A BAKONY
TERMÉSZETTUDOMÁNYI
KUTATÁSÁNAK EREDMÉNYEI 23.

Márton Veress

COVERED KARST EVOLUTION IN THE NORTHERN BAKONY MOUNTAINS, W-HUNGARY

1. The Kerteskő Gorge of Gerence stream

2. Incised meanders of a water-course in the cover sediment of karst in the foreland of Som Hill

On the cover: Cave opening in the cliff of the Dudar Magos Hill

RESULTATIONES INVESTIGATIONUM RERUM NATURALIUM MONTIUM BAKONY XXIII.

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PREFACE

This volume is the most comprehensive professional study on the covered karst phenomena of the Northern Bakony to date, a remarkable product of the Hungarian karst geomorphological school of genetic approach. Gratitude is due to the Bakony Natural History Museum and personally to the geologist and director, Dr János Futó, who found a way of publication worthy of the contents and thus contributed to making the achievements of major research efforts and the wonders of a less known karst region available for the public.

Naturally, the value of a book is measured by the joy it brings to the author and reader. Márton Veress' book must be valuable since it is a profound analysis of mostly unknown karst phenomena in the mountains selected on the one hand and also clearly reflects the obsession of its author on the other. He has been exploring the secrets of the Bakony Mountains for long years with enthusiasm knowing no fatigue and with commitment expecting no reward. Only this burning passion in research could make one capable of overcoming obstacles and compensating with deep joy for the sacrifices of work. The greatest joy on Earth is that of acquiring knowledge deserved by hard work.

Whether the Reader, studying Márton Veress' book, also shares this joy with me, I do not know. He/she will experience it himself/herself depending on his/her previous level of acquiantance with the topic, sense of style and temperament. As for myself, I like to read about new things in a new context - even if I do not totally agree with the interpretations.

The contents of the volume have been discussed in detail on the occasion of a Ph. D. dissertation at the university of Szeged. Even at the end a series of questions and confronting views between the author and me remained. For instance, the significance of mixing corrosion in the origin of blind chimneys in caves and of spherical cauldrons on cave ceilings as well as the part the solid load of water-courses arriving from non-karstic catchments play in karst cavernation are judged differently.

This is, however, no problem. It is a good thing to have debates. This is the reason why Márton Veress' dissertation was rated „Summa cum laude" at Szeged. A magnificient side of science is that, our experience not being identical, constant debates are generated. Toil and hard battles bring forward knowledge on the world. Steel is hardened in fire.

A very peculiar significance of the book is that it is not restricted to the inventory of regional karstification properties in a geomorphologically less explored area as indicated in the title but goes much beyond a mere description of landforms in the region under study. Theoretical generalisations and the creation of new concepts are also attempted at. The interactions of causes and effects, of influencing factors and resulting landforms are analysed in order to reach regularities. In this sense Márton Veress' work is more than a landscape description, it is also a treatise in general karst geomorphology.

The most modern criterion of contemporary geomorphology, the demand for revealing multilateral systems of causes, is excellently manifested here. Through this, a regulation of *sensu lato* genetic complexity of covered karst landforms to be studied by modern techniques of the earth sciences and landscape ecology is demonstrated.

Márton Veress is well-versed in the literature on the Northern Bakony and the nomothetical communications of researchers of previous times on the region. He does not only contribute to this particular knowledge. Relying on sedimentological, pedological and cartographic methods not commonly applied in classical research on karst geomorphology, sometimes rather surprisingly new scientific theses are formulated for the factors which regulate covered karst development. The comprehensive, exacting and painstaking nature of well-documented field work in itself is outstanding. The study of karst objects from various points of view and their relation to the individual elements of non-karstic surfaces are exemplary. Author's photos, figures, maps and profiles all attest to a researcher great experience, who is brave enough to produce new working hypotheses and puts forward ingenious ideas for the solution of the problems identified.

I find it an excellent recognition that the shape of chimneys is controlled by rock dip. The creation of concepts of pseudoponor and pseudobathycapture are justified and the distinction between subsidence pseudodolines, dolines-with-pseudoponors and postgenetic dolines-with-ponors. In nature products of rather contrasting processes often occur together. In such cases the complexity of influencing factors should also be presented in the morphogenetic interpretation of the landscape.

Approaches very unusual in geomorphology but nevertheless interesting are followed in the chapter „Types of karst development", where the dynamics and landforms of karst erosion are grouped according to the morphology of the underlying rock surface and how cover sediments are removed from this surface (by fluvial processes, sheet wash or material transport at depth). Great attention is devoted to the typical features of karstification on covered escarpments, karst cones and in the valleys. In the exhumation of karstic basement a decisive role is attributed to the dimensions of blocks and cones. Precise definitions are provided for the concepts of syngenetic and postgenetic karst development and detailed analyses are supplied for possible interactions between rock cavernation and valley formation .

Szeged, 1999. March

László Jakucs
Professor Emeritus

OBJECTIVES

The covered karst in the Northern Bakony Mountains had been studied for about twenty years. Findings were published in a series of academic papers. The present volume attempts to summarize karst processes and phenomena in the mountains. The contents are arranged around two topics.

– Revealing covered karst development and covered karst phenomena in the Northern Bakony Mountains and

– analysing the interactions between geomorphic evolution of and karstification on the blocks of the mountains; identifying types and subtypes of karstification.

Rocks are eroded in two basic ways. On the one hand, corrasion affects rock masses through the action of various agents (water, wind, ice) which transport sediment load and, on the other, corrosion involves the partial or total dissolution of rocks and the removal of solutes.

Non-soluble rocks, such as sandstones, granites and others, are primarily eroded by running water under temperate climates and V-shaped valleys are generally produced. Valley development may be controlled by crustal structure as in the case of valleys along grabens. Such valleys are called concordant, while for discordant ones evolution is independent of crustal structure. A group of discordant valleys is constituted by transversal valleys, which is a collective term for regressional, antecedent and superimposed types.

With the retreating erosion of their water-courses, regressional valleys are increasing their lengths. Head valleys are gradually shifting upslope. The valleys are invariably younger than the elevations they are cut into.

Antecedent valleys or valley sections are older than the elevations they are formed in. A section of the already existing valley undergoes uplift and incision may keep pace with it. As a consequence of increased relief, river energy accumulates and intense incision results in the formation of a steep-walled gorge. The speed with which the valley sides are shaped does not allow time for their lowering.

Valley incision may be inherited from cover sediments over the underlying rocks. They are called superimposed (epigenetic) valleys. The planform of their channels preserves the shape adjusted to their mechanism before inheritance, eg. meandering. In case the underlying rocks are hard and resistant to erosion and, thus, valley walls are not lowering, superimposed water-courses also run in gorges.

Inheritance often affects carbonate rocks (limestones or dolomites). If the cover rocks are removed from above carbonate sediments, the fluvial valley becomes an inactive dry valley. (Rainwater infiltrates into the easily permeable carbonate surfaces and, thus, the water-courses dry up.) The valleys in mountains of carbonate rocks are mostly of the superimposed type.

Transversal valleys are often of complex origin. Regressional-superimposed and antecedent-superimposed valleys are also common in the Bakony Mountains. In the first case a regressional valley in the side of a block is inherited from the cover deposits (eg. gravels) over carbonate rocks and along a section terrain elevation was increased by the uplift of a (group of) block(s).

Carbonates dissolve – primarily due to the influence of carbonic acid – without residue. Rock solution and the accompanying processes are called karstification. The resulting landforms are typical features of karst regions.

The rainwater infiltrated into carbonate rocks percolates through fissures and cracks. As joints are widened by solution, water conduction capacity increases with time. Since water is conducted into depth, no drainage network develops on the karst surface and existing valleys become inactive. Except for superimposed ones, no valleys dissect the karst surface. Rapid denudation in the neighbouring areas lead to the isolation of karst regions as non-dissected plateaus.

Infiltrated rainwater may percolate downwards in the rocks until it reaches down to the level of the neighbouring terrain. Flowing sideways and impounded, this water creates the zone of flowing karst water. Its surface is the karst water table. Where flowing karst water issues, karst springs occur. If there are impermeable strata above the karst water table, another, higher-lying flowing karstwater zone may develop. The flowing karstwater approximately in the level of the neighbouring terrain is called middle karst water zone, while that in lower position is the deep karst water zone. The middle karst water zone in the Bakony Mountains is mentioned as „main karst water" since it is found in Triassic „Hauptdolomit" (main dolomite). In humid periods water may percolate downwards in the rock mass above the karst water table (descending karst water zone).

As it was mentioned, there are covered and open karsts. In the first case, carbonate rocks are buried under non-karstic rocks, while in the latter, there is no sediment cover, only soil at most. The sediment cover is either impermeable (buried karst) or permeable (cryptokarst). In the Bakony Mountains open and covered karsts alternate. Buried karsts have gravel mantles, while cryptokarsts are loess-covered carbonate surfaces.

Another way of classification of karst is by water budget and age. Allogenic karsts receive water from adjacent non-karstic areas, while authigenic karsts do not. If karstification took place earlier during Earth history, it is paleokarst. Recent (Holocene) karsts are either active or fossil features. (Naturally, all paleokarsts are fossil.)

Karstic landforms are grouped as surface or underground features. All surface karst forms are undrained, either located on open or on covered karsts.

The most common landform on open karst is the solution doline, a depression of variable size and bowl shape without water conduit. Solution dolines are formed directly below soils. There are several varieties. (If adjacent dolines merge, uvalas result.) Collapse dolines are not generated by solution but by the cave-in of cave ceilings.

Ponors develop along rock boundaries of allogenic karsts since water-courses over non-karstic rocks cut valleys and continue underground when reach the rock boundary. The valley terminates in a counterslope there (blind valley). At its terminal point a depression without drainage but with a water conduit to depth is created (ponor).

In buried karsts, where the valley is inherited over the underlying carbonate rocks, a valley rock boundary with ponor develops. With progressing incision, the rock boundary is shifting towards the head valley. Accordingly, the site of ponor development is also shifting. The previously formed ponors are transformed into dolines-with-ponors.

In cryptokarsts, the solvent percolating through the sediment cover dissolves carbonates and a deficit of matter is generated in or on the underlying rock. A corresponding depression is created on the surface.

The dolines on covered karsts are grouped as follows.

A superimposed doline is formed if the cover is a cohesive sediment. Due to its higher strength, this rock only fills the surface depression if the strength of the cover sediment is reduced by weakened support. Cover sediments move rapidly (collapse) and the resulting karst feature will have steep walls.

A subsidence doline is created if the cover sediments are non-cohesive. Although there is only a minor deficit of matter in this case and the strength of the cover is so low that it cannot remain in its previous position.

The increasing deficit of matter on or in the underlying sediment is compensated by permanent dislocation of the cover sediment (only interrupted for short spells). The movement affects highly variable portions of the cover at a particular time. The velocity for the individual particles is low and the surface feature of gentle slopes takes a long time to develop.

Alluvial dolines-with-ponors are also defined. In this type a surface depression results from the reworking of cover sediments into the karst by the water-course of the karst passage.

Underground karst features may form through corrosion or erosion. Corrosional features usually develop in the zone of flowing karst water. Cavitation is explained in the following way. The infiltrated solvent becomes saturated on the surface or at a shallow depth in the percolation zone and, thus, it is unable to dissolve carbonates. The recurring solution effect in the zone of karst water is due to the mixing of waters of different hardness (Mischungskorrosion). Mixture corrosion occurs when two saturated water masses of different concentration mix. Part of the equilibrium CO_2 (which keeps Ca^{2+} ions in solution) appears in surplus. This surplus CO_2 produces carbonic acid and dissolves additional amounts of carbonate. Mixture corrosion in the zone of flowing karst water is caused by the crossing of horizontal flow and downward water percolation routes.

Among karst landforms spring caves and closed cavities are distinguished. The former are produced at karst springs, where water is collected from over large surfaces. Large amounts of water are mixing and it makes cavity formation intensive. Open branching caves of several tens of metres dimension develop. Closed cavities are created in the interior of the karst and differ from spring caves as they are closed from the beginning of their evolution. As in such places lesser amounts of water are mixing, their sizes are also smaller than spring cave dimensions. Essentially, in karst interiors groups of cavities develop which are connected into a system of passages of various cross-sections and lengths, usually impassable for humans.

Erosional caves are formed in allogenic karsts. The water-courses reaching the interior of the karst through ponors carry along sediment loads from the adjacent non-karstic terrains and erode the corrosional caverns further by corrasion. The caves expanding from the ponors towards the karst interior are called streamsink caves. Erosional caves are through caves if they are so spacious all the way from the ponors to the karst springs that they are passable by humans.

THE NORTHERN BAKONY MOUNTAINS: A GEOLOGICAL AND GEOMORPHOLOGICAL DESCRIPTION

This overview of the Northern Bakony is based on works of LÁNG (1958), KORPÁS (1981), PÉCSI (1980), FÜLÖP (1989) and JUHÁSZ (1988, 1990).

Macrotectonic position and physico-geographical divisions

The Bakony Mountains of 200 to 710 m altitude is a member of the NE–SW-striking range of the Transdanubian Mountains at its SW end. (The Bakony Mountains and the adjacent marginal hill regions of lower topographic position constitute the Bakony region.) The Transdanubian Mountains is a macrotectonic unit bordered by the Rába (Raab) lineament and the Balaton tectonic zone. It occupied its present position by way of a NE directed rotational intrusion by the Middle Miocene. The mostly Mesozoic carbonate rocks of the mountains were formed in the zone between the Eastern and Southern Alps, on the southern shelf of the opening ocean branch of the Eastern Alps. (Mesozoic formations are regarded as basement and Cenozoic rocks are cover deposits.) Particularly in the area of the Bakony, the Triassic basement of the mountain range gradually acquired a syncline structure, which has become asymmetrical by present. Along the SE flank older Paleozoic formations are exposed, while along the NW flank Triassic and Jurassic and along the axis more recent (Cretaceous and Eocene) rocks occur. Consequently, there is a general NW dip of strata in the SE and a SE one in the NW. (Since the block beyond the present mountain margin have subsided to ever increasing depths, the NW flank is incomplete.) The strikes of Mesozoic rocks of various age are mostly parallel with the overall strike of the mountains.

In a geographical sense, the Bakony region is bordered by the Little Hungarian Plain on the NW, by the Great Hungarian Plain on the SE, by the Zala Hills on the SW and by the Vértes Mountains on the NE. The Bakony Mountains is divided into two units by the Tertiary Veszprém–Devecser graben, formed between E–W faults, they are the Northern and Southern Bakony. The Northern Bakony is further subdivided along the Cuha valley into the High and Eastern Bakony. Along the margins (Pápa Bakonyalja, Pannonhalma Hills and Súr Bakonyalja) the blocks of lower elevation are mostly covered by alluvial fans out of which hill regions and glacis surfaces were carved out. The Old or High Bakony is composed of higher mountains and lower basins. The eastern part is subdivided by intramontane basins (Sűrű Mountain Group, Tés Plateau and some horst groups isolated from the latter).

The areas studied for karst evolution include parts of the High and Eastern Bakony **(Fig. 1)** of a total area of 1070 km^2.

Lithology

Most of the mountains are built up of Triassic carbonate rocks like „Hauptdolomit" (of 500–600 m thickness) and Dachstein Limestone (300–400 m).

The distribution and thickness (ca 250 m) of Jurassic limestones are more limited. Among them the Dachstein-type Liassic Limestone is of the greatest thickness.

As a result of the oscillatory basement movements, Cretaceous limestones could not form in great thickness either and their spatial occurrence is relatively restricted. The reef limestones which belong here are the Requienian limestone of 30–80 m thickness and the hippuritic limestone. Into Cretaceous limestone sequences marl and clay strata (eg. turrilitic marl or munierian clay) are locally intercalated.

At the end of the Lower Cretaceous and particularly in the Upper Cretaceous the area was mainland with bauxite accumulation.

The Middle Eocene nummulitic limestone (Szőc Limestone) is a characteristic formation over a relatively large area. Its thickness, however, is moderate (100–300 m) and intercalated with marl beds. In many cases, it immediately overlies Triassic Hauptdolomit or covers the bauxite deposits, occurring in patches in the mountains (primarily in karstic hollows). In the late Eocene and early Oligocene clays (eg. foraminiferic clay) formed.

In spite of the Tertiary denudation, a Middle Oligocene to Lower Miocene fluvial sequence of mostly gravelly material with abundant clay and silicified tree trunk remnants, the Csatka Gravel Formation, is still wide-spread. Its thickness ranges between 50–300 m. In various periods of the Miocene, abrasional gravels accumulated on the lower marginal blocks of the mountains. (Abrasional gravels are also known from earlier times, eg. from Lower Eocene).

Sporadic occurrence is typical for Miocene marine limestone (Leitha Limestone) and Pliocene travertines (eg. around Várpalota). The latter are associated with former karst springs.

Among formations of small (some metre) thickness Pleistocene blown sands (around Fenyőfő), travertines and – in the valleys – fluvial deposits can be mentioned. Loess has to be underlined since it occurs over an extensive area although in moderate thickness. Redeposited varieties are equally found over higher-lying terrain and in the valleys and karstic depressions of older surfaces. There are loess patches on the dissected surfaces of limited extension, while over undissected and extensive surfaces (Tés Plateau) and in lower-lying basins it has a uniform appearance.

Out of the listed formations Dachstein Limestone, Dachstein-type Liassic Limestone, requienian and nummulitic limestones are liable to karstification. Their distribution marks the portions of the mountains where surface karstification is possible. On younger Jurassic limestones there is virtually no karstification. It may also be missing on dolomite or occur in a characteristic manner not be detailed in this book. Cavernation, however, is typical of both rocks. Thus, regarding karst development as a whole, the occurrence of the latter rock types also has to be taken into account when delimiting karst areas.

It can be mentioned that marl and clay interbeddings in carbonate rocks cannot only modify cavern formation (for instance, storeyed karst water levels may form and promote cavernation at several levels simultaneously) but they may be exposed over large areas during denudation. At these exposures there is no surface karstification either.

