósvafő.

1960 A Speleobiological Laboratory is set up in the Róka-lyuk passage of the Baradla Cave, under the direction of Prof. Endre Dudich.

1961 The reorganized Speleological Museum reopens in the Várbarlang.

1961 The first independent Nature Conservation Act is issued. It ensures protection for all of the caves in Hungary.

1961 Led by György Dénes, cavers of the Vörös Meteor Society of Nature-Lovers succeed in penetrating into the Meteor Cave System through the Kisvizes-töbör ponor.

1961 The Hungarian Speleological Society starts a new periodical "Karszt és Barlang" (Karst and Cave), which appears twice a year.

1962 The Society launches awards named after Ottó Herman, Ottokár Kadić and Imre Vass to honour work, research, and exploration of outstanding merit.

1962 A karst water observation station is established by the Research Center in the Iván Cave, in the side of the Gellért-hegy.

1962 The cavers of Miskolc reach the horizontal section of the Létrástető Cave through the Szepesi shaft and explore the then deepest known cave of the country.

1962 The instructions for the Nature Conservation Act come into force and regulate in detail cave conservation and the granting of permissions for cave exploration.

1964 Led by Lajos Gyenge, the cavers of Miskolc penetrate into the István Cave System and explore it to a depth of 245 m.

1964 The Hungarian Post Office issues a stamp showing the Baradla Cave.

1965 The Minister of Health introduces the term "medicinal cave", and the Béke Cave is declared a medicinal cave.

1967 Led by Szabolcs Szeremley, the cavers of Miskolc explore the Szamentu Cave, entering through the Barátságkert ponor.

1971 An expedition organized to continue the exploration of the Vecsembükk Shaft, led by István Szenthe, reaches down to a depth of 235 m, the deepest known point in the cave.

1972 Students of the Tiszaföldvár Grammar School explore the Hajnóczy Cave, Bükk Mountains.

1972 Entering through the spring of the Héviz Lake at a depth of 38 m, István Plózer explores a cave.

1974 A so-called Divers Issue of the "Karszt és Barlang" is published to summaries the history of subaquarian cave exploration and its results.

1974 A Finnish-type sauna is formed in the Diósgyőr—Tapolca Cave.

1975 The National Nature Conservation Office establishes a Speleological Institute.

1975 The Alba Regia Speleological Group explores the Alba Regia Cave.

1975 The cavers of the Bükk Mountains penetrate into the system of the Fekete (Black) and Diabáz Caves.

1976 In Vol. VIII. of the "Karszt és Barlangkutatás", authors and cave indices are supplied for the bibliography of Hungarian speleology, 1931—1945.

1977 On the occasion of the 7th International Speleological Congress a special issue of the "Karszt és Barlang" is published in the English language to summarize the results of Hungarian karst research and cave exploration.

1980 Attila Kiss and József Kurucz explore a new section of the Pál-völgy Cave and additional explorations extend the known length of the cave almost sixfold in just a few years.

1982 The subsiding water table caused by continuous water intake allows the exploration of the Lower Cave of the Baradla along a 1 km length.

1983 Led by Mrs. Zoltán Vidics, cavers of the FTSK sport club cross the siphon of the Danca-lyuk and explore the Danca Cave.

1983 The Hungarian Geographical Museum is opened in Érd, and presents the scientific exploration of major caves in Hungary.

1984 Cavers of the Kinizsi Sport Club of Rózsadomb, led by Péter Adamkó, penetrate into the József-hegy Cave.

1984 An explosion in the limestone quarry of the Szőlő-hegy of Beremend reveals a system of hollows, named after its rich mineral formations, the Beremend Crystal Cave.

1986 After more than 10 years of construction work, the Szemlő-hegy Cave is opened to visitors.

1986 A limitation on housing is imposed in the Rózsadomb area aimed at the preservation of the cave system below.

1986 Author subject, and regional indices are published to the 25-year bibliography of the "Karszt és Barlang".

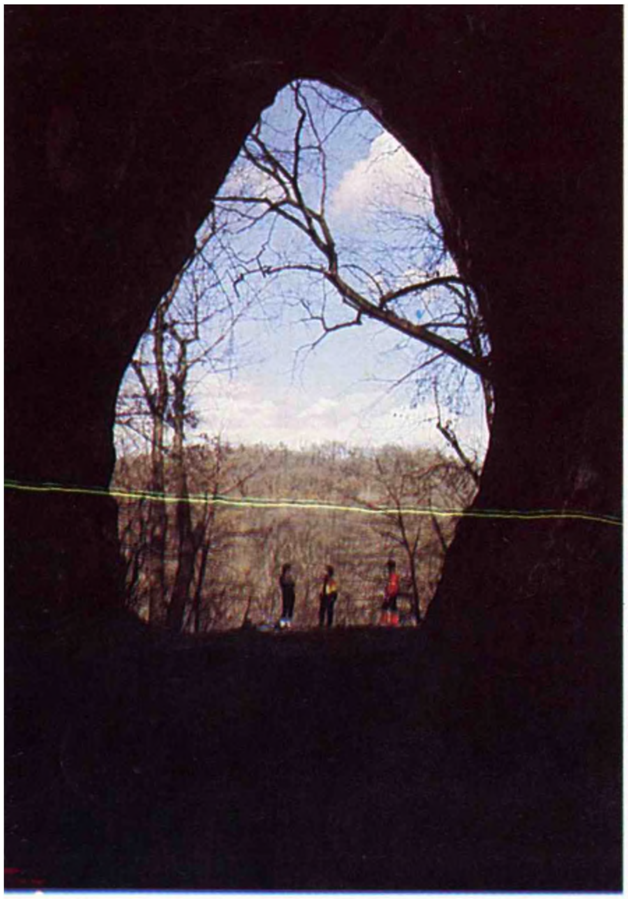
1987 The first course for tourist guides in caves is organised by the Society and the Speleological Institute.

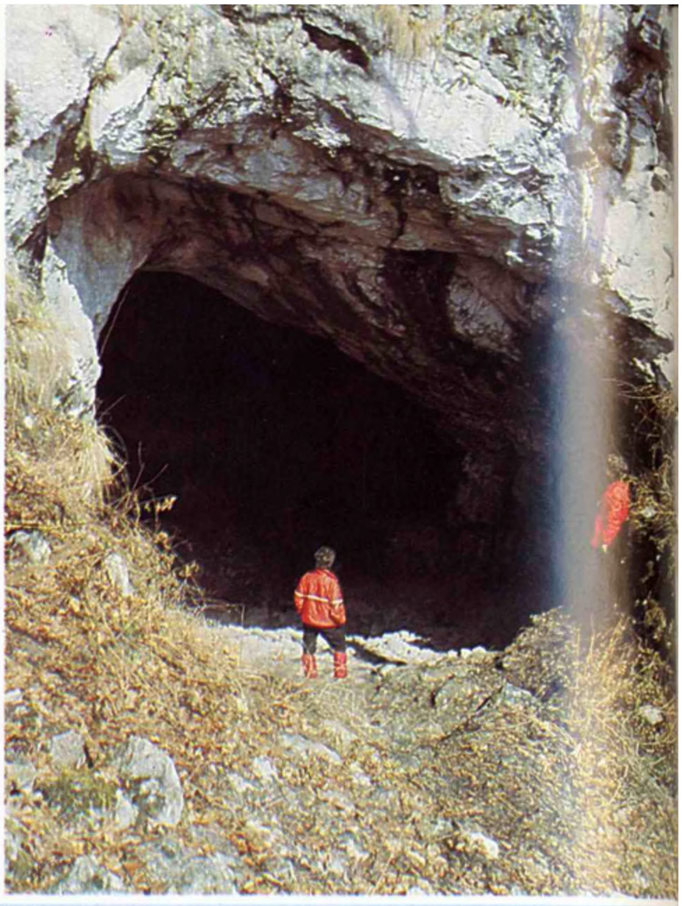
1987 An exhibition entitled "Human evolution in Hungary" is opened in the Hungarian National Museum and the jaws of the Subalyuk Man are presented.

Kinga SZÉKELY
geographer
Institute of Speleology
Budapest
Füst Milán út 12.
H—1039

Top: Patients in the Tapolca Hospital Cave (by L. Szám)

Bottom: Cave rescue training near the entrance of Baradla (by G. Salamon)





THE MOST OUTSTANDING PERSONS OF THE HUNGARIAN SPELEOLOGY

Sándor Hadobás

The mysterious underground caverns of Hungary probably attracted the attention of the early people who lived in the limestone regions but few written documents have survived to our days. With few exceptions, reliable evidence on the exploration of Hungarian caves exists from only the early 19th century. Since that time are known the names of brave men who dared to descend into the cool, dark depths and found – instead of dragons and demons – a colourful world of wonders there.

SARTORY, József (1766–1839), a mining engineer, became memorable in the history of Hungarian cave exploration by preparing the first map of the Baradla Cave of Aggtelek in 1794. According to current information, this is one of the oldest cave maps drawn by an engineer in the world. Unfortunately, the original was not preserved, and the only copy, discovered in 1962, is stored in the National Széchényi Library in Budapest. Originally, a text also accompanied the map (written by SARTORY's friend, János FARKAS), but it was lost.

RAISZ, Keresztély (1766–1849), surveyor of Gömör county, surveyed and studied the then known section of the Aggtelek Cave in 1801. His map and description was published in 1803 and 1807, respectively, in Vienna. His German language work is the first detailed description of the Baradla. However, he was already criticized by his contemporaries for his incorrect interpretation as to the origin of the cave. Raisz emphasized fire as having a primary role in cave formation and this opinion was not consistent with even early 19th century scientific knowledge. The map, with Russian inscriptions, was included in F. N. Glinka's book, published in Moscow in 1815.

VASS, Imre (1795–1863) was a surveyor, successor in office to Keresztély Raisz. In the 1820s he carried out repeated explorations in the Aggtelek Cave in order to find assumed but unknown passages. In 1825 he penetrated the water marking the contemporary terminal point, which was at a low level due to several years of drought. He explored 4.5 km of the main cave passage and performed precise surveying. His results appeared in Hungarian and German in 1831. He described the geological and hydrological conditions of the surroundings and the exploration history of the cave, and he presented the recently explored sections in detail. A hand-colored map detailing the basic structure, longitudinal sections, and surface area of the cave was provided with this volume. This work is the first scientific document about Hungarian cave exploration.

SCHMIDL, Adolf (1802–1863), a geographer, 'father of modern speleology', lived in Hungary from 1857 to his death. Besides his important investigations in Slovenia, he also had a major contribution in the exploration of Hungarian caves. In 1856 he studied the Baradla Cave of Aggtelek and the Szilice Ice Cave, currently in Czechoslovakia. Between 1858 and 1862 he investigated the hardly known caves and karst phenomena of the Bihar Mountains of Transylvania, now in Romania. Finally, in 1863, he worked in the Abaliget Cave. He published his results in outstanding papers.

SIEGMETH, Károly (1845–1912), a railway engineer, is a great figure in Hungarian cave exploration in spite of his foreign origin. He established the Eastern Carpathian Department of the Hungarian Carpathian Association and commissioned by this organization, visited the Aggtelek Cave. Finding it in a neglected state, he made a proposal for saving the cave. At his initiative the Eastern Carpathian Department undertook the supervision of the cave, surveyed it, made it easily passable, and also opened a new entrance. Siegmeth was also an enthusiastic popularizer of caves. He lectured on speleology in the major towns of the country, using his own slide series. He published several papers on caves at home and abroad, particularly about the Baradla Cave. In 1910 he became the first president of the first Hungarian scientific cave exploration organization. He collected literature on the caves of Hungary; this was edited for publication by Henrik Horusitzky after his death.

Top left: Archaeological site in Büdös-pest Cave, Bükk Mts.
Top right: Szeleta Cave, Bükk Mts.
Bottom: Karrenfeld around the Aggtelek Lake (by T. Hazslinszky)

JORDÁN, Károly (1871–1959), Professor of Mathematics, was the first important figure who employed climbing technology and equipment in his cave explorations. He participated in the exploration of the Pál-völgy Cave, studied the Rév water cave in Transylvania, and surveyed the Tapolca lake cave. In 1910 he played a major role in the organization of the first scientific organization of Hungarian cave exploration, and he became vice-president of the Society. In 1911 he investigated the shafts (potholes) of the Alsó-hegy. The event is a landmark in Hungarian speleology, the starting-point towards the exploration of shafts. Applying rather primitive equipment, he explored, surveyed and took photographs in 12 caves within three days.

KADIĆ, Ottokár (1876–1957), was a geologist and paleontologist, whose name is associated with the launching of organized cave exploration in Hungary. His interest in paleontology attracted him to caves. His excavations of the Szeleta Cave, which began in 1906, marked the advent of systematic cave exploration for scientific purposes in the caves of Hungary. Subsequently in other caves of the Bükk Mountains and also in the Pilis, Gerecse Mountains and in almost all important caves of the country, his discoveries achieved results meriting international appreciation. He carefully documentated his work. He surveyed and described not only the caves where excavations were under way but also studied all the caves in the neighbourhood. He was the first to provide a description of the István Cave, and when it was opened for tourism, he worked there as an adviser. He was influential in the exploration of the caves of the Buda Mountains. He drew the first map of the Szemlő-hegy Cave, explored in 1930. He was responsible for the clearing and opening of the partly natural, partly artificial system of caverns below the Castle Hill of Buda. On the upper level of this cave, he established the first Hungarian speleological exhibition. He described the Lóczy Cave and developed it for tourism. His activity aimed at the protection of caves is also noteworthy. Anually, he prepared a list of literature on Hungarian caves. He edited the first speleological journals (Barlangkutatás and Barlangvilág). He had an outstanding role in the development and evolution of the scientific organisation of Hungarian cave exploration. He was first secretary and then president of the Hungarian Speleological Society, formed in 1926. In 1952 he prepared a comprehensive work on the caves of the Carpathian basin, but it has remained unpublished.

STRÖMPL, Gábor (1885–1945), a geographer and cartographer, was an eminent figure in Hungarian cave exploration in the first decades of this century. Especially prominent is his research work in the caves of the Abaúj–Gömör region (1911) and Transylvania (1912). He was particularly interested in speleological and karst terminology. General issues such as karst morphology, hydrology of the Buda, Bükk, and Aggtelek Mountains, and the origin and destruction of caves, were also among his interests.

DUDICH, Endre (1895–1971), Professor of Biology, was an internationally recognized biospeleologist. In 1928–29 he intensively studied the faune of the Aggtelek Cave. His results were summarized in a German-language monograph published in Vienna in 1932. This was a fundamental work in speleobiology, still highly acclaimed and considered, indispensable, which brought him international fame. As a university professor, Endre Dudich nurtured the growth of eminent biologists who engaged in the study of speleofauna and speleoflora. In 1957 he established the fourth biological cave laboratory in the world in the Baradla. In order to publish the achievements of Hungarian speleobiology, the launched the series 'Biospeleologica Hungarica'. He was an officer of the Hungarian Speleological Society for a long time.

BOROS, Ádám (1900–1973), Professor of Botany, was one of the founders of the Hungarian Speleological Society in 1926. He was a scientist with diverse interests and great interest in the education of the younger generation. Of his many activities, his pioneering investigation of cave mosses in the most valuable.

PAPP, Ferenc (1901–1969), Professor of Hydrogeology, only became involved in the management of Hungarian cave exploration in the early 1950s. At his university department and elsewhere in the country he encouraged the activity of cave exploration groups. In 1957 he established a karst and cave research station at Jósvafő, named after Imre Vass. He published several papers on the geological implications of speleology. In his articles on the role of karst phenomena in engineering geology and on the indexing of underground caverns he provided a detailed program for the scientific exploration of caves and karst areas.