Two rocks have to be cited under which carbonate rocks are buried: the Csatka Gravel Formation and loess. The former is virtually impermeable and, therefore, runoff from its surfaces flows over carbonate surfaces (or leaves the mountains) and thus the water influx into karst increases. Under these cover deposits only buried karst can develop. In areas, however, where limestone is overlain by loess, permeability allows the development of cryptokarsts.

Tectonics

Folding is only found scattered in the mountains, while faulted structure are much more common. Fractures and faults of NE–SW strike primarily formed by compressive strain (joints, paraclases, inverse faults and imbrications). (Extensional joints favour karst water movement along the strike of the mountains.)

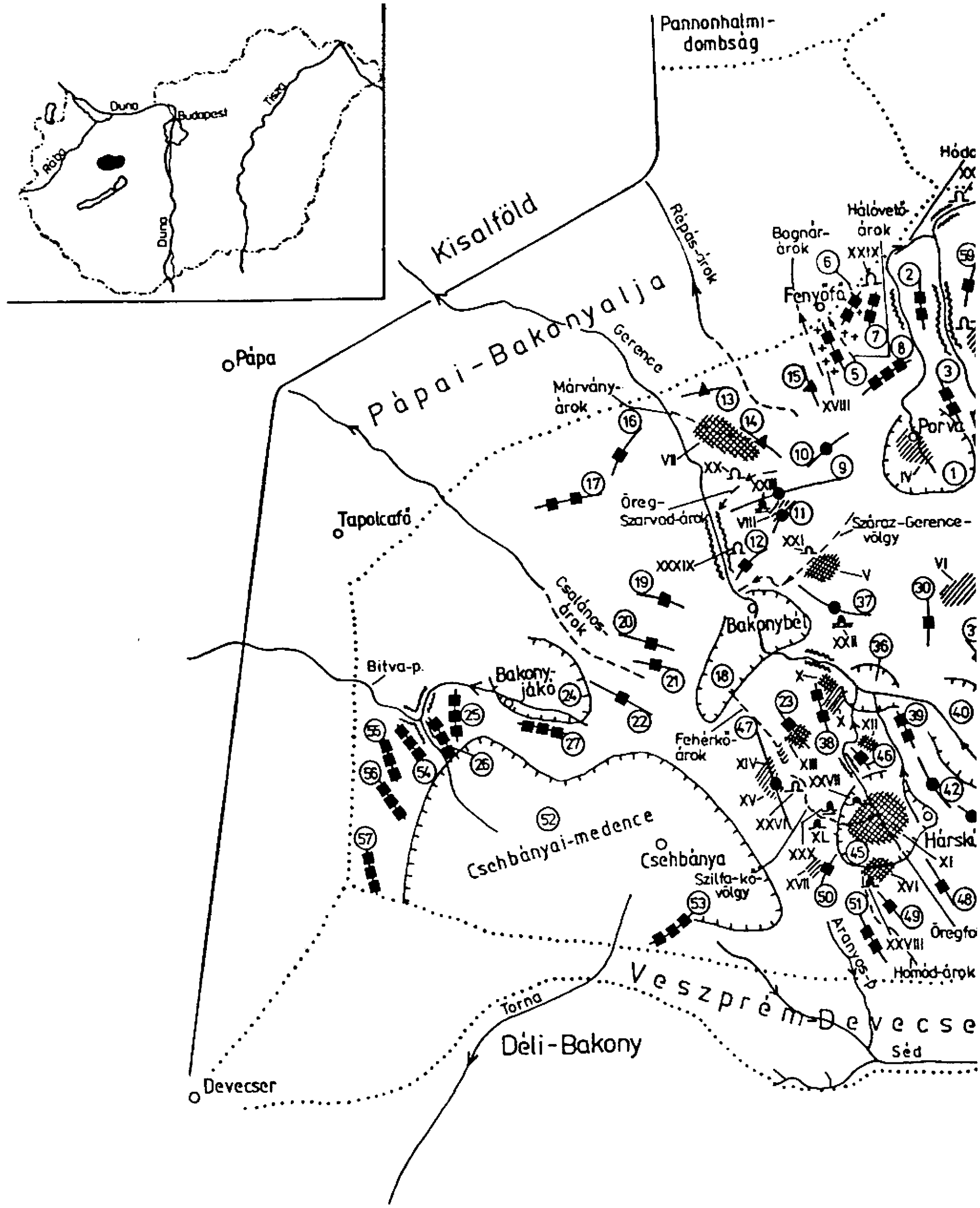
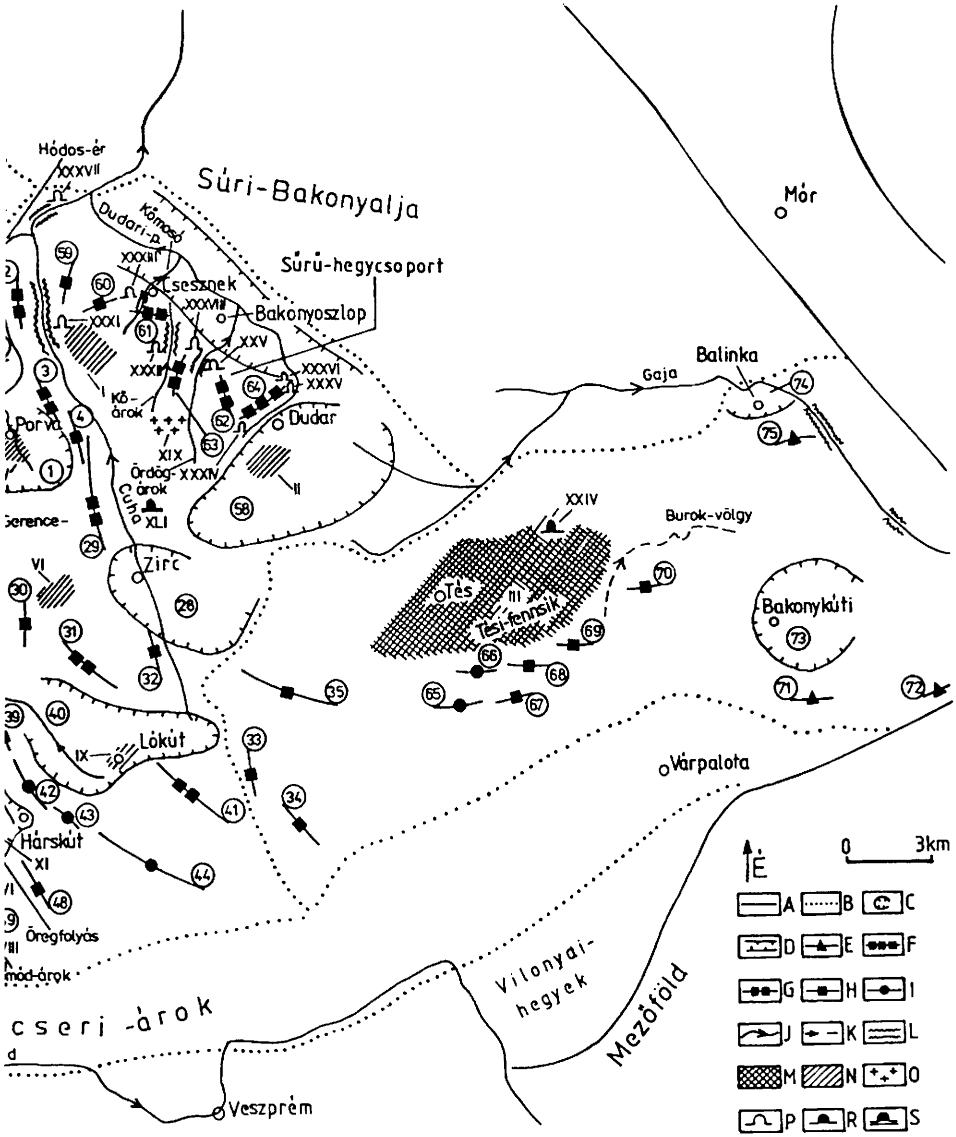


Fig. 1. Parts of Northern Bakony

Legend: A. margin of Bakony region; B. margin of Northern-Bakony and neighbouring microregions; C. basin; D. graben; E. threshold; F. buried horst in summit position; G. semiexhumed horst in summit position; H. exhumed horst in summit position; I. horst in summit position; J. water-course (regressional-superimposed valley or section); K. intermittent water-course (regressional-superimposed valley or section); L. superimposed-antecedent valley section; M. terrain with surface karstification (estimated average frequency of surface karst features above 1 per 10000 m^2); N. terrain with surface karstification (estimated average frequency of surface karst features below 1 per 10000 m^2); O. terrain with collapse dolines; P. cave remnant mentioned in text (remnant of cavity formed by flowing karst water); R. streamsink-like (chimney) or streamsink cave mentioned in text; S. inactive, truncated streamsink-like or streamsink cave not mentioned in text; 1. Porva Basin; 2. Keselő Hill; 3. Kopasz Hill; 4. Csesznek-erdő; 5. Kakas Hill; 6. Dörgő Hill; 7. Szent László-erdő; 8. Télizöld Hill; 9. Kőris Hill; 10. Kék Hill; 11. Parajos Hill; 12. Tönkölös Hill; 13. Kopasz Hill; 14. Répás-tető; 15. Hosszú Hill; 16. Somberek Hill; 17. Durrogós-tető; 18. Bakonybél Basin; 19. Hideg Hill; 20. Tevelvár; 21. Pápavár; 22. Hajszabarna; 23. Mester-Hajag; 24. Bakonyjákói-medence; 25. Kőpad; 26. Som-hát; 27. Hallgató Hill; 28. Zirci-medence; 29. Bocskor Hill; 30. Kő Hill; 31. Csengő Hill; 32. Kakas Hill; 33. Ámos Hill; 34. Hagymástető; 35. Tunyok Hill; 36. Pénzesgyőr Basin; 37. Som Hill; 38. Iharos-tető; 39. Kőrisgyőr Hill; 40. Lókút Basin; 41. Kávás Hill; 42. Kőris Hill of Hárskút; 43. Borzás;



44. Papod; 45. Hárskút Basin; 46. Égett Hill; 47. Hajag; 48. Gyöngyös Hill; 49. Kis-bükk Hill; 50. Kis-Fekete-erdő; 51. Vejemkő; 52. Csehbánya Basin; 53. Csiga Hill; 54. Gannai-Manc-hegy; 55. Nyúl Hill; 56. Kerék Hill; 57. Öreg Hill; 58. Dudar Basin; 59. Örök Hill; 60. Várbükk; 61. Vár Hill; 62. Sűrű Hill; 63. Kő Hill; 64. Magos Hill; 65. Öreg-Futóné; 66. Kis-Futóné; 67. Téses-tető; 68. Márkus-szekrénye; 69. Vár-berek; 70. Sár-berek; 71. Baglyas Hill; 72. Iszka Hill; 73. Bakonykút Basin; 74. Kisgyón-Balinka Basin; 75. Vár Hill; I. NW part of Sűrű Mountain Group; II. SW margin of Dudar Basin; III. Tés Plateau; IV. Porva Basin; V. area between Som Hill and Kőris Hill; VI. area between Bocskor Hill and Kő Hill; VII. Márvány-árok area; VIII. Kőris Hill; IX. Lókút Basin; X. area above Judit Spring and Iharos-tető; XI. Hárskút Basin; XII. Égett Hill; XIII. Mester-Hajag; XIV. Fehér-kő-árok area; XV. Középső-Hajag; XVI. Homód-árok area; XVII. Kis-Fekete erdő; XVIII. Dörgő Hill and Szent László-erdő; XIX. area between the Ördög-árok and Kő-árok; XX. Odvaskő Cave; XXI. Pörgöl Hill Cave; XXII. Nagy-Pénz-lik and Kis-Pénz-lik; XXIII. Ördög-lik of Kőris Hill; XXIV. Alba Regia Cave; XXV. Ördög-lik of Sűrű Hill; XXVI Nagy-Törkü-lik and Kis-Törkü-lik; XXVII. passage of doline-with-ponor Gy-12; XXVIII. passage of doline-with-ponor Ho-1 (Ereszes aven); XXIX. Likas-kő of Hódos-ér; XXX. Gyenespuszta Cave; XXXI. Cave C-3; XXXII. Cave K-8; XXXIII. Cave Km-1; XXXIV. Cave M-4; XXXV. Cave M-5; XXXVI. Caves M-6 és M-7; XXXVII. Cave C-4; XXXVIII. Cave Ö-32; XXXIX. Gerencepuszta Cave; XL. passage of doline-with-ponor G-5/a; XLI. Cseresi aven

The blocks bordered by faults constitute horsts, escarpments, grabens and basins. Thus, the mountain range is built up of a cluster of blocks of various elevation. In the basins the extension along NW–SE faults allowed differential subsidence of blocks, while tilted uplift was mostly due to compression in NE–SW direction. The individual blocks were affected by considerable relative displacement.

Geological evolution

The Triassic formations indicate a shallow marine environment, which was gradually replaced in the Jurassic by a deeper sea (ammonitic limestones). Towards the end of the Lower Cretaceous terrestrial conditions prevailed and in the Middle Cretaceous shallow marine sedimentation resumed. The area emerged as a land surface in the late Middle Cretaceous. The karstification under tropical climate transformed the landscape into a peneplain with isolated conical karst hills (inselberg type karst). At the end of the Cretaceous the peneplain was dissected into horsts, which underwent oscillatory movements during the Cenozoic.

As a consequence of emergence from the sea, tropical karst processes affected the carbonate surfaces from the Lower Cretaceous to the Upper Eocene with interruptions of various length in the Middle Cretaceous and Middle Eocene. Interruptions are indicated by bauxite niveaus and varieties of inselberg type karst. Karstic planation probably did not extend over the whole mountains but it was restricted to portions where the time interval was sufficiently long for karstification. In certain parts the development of inselberg type karst came to halt at various stages and it is also manifested in landforms.

As a result of oscillating block movements, the Middle Eocene transgression produced an archipelago sea. Considerable subsequent inundation followed in the Middle Oligocene and Lower Miocene. The Csatka Gravel Formation is a delta sequence accumulated by a river (or rivers) arriving from S or SW. It is probable that cover deposits did not extend over the whole mountains but the highest elevations were not inundated.

Until the Middle Miocene the area of the present mountains functioned alternately as a site of accumulation for sediments removed from the environs and, at least in part, a terrain of erosion. This erosion under warm or semiarid climate can be best described as pedimentation. The cover sediments (eg. the nummulitic limestone) were partly or entirely removed from the Mesozoic basement and extensive pediments formed. Pedimentation also involved the exhumation of the karstic peneplain as well as the truncation of the inselberg type karsts of various development (morphological) stage.

The blocks of various elevation became buried to various degrees in a given interval and in another cover sediments were removed to variable extent. Over certain portions of the individual blocks pediments developed even in the Pliocene and Pleistocene. (Pedimentation could have repeated between the late Miocene and the Pleistocene.) Along the margins of some blocks abrasion platforms and raised beaches could have also developed in the Miocene and Pliocene.

The present altitude and dissection of the mountains are due to late Pliocene and Quaternary differential vertical crustal movements. The present landscape is a mosaic of blocks of the late Cretaceous peneplains exhumed to various degrees and uplifted to various elevations.

Land form

As a consequence of dismemberment into horsts, the Cretaceous peneplain ceased to exist by the end of the Cretaceous. During the Cenozoic, the dismembered fragments were buried and (resulting from the oscillating movements of blocks) exhumed at various dates and to various extent. Regarding the cover sediments and present altitudes, the following types of horsts are identified:

– threshold surfaces are constituted of Triassic carbonate rocks and have altitudes below 300-400 m. Pedimentation deprived them from their sediment cover and they acquired their present positions through subsidence.

– Cryptopeneplains in basins have altitudes between 300 and 400 m. During the Cenozoic they were in low positions and, therefore, the basement is covered by well-preserved Cenozoic sediments.

– The altitude of horsts in summit position ranges between 400 (occasionally 300) m to 550 m. In the Cenozoic they may have suffered repeated subsidence and uplift. There are several varieties, including buried horsts in summit position, where Middle Eocene limestone covers the Mesozoic basement, semi-exhumed horsts in summit position, where Cenozoic cover sediments are only preserved in patches and exhumed horsts in summit position, where Cenozoic sediments have been entirely removed.

– Some horsts in summit position rise ca 550 m above sea level and are built up of Triassic and Jurassic limestones. There are no cover sediments since the blocks remained in higher position to escape inundation or the cover sediments were removed by subsequent erosion.

The loss of cover sediments (the Csatka Gravel Formation) is usually associated with the process of pedimentation. It is assumed that during the process the landforms of the inselberg type karst were destroyed. Author has the opinion that some have probably survived. His arguement is that some surfaces were not buried under unconsolidated cover sediments or they (like the Middle Eocene limestone) showed a large degree of heterogeneity in the first place. In the absence of nummulitic limestone, the removal of unconsolidated cover deposits did not involve the destruction, only the truncation of landforms of limestone much more resistent to erosion. Examples are found on horsts of summit position with Middle Cretaceous Limestone exposed and inselberg type karst landforms developed. Similar landforms could also develop in nummulitic limestone (a cover sediment). In this case the tropical karst features could only have been destroyed if the nummulitic limestone cover had been entirely removed.

The decisive elements of the mountain landscape are mountains, grabens, basins and the escarpments encircling them – all formed by tectonic movements (uplift and tilting). The summit levels are constituted of portions of the late Cretaceous peneplain varying in size, altitude and degree of burial or exhumation with spots of various size where remnants of the inselberg karst, eroded differentially, also occur.

Older pediments developed almost everywhere in the mountains, while more recent ones are restricted to the marginal zone or edges of the individual blocks. Abrasional platforms and raised beaches are typical of the margins.

Valleys (of both derasional and fluvial type) are also marked in the landscape. Fluvial valleys formed in grabens or along tilted structures (or occasionally along the axes of anticlines). Transversal valleys are more common than longitudinal ones. There are many regressional valleys but superimposed valleys even more often occur. Indicating that during their formation they had a meandering river mechanism, most of the latter show incised meanders. Among valleys with incised meanders asymmetric cross-sections are common.