SCHŐNVISZKY, László (1901–1979), was a librarian whose life was closely interwoven with Hungarian cave exploration. From his youth he conducted excavations in various cave regions of the country. In the early 1930s he began to collect Hungarian speleological literature. As a result of his work, in collaboration with Károly Bertalan, the Hungarian cave bibliography from 1931 to 1945 can be regarded as almost complete. In 1926 László Schőnviszky was among the founders of the Hungarian Speleological Society and served as its secretary for some time. In 1961, by then retired, he became chief of office, secretary and deputy secretary general of the reorganised Society. He established a new library for the Society.

VÉRTES, László (1914–1968), was a paleoarchaeologist whose life-work is of international significance. As a disciple of Ottokár Kadić, he studied the problems of cave fills. The excavation in the Istállóskő Cave, Bükk Mountains, was an important event in his life. It was here that he recognized the need for comprehensive investigations; this he applied in his further excavations (Lambrecht Kálmán Cave). The data on Hungarian caves is summarized in his vast manual (Monuments of the Paleolithic and Mesolithic in Hungary, 1964). He also participated in the social organization of cave exploration and in the work of the Society. He fought for the protection of caves at a time when few people in Hungary were concerned with the protection of the environment.

CHOLNOKY, Jenő (1870–1950), Professor of Geography and an outstanding figure in the history of Hungarian geography, made important contributions to the development of Hungarian karst and speleological research. As part of his earlier investigations in physical geography, he had been concerned with this field, but he became deeply interested in the relatively new discipline of karstology only in the early 1900s. First he studied the karsts of Transylvania followed by those in the Bükk, Mecsek, Bakony and Buda Mountains and those in Upper Hungary. His most valuable observations were in the Karst Mountains of Slovenia where he made currently still accepted observations about limestone areas and caves in general (1916). His later scientific activity touched upon many details of karstification, and his views on this process developed the foundation of the modern approach to karst. He also studied the origin of caves. In 1926, he became executive president of the Hungarian Speleological Society and was president from 1932 until 1944. In this capacity he frequently lectured on speleological subjects and promoted the development of this discipline.

MOTTL, Mária (1906–1980), a paleontologist, was the most important woman cave researcher. Starting in the 1930s, she was secretary to the Society. She meant continuity in the life of the Society as she was in charge of operative tasks. For example, she prepared the minutes of meetings and extracted them for the public. As a paleontologists, she conducted many excavations, first in the Bükk Mountains, and then in Transylvania in 1941–42.

BERTALAN, Károly (1914–1978), a geologist, was an active contributor to Hungarian speleology throughout his life. His greatest achievement was collecting, categorizing, and making available documents research reports. He regarded the compilation of the Hungarian speleological bibliography his main tasks. It is because of him and László Schőnviszky that the list of Hungarian speleological works is almost complete to 1945.

PLÓZER, István (1948—1977), cave diver. He started cave diving in 1964. His most important fields of activity were the Tapolcai-tavas Cave, the Molnár János Cave and the resurgence-cave of the Héviz Lake, that latter had been discovered through his efforts. He collected and edited publications on Hungarian cave diving. To promote cave diving activities he organized the Underwater Caving Committee within the Hungarian Speleological Society in 1975. He was killed by accident during a dive to the cave of the Héviz Lake.

Sándor HADOBÁS
geographer
Rudabánya
Postafiók 20.
H–3733

AN OUTLINE OF THE HISTORY OF INSTITUTIONAL CAVE EXPLORATION AND ITS PRESENT ORGANIZATION

Péter Szablyár

The beginnings

The origins of institutional speleological research in Hungary date back to the Speleological Committee, proposed during the session of the Hungarian Geological Society on November 5th, 1909, and formed on January 28th, 1910. The first president of the Committee was Károly Siegmeth, the vice-president was Dr. Károly Jordán, and the secretary was Dr. Ottokár Kadić. The charter of the Committee summarized its scientific task in 14 points. The expansion of the Committee and the rising level of professional work called for a new form of the organization in 1913: the Speleological Section of the Society. In the same year, the bilingual journal "Barlangkutatás" was first issued.

Between the two world wars

The First World War brought an interruption to the earlier upswing of this field. The territory of Hungary shrunk to one-third of its previous size and major karst regions remained outside of the new borders.

Another stage of development began in 1926 with the foundation of the Hungarian Speleological Society with Jenő Cholnoky, Professor of Geography, as executive president and Dr. Ottokár Kadić, chief geologist, as secretary general. Besides the journal 'Barlangkutatás', the popular periodical 'Barlangvilág' was also issued. Another successful period followed until the outbreak of the Second World War, to which a new impetus was given by the re-annexation of Hungarian areas with karst regions and by the ensuing research activities.

After the Second World War

In the post-war years the former associations and other organizations were dissolved. As a consequence, the society of cave explorers in Hungary, ever growing in number, was again left without an independent organization for some years.

In 1952, a Speleological Section formed under its former parent association, the Hungarian Geological Society. Concussently a Cave Exploration Committee was created within the Hungarian Geographical Society. In 1955 the two organizations were united as a Karst and Speleological Section of the Hungarian Geographical Society. Simultaneously, a Central Karst Hydrological and Speleological Committee was formed in the Hungarian Hydrological Society.

Renewal

Following the renewal and consolidation of the country, the Hungarian Speleological Society was reorganized on December 16th, 1958, with Dr. Endre Dudich, member of the Academy and University Professor, as president. The Society was supervized by the Ministry of Heavy Industry. In 1967 the Society was left without supervision and experienced a crisis which was solved on February 26th, 1970, at the General Assembly of the Federation of Technical and Scientific Societies which approved the enlisting of the Society as a member. It has remained a member ever since.

The objective of the reorganized Society is stated in the Basic Regulations as follows:

The objective of the Society is to explore, survey and describe karst regions and caves, to unite the community of the sciences of karst and speleological research as well as of related disciplines, to represent the interests of cave explorers and cave exploration, to organize activity on the theory and in the practice of this field, to popularize results, to discuss the initiatives and proposals from members and the forwarding of them to state and social bodies, and through all these activities to promote scientific and technical progress as well as the protection of karst areas and caves."

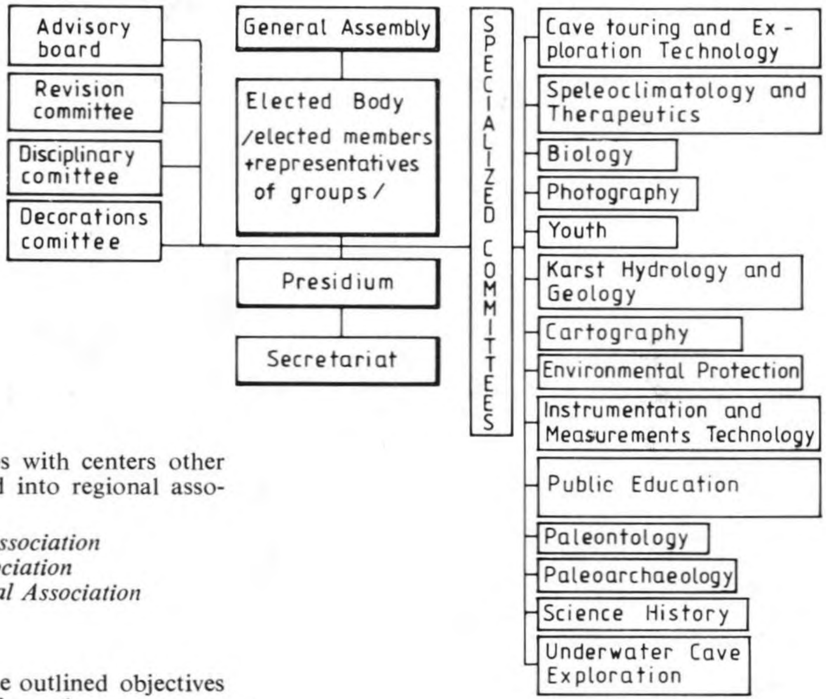
Organization of the Society

The membership of the Society exceeds one thousand, including 920 people in exploration groups and 280 individual explorers. The organization of the Society is similar to other scientific associations in Hungary:

The Officers of the Society are elected at the General Assembly.