This points to a periodical uplift of the area. The meander loops formed during meander shifts are often of considerable size. They may have been formed both in unconsolidated cover sediments and in the underlying carbonate rocks. In loose deposits erosional inselbergs may also occur.

It is frequently observed that a water-course is inherited over the present-day surface through backward incision (regressional superimposed valley). In the karst gorges of the mountains superimposition is mostly of antecedent nature (superimposed antecedent valley). Such valleys develop on elevated blocks encircling basins if they are mantled by cover sediments.

Although terraced valleys are more typical along the mountain margin, some of the valleys in the mountains also show terraces, which are either gravel terraces (in the Gaja valley) or rock terraces (the section of the Gerence Valley between Bakonybél and Huszárokelőpuszta).

Along the margins (and sporadically in basins) active alluvial fans are common. Around more elevated blocks abandoned alluvial fans occur, in the sides of valleys dissecting horsts debris fans and rockflows, while on valley floors accumulations of collapsed material can be detected.

Subdivisions

The High Bakony is constituted of several basins (cryptopeneplains) encircled by horsts of various type (**Fig. 1**). The basins are aligned in two NE to SW rows. The northern row of basins includes the Porva, Bakonybél and Bakonyjákó Basins and the more southerly one the Dudar, Zirc, Lókút, Pénzesgyőr, Hárskút and Csehbánya Basins. (The first, SE member of the southern row, the Dudar Basin belongs to the Eastern Bakony.) The two rows are bordered to the NE by the Csesznek-Bakonyoszlop Graben. Among the basins the Zirc, Porva and Hárskút Basins lie at relatively higher altitudes and the basement is exposed in several places. Consequently, they are transitional terrains to semiexhumed horsts.

To the N and E, the Porva Basin is closed by a series of semiexhumed and exhumed horsts in summit position (Keselő, Kopasz and Csesznek-erdő Hills), although some valleys dissecting the blocks have retreated from the Cuha stream to the basin area. The blocks which border the basin to the N between the Hódos-ér and Bognár-árok streams (Kakas, Dörgő, Szent László-erdő and Télizöld Hills) are horsts or groups of horsts in summit position, buried or semiexhumed. The group of blocks along the W boundary, to the Gerence stream (Kőris, Kék and Parajos Hills) ia composed of horsts in summit position and an exhumed horst in summit position (Tönkölös Hill). To the N, to the Pápa Bakonyalja, horsts in threshold position (Kopasz, Répás-tető and Hosszú Hills) follow. The horsts W of the Gerence stream are the continuations of the Kőris Hill. They are classified as either low threshold surfaces or semiexhumed horsts in relatively low summit position (Somberek and Durrogós-tető Hills).

The Bakonybél Basin is bordered to the N by the mentioned Kőris Hill. The W (Hideg, Tevelvár, Pápavár and Hajszabarna Hills) and the S boundaries (Mester-Hajag, ie. the northern member of the Hajag group of blocks) are exhumed horsts uplifted to summit position.

The Bakonyjákó Basin is enclosed to the W, S and E by buried horsts in relatively low summit position (Kőpad, Som-hát and Hallgató Hills). To the N the basin is separated from the Pápa Bakonyalja by some smaller and lower blocks. (The E boundary is the mentioned Pápavár and Hajszabarna).

The Zirc Basin is bordered by numerous smaller fragments (to the N: Bocskor Hill; W: Kő, Csengő, Kakas Hills etc.) of planated and exhumed horsts in summit position. The S and E boundaries (towards the Tés Plateau) are constituted by exhumed horsts in summit position (Álmos, Hagymás-tető and Tunyok Hills).

The Pénzesgyőr Basin is closed by the Som Hill (a horst in summit position) to the N, by the Iharos-tető (a semiexhumed horst in summit position) to the S and by the Kőrisgyőr Hill (an exhumed horst in summit position).

The Lókút Basin is separated from its E environs by an exhumed horst in summit position (Kávás Hill) and by horsts in summit position (Kőris Hill of Hárskút, Borzás and Papod Hills) from the Hárskút Basin to the S.

The Hárskút Basin (the central part of the Hárskút Plateau) is encircled by exhumed horsts in summit position (Mester-Hajag and Égett Hill) to the N, horsts in summit position to the W (Hajag) and E (Kőris Hill of Hárskút, Borzás and Papod Hills). On the S boun-dary horsts uplifted to summit position and exhumed (Gyöngyös, Kis-bükk, Kis-Fekete-erdő Hills) and semiexhumed horsts in summit position (Vejemkő) follow.

In the area of exhumed horsts in summit position (of Middle Cretaceous limestone) between the Zirc, Porva, Pénzesgyőr, Lókút and Hárskút Basins remnants of the inselberg type karst are common in patches of variable size and exhumed to various degrees. All the basins are lined with an almost uninterrupted loess mantle.

The Csehbánya Basin is encircled by the Hajag mass to the E and buried horsts in low summit position (Csiga Hill, Manc Hill of Ganna, Nyúl, Kerék and Öreg Hill) to the S and W. To the N, it is separated from the Bakonyjákó Basin by the Hallgató Hill.

Waters from the non-karstic terrains of the basins are collected by water-courses with superimposed-antecedent valley sections (mostly karst gorges) along the basin margins. The Porva Basin is drained by the Hódos-ér and the Hárskút, Lókút, Pénzesgyőr and Bakonybél Basins by the Gerence stream. (Part of the Hárskút Basin is drained by the Öregfolyás.) The water-course of the Zirc Basin is the Cuha stream and those of the Csehbánya Basin are the headwaters of the Séd and the Köves stream. Surface waters from the Bakonyjákó Basin flow into the Bittva stream. The Dudar Basin, presented below, is drained by the Ördög-árok, the Dudar and Gaja streams.

The Dudar Basin divides the Eastern Bakony into two parts: the Sűrű Mountain Group to the N and the Tés Plateau to the SE. The N section of the Sűrű Mountain Group is dismembered by some NE–SW tectonic grabens into rows of exhumed horsts in summit position (Örök Hill or Zörög-tető, Várbükk). The Csesznek Castle Hill is a semiexhumed horst in summit position. It is divided into two units by the superimposed-antecedent gorge of the Kőmosó into two parts. Its water-course drains the non-karstic surface in the tectonic graben S of the Castle Hill. In the S part of the mountain group semiexhumed (Sűrű and Kő Hills) and buried horsts in summit position (Magos Hill) occur.

On the Tés Plateau, particularly along its S margin, marked hills rise, which are either horsts in summit position or exhumed horsts in summit position (Öreg-Futóné, Kis-Futóné, Téses-tető, Márkus-szekrénye, Vár-berek and Sár-berek). The central part of the plateau gently slopes to the N and dissected by NW to SE superimposed „hanging" valleys. The loess mantle has been preserved both in the valleys and on interfluvial ridges in thicknesses of several metres. (The water-courses of the plateau margin could not reach the plateau or only retreat to a small degree.)

To the E the Baglyas–Iszka Hills group of horsts (in threshold position) are separated from the Tés Plateau by the Bakonykút Basin. (The group of horsts looks upon the Mór Graben.) To the N the Tés Plateau is bordered by the Kisgyón–Balinka Basin, which extends to the Castle Hill (a threshold surface) to the E. The terraced valley of the Gaja stream forms a superimposed-entecedent gorge here.

Finally, the areas are listed where surface karstification is of remarkable rate:

- NW part of the Sűrű Mountain Group,
- the SW margin of the Dudar Basin,
- the Tés Plateau, the Porva Basin and terrains to the S (between Som and Kőris Hills and between Bocskor and Kő Hills),
- the N foreland of Kőris Hill (the Márvány-árok area), Kőris Hill,
- Tés Plateau, Lókút Basin,
- Pénzesgyőr basin (Kerteskő Gorge, the area above the Judit spring and Iharos-tető),
- Hárskút Basin and the blocks to the W and S (Égett Hill, Mester-Hajag, parts of Középső-Hajag in the vicinity of Fehérkő-árok, at Augusztintanya, the Homód-árok area, Kis-Fekete-erdő).

The extension of underground karst features is more difficult to determine. The streamsink-like or true streamsink caves formed during surface karstification, now inactive, are found in the areas enumerated. The same genetic type is represented by areas where karst processes were active at an earlier stage and thus they are left out from the list (eg. summit level of Nagy-Som Hill and Középső-Hajag). Some surface karst features are due to collapses of cavities and, therefore, should be mentioned under underground karstification. There are quite a few of such terrains in the mountains, for instance, N of the Porva Basin between the Hódos-ér and Bognár-árok (Dörgő Hill and Szent László-erdő) and in the Sűrű Mountain Group between the Ördög-árok and Kő-árok.

The caves of the mountains associated with non-surface karstification are primarily grouped in valley sides (particularly along sections of superimposed-antecendent origin). Citing only a few of them, the most typical are the following: Gaja Gorge, part of the Ördög-árok, Kő-árok, Kőmosó Gorge, Cuha Valley, Hódos-ér, several sections of the Gerence Valley, upper section of Szilfakő Valley (Középső-Hajag) and Öregfolyás Gorge (Kőszoros Valley). In addition to the above, there are a number of regressional-superimposed valleys (Burok Valley, Hálóvető-árok, Öreg-Szarvad-árok, Csalános-árok, Száraz-Gerence Valley) in the sides of which caves or smaller hollows also occur.

MAIN CHARACTERISTICS OF THE NORTHERN BAKONY KARST

Below those features of karstification are emphasized which differ from karst in medium-height mountains in general:

– Surface karst landforms most typically occur in summit level, while underground features are usually found in the sides of valleys incised into the blocks. (There are no or very few caves in the slopes of blocks.)

– The coupling of karstic and non-karstic processes is stronger than in the case of other karst areas. Karst processes influence non-karstic landforms and resculpture them and, at the same time, non-karstic processes also shape karst features further.

– Karst features (particularly surface features) are absent from the surfaces of rocks otherwise suitable for karstification. Surface karstification takes place over covered surfaces. The density of karst landforms is not too high and in size they are also behind landforms in the Bükk or Aggtelek Mountains of North-Hungary.

– Autogenic and allogenic karsts and karstification are not present in the mountains. (Cryptokarsts, however, are widespread. Buried karst features are also typical of the mountains or were common in the past. The products of this type of karstification, however, are only observed after exhumation.) As a consequence, ponors developed on rock boundaries, blind valleys, ponors (swallow holes) developed on valley rock boundaries and swallow sinkholes produced by retreating bathycapture are all absent. Corrosion sinkholes are also virtually absent. The surface karst of the mountains is characterized by features presenting the properties of both ponors and dolines (sinkholes) and fossil karst features are also common. Fossil karst features mean formations created by karstification in or reaching over to recent times, but not active, not developing at present.

– Caves are of small dimensions and occur at variable altitudes. Cave systems and erosional caves are equally absent from the mountains.

RESEARCH HISTORY

When summarizing the history of scientific investigations, the treatment is not restricted to the Northern Bakony since the individual authors do not present this part of the mountains in isolation. In the case of certain karst phenomena (eg. karst water) it is not even possible or to the purpose.

Mentions of the Bakony karst date back to very early times. According to NÉMETH (1965), the Odvaskő Cave was mentioned in a donation document in 1330 and according to BERTALAN (1977) as early as 1037. The first description of a karst object derives from BELIUS (caves of Som Hill – BERTALAN 1963b).

Actual research, however, began at a much later date. The history of investigations in the mountains is presented in the following sections:

- karst water,
- paleokarst,
- underground karst features,
- surface karst features,
- general characteristics of karstification.

Karst water

Beginning with the 1930's the investigation of karst water conditions has been most intensive. Among the publications on karst water a pilot study was prepared by JASKÓ (1935), who did not only describe the Tapolcafő springs very thoroughly but provided evidence for the existence of a uniform karst water table in the environs of the springs. Several authors studied the karst water system of the mountains and its borader environs and a single communicating system is assumed (HORUSITZKY 1942; SZÁDECZKY-KARDOSS 1948). In the Transdanubian Mountains, including the Bakony, a middle karst water niveau (main karst water) and karst water storeys are identified (SZÁDECZKY-KARDOSS 1942; PAPP 1942). Karst water storeys above the main karst water are described, for instance, above main karst water. Research, however, have been focused on main karst water: the temperatures and compositions of springs issuing from main karst water are analysed (VADÁSZ 1940, SZÁDECZKY-KARDOSS 1941); the regional extention and altitudinal conditions of main karst water are surveyed and from the collected data the first karst water table maps are constructed (VADÁSZ 1940; SZÁDECZKY-KARDOSS 1941, 1948, 1950; KÁLMÁN–PETHŐ 1950). The papers also deal with the directions of karst water movements in the mountains. It is regarded probable that karst water does not only emerge in springs and bogs along the mountain margin but also transferred to the sediments of the neighbouring basins. From the temperatures of certain marginal karst springs the conclusion is drawn that water from the middle karst water zone reaches the mountain margins through the deep karst zone (LÁNG et al. 1962). The role of non-karstic (covered karst) surfaces in karst water recharge is recognised. JASKÓ (1959a, 1961) describes gorges in the Bakony Mountains as ponors and this view is supported by measurements. JASKÓ (1959b, 1961) finds water seepage in the channels of several water-courses in the Bakony (Cuha Valley, Ördög-árok). This is confirmed by the measurements by BRATÁN–MOHOS–ZSUFFA (1967) in the Kerteskő Gorge. (At 600 l/sec discharge ca 75 per cent of the water of the Gerence stream infiltrated.) The catchment areas of major gorges and annual amount of water swallowed in the gorges (ca 8 000 000 m^3 - SCHMIDT ELIGIUS–LÁNG–OZORAY 1962) are identified.

The extension of sequences containing main karst water and karst water storeys is delimited (JASKÓ 1961). It is described that main karst water is stored in „Hauptdolomit", Dachstein and Dachstein-type Liassic Limestones, the aquifers of karst water storeys are Alban Requienian, Upper Cretaceous Hippuritic and Middle Eocene Nummulitic Limestones, while karst water storeys below the main karst water occur in Megyehegy Dolomite, „Muschelkalk" and Füred Limestone. The flow conditions of main karst water and changes in karst water table are studied in detail (BÖCKER 1972) and subsidence of karst water table as a result of mining are investigated (SÁRVÁRY 1971). Establishing a network of observation wells (BÖCKER 1977), detailed and reliable maps of karst water table have been prepared in recent decades. With the abundant data, attempts have been made to construct a model of the main karst water system (SZILÁGYI 1976; CSEPREGI 1995).

Paleokarst

In the Transdanubian Mountains several stages of karstification have been identified: Tithonian-Aptian, pre-Senonian, pre-Eocene, pre-Oligocene, pre-Pannonian and neokarstification (VÉGH 1976). The paleokarst landform assemblage was first mentioned by FÖLDVÁRI (1933), who claimed that the manganese ore at Úrkút and Eplény accumulated in pre-Eocene dolines. Dolomite pulverisation is also regarded a consequence of paleokarstification. The paleokarst landform assemblage is particularly well exposed in and described from quarries and mines. The paleokarst landscape has been described in numerous papers (BÁRDOSSY 1977; BÁRDOSSY–PATAKI–NÁNDORI 1983; PATAKI–NYIRŐ 1983; MÉREI–ERDÉLYI 1989) and exhumed paleokarst landforms have also been studied (SZABÓ 1966; VERESS–FUTÓ–HÁMOS 1987; VERESS–FUTÓ 1990; VERESS 1991). The buried paleokarst of Triassic dolomite (Megyehegy Dolomite) in the mountains, Which developed on the Triassic surface and was later covered by younger Triassic limestone (Berekhegyi Limestone), has been studied by KORPÁS (1999):

BULLA (1958, 1964) and LÁNG (1952) interpreted the surfaces of blocks at various elevations as planated surfaces of various age. Their starting point was that tropical peneplanation was continuous from the Upper Cretaceous to the Middle Miocene. During the prolonged peneplanation, however, karst landforms must have been destroyed entirely. According to PÉCSI (1980, 1991) tropical planation ceased by the end of the Cretaceous. As a consequence, a peneplain with conical karst developed and its dissection began in the Upper Cretaceous.

The oscillating movements and burial of blocks favoured the partial preservation of the paleokarst landform assemblage. On exhumed blocks karstification could resume but this time outside the tropical belt. According to SZABÓ (1956), this primarily resulted in cavity formation. SZABÓ (1956) claims that fossilised karst features did not activate in a later stage of karstification. Consequently, the landforms resulting from a recent stage of karstification cannot be considered further developed varieties of the products of older karstification periods.

The various authors have described the following paleokarst features:

- karstic plains, peneplains (SZABÓ 1956, PÉCSI 1980), tower karsts and planated karsts (BULLA 1968);
- paleopoljes (SZABÓ 1956, 1966), denudation poljes (BULLA 1968);
- basins bordered by dolomite hillocks (VADÁSZ 1946);
- shallow and deep dolines (PATAKI 1983) and steep-sided dolines (SZABÓ 1956);
- composite dolines (BÁRDOSSY–PATAKI–NÁNDORI 1983);

- cockpits, where bordering cones are arranged in irregular patterns and tropical maze-like depressions, where cones are arranged in rows (VERESS 1998);
- saucer-like depressions formed by subsequent denudation (SZABÓ 1956, 1966);
- shafts (VERESS–FUTÓ–HÁMOS 1987);
- dolomite hillocks (VADÁSZ 1951), conical elevations or various shape and size further sculptured by subsequent denudation, buried or exhumed (SZABÓ 1966; VERESS–FUTÓ 1990; VERESS 1991);
- dolomitic barriers (VADÁSZ 1951), dolomitic crests (SZABÓ 1966);
- karst hills on a common base (fengzong type inselberg karst – VERESS 1998);
- cavities, passages (SZABÓ 1966, VÉGH 1976) or solution horizons in two levels developed in two stages (late Jurassic to Lower Cretaceous and Eocene–Helvetian) above each other (JAKUCS 1977).