The present Officers are:

Honorary President:	Dr. Hubert Kessler
President:	Dr. István Fodor
Co-presidents:	Dr. Dénes Balázs Dr. György Dénes Tamás Hazslinszky Dr. András Juhász
Secretary General:	Miklós Gádoros
Deputy Secretary General:	Péter Szablyár
Secretaries:	Éva Hevér József Kárpát Ödön Vid
Presidium:	Péter Adamkó Dr. Ferenc Cser Sándor Kalinovits László Maucha Kinga Székely Ferenc Szolga Dr. János Tardy
Executive secretary:	Nóra Fleck



Organization of the Hungarian Speleological Society

The cave exploration groups with centers other than the capital are organized into regional associations within the Society:

North-Hungarian Regional Association
Transdanubian Regional Association
South-Transdanubian Regional Association

The objectives

In order to achieve the above outlined objectives the following activities are performed:

- Organization of professional activities according to the specialized committees,
- Paper sessions and discussions are held to present and discuss the results of cave explorations at home and abroad,
- Organization of nation-wide cave exploration meetings and central exploration camps,
- Operation of a competitive system, with the winner annually declared, which ensures the documentation of cave explorations and research works. Also, occasionally having professional competitions (photography, survey, legends, etc.),
- Organizing and running an education system for the training of cave explorers, in cooperation with the Association of Nature-Lovers,
- Editing and publishing of materials,
- Contracting work in order to procure the necessary funds for the Society, professional conduct, and organization,
- Maintenance of the speleological and divers library, unique in Hungary, gradual increasing volume on the basis of international exchange of publications,
- Maintenance and extension of the collection on science history.

Publications of the Society

The annals of the Society are "Karszt- és Barlangkutatás", a collection of papers with major results in foreign languages. The first volume was issued thirty years ago, in 1959. To date, nine volumes have been published, the last (no. 9) in 1980.

Since 1961, one or two issues of the journal "Karszt és Barlang" have been published yearly. Among its permanent sections, "Studies" is significant, including 4—6 longer papers in each issue. Under the heading "Reviews", discussions, news from abroad and journal reviews are found. The sections entitled "Our researchers abroad", "Results in karst and speleological research in Hungary" and "The Society's Life" intend to provide a complete picture of the actual situation in Hungarian cave exploration. "The book-shelf of the Speleologist" reviews books and other publications from Hungary and abroad. The researchers who died during the past period are remembered ("In memoriam"). The important papers are supplemented with summaries in foreign languages.

The Special Issue of 1977, published in English for the 7th International Speleological Congress is followed by the Special Issue for the 1989 Congress in Budapest, also in English.

The first regular periodical of speleology, reorganized after the Second World War, was the 'Karszt és Barlangkutatási Tájékoztató' (Information on Karst and Speleological Research), published by the Society between 1956 and 1974 with research reports, brief papers and news from home and abroad for the members of the Society.

For technical reasons the journal ceased and in 1975 was replaced by the volumes of the annual "Beszámoló" (Reports), summarizing the activities of groups and specialized committees of the Society, lately appearing with brief English-language summaries.

The programs of the Society are included in the brochure "Műsorfüzet" (Programs), issued (bi) monthly since 1974. Although its content is restricted, it includes increasingly more news and seems to be taking over the function of the former "Tájékoztató".

Prominent persons of the Hungarian Speleological Society in 1989. Top from the left to the right: Sándor Kalinovits, László Maucha, Ferenc Szolga, Tamás Hazslinszky, Péter Szablyár, György Dénes, László Lénárt, Dénes Balázs, Péter Adamkó; bottom from the left to the right: Kinga Székely, István Fodor, Hubert Kessler, Miklós Gádoros, Nóra Fleck. (Photo: P. Borzsák)

In 1981 the Society published the first leaflet in the series "Cave maps of Hungary", which was followed by additional publication. With the presentation of major caves in an atlas format (at scales of 1 :100, 1 : 200 and 1 : 250), this is a summary of the exploration history, morphology, formations, history of mapping, important data from the survey for the base map of the atlas, and literature related to the cave.

Since 1982 the "Barlangbibliográfiai Figyelő" (Cave Bibliography Actual) has been published twice a year and presents the list of new publication acquired by the Society's library and the selected thematic annotations of papers and publications in speleology at home and abroad.

In addition to the regular publications, the Society also issues occasional publications for major international events. These have been the following:

Symposium on Karst Morphogenesis. Papers.
  Budapest, 1973. 264 p.

Report on the (Second) symposium of the International Speleological Union Speleotherapeutica Committee in Hungary.
  Budapest, 1975. 168 p.

International Conference 'Baradla 150', 1975.
  Budapest, 1975. 246 p. (in Hungarian and English)

Field-trip guide to the International Conference Baradla 150.
  Budapest, 1975. 45 p.

International Symposium on Karst Hydrology.
  I. Karst Water Budget
  II. Utilization and protection of karst water.
  Budapest, 1978. 498 p. (in English, Russian, and Hungarian)

Seventh International Speleotherapeutical Symposium
  November 2—6, 1982.
  Budapest, 1984. 364 p.

International Colloquium on Lamp Flora
  October 10—13, 1984.
  Budapest, 1985. 164 p.

In the series of occasional publications, the high quality notes for education have to be mentioned. They are of great importance in the training of members, with special regard to the included special information not available anywhere else.

Péter SZABLYÁR
metalurgist
ALUTERV
Budapest
Váralja út 15.
H—1013

THE INSTITUTE OF SPELEOLOGY AND ITS ACTIVITY

Dr. János Tardy

Hungarian karst and cave research had been concerned with setting up a speleological institute from 1929. However, Kadić's idea came to be realized nearly half a century later, in 1975. Over the past 15 years the institute was severally abolished, reorganized, renamed, its function redefined. In 1981 the Speleological Department of the Institute for Environmental Protection, and as of 1st January 1986 the new Speleological Institute started work as an independent unit of the National Office of Environmental Protection and Nature Conservation. The scope of its activity and jurisdiction was considerably expanded compared to its predecessors. Besides cave conservation and documentation, the Institute has administrative and control functions concerning the utilization, research and public attendance of the caves and besides it supervises and coordinates the other activities of geological nature protection. It controls the tasks of environmental protection related to open mining within the nature conservation areas of some 600,000 hectares, it sees to the cadastral survey of geological-geomorphological values, to the professional supervision of public caves and sites of geological demonstrations, and to the organization and realization of research projects. From 1st January 1988 the Institute of Speleology works as a department of the Ministry of Environment and Water Management, otherwise unchanged.

The *personnel* of the Institute of Speleology numbers seven including mainly specialists of speleology with qualifications in the earth sciences (geography, geology, hydrogeology, cartography) and an administrator. As the staff is small for the wide range of tasks and certain specialties are not represented in it, a permanent external staff have been engaged. The mining engineer, biologist, mineralogist, electrical engineer, archeologist, physicist and various laboratories help us by occasional contractual work. The Institute is in direct contact with several authorities, academic and university research places.

The main reasons underlying the occasional reorganization of the Speleological Institute derive from regrettably decisive circumstances not devoid of personal aspects either.

1. The changing evaluation of the "genre" and institutional system of environmental protection, of its role and performance.

2. Due to the traditions of Hungarian environmental protection, the attitude of the controlling and executive apparatus is centered around animate nature, interpreting the concept of ecology rather narrow-mindedly.

3. The protection of geological nature has no traditions similar to the conservation of living nature in Hungary. The authorities ignorant of speleology (and nature conservation, for that matter) regarded the caves as natural formations for sports and hobby activities for a long time.

Most recently, however, the daily practice of nature and environmental protection has adopted a new attitude to caves as a result of the rise of certain damage and risks, the gravity of the problem of karst waters and the emergence of some spectacular sites.

The main lines of research are powerfully influenced by the fact that the Institute of Speleology belongs to environment and nature protection. The high-priority research projects include (with special regard to speleological tasks):

A) Creating the information system of the speleological, geological conservation of nature.

1. Preparing the cave cadaster of Hungary with the concomitant documentation.
2. Surveying the geological-geomorphological values in the areas already protected or requiring protection.
3. Registering the active and abandoned open mines in areas already protected or requiring protection.
4. The complex information system of the karstic region of Rózsadomb (Buda Hills, Budapest).
5. The complex analysis of caves under increased protection.

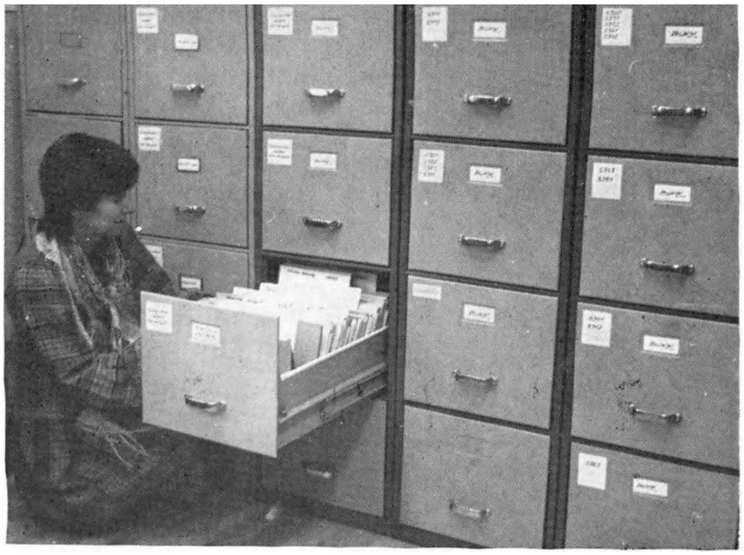
B) Caves as indicators of the management of the surface environment:

— Study of passage links under surfaces of various land use (urban area, forest, karstic, arable land); examination of the interaction of natural circumstances and anthropogenic processes, with special regard to some caves of the Aggtelek Karst and the hydrothermal caves of Budapest.

— Study of the quality parameters (chemical, bacteriological and mycological characteristics) of dripping-oozing waters, water-flows and soils, the exploration of connections, research of the tendency of change (at 40 observation points in the 5 cave systems under Budapest and as standard measurements in the Vass Imre Cave of the Aggtelek Karst).

— Studying the quantity and composition of the bat species in the caves, monitoring the changes under the surfaces of various land use (Gerecse, Bükk, Buda Mountains).

— Examination of the effect of various extracting methods (mining, exploding) on the formations and encasing rocks of caves in (and under) the active mines (Beremend, Esztramos). Study of the intensity of deterioration processes.



Hungarian Cave cadaster in the Institute of Speleology

C) The ecological aspects of cave protection and use. (A study of the factors and processes promoting or hindering, or concomitant with cave use.)

1. *Tourism.* Researching the emergence and prevention of cave flora (chemical and mechanical intervention, possibilities of prevention, follow-up of biological changes).

2. *Speleotherapy*, its climatological implications.

Registering the bioclimatological factors and processes (change of the aerosol composition of caves under different types of loading; monitoring the regeneration processes of climatological, chemical, bacteriological and mycological parameters; liability tests, flow measurements in caves under polluted urban areas and in public caves, etc.

The Institute of Speleology is a central institution of the protection of nature and the environment. Accordingly, the researches planned, carried out or financed by the Institute must serve the aims of nature conservation and environmental protection. Most of the studies highlight concrete questions preparing decisions on actual problems. However, karst and cave protection, and nature conservation in general can less and less do without the findings of *basic research*, to carry on which is increasingly hopeless with the dwindling of funds.

Let us refer to a few measures taken as a result of the listed research programmes.

1. The caves requiring increased protection were defined, case studies, development projects and protective investments were designed and ordered on the basis of the *cave cadaster.*

The information of the *cadaster of mines* enables research to work out recultivation projects, to expose illegal waste dumps, to get to know new biostratotypes, geological (mineralogical, paleontological) sites, to protect indirectly the karst waters.

2. As a result of research findings concerning the hydrothermal caves under Budapest in communication with the surface and the spring zone along the Danube, strict bans and restrictions on building were introduced in the most affluent housing area of the country.

3. On the basis of a complex analysis of caves and mineral formations in active mines, protective stoops were designated, the explosive techniques were replaced, and the ethical, professional, legal and financial problems of minerals found there began to be settled.

4. Climatological examinations related to *speleotherapeutic utilization* enabled the elaboration of a system of conditions approved by the Health Ministry that make strict conditions binding for human experiments including a year-long complex natural science test series (basic and special climatic parameters). Most recent studies seem to call for the revision of some "axioms" in connection with speleotherapy.

5. One outcome of researches on *tourist caves* is that 8 of the 10 public caves of Hungary are being reconstructed now. New lighting equipment will be installed as part of the technical renewal.

Upon the professional guidelines of the Institute, some 30 endangered caves are being looked after and reinforced for protection at the moment. Our fellow workers are all members of the leadership of the Hungarian Speleological Society whose activities we support financially, too, within our means.

(The research work of the Institute of Speleology carried out or coordinated in 1986—88 is described in more detail separately.)

Dr. János TARDY
geographer
Institute of Speleology
Budapest
Zugliget út 40.
H-1021

THE WORKS OF CAVE EXPLORATION GROUPS

Péter Szablyár

More than 40 cave exploration groups of the Hungarian Speleological Society are currently active, and consist of communities of people with different professional training, interests and age.

There are groups specialized in cave sciences, while others focus on cave exploration. Special attention is due to groups which are self-taught, developing their own knowledge and practical skills. Groups with special features or contrasts are described in this review, which is intentionally not exhaustive.

Alba Regia Cave Exploration Group

The group was formed in the General Engineering and Communication Industrial School of Székesfehérvár in 1961. Its activity is closely associated with the exploration of caves on the Tés Plateau, eastern Bakony Mountains.

When the group started its work, there were only two minor caves known there, and the geology and geomorphology known at that time had indicated only limited speleological potential.

The primary goal of the group was the through geomorphological and speleological research of the Tés Plateau. A basic condition for the diverse, but intensive activity was the formation of a permanent research base, which was established at Csősz-puszta in 1965. The research station, under continuous development from its own resources, became the centre of exploration and scientific research on the Tés Plateau. The facility occupies 1700 m^2 and houses chemical and biological laboratories as well as mechanical workshops, stores and residential rooms with dressing-rooms and showers. A small exhibition room is also at the explorers' disposal and the centre of the Bakony Mountains cave rescue service is also accommodated here.