The presence of various paleokarst features is explained by changes in climate and thus in the nature of karstification (SZABÓ 1968) and also by different rates of denudation (SZABÓ 1966; VERESS 1998). The variation in paleokarst features could be apparent, resulting from various degrees of exhumation (VERESS 1991, 1998). Regarding the rate of exhumation, VERESS (1998) identifies buried cones being exhumed (hillock with cover sediments), cone under exhumation (carbonate rock outcrops on the hillock, the surface slopes in three directions towards the environs with cover sediments) and semiexhumed cones (the surface slopes in alldirections from the carbonate rock outcrop towards the environs with cover sediments).

A genetic classification of paleokarst landform asseblage was made by SZABÓ (1966) and it was confirmed by data collected from bauxite exploration and mining (PATAKI 1983). In SZABÓ's system karstification produces a karstic peneplain (intermountain plain) encircled by cones. Further away from the cones, over higher surfaces in the initial stages of karstification a landscape with depressions filled in by bauxite develops. The dolines filled by red clay or redeposited gravels, however, developed during Tertiary (post-Eocene) karstification stages (JUHÁSZ 1988).

Using modern terminology (BALÁZS 1986), the former landforms correspond to the fenglin type of inselberg karst and the latter to the fengzong type of inselberg karst. Information collected on terrains of Middle Cretaceous rocks suggest that the fengzong type inselberg karst, being composed of compound structures with a common base (subsequently truncated to various degrees), is heavily dissected. The sizes and shapes of depressions between mountains shows great variation (VERESS 1998).

Underground karst features

The inventory and documentation (locality, access, size, properties of enclosing rock, spatial pattern) of caves in the Bakony (including the Northern Bakony) are initiated by BERTALAN (1935), who continued this work for decades (BERTALAN 1938, 1943, 1955, 1962, 1972, 1977; BERTALAN–SZOKOLSZKY 1935). He describes caves with open entrances. Most of them are karst features of various size in valley sides, cave remnants (see below) but vertically developed objects (avens or aven-like shafts) and ponors or ponor-like objects also occur in his inventory. In a separate work BERTALAN (1958) deals with caves of non-karstic origin in Hungary, including the main parameters of and references to non-karstic caves in the area of the Northern Bakony.

Approximately in the same period, other authors also published papers on similar topics (FÖLDVÁRY 1933; JASKÓ 1936). In the 1960's and 1970's various cave exploration groups carried out remarkable work in the inventorying and exploration of caves (MARKÓ 1960; Alba Regia BKCs. 1976a,b, VERESS 1979a).

In the 1960's BERTALAN became interested in the history of cave exploration and published documents on the exploration of major caves in the Bakony (BERTALAN 1963a,b). Some caves are surveyed and documented in detail (KASSAI 1963; HORVÁTH 1963).

A comprehensive investigation is performed in the caves of the valley sides around Csesznek (VERESS 1980a,b, 1982; VERESS–PÉNTEK–HORVÁTH 1992a,b). Here development in the zone of karst water and origin by cavern exposure.

In the 1950's paleontological and archeological research began in several caves (ROSKA 1954a,b; VARRÓK 1955; BERTALAN 1962). Compared to expectations, the achievements in archeology are rather modest. Some finds (eg. from Pörgölhegy Cave) proved to be forgeries (VÉRTES 1965).

Another type of the Bakony caves is represented by those which had to be opened artificially for exploration. Most of them are active karst conduits of streamsink caves. Their exploration and description was accomplished by cavers' groups (Tés Plateau, Papod-Hajag Mountain Group, Kőris Hill, the environs of Csesznek and areas outside the Northern Bakony, like Kab Hill).

The various opinions on the origin of caves in the Northern Bakony (or the whole of the Bakony Mountains) are summarised below.

The vertical shafts directly opening to the surface are truncated remnants of karstic water conduits (HEVESI 1991b; VERESS 1991, 1993). It is mentioned here that LÁNG (1958) and BULLA (1964) regard the Nagy-Pénzlik and Kis-Pénzlik caves of Som Hill and the Ördög-lik of Kőris Hill to be caves of thermal origin.

The vertical shafts opening from surface karst landforms and are active water conduits even today are of corrosional origin (VERESS 1982a). As far as the origin of the streamsink-like caves of the Tés Plateau is concerned, in addition to erosion (KORDOS 1984), some of them (eg. Alba Regia Cave) also indicate corrosion at least in some stage of development (ESZTERHÁS 1983). In this cave corrosion is attested by chimneys on the ceiling of the main branch as well as the trough-like depression on the floor of the corridor. In the same cave, however, erosional origin is probable from large dimensions and the fact that a considerable portion of the main corridor formed in a calcareous marl intercalation (ESZTERHÁS 1983). The members of the Alba Regia Cave Exploration Group, who explored caves on the Tés Plateau, could not associate the erosional stage in cave evolution with the overall geomorphic evolution of the area.

On the origin of the short caves with horizontal axes in valley sides (cave remnants) the following opinions were sounded. The remark has to be made here that most of the researchers regard these karst features – with the exception of som non-karstic cavities – ruined remnants of older major caves or caverns (VADÁSZ 1940; BERTALAN 1962; VERESS 1980a,b, 1981a, 1982b; VERESS–FUTÓ 1987; HEVESI 1991b).

In the opinion of TOMOR-THIRRING (1934) and HEVESI (1991b) these karst features are tributary branches to caves, the main branches of which are exposed and form valleys (gorges). The cave origin of gorges, however, can be excluded not only because the valleys are of superimposed nature (LÁNG 1958, JAKUCS 1971a) but because most of the watercourses could only have limited catchments in the minutely dissected mountains. Watercourses with small catchments could not form caves of several kilometres' length to be expected from the lengths of the gorges. The morphology of gorges do not support this view either since there are no rock arches, streamsink dolines or remnants of former swallow holes are missing.

According to BERTALAN (1955), some of the caves resulted from seeping waters.

BERTALAN (1955), JASKÓ (1959) and VERESS (1981a) emphasize the role of geological conditions (faults, stratification, bedding plane, lithological variation) in their development.

ESZTERHÁS (1981) claims that caves in Burok Valley were not formed by karst processes but frost shattering and insolation weathering contributed to their development. It is undoubted that in the case of some caves non-karstic processes could have an exclusive (like pseudotectonics or erosion) or a complementary (frost shattering) role (BERTALAN 1962; VERESS 1981a).

In the opinion of VADÁSZ (1940) and VERESS (1980a,b) valleys deepening into the zone of flowing karst water exposed the caverns which developed there. A similar evolution through cavern exposure is described by KEREKES (1948) from Bükk Mountains. In this zone infiltration from water-courses on valley floors mixes with flowing karst water and – through mixing corrosion – increases the intensity of cavern formation (VERESS 1980a). It is to be noted here that excavations support this kind of evolution. From the fills of caverns of various size in valley sides (eg. Tekeres Valley rock niche, Southern-Bakony) quartz gravels and dolomitic debris reworked by water-courses was recovered (BERTALAN–KRETZOI 1962).

LEÉL-ŐSSY (1987) cites the Ördöglyuk (correctly: Ördög-lik) cave of the Sűrű Hill, which belongs to the above group, among caves of thermal origin. As in the case of the caves in Som Hill, already mentioned, thermal origin can be excluded – not only in view of the geological evolution of the area but also because of the lack of thermal water features and the spatial location of caves.

For some caves (Törkü-likak and Hódasér through cave) where – on the basis of features – solutional origin is hardly disputable, BERTALAN assumes erosional origin.

According to LEÉL-ŐSSY (1987), some caves, eg. the Odvaskő Cave, are spring caves. The same cave is described by GERGELY (1938) as a streamsink cave. The landforms of the cave and its environs (together with two neighbouring cavities) indicate that it is an exposed cave remnant.

LÁNG (1962) mentions eroding spring caves in the sides of elevated planated blocks W of the Cuha stream. Author's opinion is that eroding caves in faulted escarpments must have also formed through subsequent unroofing. An evidence to this is the lack of travertine accumulation in the foreground of these caves (similarly to caves opening in valley sides).

Surface karst features

Several authors deny the decisive role of surface karst features in the landscape of the mountains (LÁNG 1958; BULLA 1964; LEÉL-ŐSSY 1987). Their opinion may be motivated by various reasons:

– The inventory and description of surface karst features began rather belated and have not been completed to this day.

– Karst features are of small dimensions.

– Karst features do not form an extensive and continuous zone. The reason for this is the covered nature of blocks on the one hand and the wide distribution of dolomites and relatively impure limestones.

The surface features of the Bakony karst are first reported on by the father of Hungarian physical geography, HUNFALVY (1864): „The mountain plateaus locally show karst-like phenomena; there are swallow holes and sinkholes and from some ruptures rich springs issue forming entire streams which often disappear again under rocks." He regards the Tés Plateau a karst area but emphasises the peculiar features of the karst („in fertility they are very different from the karst on the Istrian Peninsula").

Researchers engaged in the study of the Bakony karst describe the following karst features. (In author's opinion most of them use the terms denoting morphological types in other areas, that is the reason why the essential points of karstification in the study area could not be grasped completely.)

The distribution of dolomite with the corresponding features is remarkable in the mountains. Under temperate climate, however, dolomite weathering differs from limestone weathering and the resulting features are also different. Dolomite weathering has been studied by JAKUCS (1971a,b, 1980, 1994), who claims that, affected by cold water, due to the dissolution of calcite, dolomite disintegrates into fine products (pulverised – JAKUCS 1971a,b, 1994). On the dolomite surfaces of the Northern Bakony the present-day erosion of existing landforms (dry valleys and conical hillocks) takes place through mechanical weathering.

Karren are mentioned by several researchers (LÁNG 1958; LEÉL-ŐSSY 1987; HEVESI 1991b) but described only superficially. This is not surprising as karren in the mountains are of small size and of less marked type, subcutanous karren (mostly root karren). A comprehensive description of karren is provided by LÁNG (1958) from the W margin of the Fekete-Hajag (Középső-Hajag). In his opinion karren form on outcropping strata and karren formation and mechanical weathering combine to cause the parallel retreat of the surface leading to a stepped escarpment.

The depressions of the covered karst of the mountains are described as ponors or dolines by various researchers.

GERGELY (1938) identifies ponors ponors and dolines from various parts of the mountains (Tés Plateau, the area between Zirc and Csesznek). Loess karst phenomena are also mentioned from the area of Zirc and Porva. (Here he may have misinterpreted covered karst features.) He recognises fossilised covered karst features (Kőris Hill, Tés Plateau) and uses popular names for them: the smaller is called by locals „kálistó", the larger „förtés".

RÉVÉSZ (1947) provides a good description of covered karst on the Tés Plateau and around Hárskút. In his opinion the karst features of the Tés Plateau (38 ponors are mentioned) are composite landforms: the upprt parts are bell-shaped (doline), while the lower are funnel-shaped (ponor). The development of the covered karst feartures derives from the collapse of the cavern in place of the funnel-shaped part. Forty depressions are mentioned in the Hárskút area and the subsequent subsidence of cover deposits is emphasised here. He claims that both dolines and ponors occur in the mountains. He describes that a „kálistó" is only partially a natural festure. The depression itself is of natural origin but premanent ponds can only exist in them if impounded artificially. He also deals with sedimentation associated with activity: around the flat funnel of 3-4 m diameter of the Bükkös-árok on Tés Plateau 30-40 cm deep accumulations are observed in a 30 m circle.

The transitional nature of covered karst features was recognised by LÁNG (1948), who writes about dolines being transformed into ponors. He mentions the overflow of water from dolines conducted further by a „surface water-course" (correctly: valley). In his opinion there are few true ponors in the Transdanubian Mountains. he outlines the morphological and functional characteristics of covered karst depressions in the Northern Bakony. Abandoning the above karst moprhological typology, he differentiates between ponors (on the Tés Plateau) and dolines (around Pápavár) in the mountains (LÁNG 1958). No further details, however, are supplied on this type of karst depression.

BERTALAN (1955) mentions surface karst landforms from many places (from the environs of Csesznek, Fenyőfő and Lókút) and calls them ponors. Occasionally he points to their origin in loess or to their transformation. (Around Lókút he describes senile ponors and one filled with sediment and being transformed into a doline.)

VERESS (1982a) calls the covered karst depressions around Hárskút – using LÁNG's (1962) terminology – dolines-with-ponors, allowing evolution into a ponor proper. Changing his opinion later, however, he claims that dolines-with-ponors cannot develop into true ponors, only the increasing activity of some varieties (VERESS 1986) manifest such a trend. A doline-with-ponor is a transitional landform of covered karst. Since dolines-with-ponor do not form along rock boundaries as conventionally described in karst research (JAKUCS 1968, 1971a; HEVESI 1980, 1986) and, thus, they are not true ponors. At the same time, they are not typical dolines either since they have a water conduit function. Their development does not take place through surface erosion characteristic of dolines (JAKUCS 1980; ZÁMBÓ 1987, 1993; VERESS–PÉNTEK 1990, 1996) since they continue in well developed chimneys of corrosion origin in carbonate rocks. The corrosion origin of chimneys excludes erosion, ie. the erosional stage of development typical of conduit passages belonging to ponors formed along rock boundaries (JAKUCS 1971a). As a consequence of bathycapture (JAKUCS 1971a), the evolution of surface valleys on typical allogenic karsts is displaced underground but it is not observed for dolines-with-ponor. Even if this covered karst landform develops on the valley floor, it contributes to further valley evolution in the way that runoff on the valley floor reaches the chimney and increase the rate of dissolution. Over valley floors of gentle slope with loess fill conditions do not favour the erosional development of chimneys. This landform type is widespread in the mountains.

Classifying surface karst features, HEVESI (1991b) distinguishes between blind valleys ending in loess, in red clays and in subjacent ponors and dolines (Nagy-Som Hill) and shallow incipient dolines (on the Tés Plateau).

In author's opinion the reasons for classifying covered karst depressions of „doline-with-ponor" type either as ponors or dolines can be the following:

- It was not recognised that surface karst features are not formed along rock boundaries.
- The sediment accumulation at the bottom of karst features often made them similar in shape to dolines.

The morphology, activity, evolution, filling deposits and origin of covered karst landforms are studied by FUTÓ (1980a,b); VERESS (1982a, 1984a, 1986, 1987a,b, 1995); VERESS–SAJTOS–FUTÓ (1990); VERESS–PÉNTEK (1995a,b).

In recent years mostly manuscript reports were prepared on covered karst objects not yet described or inventoried from various parts of the mountains (KÁRPÁT 1974, 1977, 1978a,b, 1979, 1980; SZOLGA 1975, 1979; Alba Regia BKCs. 1976a,b; NÉMETH 1976, 1989; KOCSIS 1979; VERESS 1979b, 1980c, 1981b,c, 1984b; VASKOR 1983, 1986, 1988; JAKAB 1986; ESZTERHÁS 1985).

Several authors have described area of interior or poor drainage from the mountains (GERGELY 1938; LÁNG 1958; SZABÓ 1966), which are more extensive compared to karst features. A common characteristic of these areas that they may include several covered karst features. They are common on dolomite terrains but also occur on limestone. Certain terrains with no drainage are described as paleopoljes by SZABÓ (1966). The survival of old poljes exclusively through inheritance is not very probable and they are supposed to be rather rare landforms. A more common way for the development of such features can be compaction and material removal in depth accompanying recent karstification in the study area (VERESS 1998).

The gorges or gorge-like valleys or valley sections in the mountains are, according to LÁNG (1958), of superimposed-regressional (Ördög-árok, Kő-árok and Kőmosó) or superimposed-antecedent (Gaja Gorge) origin. In addition to those listed above, superimposed-antecedent valleys are certain sections of the Hódos-ér, Öregfolyás and Cuha and the Kerteskő section of the Gerence stream. Opposing the views of LÁNG, however, the Kőmosó Gorge as well as parts of the Ördög-árok and Kő-árok are also referred to this group. One of the conditions to superimposed-regressional and superimposed-antecedent valley formation is cavitation below valley floor. At the same time, superimposition of valleys favours cavern formation (VERESS 1980a).

General description of karstification in the mountains

Various researchers often hold confronting views on the nature of the karst and particularly of surface karst in the mountains. Opinions agree on the low rate of karstification and on the different character of karst features here compared to those on the Aggtelek Karst. The reasons proposed for the explanation of variation are the following.

According to RÉVÉSZ (1947) the Bakony Mountains are dominated by covered karst terrains. In places where the cover sediments are permeable, the subsidence of the limestone surface is inherited over the surface of cover sediments.

LÁNG (1958) makes the recent uplift of the mountains responsible for the moderate degree of karstification.

In the opinion of LEÉL-ŐSSY (1959) the minute dissection of the mountains prevented a more developed karstification.

BULLA (1964) explains the poor development of karst features with the terrain being a low-lying surface until the Lower Pannonian also buried under a thick sequence of non-karstic cover sediments.

Analysing the development of karst, JAKUCS (1968) claims that the absence of bathycapture is due to the properties of cover sediments. Impermeable cover sediments could prevent the development of water conduit passages and provide favourable conditions to valley incision to the karst water table. As an example, the Cuha Valley is cited. It is to be noted here that the rapid incision of valleys, made possible by the extensive catchments over covered karst terrain, works against the occurrence of bathycapture as the passages already developed are destroyed by the erosional incision of valleys. The slow rate of karstification is explained by JAKUCS (1977) with the destruction of karst features formed previously and with the formation of newer and newer surfaces on newer and newer carbonate rocks. Thus, the karstification effects could not cumulate on the present-day surfaces.

KÁRPÁT (1974) identifies two phases of karst development on the Tés Plateau: an older one with open karst development and and a more recent (present-day) one with covered karst development. In the case of the older stage the superimposed valleys and water conduit passages (streamsink caves) prove allogenic instead of autogenic karstification. The presence of cover sediments and older allogenic karstification is evidenced by (redeposited) gravels in karstic depressions (VASKOR 1983).

KÁRPÁT distinduishes two phases of karst development on Kőris Hill: in Phase 1 ponor formation and erosional cavitation is characteristic, while in Phase 2 the ponors buried under loess in Phase 1 are reactivated and additional covered karst landforms develop. Although there is no morphological evidence of Phase 1 on Kőris Hill, in other parts of the mountains (eg. Som Hill or Tés Pateau) a development similar to the one outlined by KÁRPÁT has occurred.