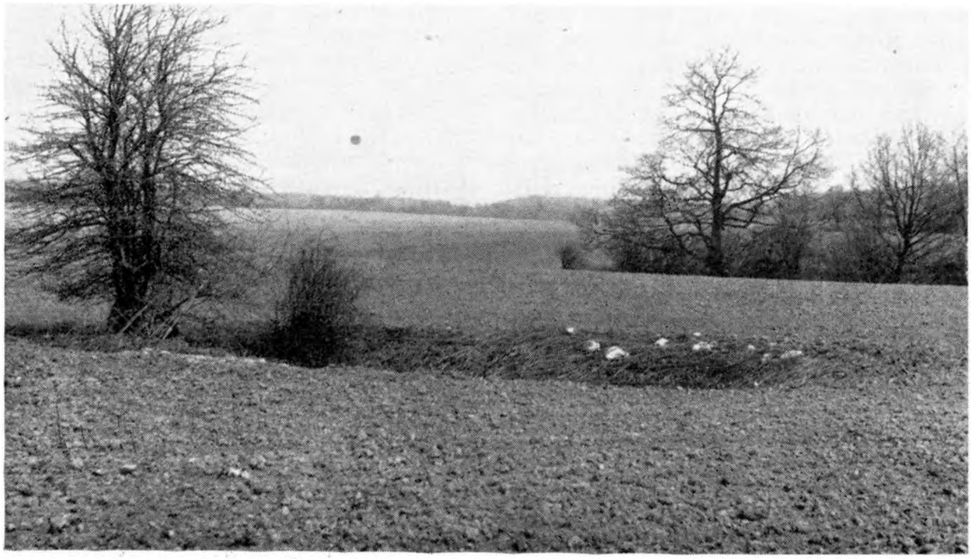
The core of the activities here is exploration, which has resulted to the survey of almost 150 caves on the Plateau. Several of these are deeper than 100 m and the Alba Regia Cave, with 3 km of passage, is the longest in Transdanubia. The major exploration successes have been founded on theoretical and practical scientific work and the regular evaluation of new results.

Most of the equipment necessary for regular explorations in the 5 km of caves on the Plateau was produced by group members themselves. The most outstanding are the several generations of electric and electronic instruments developed and employed in the past decades.

They conducted important biospeleological research in the caves of both the Plateau and the Bakony Mountains, and this led to the identification of 293 species. The primary task is the collection and identification of cave microfungi.

Other activities are hydrological, climatological, radiochemical, petrographic, mineralogical and pedological analyses in caves and on the surface; they also undertake volcanospeleological investigations all over the country.

Typical landscape of Tés Plateau with small sinkholes



The group presented a good example to be followed when it published the annual summary reports of research in a year-book. Survey data, maps, measurements, observations and the conclusions drawn from them provide the foundation for the gradual expansion of knowledge on the Tés Plateau.

The work of the group in the popularization of science is also important. They guide 200 cave tours in an average year involving 600—800 people. There are 10—15 annual lectures on the activities and results of the group, and these recruit new contributors to cave exploration in the area.

The group has a history of successes and forms a true cave-exploring community and acts as a decisive component of Hungarian speleology. This statement is also confirmed by numerous awards.

Bekey Imre Gábor Cave Exploration Group

The name of the group grew from its involvement with the exploration of the Pál-völgy Cave, greatly extended in length due to their work. Today the total length of this cave is almost 7 km and it is the third longest cave in Hungary.

Until the end of 1980 there had been no important exploration in this cave, since its discovery in 1904, although generations of Hungarian explorers visited it and attempted to advance further. Its survey in 1910 shown a length of 1,200 m.

The group was formed in 1979 and took the name of Imre Gábor Bekey, one of the first explorers of the cave. Studying the surveyed plan of the tectonically influenced cave, some points of attack were identified and then led to new explorations.

The length of the known cave grew year by year *(Fig. 1)*. Almost simultaneously with the explorations, the new passages were surveyed. This allowed the efficient recognition of new points of attack and further exploration.

Along with the explorations, scientific observations were made and data collected. Geological mapping and geomorphological observations were continued to increase knowledge of the cave system and to provide preliminary information for further exploration. Sediment analyses proved that, during the history of the cave, water from the surface had found its way into the system, which was basically formed by thermal waters. The fluctuating water level of the intermittent lake at the cave bottom is regularly gauged. Climatic data, of air CO_2 content, temperature and air current at various places are gathered. They have long-term data records on the bats which spend the winter in the cave; when compared to observations from the fifties, these clearly show the ecological consequences of environmental change.

The annual reports contain the detailed presentation of scientific results and also the detailed exploration diaries, with photographs of excellent quality to illustrate their work.

The group of 20—30 people spend most weekends in the Pál-völgy Cave and they organize explorers' camps for work requiring team effort. They take special care over the cave maintenance, building signed paths and providing guides for visitors.

Hajnóczy József Cave Exploration Group

For the students of the Hajnóczy József Grammar School of Tiszaföldvár (in the Great Hungarian Plain), summer camps of cave exploration have been organized on the Odorvár, southern Bükk Mountains, since 1963.

The teachers (Gy. Németh and L. Varga), who first conducted the cave visits and geographical work, found tasks suitable for secondary school children in the area, where interested pupils could be involved in the mysteries of ethnography, archaeology, biology, geography and, last but not least, the special excitement of speleology.

The first area of work was the Hasadék Cave at Odorvár, but after 10 years of perseverance the cave was still only 215 m long in 1971. Then, that year when opening a "fox-hole" they discovered the major cave named after their school, József Hajnóczy, and year by year they explored long additional sections. The stages of exploration are shown in *Fig. 2*. As a result of more than 15 years work by several generations of secondary school children, the Hajnóczy Cave is the 13th longest (2,250 m) and 15th deepest (117 m) cave in Hungary today.

The explorations are immediately followed by surveying and photographic documentation. Regular climatological measurements are made in the cave. Analysing the chemical composition of infiltrating and dripping waters the effect of acid rain in the cave environs is investigated. The diversity of the Hajnóczy Cave also allows morphological and morphogenetic observations. Since 1977 the Nuclear Research Institute of Debrecen performs radiation measurements in the cave.

The results are published in papers; eight of them were presented to students' scientific circles, and six were diploma works, one as a doctorate dissertation, and about 15 academic article appeared.

The activity and results of the group prove a secondary school of progressive spirit and high level of scientific education can also succeed in cave exploration and motivate a generation which loves nature and protects the environment.

Papp Ferenc Karst Research Station

The station was established by the Budapest Technical University in 1957, at the initiative of Dr Ferenc Papp, Professor of Mineralogy and Geology. He set a research objective of climatological, hydrological and geological research of the Aggtelek Karst, as well as the detailed study of karst processes.

The measurement network of the station first covered the Vass Imre Cave, and flow temperature and conductivity of the water at the Kis-Tohonya spring were measured from 1959 on a daily basis.

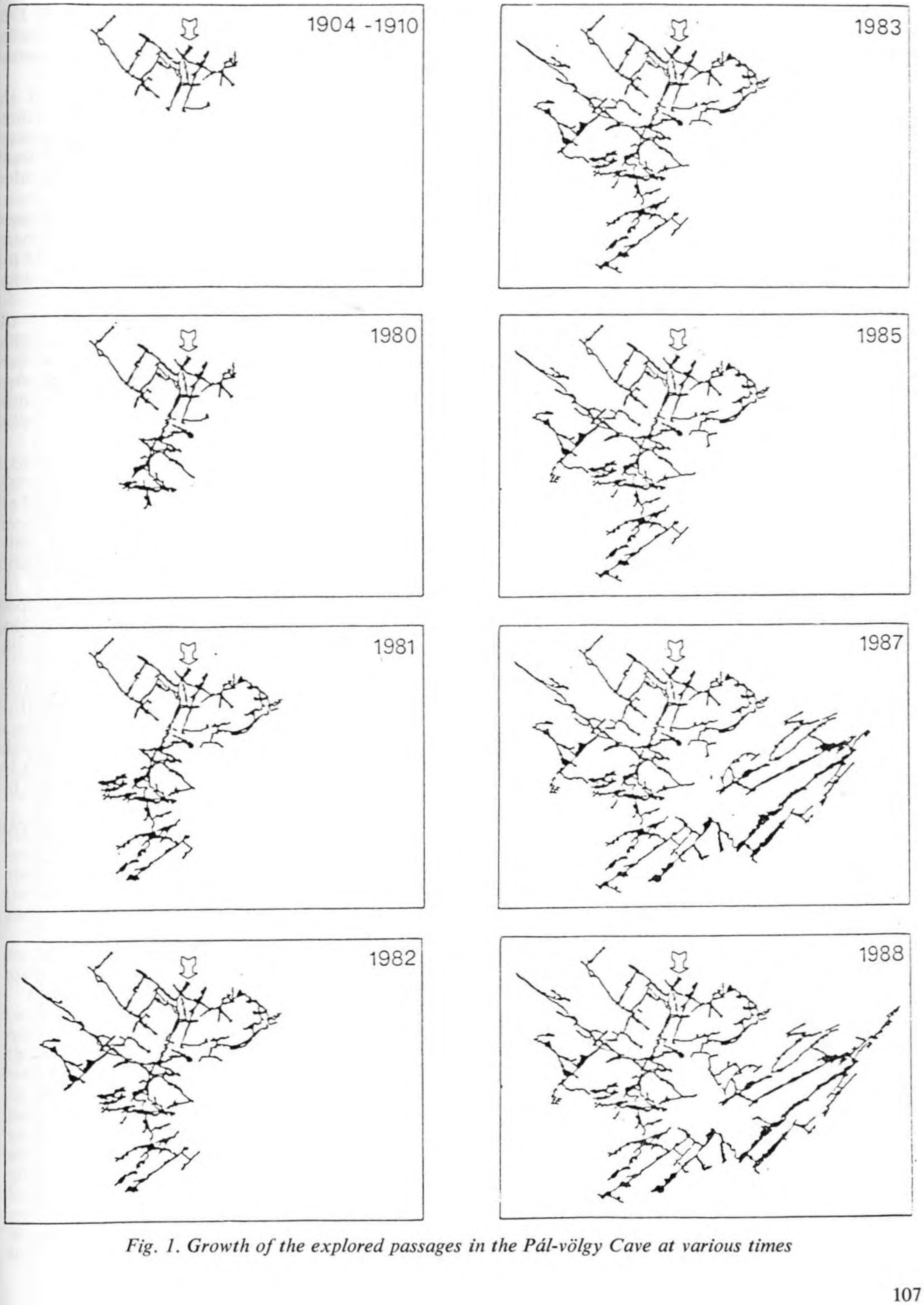


Fig. 1. Growth of the explored passages in the Pál-völgy Cave at various times

In the meantime, the National Meteorological Survey established a surface meteorological station next to the karst research station. The cave exploration group of the Budapest Technical University set up an automatic recording station to measure microclimate and the flows of dripping waters in the Vass Imre Cave three times a day. In 1960, regular quantitative and qualitative measurements of the neighbouring springs were started, and were gradually replaced by the monitoring of flow and the weekly recording of water temperature and resistance. In 1965 an indicator-clock, and in 1967 an electric telerecording instrument, was installed to observe and record the rock tide phenomenon in the Vass Imre Cave.

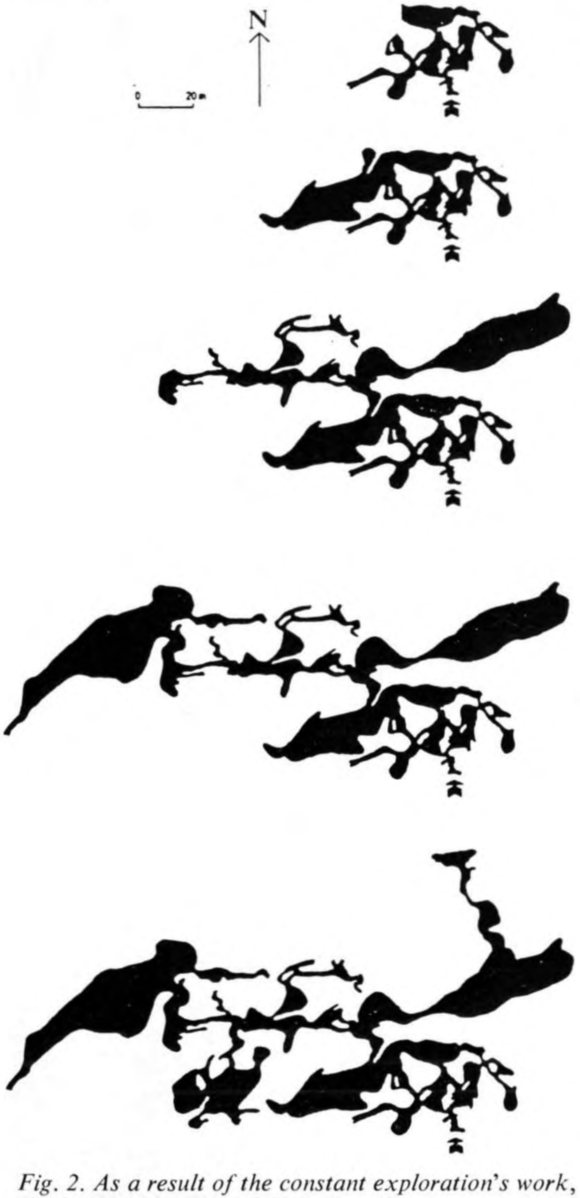


Fig. 2. As a result of the constant exploration's work, the known passages of Hajnóczy Cave were growing from year to year

According to the objectives formulated at the foundation of the research station, in the last three decades there has been a systems-theory-based investigation of the solid, fluid and gaseous phases of karst to allow the analysis of the intricate interactions governing karst development.

Both surface and underground clastic sediments within the karst, and also aragonite-calcite mineral deposits in the caves were studied. Of special importance were results concerning transformations, helictite formation and dripstone colouring.

Investigations of the fluid phase involved the recording and analysis of quantitative and qualitative drainage data series. Notable achievements were made in modelling karst spring activity, in the interpretation of earth-tide changes, and in the recording and evaluation of temporal changes in dripping waters.

The investigations of the gaseous phase included the automatic recording of climatic parameters from the Vass Imre Cave, the effect of external air pressure changes on cave climate, and the observation of helictite formation related to aerosol generation. They developed the necessary instruments and methods themselves.

In the first decades of operation, the station took a major share in the practical training of engineering students. The results of field-work appear in numerous publications.

The long tradition of the karst research station of Jósvafő confirmed the commendable objectives of its founder. In spite of the undeniable achievements, the future of the station became uncertain on several occasions. The survival was ensured by the strong spirit bestowed by the founder on his succeeders.

Péter SZABLYÁR
metalurgist
ALUTERV
Budapest
Váralja út 15.
H–1013

HUNGARIAN CAVE RESCUE SERVICE

Dr. György Dénes

With a past of three decades, the Hungarian Cave Rescue Service is one of the oldest of its kind.

Undoubtedly the major reason for the early emergence of the system is that there are now six inexplicably intricate labirynths of caves each several km long amounting to a total length well over 30 km under the inhabited central areas of the Hungarian capital with a population over 2 million. Often by breaking open locked gates, reckless youths regularly ventured inside without the appropriate equipment and lighting, losing their way or suffering accidents.

In the past three decades the rescue service was alarmed more than a hundred times in Budapest alone. In most cases the lights ran down and people got stuck in the cave. Usually the families of those missing called for help. No one should take the risk of losing his way or getting stuck too lightly. For example, only the bodies of four young men, of whom nobody knew they would go into a cave, were found by speleologists two months later. In a luckier case three missing young men were salvaged by the Rescue Service seven days after they had got stuck in a cave.

During the past three decades 13 people were killed in Hungarian caves. Apart from the four young men mentioned, three young speleologists died in a difficult section of Baradla Cave with syphons and the stream due to lack of oxigene and cooling. Two cave researchers died of nitrogenous gas poisoning a day after an illegal explosion in one of the caves of the Bükk Mountains. In mental and physical exhaustion, a speleologist suffered cranial fracture when the makeshift life-line was broken in the Meteor Cave, and though the rescue team got him out safely, he died of the injury some weeks later. Two cave divers were killed in the underwater spring cave in Lake Héviz. Another diver died in the syphon of the Szalajka Spring Cave in the Bükk Mountains.