In the view of VERESS (1983) horsts elevated to summit position and exhumed (altitudes of 421–450 m) are affected by karstification and karst processes of slower rate are observed on horsts in summit position (581–620 m). Because of the mosaical distribution of these types of plantated surfaces, the rate of karstification is also unevenly distributed. Out of the mentioned types of planated surfaces only those (parts) are affected by karstification where the underlying karstic surface is uneven and buried under cover sediments (VERESS 1991).

HEVESI (1991a) explains the karstification properties of the mountains partly with repeated burial and partly with the fact that on horsts of limited areal extension no drainage could form - even under buried conditions. Therefore, in lack of bathycaptures, there are no karst valleys with rows of swallow dolines. Although elsewhere he mentions ponors from the mountains (HEVESI 1991b), author shares his opinion that bathycapture is not characteristic of the present-day karstification of the mountains. The lack of bathycapture, however, cannot be explained by missing surface drainage which is found on several blocks. JUHÁSZ (1988) writes about a well-developed drainage in the area.

METHODS

Author's investigations covered the following areas (**Fig. 2**): the Hajag–Papod Mountain Group or Hárskút Plateau (karstic terrain along the Homód-árok, central part of the Hárskút Plateau or Hárskút Basin, Mester-Hajag, Égett Hill, the environs of Augusztintanya, the area above Judit spring), Som Hill, Kőris Hill (first of all, the area of the Márvány-árok), Dörgő Hill and environs (the area between the Hódos-ér and Pápalátókő), Ördög-árok, margin of Magos Hill, Kő-árok, Kőmosó Gorge, Cuha Valley and parts of the Tés Plateau (Tábla Valley).

Observations and documentation

Observations involved surface karst features, the phenomena of their activity and underground karst objects.

Activity phenomena were monitored between 1978 and 1984 in the central portion of the Hárskút Plateau (Hajag–Papod Mountain Group). Various phenomena (flood pond, overflow, hidden activity etc.) were recognised and identified. The monitoring of phenomena allowed the description of recent sedimentation processes in karstic depressions, the classification of sediment types and the interpretation of their development.

The features developed in cover sediments as a consequence of the karstification of underlying sediments were observed. The assemblage of corrosional features in chimneys formed in the prolongation of covered karst depressions were observed and documented. The ruined chimneys filled with soils and redeposited cover sediments were also identified.

The study of the assemblage of corrosional features and landforms in cover sediments helped author explain covered karst features, while the investigation of recent sedimentation processes allowed the analyses of fossilization. The tree-trunks in the depressions of the covered karst, often buried to their foliage, contributed to the recognition of intensive accumulation in such depressions. It was useful for the interpretation of both activity and fossilization.

The mass movements significant in the accumulation and material transport of karst depressions were recognised from the curving and tilting of tree-trunks.

The landform assemblages of valley sides (Ördög-árok, Kőmosó Gorge, Magos Hill, Kő-árok) were observed and mapped. Some properties of caves (like hanging position, several

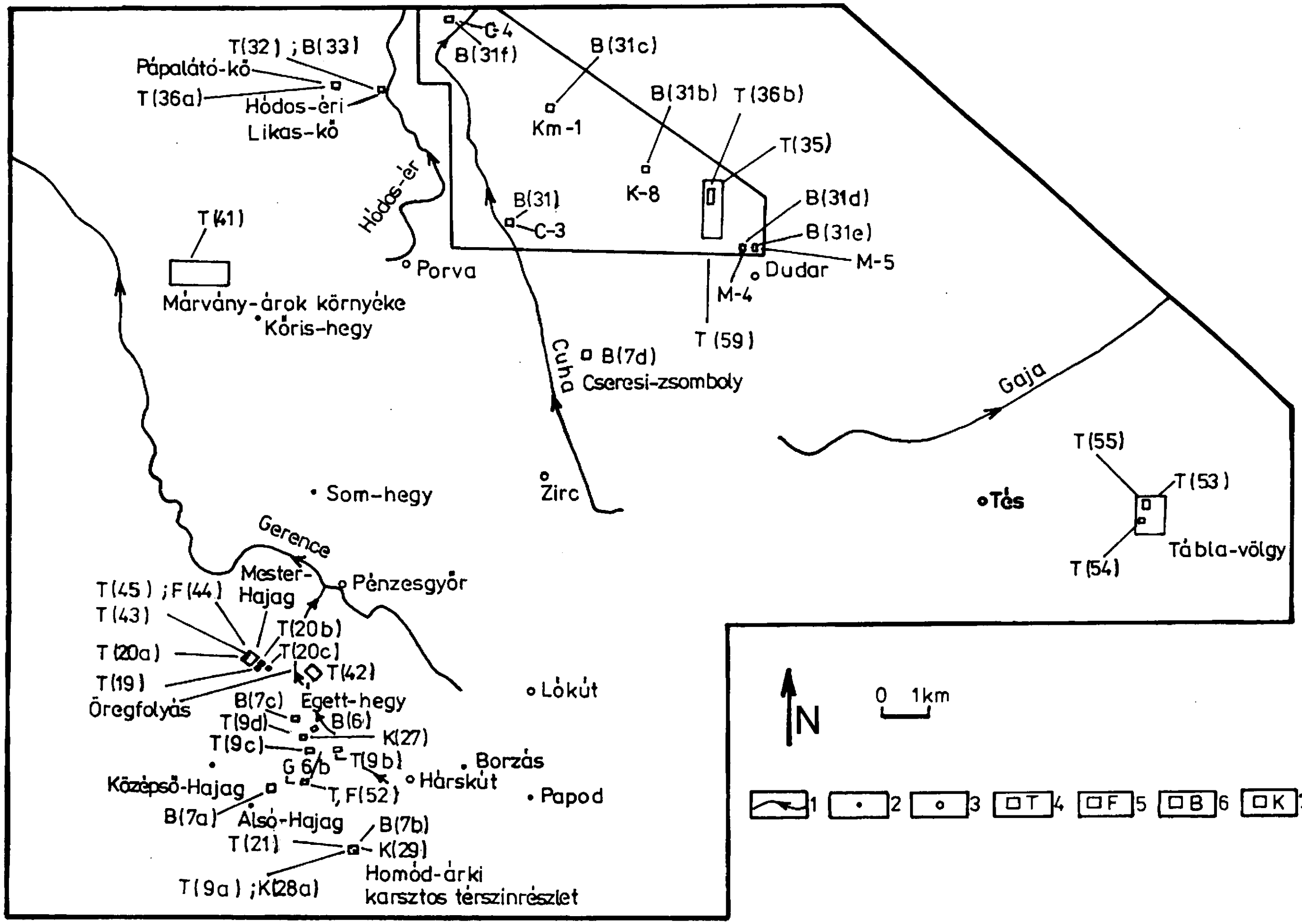


Fig. 2. Mapped areas in Northern Bakony

Legend: 1. water-course; 2. hill; 3. settlement; 4. karst topographic and karst morphological map, longitudinal section; 5. map of underlying rock; 6. cave map; 7. exploration pit entrances, damaged ceiling) their remnant character was proved. The spherical niches recognised in the caves allowed conclusion for their place of origin (zone of flowing karst water). The spherical niches observed in many places in the rocky valley sides supplied evidence to the entire destruction of exposed caves and to their contribution to valley formation.

Mapping

Maps of various scale and themes were prepared for the karst of the mountains.

Mapping surface karst features

– Several karstic depressions were surveyed and represented on 1:50 or 1:100 scale karst topographic and karst morphological maps. Cave maps were drawn on the conduits of covered karst depressions and interpreted.

– Surface karst areas were surveyed by tachymeter and mapped for karst topography (three subareas of Mester-Hajag, Égett Hill, karst terrain around the Homód-árok, environs of Fehér-kő-árok, karst terrain above Judit spring, two areas of the Tábla Valley environs on the Tés Plateau (at 1:250 or 1:500 scales). On the maps karst objects were represented using 0.5 m or 1.0 m contour intervals. These became the base maps for karst morphological mapping.

– Karst topographic maps were also made using 1:10 000 scale maps as base (for the Hajag–Papod Mountain Group and for the environs of the Márvány-árok). They were also developed into karst morphological maps.

– The above mentioned maps were developed into karst morphological maps in some cases. It means that the distribution and thickness of cover deposits were represented on karst topographic and karst morphological maps. This way, the surface of the underlying karstic sequence is mapped (eg. in the case of the karst objects Mb-50 and G-6/b).

The above maps are applied for the following purposes:

– to represent the distribution of karst objects and their relationships with other, non-karstic landforms;

– to analyse the properties and processes of karstification on individual terrains and to identify various types of karstification in the mountains;

– mapping the areas of karstic depressions, the landforms developed in cover deposits during the evolution of these features can be documented and thus data can be supplied to judge the role of cover sediments in karstification;

– to obtain data on chimney development in covered karst areas.

Mapping exposed caves and their remnants

– Maps of caves were drawn for several areas (Ördög-árok, Kő-árok, Magos Hill etc). Their interpretation shows that cave remnants are concentrated in valley sides at highly variable elevations above present-day valley floors. From the positions of caves relative to water-courses in the valleys conclusions can be drawn for the dimensions of cavities formed below the one-time valley floors.

– Destroyed cavities at various morphological positions were also mapped. These maps provided information for the clarification of processes of cave exposure and destruction.

Drawing profiles

– Profiles were drawn from topographic maps. The profile of the underlying limestone sequence was constructed along a section of the Öregfolyás Valley using data from outcrops and a well deepened into cover sediments on the valley floor. It was found that the valley formed in cover sediments filling the cone series. In its side an incipient exhumation of the cones is observed (from under the Csatka Gravel Formation). Consequently, the valley sides are composed of the slopes of exhuming cones.

The caves of the Ördög-árok are represented in the longitudinal section of the channel. The profile shows a scattering of caves and this excludes their origin as spring caves. It is also clear that scattering increases from the upper end of the valley towards the lower one. It can be only explained if the earlier developed lower valley sections are assumed to have even exposed cavities at lower altitudes.

Boreholes

More than a hundred boreholes were deepened by motor-driven spiral borer, often in some metres' intervals, into the cover sediments in the Mester-Hajag area, around karst object G-6/b and on the karst terrain along the Homód-árok. The interpretation of information from boreholes and the maps of underlying karst sediment surface provided the following results:

– In some boreholes (eg. in the environs of karst object G-6/b) the water table was reached. This indicates the lasting presence of water in cover sediments and allows the conclusion that even in periods without precipitation dissolution can take place in the karst chimneys of covered karsts (hidden activity).

– Karstic depressions are located where cover sediments are thinner (hidden rock boundary).

– Under cover sediments, over buried cones filled fossil surface karst features occur in higher positions than of now active unfilled karstic depressions. This is an indication of the shifting of sites of karstification.

– The composition of cover sediments on presently karstifying terrains points to karst processes active prior to the development of conical features but preceeding present-day karstification.

– The shifting of the sites of karstification and lasting karstification over the uneven surface of underlying rocks results in the removal of cover sediments in depth. The process produces spots of cover sediments where interior drainage develops (depressions).

– The carbonic sequences recovered from cover sediments provide further data for fossilization.

Exploration pits

With the assistance of the Cholnoky Jenő Karst and Cave Exploration Association and students of geography, exploration pits were dug in karstic depressions (Gy-9, Hu-1, Hu-7, G-6/b, G-10, G-12, G-14); in several sites of Mester-Hajag, in three „wallows" of the karst area along the Homód-árok and in some collapse dolines of Dörgő Hill.

Exposing the sediments filling karstic depressions, the sedimentation accompanying fossilization, the way of deposition (eg. the dips of strata decrease towards the top of the sequence, there are lenses of intercalations locally), sedimentation structure (eg. laminite), sediment types (plant detritus series, charcoal series, limonite concretions) can be detected. The roots of some curved trees in the side of a karst object (Gy-9) were excavated and they were found to have adjusted to the strain produced by mass movements.

During the excavation of collapse dolines rich assemblages of corrosional features (spherical niches, ruined chimneys) were found on limestone surfaces. The rock fragments of small thickness recovered from fills mey derive from the ceiling of the cavity. Truncated fragmetns of ceilings also occur in the sides of collapse dolines in some places. The morphological evidence confirms the collapse origin of these landforms. Corrosional features are identified at several decimeters' depth from the limestone surface (ie. the present-day surface). It allows the conclusion that cavitation took place close to the limestone surface and this means that the karst water table of the flowing karst water zone was close to the present-day surface or may have even located above it. The gravels found in some chimneys of summit position or in caves (like in cave M-7) clearly indicate that during cavitation it was a covered karst.

Measurements

The investigations also involved measuring the geological properties of mass movements and of the enclosing rocks and their statistical processing.

Mass movements

In order to measure mass movements in cover sediments, rows of piles were placed down to ca 30 cm depth in the sides of some karstic depressions of the central Hárskút Plateau. Displacements were measured related to the outer piles. During repeated measuments the direction between two outer piles was set by tachymeter and displacement was calculated from the distance between the measuring pole (placed in the fixed direction) and the pile. Measurements have been made at karst objects like G-5/a for more than 10 years (repeated twice annually in approximately the same time of the year). In some places displacements reached rates of 1-2 cm per year.

Remeasuring the distances between trees in some karstic depressions (Gy-3 and Gy-9), author wanted to obtain new data on the activity and rate of mass movement. Repeated measurements, however, did not indicate changes in distances between trees. In these depressions rapid accumulation was observed. The conclusion was drawn that as a consequence of accumulation the material transport in covered karst depressions was being rearranged or the input gradually reduced.

Comparisons between the spatial positions of chimneys and enclosing rocks

The investigations involved the comparative study of the spatial patterns of chimneys (water conduits) of surface karstic depressions and structures formed in the enclosing rocks.

In the case of vertical chimneys the dip of enclosing rock was less than 10-20°. Such chimneys formed at the intersection of fractures. When intersections occurred close to each other, chimneys developed in each other's immediate vicinity. When dip was above 10-20°, the spatial position of the chimney coincided with the spatial position of the stratum, ie. the chimney developed along a bedding plane. In case of steeper dipping strata, if the rock is properly fractured, composite chimneys develop. Composite chimneys are built up of oblique sections (developed along bedding planes) and vertical ones (developed along fractures).

Comparative statistics of alignments of cave remnants and dips of enclosing rock strata

Most of the cave remnants in the valley sides around Csesznek were formed along bedding planes. The frequency distribution of differences between cave alignment and dip direction were calculated for 66 caves. The χ^2 test of the obtained data was made by BARTA.

The question was asked: among the cavitation alignments directed along dip (0° difference), along strike (90° difference) and opposite to dip (180° difference) which are accidential and which are regular. It is remarked that the 0° difference category included values from 0 to 60°, the 90° category those between 60 and 120° and the 180° category direction differences of 120–180°.

The calculations resulted in a 99.0 per cent probability of 0° direction difference compared to 90° and 99.9 per cent probability compared to 180°. 0° direction difference has a significant frequency compared to the other two direction differences. The direction difference 90° does not have a significant frequency compared to 180°.

Therefore, the water dissolving caves in the valley sides around Csesznek must have arrived from the direction of their entrances. Since they open to valley sides, it is claimed that the rocks (and their cavities and cave sections) along whose bedding planes waters produced cavities have been partly removed by erosion. Consequently, the caves formed through the exposure of enclosed cavities.

Direction frequency investigation of collapse dolines

The collapse dolines of Dörgő Hill and Szent László-erdő are classified into circular, elongated wide and elongated narrow collapse dolines. The circular collapse dolines (n=22) are located close to the rock boundary between Middle Eocene limestone and Triassic „Hauptdolomit”. The elongated wide (n=10) and the elongated narrow (n=6) collapse dolines are further away from these rock boundaries.

The widths and alignments of collapse dolines points to the widths and alignments of cavities from which they developed. Cavity width and alignment, however, indicates current conditions of the karst water producing the cavities. The widths of cavities (collapse dolines) reflects a plan view of karst water movement, while their alignments a cross-section.

The widths of collapse dolines decrease away from the outcropping rock boundary. The reason for this is that in the vicinity of the rock boundary karst water movement is horizontal, while it is gradually becoming subvertical moving away from the boundary. During horizontal movement broad and low cavities form due to dissolution along bedding planes and along the boundary of Middle Eocene limestone and dolomite. Vertical water current produces narrow but high cavities through dissolution along fractures.

The flow system can be explained in the following way. The flow directions of karst water near the actual surface are closely determined by the relief between the terrain surface and the dolomite surface. The less cavernous dolomite has a lower permeability and, therefore, closer to its surface the karst water in the cover sediment would increasingly flow in lateral direction. Since the Triassic dolomite surface is rather uneven, the dolomite surface sinks lower and lower below the terrain surface moving away from the surface outcrop (rock boundary) and, parallelly, the nummulitic limestone cover grows ever thicker. (Assuming a more or less uniform rate of denudation, this was the case too when karst water table was close to the present-day surface.)

The standard deviation of the longer axes of collapse dolines has been studied statistically. Minimum standard deviation (S=0,67) was found for narrow collapse dolines, followed by the value for wide collapse dolines (S=0,83) and for the circular collapse dolines (S=1,27).

The above distributions can be interpreted in the following manner. Closer to the rock boundary, where karst water flow is horizontal, theoretically the current can take any direction. Therefore, the cavities formed by the current may have variable alignments. Away from the rock boundary the more and more vertical movement follows the fracture pattern of the nummulitic limestone. Thus, the alignments of cavities are controlled by fracture lines. Cavitation along fractures cannot produce such a wide range of fracture alignments.

Laboratory analyses

The material deposited in flood ponds on the plants of karstic depressions was analysed and found to be colloids. Sedimentation in flood ponds was modelled. It was investigated how the coarser (hair) and finer (foam) materials deposit on the sides and floors of basins during water subsidence of uniform, growing or changeable rate.

Theoretical approaches

The methods and laws described in the literature on karst were applied to the covered karst and karstification of the mountains.

– The role of rock boundary in karstification was investigated by JAKUCS (1956, 1971a). Author introduced the concept of hidden rock boundary which marks those sites on covered karst where the thinning out of cover sediments allows karstification.

– The term bathycapture was first used by JAKUCS (1956, 1968, 1971). Although in the mountains studied there are no recent sites of bathycapture, over certain terrain (eg. on the Tés Plateau) present-day karst processes cna only be explained if previous bathycapture is assumed.

– Investigation covered karst depressions, the already described types of covered karst landforms were regarded (QUINLAN 1972; JENNINGS 1975, 1985; BULL 1977; BÁRÁNY–JAKUCS 1984).

– When studying paleokarstification and recent karstification, the data collected during various research were relied upon (SZABÓ 1956, 1968; BALÁZS 1984; FORD 1995).

Valley formation

Valley typology

A successful study of processes on covered karst is only possible if types of valleys developed on covered karst are identified. Based on literature (LÁNG 1958), field observations, analyses of geological maps and theoretical considerations the following types of valleys are distinguished.

– Well-developed superimposed valley: inherited over the carbonate rock surface before loess formation. Within this type the following varieties occur:

The valley is not active any more; it has no or negligible catchment on covered karst; partly filled with loess or other redeposited cover sediment. Inactive well-developed superimposed valleys also have a variety without or with negligible fill.

There are also active well-developed superimposed valleys. These valleys receive an abundant recharge of water from the neighbouring non-karstic terrain even today. The group primarily includes gorges and narrow valleys. Although on carbonate rock surfaces part of the water from the water-courses of valleys is lost by infiltration, they still have a sufficient discharge for incision. (Valley floors can be at highly variable elevations above the karst water table, depending on the rate of valley incision related to the general uplift of the surface.) These valleys can be regressional-superimposed or antecedent-superimposed.

– A developing superimposed valley: locally cutting through cover sediments, superimposed or superimposed-regressional valleys reach carbonate rocks along certain sections.

Developing superimposed valleys could form on block surfaces covered by the Csatka Gravel Formation or older (eg. Cretaceous) cover sediments. Within this variety valleys occur with sections incised into the Csatka Gravel Formation and other sections in carbonate rock but their floors are mantled by loess in original deposition or redeposited.

Developing superimposed or developing regressional-superimposed valleys may also form on the floors of superimposed valleys. In this case, the developing superimposed valleys more or less consume the infilled floor of the older valley and their floors may locally reach carbonate rock. Double composite valleys are created this way. Sometimes on the floors of well-developed or developing superimposed valleys minor incision may produce channels called developing regressional-superimposed channels. As a consequence, some valleys in the mountains are triple composite landforms.

Valley formation and karstification

The inheritance of karst valleys over carbonate rock can take place before the formation of the flowing karst water zone (pregenetic valley), more or less simultaneously (syngenetic valley) and after that date (postgenetic valley).

Pregenetic valleys – if in their environs cover sediments are removed rapidly – become inactive even before their floor reaches the cavities of the karst water zone.

The inactive superimposed valleys which during incision have not reached the cavities of the flowing karst water zone are pregenetic valleys, while the ones which have are syngenetic or postgenetic valleys.

According to JAKUCS (1956, 1968, 1971) the surface water-courses of karst areas enter into the interior of the karst through valley floor ponors by way of bathycapture. Author distinguishes between true and pseudobathycaptures. True bathycapture occurs on true rock boundaries (where karstic and non-karstic rocks are in contact on the surface). The water from water-courses leaves through conduits which form in the zone of flowing karst water. Pseudobathycapture occurs along hidden rock boundaries (where limestone karstifies under cover sediments). In this case, water is conducted through chimneys created by water infiltrating from the surface through cover sediments and opening onto the valley floor (see below).

According to HEVESI (1980), bathycapture (in our classification: true bathycapture) can occur if the rate of karst water table subsidence exceeds the rate of valley incision. The valley floors of the study area, however, are in a hanging position above the karst water table and, to author's present knowledge, no recent bathycapture exists. A possible way of resolving this contradiction is to consider the type of superimposed valley and the altitude of the floor of the superimposed valley and of the upper limit of the cavitation zone (ie. the highest karst water table existed to date). Then the following cases can be distinguished.

– At the beginning, the karst water table is found at the elevation of the valley floor (syngenetic or postgenetic valley). Because of the more rapid subsidence of the karst water table the cavities in the flowing karst water zone develop into water-conducting passages and true bathycapture takes place. True bathycapture can occur when the karst water table was close to the surface of carbonate rock at the beginning of karstification and the inheritance of the superimposed valley happens in an early stage of geomorphic evolution. There is no such a geomorphological and hydrological situation in the mountains, in the initial stage of the present karstification period, however, it occurred in several isolated spots (eg. on the Tés Plateau, Som Hill and Hajag). The valley floor ponors formed by bathycapture have filled ap and fossilized by now.

– Superimposed valleys have not yet inherited over the surface or only partly (postgenetic valley) but valley floors are subsequently partly lined with cover sediments. Valley incision has stopped or slowed down considerably. The valley floor does not reach the cavitation zone of the flowing karst water zone. The water collected and running off on the valley floor may trigger karstification where cover sediments are thinning out (chimney development). From the intermittent or permanent water-courses of valley sections, water infiltrates into covered karst depressions (pseudobathycapture). The developing superimposed valleys of the mountains belong to this type.

The developed varieties of pregenetic valleys could have reached cavities of former karst water. At that time subsequently exposed cavities could occur in the valley side. On the valley floor, however, there were no bathycapture sites since in the active period of rapid valley incision potential conduits may have been destroyed (see below) or by the time bathycapture could occur, the valley had lost its water-course.

JASKÓ (1961) observed how water conduits are eroded. He describes a crack in the channel of the Vörös János-séd which tapped the water-course entirely (at 50 litres per minute discharge). There the upper part of the ponor funnel have been eroded entirely or could not form at all because of channel deepening. The lower part, the water conduit, could take shape and it can function as a ponor to some degrees. Bathycapture, however, is interrupted here as with lack of a surface depression the water-course overflows the site. Probably bathycapture can only be complete if a surface depression can form and more water is collected by the conduit, the passage can develop more quickly and the surface depression can widen. (Bathycapture is most probably the result of a positive feedback mechanism.) Bathycapture cannot happen if the cavitation zone lies close to the surface but it is of limited vertical extension. (Due to the periodically more intensive subsidence of the karst water table a new cavitation zone develops in greater depth or the evolution of a contiguous zone is hindered by the intercalation of impermeable strata.) In this case the incising valley can cut across the cavitation zone.

During inheritance several other factors may prevent bathycapture on the ever longer limestone valley floors. According to JASKÓ (1961), in the Cuha stream there is no seepage from the channel to the influence of the Borzavár stream since the Cuha carries a load of high clay content from the Zirc Basin and lines its valley floor. The lining is impermeable.

If incision did not reach the zone of flowing karst water, there are no subsequently exposed cavities in the valley side. It may occur that the floors of such valleys are subsequently lined by sediments. In this case, covered karst landforms can also develop on these valley floors.

– A well-developed superimposed valley is active and receives abundant water from the covered terrains of the enclosing or neighbouring blocks in the early stage of inheritance (syngenetic valley). Particularly in the superimposed-antecedent (to a lesser extent in the superimposed-regressional) valleys intense incision exposes and destroys cavities in the flowing karst water zone. Rapid valley incision and, as it has been mentioned, because of the continuous exposure and destruction of caverns and passages no bathycapture could take place. A large part of the water, however, seeps away. The water lost by seepage further increases cavitation (see below) and the rate of valley incision.

The different sections of valleys in the mountains vary according to the process of inheritance and thus in karstification. In the area of Hajag, for instance, the upper section of the Szilfakő Valley is a developed inactive superimposed valley, which exposes cavities in several sites. Along its lower section, in the central part of the Hárskút Plateau, however, the position of the enclosing block was lower and inheritance over limestone was of more moderate rate and the valley floor did not reach the zone of cavitation. Moreover, the valley was lined with unconsolidated cover sediments (mostly loess) or such sediments were preserved on the valley floor. Along the latter section of the valley the sites of recent karstification are associated with chimney formation.

KARSTIFICATION

Recent surface landforms in the mountains could develop independent of flowing karst water or their origin was bound in some way or another to karst water or to cavities formed by karst water.

COVERED KARST FORMATION INDEPENDENT OF FLOWING KARST WATER

Since water infiltrating from the surface and seeping through cover sediments motivated their development, karst features independent in their origin from flowing karst water came about through processes of hidden karstification. Cavitation due to flowing karst water can take place even under permeable cover sediments. The terrains covered by permeable sediments, where underground karst processes could or can be active are the buried karsts of the Northern Bakony.

Rock boundary and karstification

On buried karsts allogenic karstification can take place where carbonate rocks outcrop from below non-karstic cover sediments (unhidden rock boundary). Hidden karstification occurs where partly or entirely permeable cover sediments thin out to the extent that the percolating waters from surfaces at least partly covered by impermeable cover sediments (further: solution) is still capable of solution when reaches the karstic rock (hidden rock boundary). At the places where permeable cover sediments are thinning out, karstification is promoted by the following factors.

– Loess decalcifies in the vicinity of the surface. Thus, where it is thin, there is no or hardly any $CaCO_3$. Where loess is thicker, decalcification cannot be so intensive at lower levels. Therefore, under thicker loess series the solvent is hardly capable of dissolving the rock.

– At the beginning of accumualtion on the uneven carbonate surface, there is material transport from more elevated surface to lower-lying ones. Therefore, thinner covers are richer in clay. Piping adds to impermeability and it is also stronger in thicker loess mantles. Infiltrating water moves partly laterally in thick loess towards areas with thinner loess cover. Where loess is thinner, water collects not only from vertical infiltration but also from lateral seepage. Thus the buried elevations of the carbonate surface become sites of concentrated solvent recharge.

– It seems probable, however, that, in spite of this, where cover sediments are thinner, the limestone may also be affected by karstification but the resulting passages are filled by cover sediments. Therefore, the thicker are cover sediments, the shallower depression – possibly with outlet – can develop on the surface of the cover sediment. For this reason, most of the rainwater keeps on running off on the surface. Consequently, in the environs of the site where cover sediments are thicker, geomorphic evolution does not favour increased infiltration into the karst and this results in the stagnation of karst processes and in a final halt of karstification.

The intensity of karstification along hidden rock boundaries considerably depends on the recharge of water. This latter factor, however, is a function of the impermeable nature of the neighbouring surfaces. The growth of impermeability with time may be caused the already mentioned process of loess decalcification, compaction through piping and reworking. The spatial variation of impermeability results fro the occurrence of loess locally under the Csatka Gravel Formation or the variable contamination of the carbonate rock, but the intercalation of non-karstic rocks outcropping to the surface may also lead to increased impermeable character. Tectonic circumstances explain why Requienian limestone and munierian clay alternate on the surface. In this case, in Requienian limestone but along the contact between the two rocks, as a consequence of karstification on hidden rock boundary, a range of karst landforms may develop (VERESS–SAJTOS–FUTÓ 1990). The amount of solvent arriving at the rock boundary also depends on the geomorphological conditions prevailing on the covered karst terrain. With the same cover sediment, the larger surfaces (eg. valley sides) slope towards hidden rock boundaries , the more solvent could arrive to these sites. Therefore, geomorphic evolution prior to karstification and the resulting assemblage of landforms are of decisive role in the activation of potential hidden rock boundaries. The covered karst landforms developed on hidden rock boundary, however, do not have distinct catchments since they have not been formed through bathycapture of surface water-courses. After their development, there are no major changes in the slope conditions of the surface (the only exception is presented by depression formation) and part of rainwater runoff takes place on the surface bypassing covered karst depressions.

The terrains where permeable cover sediments are sufficiently thin but carbonate rocks do not outcrop yet are symmetric hidden rock boundaries, while those with carbonate outcrops are asymmetric rock boundaries (**Fig. 3**). At the same time, the uncovered smaller portions of carbonate terrain elevated above their environs are hardly affected by karstification, disregarding karren development (VERESS 1989, 1991; VERESS–FUTÓ 1990).

The local thinning of cover sediments (primarily loess or its reworked varieties) are caused by unevenness of deposition, erosion or accumulation. Unevenness of deposition depends on the topography of the basement surface of the underlying carbonate rock. The variation of basement may be casued by tectonic impacts (basement dismembered by fault scarps) or paleokarstification (basement dissection with cones and enclosed depressions – **Pict. 1** – VERESS 1991; VERESS–FUTÓ 1990). The strikes, lengths and degrees of dismemberment of various hidden rock boundaries and thus the sizes of areas capable of karstification, the surface pattern and frequency of sites suitable for karstification primarily depend on the unevenness of deposition of cover sediments, ie. from the topography of the carbonate basement.

The unevenness of deposition is not permanent, but changes with the balance of erosion and accumulation. Therefore, during erosion the hidden symmetric and then the hidden asymmetric rock boundary develops gradually over the dissected basement. With further erosion of cover sediments the rock boundary and thus the site of karstification is shifting. The steeper slopes border the landforms of the carbonate basement, the more vertical is this shift. During exhumation rock boundary and thus karstification is shifting upwards and during accumulation downwards (**Figs. 3, 46**). During exhumation, over terrain fragments higher lying than the neighbouring ones covered by cover sediments karstic features are truncated (**Pict. 2; Fig. 7**) or fossilized with accumulation. During accumulation, the already existing karst landforms are first fossilized and then buried. Truncated, fossilized or buried karst landforms may be suitable for the reconstruction of geomorphic evolution and tectonic events in the area (VERESS 1991).

In covered karst areas of the mountains surface karstification is associated with chimney formation (VERESS 1982a; VERESS–PÉNTEK 1995a,b). Where chimneys open to the surface, covered karst depressions are created. Chimney formation can expand in the rock mass. The present-day primary chimneys may have developed into secondary chimneys only partially. Therefore, chimneys are formed by solution (**Pict. 3**). Along the hidden rock boundaries of the carbonate basement, because of the increasingly impermeable character of loess and sloping surfaces, infiltration locally intensifies. This favours the penetration of solution several metres deep along water conduit lines (fractures, faults, bedding planes – **Fig. 4**). Cracks of small width and chimneys of small diameter develop (primary chimneys).

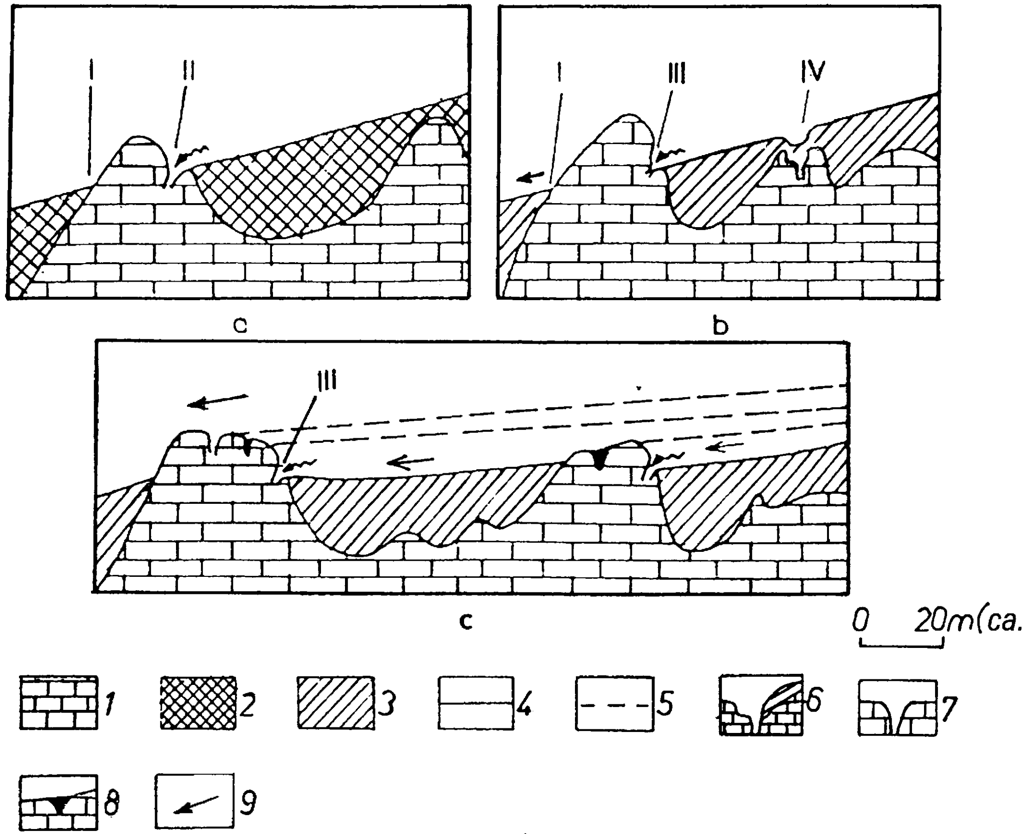


Fig. 3. Karstification on various rock boundaries in case of impermeable (a); permeable rock (b); and exhumation (c); (VERESS-FUTÓ 1990, modified)
Legend: 1. limestone; 2. impermeable cover sediment; 3. permeable cover sediment; 4. present surface; 5. previous surfaces; 6. active karst depression (ponor, doline-with-ponor); 7. inactive, destroyed karst formation; 8. inactive, filled karstic formation; 9. direction of transport; I. inactive rock boundary; II. active rock boundary, not hidden; III. active, hidden, asymmetric rock boundary; IV. active, hidden symmetric rock boundary