Thus of the 13 deaths in caves, 4 were inexperienced young people and 9 were experienced speleologists, including 3 divers.

Besides the deaths, several critical injuries also occured in the Hungarian caves when only the quick help from the rescuers saved the lives of those involved. For example, a photographer who was taking photos on the surface went into a cave to change films in the dark but fell into a crevice suffering severe fractures and internal lesions. On another occasion two young speleologists, a boy and a girl, went for a weekend cave tour, but the girl lost her footing over a chasm suffering severe fractures. The rescuers took very long to get her out from the extremely hard part of the cave. Tests showed that both had drunk alcohol before going into the cave.

After a tour of the Meteor Cave another speleologist girl, climbing the rope ladder in exhaustion, lost her balance when her incorrectly fixed life-line slipped off her and fell into the abyss. The rescue team succeeded in taking her to the surface and she recovered in hospital.

There were cases when the help of the Hungarian Cave Rescue Service was asked from abroad. A diver did not return to the appointed time from a large spring cave in Rumania. As he was believed to have been stuck in the dry cave beyond the syphon and there were no rescuers on the spot, his colleagues and family called on the Hungarian Cave Rescue Service for help. With due help from the authorities, the rescuers crossed the border with their equipment and some hours after the alarm they were on the spot. Unfortunately only the body of the diver stuck in the syphon could be recovered.

Examples could be listed on end, but I only wanted to illustrate how vitally important the work of the Hungarian Cave Rescue Service is and how many lives they have saved over the past thirty years.

We are convinced that a rescue service is really effective if it can contribute a lot to the education and training of young speleologists, if the most experienced rescuers can pass on their knowledge after analyzing the cave accidents so that the new generation may avoid similar accidents.

The results of the training and preventive efforts of the Hungarian Cave Rescue Service are tangible: less than half as many accidents have occured in the past decades than in the 1960s. One reason is that the Hungarian speleological training system stipulates that only those can be cave tour guides and leaders of cave research who have taken part in a course of speleological technical and safety knowledge and passed exams testing their theoretical and practical attainments.

Apart from the National Cave Committee of the Hungarian Association of Nature Lovers, the Hungarian Cave Rescue Service under the aegis of the Ministry of Environment Protection and Water Management does its utmost to be capable of carrying out the most complex rescue operations both in regard to its equipment and the experience of its staff.

Dr. György Dénes
hydrologist
Budapest
Borbély utca 5.
H—1132

THE SPELEOLOGICAL EDUCATION SYSTEM IN HUNGARY

Dr. László Lénárt

Since the beginning of institutional cave exploration in Hungary, there has always been demand for further training and increased technical skills and professional knowledge. During the past few decades rope and other cave exploring equipment have been significantly improved technologically. Environmentalists have become a significant factor in descisions related to the environment, and an increasing number of people (including increasing numbers of the younger generation) have joined in cave exploration. These developments motivated the formation of a unified system of speleological training in Hungary.

Recognizing this necessity, the Public Education Committee of the Hungarian Speleological Society and the Speleological Committee of the Hungarian Association of Nature-Lovers established a unified system of speleological education in 1983, and this system was approved and supported by the Speleological Institute of the Ministry of Environmen and Water Management.

Objectives of the education system

The main objective of the speleological education system is to provide further training for cave hikers and explorers in organizations commensurate with previous training, skills, and plans concerning cave exploration.

Basic cave exploration course (no 1)

The first organized training for future explorers, whereby students are able to acquire basic knowledge about cave hiking (and minimal information on cave exploration) during tours to caves with the exploration group.

Safety technology course (no 2)

For more experienced cave-hikers this provides caves safety and technical information necessary for touring in major caves.

Cave tour guide course

This course is designed for experienced cave hikers who wish to conduct cave-hiking tours.

Cave exploration leaders' course

For those who have experience not only in cave-hiking but also in cave exploration, this is the proper level of education. In completing the course the participant acquires organizational, guiding, and professional knowledge which enables him to conduct cave exploration successfully in any cave.

Table 1.

Courses in the Hungarian speleological education system

Course	Number of *lessons*	Number of *participants*	Number of *examinees*
basic	16	257	235
safety technology	5	75	71
cave tour guide	2	16	14
caveexploration leader	4	59	45
cave tourist guide	3	47	45
cave mapping	2	19	18
speleogeology	1	8	
maintenance cave exploration leaders	2	6	
total	*35*	*487*	*428*

Table 2.

Structure of the Hungarian Speleological Education system

A: Courses organized by various Hungarian societies in cave exploration
B: courses organized by the Speleological Committee of the Hungarian Association of Nature-Lovers
C: Courses organized by the Public Education Committee of the Hungarian Speleological Society
D: Courses organized by the Public Education Committee of the Hungarian Speleological Society and the Speleological Institute of the Ministry for Environmental Protection and Water Management

The prereguisite to acceptance to the courses written above is the completion of the course below:

Specialized courses in cave exploration

Highest level professional knowledge is provided for experienced cave explorers or those interested in exploration (in speleogeology, cave mapping, speleobiology or other topics).

Cave guides' course

Professional training for cave guides (full-time or part-time). In addition to local information, the goal of training is for the guide to acquire skills in cave exploration and guiding. Those who pass are awarded a distinctive badge upon completion.

Maintenance course

The latest technological, exploration and administrative facts are communicated to participants (cave guides, exploration leaders and tour guides) on a regular basis.

In 1984 regular education began and to date the courses in *Table 1* have been finished. The structure of the education is shown in *Table 2.*

Dr. László LÉNÁRT
geologist
Technical University
of Heavy Industry
Miskolc
Egyetemváros
H—3515

MAGYAR OLVASÓINKHOZ

A Karszt és Barlang jelen száma a Magyarországon megrendezendő 10. Nemzetközi Szpeleológiai Kongresszus alkalmából angol nyelven jelenik meg. E kiadványunkban áttekintő képet adunk hazánk karsztvidékeiről, barlangjairól, valamint a magyar karszt- és barlangkutatás eredményeiről, történetéről tájékoztatjuk a külföldi szakembereket. A cikkek egy részét magyar nyelven a Karszt és Barlang 1989. évi száma fogja tartalmazni. Az MKBT tagjai, térítés nélkül, tagdíjfizetésük fejében csak az utóbbi számot kapják meg.

Szerkesztőség

KARST and CAVE

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on the occasion of 10th International Speleological Congress held in Hungary 1989

Edited by
Dr. Dénes BALÁZS—Kinga SZÉKELY

Editorial board:
Dr. György Dénes, Nóra Fleck, Márton Juhász,
László Maucha, Péter Szablyár

Translated by
Dr. Dénes Lóczy, Judit Pokoly, Dr. Ödön Ráday

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Contributors to the edition of the special issue "Karst and Cave"

Manuscripts revised by
Dr. Tivadar Böcker, Dr. László Jakucs, Dr. Dénes Jánossy, Dr. Attila Kósa, Dr. Pál Müller, Dr. István Sárváry, Kinga Székely, Dr. János Tardy, Péter Taródy

Translation corrected by
Dr. Derek Ford (Canada), Dr. Reka Gabor and Dr. Vazul Gabor (USA), Dr. Richard Halliwell and dr. Antony Waltham (England)

Photographs credits:
author's names are given individually by their own work

Colour picture plates edited by
Péter Borzsák

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Márton Juhász

Technical editors:
Dr. Dénes Balázs, Kinga Székely

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Photo top left: entrance to the Baradla Cave in Aggtelek (by T. Hazslinszky), right: exhumed paleokarst rocks in the vicinity of Jósvafő (by G. Salamon) bottom: the Red Lake (Vörös-tó), a doline lake near Jósvafő, Aggtelek Karst (by G. Salamon).

Back cover photo: Tótfalusi Valley in the Bükk Mountains (by T. Hazslinszky)