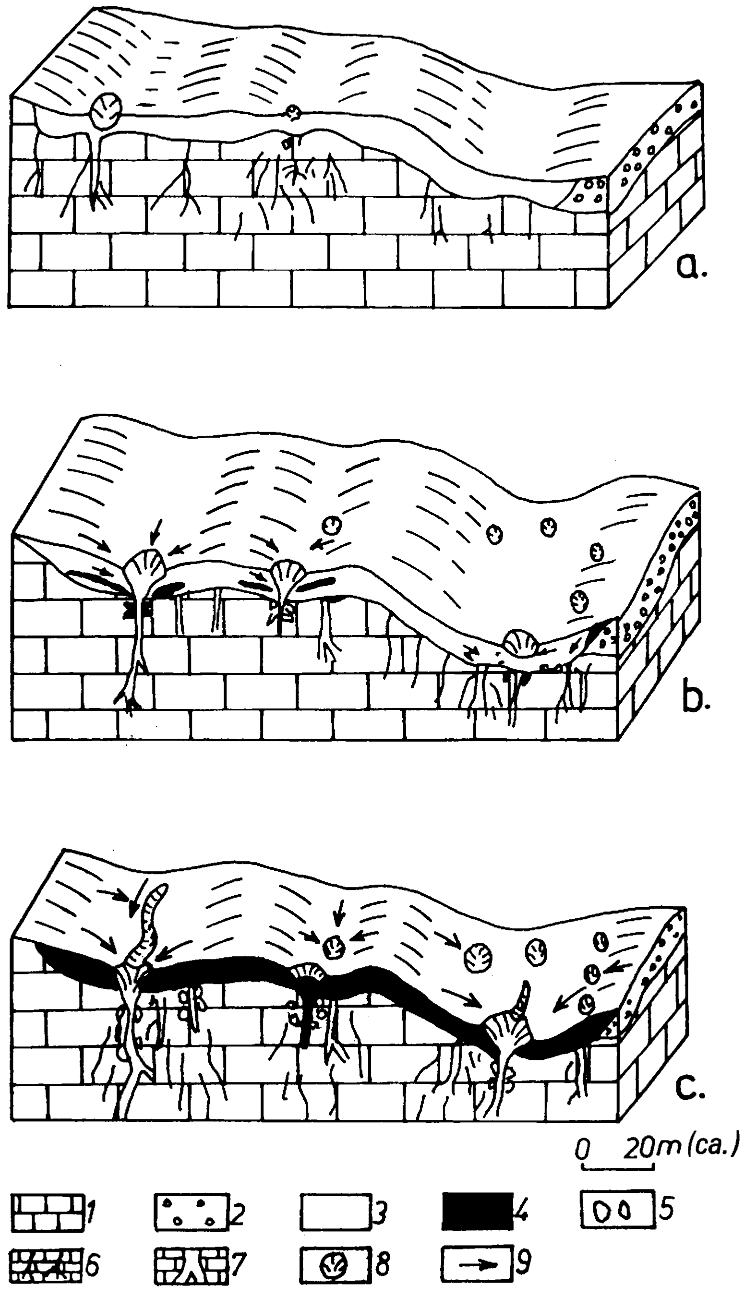


Fig. 4. Chimney formation: a. passage formation; b. formation of depression in cover sediment; c. formation of dolines-with-ponor (VERESS 1982a, modified)

Legend: 1. limestone; 2. gravel; 3. loess; 4. decalcified loess; 5. collapsed material; 6. primary chimneys; 7. secondary chimneys; 8. karst depression; 9. surface water-course and percolation above impermeable sediment

Chimney development

The upper parts of primary chimneys are filled by inwashed cover sediments. In the zone of filling development through solution stops as rock surfaces are sealed by a thin veneer of sediment. Below the zone of filling the chimneys and cracks further broaden through solution. The solution percolating through the fill does not saturate, its solution capacity can even increase with the uptake of biogenic CO_2. Chimney formation is a particular manifestation of surface solution on covered karsts. the covered karst features associated with chimney formation are genetically analogous with solution dolines. With the solutional merging of primary chimneys a secondary or blind chimney forms **(Pict. 4; Figs. 5, 6)**. In the rock, not only above and below the blind chimney but also around it, a zone of primary chimneys come about. The side-walls of blind chimneys are dissected by ruins of primary chimneys not affected by solutional merging **(Picts. 5, 6)**. The infilled primary chimneys above blind chimneys may reactivate when the clay fill is redeposited from their lower part into the blind chimney. For this reason, blind chimneys develop towards the surface. Through the solutional merging of bordering primary chimneys they may also widen. Subsidiary blind chimneys may also develop when within the zone of primary chimneys around blind chimneys local merging occur by solution.

Blind chimneys occur at the intersections of fracture planes or on rock boundaries. In the former case the stratification of the rock is less predominant and the dip of strata is low. In the latter case, the rock is well-stratified and the dip of strata is steep and the chimney itself becomes like a crack. The position of the developing landform accords with the spatial positions of the strata of the enclosing rock. Chimneys can also be composite. Then the chimneys developed at the intersections of fracture planes are connected by passages formed along bedding planes **(Figs. 7, 8; Table I)**.

The development of chimneys opening to the surface is accelerated by the growth of the duration of solution. It is promoted by the sediment accumulation in the surface depression which retards the rate of water recharge.

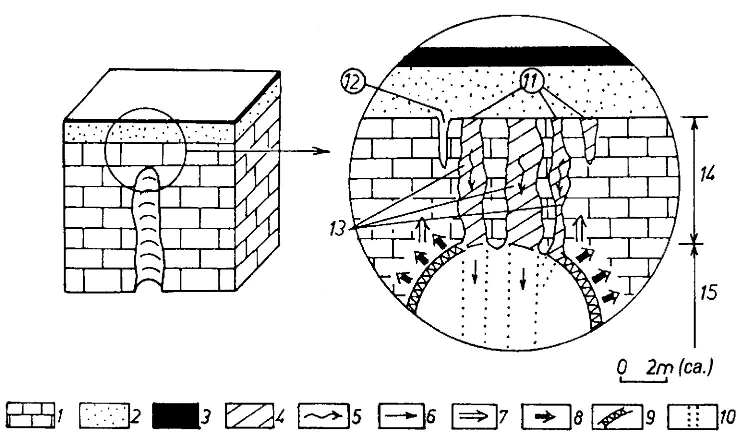


Fig. 5. Development of covered karst blind chimney (VERESS-PÉNTEK 1995b)
Legend: 1. carbonate rock; 2. permeable cover sediment; 3. soil; 4. redeposited soil and cover sediment in crack and chimney fill; 5. percolation; 6. rainwater; 7. chimney extension upwards through solution or collapse of dividing walls; 8. blind chimney broadening by solution of walls 9. water (solvent); 10. old dividing wall; 11. filled primary chimney, temporarily inactive; 12. unfilled active primary chimney; 13. biogenic CO_2 uptake; 14. zone of primary chimneys, 15. blind chimney

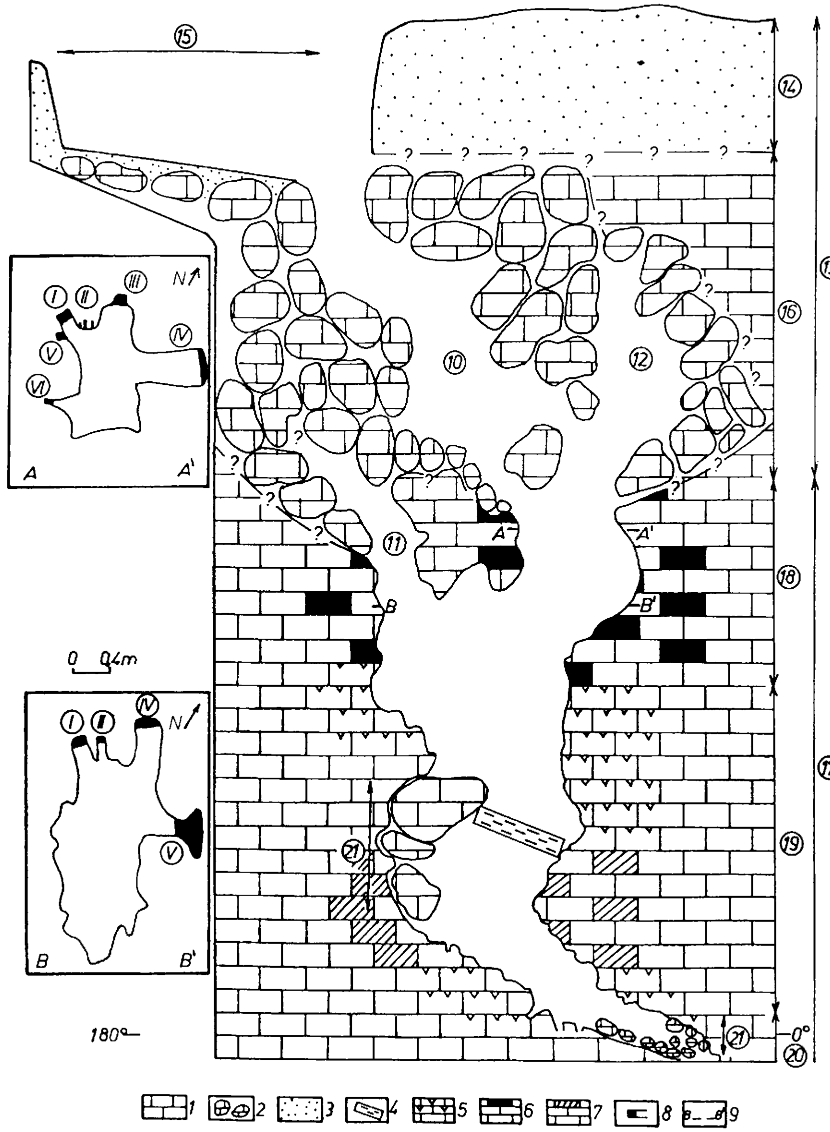


Fig. 6. Genetic map of chimney formed in Dachstein-type Jurassic limestone in covered karst **depression** Gy-12 (valley side of Öregfolyás) (subsidiary chimney turned into the plane of longitudinal section)
Legend: 1. limestone; 2. collapsed material; 3. cover sediment (loess); 4. wooden scaffolding; 5. zone of unfilled primary chimney ruins; 6. zone of primary chimney ruins filled with soil; 7. zone of primary chimney ruins partially filled with clay, redeposited quartz gravel and rock debris; 8. ruined primary chimney (identification symbol on cross-section) with soil fill; 9. location of section; 10. main (secondary) chimney; 11. subsidiary chimney; 12. subsidiary chimney (not yet inherited over the surface); 13. zone of exposure; 14. caving and subsidence in cover sediment; 15. surface depression formed by caving and sheet wash; 16. caving in the enclosing rock; 17. zone of blind chimney development; 18. zone of blind chimney extending upwards by solution; 19. blind chimney section formed by lateral solutional merging (collapsed material removed); 20. blind chimney section formed by lateral solutional merging, filled by collapsed material; 21. collapsed material in depth

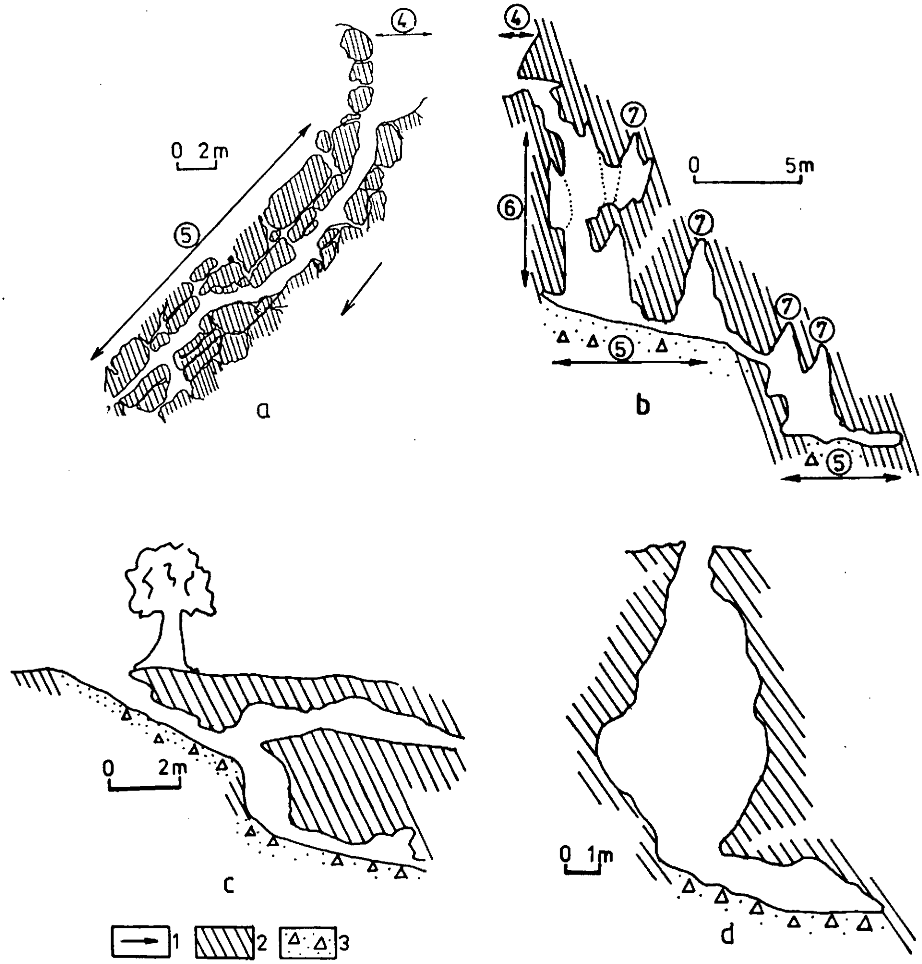


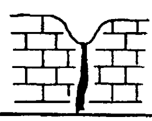
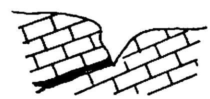
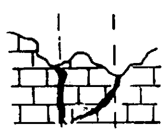
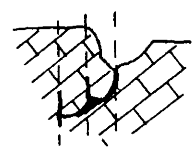
Fig. 7. Simple chimney (a) in doline-with-ponor G-5/a, composite chimney (b) in doline-with-ponor Ho-1 (Homód-árok area) and truncated chimneys in the Gyenespuszta cave (c) and Cseresi-zsomboly aven (d) (surveyed by KÁRPÁT 1977, figures b, c and d are from Reports for 1978, 1979 and 1984 of Cholnoky J. Caving Group)

Legend: 1. dip of enclosing rock; 2. enclosing rock; 3. soil, debris and other redeposited sediment; 4. doline-with-ponor; 5. chimney (section) formed along bedding plane; 6. chimney section formed along fracture; 7. blind chimney

The above outlined origin of chimneys is evidenced by the following observations:

– chimneys form where bedding planes or fractures intersect with the surface (surface waters infiltrate and dissolve along these surfaces);

– the spatial pattern of chimneys is adjusted to the spatial pattern of fractures and stratification (when eroded, for example, there would be no alternation of sections formed

position of beds of enclosing rock / fracturing of enclosing rock		dip increases: low dip (0 to ca 10°)	dip increases: high dip (ca 11 to ca 42°)
increasing number of fractures (fracture zones), individual fractures distinct ↓	low	I/a 1. circular, symmetric 2. in centre 3. chimney  Gy-3 doline-with-ponor	II/a 1. elongated asymmetric 2. on margin 3. oblique passage  G-5/a doline-with-ponor
	high	I/b 1. circular, symmetrical twin doline 2. in centre 3. chimneys and oblique passages  Gy-12 doline-with-ponor	II/b 1. elongated 2. on margin 3. chimneys and oblique passage  Ho-1 doline-with-ponor

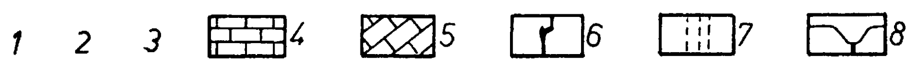


Fig. 8. Geological structure, chimneys and karst features (along the dip direction of enclosing rock, VERESS 1982a)

Legend: 1. shape of karst depression in plan and side view; 2. location of conduit in depression; 3. character of cave; 4. horizontally bedded limestone; 5. dipping limestone beds; 6. cave passage (secondary chimney); 7. fracture planes; 8. karst depression

along bedding planes and fractures);

- solution landform assemblage of chimney walls;
- primary chimney ruins filled by soils and redeposited cover sediments on the chimney walls (secondary chimney);
- the gradual narrowing of chimneys in the base rock;
- blind and subsidiary chimneys of various position, branching out from main chimneys;
- the presence of collapse material zone above the solution zone (it does not only indicate origin through exposure but also the peak of solution intensity being further away from the surface);
- the steep-sided depressions in cover sediments indicate the inheritance of the blind valley formed in carbonate rock into the cover sediment by collapse.

Table I.: Main geological parameters of chimneys, karst depressions and their enclosing rocks from the central Hárskút plateau (VERESS, 1982)

locality	geological parameters of enclosing rock				cave					shape of depression		position of conduit in depression
	direction of fracture or fault	strata			type	direction from entrance	vertical extension (m)	angle of passages to horizontal		planform	lateral view	
		direction of dip of strata	angle of dip of strata	thickness of strata (m)				single passage	share of sections of various slope from total length (%)			
Gyenes-puszta cave	305°	305°	15°	0,3–0,5	chimney, oblique passages	240° (a) 265° (b) 310° (c)	6	-	a 10° (33) b 14° (filled) b 30° (59) c 90° (8)	-	-	-
G-5/a stream-sink cave	?	192°	42°	0,55	oblique passage	196-204°	13 (1981)	42-48°	-	elongated, longer axis: 97-277°	asymmetrical	close to sleep wall
Gy-3 stream-sink cave (1)	?	170°	9°	1,1	chimney	340°	11 (1977)	-	8° (12) 90° (82)	rounded, slightly elongated, longer axis: 110-290°	symmetrical	central
Gy-12 stream-sink cave	177-357°	-	0-5°	1,2	double chimney	177°	16 (1981)	-	90° (100)	rounded	symmetrical	central
H-1 stream-sink cave	2-182° 134-314° 123-303°	11°	27°	0,7	?	140° (?)	6 (1978)	50° (caved in)	-	elongated, longer axis: 170-350°	asymmetrical	foot of rock wall
Ho-1 ponor (Ereszes-zsom-boly) (1)	?	115°	11°	1,2–1,5	series of chimneys with horizontal or oblique passages	120°	16 (1977)	-	15° (59) 50° (41)	elongated, longer axis: 170-350°	asymmetrical	foot of rock wall

(1): KÁRPÁT, 1977

Development of karst depressions

The counterparts of blind chimneys on the surface are covered karst depressions. Their shapes are controlled by blind chimney development and surface erosion. (If accumulate in considerable thickness, cover sediments probably fill in chimneys without the development of covered karst features on the surface.)

Above the chimneys extending towards the surface, the thin enclosing rock caves in. Collapse also affects cover sediments and on the surface depressions of interior drainage, steep-sided or broadening with depth, originate (**Picts. 7 and 8**). The explanation probably lies in the fact that, instead of solution on the limestone surface, a chimney forms in the karstic rock. While chimney development is a relatively slow process, the blind chimney caves in and cover sediments collapse rather rapidly. If chimney widening continues in the karstic rock, the surface landforms keeps widening through the subsidence of cover sediments.

Since rainwater from the environs collects in the chimney as solvent, the surface depression increases the intensity of chimney development. The genesis of a chimney and a surface covered karst depression mutually assume each other's existence and develop in close interaction.

If a chimney opening to the surface reaches a channel floor, pseudobathycapture happens.

If a single chimney forms at the intersection of fracture planes, a circular symmetric depression is created on the surface of the carbonate basement. If several chimneys develop in each other's immediate vicinity, twinned landforms originate on the surface (**Pict. 12**). If the main chimney is accompanied by one or more subsidiary chimneys which reach the surface relatively further away from the edge of the depression above the main chimney, there occur minor depressions next to the main one. If a composite chimney forms, the chimneys reaching the surface produce a row of depressions (VERESS 1982a). If the chimney formed along a bedding plane, the surface depression will have an elongated planform in the direction of the strike of beds and in cross-section its inclination is variable: the gentler side is composed of bedding planes, while the steeper side is of bed scarps. If the carbonate rock sequence contacts with a non-soluble rock (munierian series), in sculpting the steeper side retreat through solution (local corrosional scarp) may be also effective.

The side slopes of the surface karst feature formed in cover sediment may become gentler to the effect of sheet wash or they may be dissected by erosional gullies. Creeps also produce gentler slopes. Measurements indicate that their rates can be as high as 1-2 cm per year (**Table II**). On side slopes of depressions cavings and slides may generate scars. Mass movements are evidenced by curved tree-trunks in depressions (**Pict. 9**). In the intermittent ponds deposition flattens the floors of depressions (**Pict. 10**). On the fill secondary features, partial depressions (**Pict. 10; Fig. 9**) can occur (VERESS 1982a, 1987a). The development of these small-size depressions takes place by the collapse (above upward-extending subsidiary chimneys) or by the subsidence (transportation of passage fill into depth) in the cover sediments. Partial depressions may fill from channels formed on their margins and deepen again. The cycles of generation and regeneration of partial depressions is an indication of the interrupted character of the karstification process. Partial depressions may also form in the channels of the main depressions. This is caused by chimney development.

The formation of partial depressions and even of passages without partial depressions (**Fig. 9a**) results in the bathycaptures of intermittent water-courses in the channels. These are pseudobathycaptures on hidden rock boundaries (where cover sediments are thinning

Table II.: Mass movements in the sediments on side slopes of dolines-with-ponor G-5/a and G-9 (dislocations of stakes, cm)

Doline-with-ponor G-5/a

identification number	dates of checking																	
	1985. 8.24.	1986. 4.4.	1986. 8.18.	1987. 5.1.	1988. 5.13.	1988. 8.21.	1989. 7.18.	1990. 5.11.	1990. 11.14.	1991. 5.10	1991. 10.23.	1992. 5.7.	1992. 10.25.	1993. 6.5.	1993. 10.30.	1994. 5.27.	1994. 11.19.	1995. 5.28.
1	0,0	+1,5	-0,5	-0,5	-0,5	0,5	0,0	0,0	-1,0	+0,8	+0,5	+1,0	+0,7	+1,4	+0,8	+1,2	+0,8	+1,8
2	0,0	+2,0	+2,0	+1,2	+2,5	+1,5	+2,5	+1,4	+2,5	+3,6	+3,0	+4,0	+4,1	+4,4	+3,7	+3,9	+4,1	+4,2
3	0,0	+4,0	+4,0	+3,5	+3,5	+4,0	+4,5	+1,3	+3,8	+5,1	+10	+6,7	+6,4	+7,4	+6,9	+6,6	+6,8	+6,1
4	0,0	+4,5	+4,5	+2,5	+3,3	+2,5	+3,8	+2,7	+3,5	+4,2	+3,6	+4,6	+4,6	+4,6	+4,7	+4,7	+5,3	+5,4
5	0,0	+3,0	+3,0	+2,0	+1,5	+2,0	+3,4	+1,4	+3,0	+2,8	+3,0	+3,0	+4,1	+3,5	+3,0	+3,6	+3,3	+2,8
6	0,0	+5,5	+5,5	+3,5	+3,5	+3,5	+5,2	+3,6	+4,5	+3,9	+5,5	+4,1	+4,7	+3,8	+4,3	+3,1	+4,3	+3,6
7	0,0	+3,7	+3,7	+2,5	+1,5	+2,0	+4,4	+1,2	+3,7	+3,3	+4,1	+3,4	+4,4	+4,4	+4,1	+3,9	+3,5	+2,6

Doline-with-ponor G-9

identification number	dates of checking														
	1987. 5.2.	1987. 8.15.	1988. 5.13.	1988. 8.25.	1989. 7.17.	1990. 5.11.	1990. 11.14.	1991. 5.10.	1991. 11.23.	1992. 5.7.	1992. 9.25.	1993. 6.5.	1994. 5.27.	1994. 11.19.	1995. 5.28.
1	0,0	+1,0	-1,0	1,0	0,0	-1,0	-0,6	+0,8	+0,7	-0,5	+0,7	-0,6	-0,5	+0,5	+0,6
2	0,0	+0,9	-0,6	-0,1	-0,6	+0,7	-0,6	+2,0	+0,9	+0,4	+1,1	+0,6	+0,4	+0,8	+1,3
3	0,0	+2,5	-1,0	-0,6	-0,5	-0,5	-0,9	+0,2	0,0	-0,2	+1,1	-1,3	+0,5	+0,6	+1,6
4	0,0	+1,8	0,0	0,0	-0,2	+2,5	+1,0	+1,5	+1,2	+1,7	+2,8	+0,9	+2,5	+3,3	+3,2
5	0,0	0,0	-1,0	-0,7	-0,5	+0,7	-0,3	+0,4	+0,1	-0,2	+1,2	-0,6	0,0	+0,6	+0,6

Remarks

\+ values mean dislocations towards the interior of the depression
\- values mean dislocations in the opposite direction
negative values and deviation are explained by measurement error

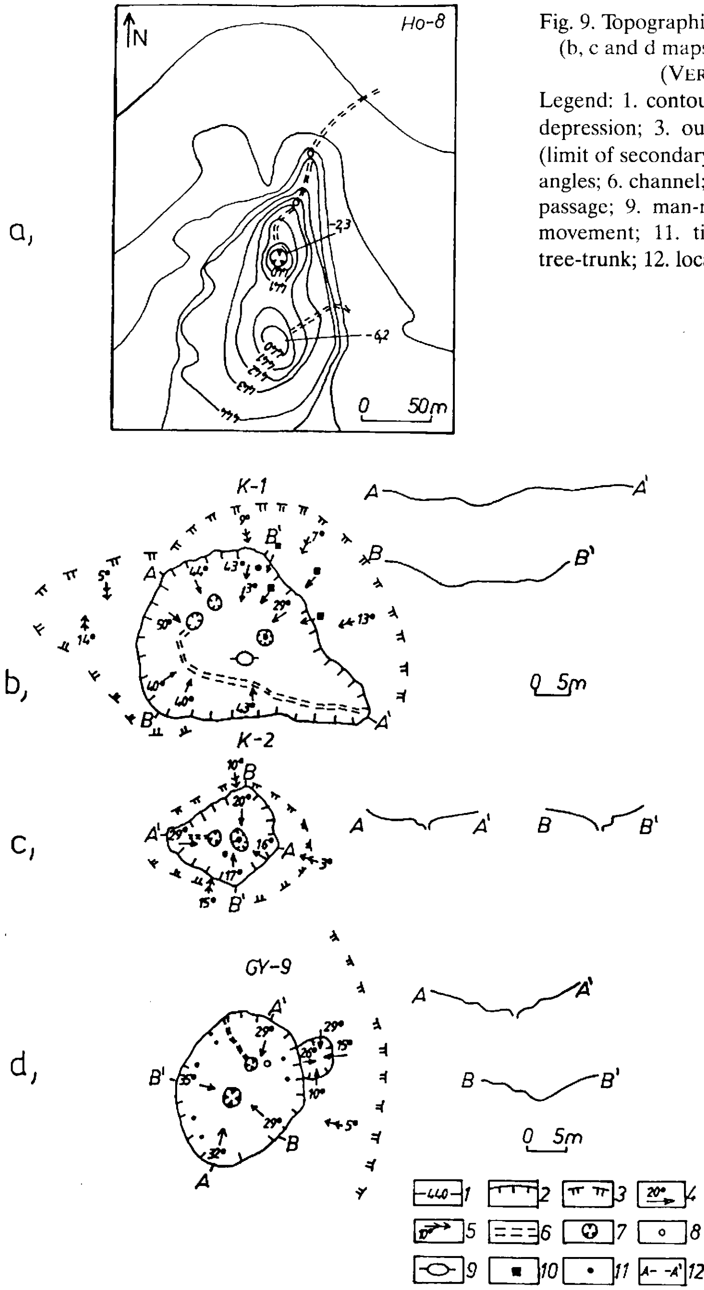


Fig. 9. Topographic (a) and morphological (b, c and d maps) of karst depressions (VERESS 1979a)

Legend: 1. contour line; 2. inner edge of depression; 3. outer edge of depression (limit of secondary subsidence); 4-5. slope angles; 6. channel; 7. partial depression; 8. passage; 9. man-made feature; 10. mass movement; 11. tilted, curved or buried tree-trunk; 12. location of section out). An evidence for this is that there is no difference between the activity of passages aligned in the channels and of partial depressions; consequently, sites of bathycapture does not show a retreat.

Human activities also exert an indirect influence on the development of chimneys and the surface karst depressions above them (VERESS 1984a). In numerous depressions intensive accumulation caused by human intervention is observed (around Hárskút, on the Tés Plateau). Accumulation is a result of forest clearing and cultivation, particularly on large scale. The influences are not simultaneous and may repeatedly occur for the same depression.

Accumulation increases the rate of corrosional development since water seepage in the sediment fill slows down. Corrosion of the chimneys is also favoured by the treeless environment of karst depressions filled by snow. This way not only more water reaches the chimneys but also the duration of solution can grow if snow fill lasts long.

Origin by solution and its evidence

On allogenic karsts ponors (JAKUCS 1971a) and on covered karst terrains covered karst dolines were identified (QUINLAN 1972). Ponors form on rock boundaries through the erosional transformation of cavities in the flowing karst ware zone by the water-course. On covered karsts a depression forms in the cover sediments owing to the matter deficit in the karstic basement resulting from karstification.

According to BULL (1977), the origin and morphology of covered karst landforms depends on the thickness and type of cover sediments and on the nature of karstification of the basement. The more cohesive is the cover sediment and the larger cavities are formed by karstification, the steeper landforms are created in the cover sediment and caving is more important in their origin. If the cover sediment is less cohesive and karstification involves surface solution, the slopes of the karst landform will be gentle and subsidence will be the decisive process.

It is to be noted that some authors (BÁRÁNY–JAKUCS 1984) do not refer depressions in cover sediments to landforms of karstic origin. This view reflects the concept that cover sediments do not influence the karstification of the carbonate basement; they are only passive objects of the process. In reality, cover sediments and carbonate basement are interactive systems during the process of karstification. The cover sediments are only passive if the limestone is a closed inactive mass and early developed cavities cave in to induce collapses in cover sediments.

Various authors (QUINLAN 1972; JENNINGS 1975, 1985) identify steep-sided subjacent dolines, gentle-sided subsidence and alluvial streamsink dolines on covered karsts **(Fig. 10)**. The generation of subjacent dolines is preceded by the caving of limestone cavities, which is also spreading to the cohesive cover sediments. According to BULL (1977), the development of various subjacent dolines is allowed by differential cavitation between the surface and a deeper horizontal cavern **(Fig. 11)**. Subsidence dolines form in unconsolidated cover sediments. In the case of subsidence dolines, the matter deficit resulting from the karstification of the basement results from the development of passages reaching to the surface of the carbonate rock (TRUDGILL 1985; JENNINGS 1985), while others (BÁRÁNY–JAKUCS 1984; HEVESI 1987) explain it with the surface solution of the karstic rock. During the generation of alluvial streamsink dolines, the cover sediment is transported by water from the sides of the developing depression into the passage system of the karst.

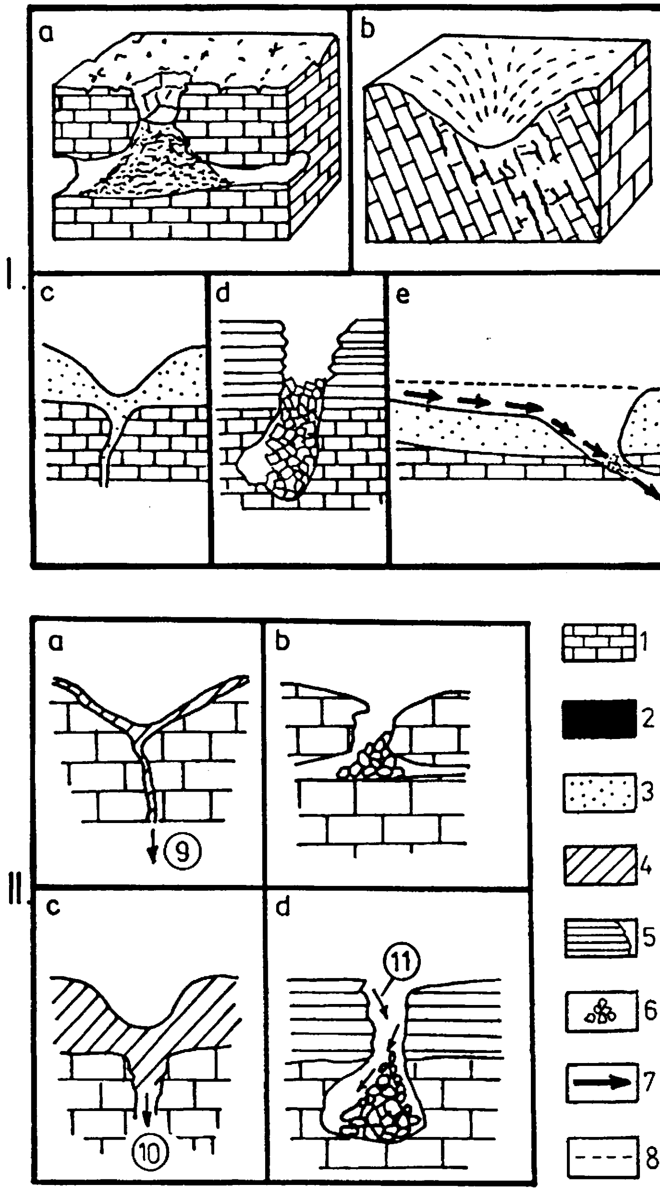


Fig. 10. Doline types, modified after JENNINGS (1985) (I) and TRUDGILL (1985) (II)
Legend: 1. limestone; 2. material deficit caused by solution; 3. soil and cover sediment; 4. soil; 5. cohesive sediment; 6. collapsed material; 7. water flow; 8. accumulation surface; 9. solution removal; 10. soil removal; 11. caving in; I.a. collapse doline; I.b. solution doline; I.c. subsidence doline; I.d. subjacent doline; I.e. alluvial streamsink doline; II. solution doline; II.b. collapse doline; II.c. subsidence doline (only for soil); II.d. subjacent doline

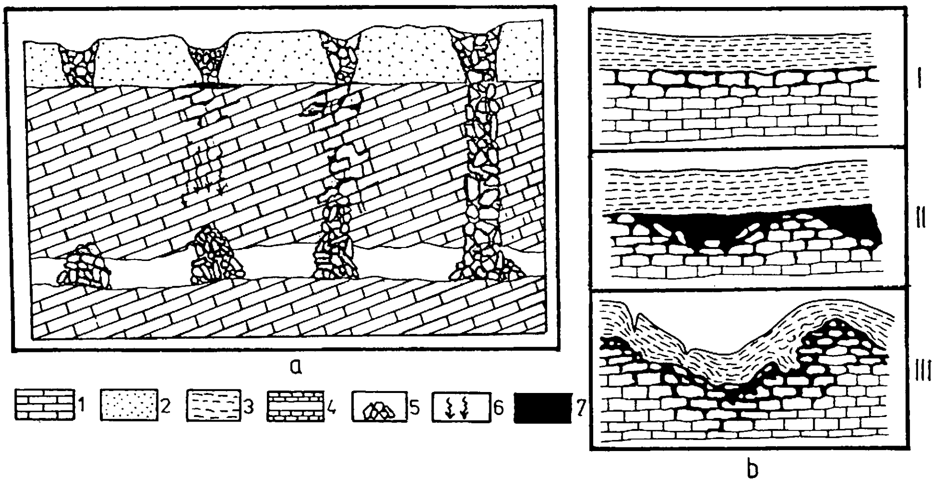


Fig. 11. Varieties of subjacent dolines and their origin after BULL (1968) and formation of subsidence dolines after BÁRÁNY–JAKUCS (1984) (b)
Legend: 1. limestone; 2. cohesive non-karstic rock; 3. permeable (cohesive or non-cohesive) non-karstic rock; 4. cave; 5. collapsed material; 6. water percolation; 7. material deficit caused by solution; I-III. phases

The chimneys of the covered karst depressions in the mountains did not form along a rock boundary and thus they are not of erosional origin. They cannot be referred to any of the above mentioned types of karst doline either. In the covered karst landforms of the study area the genetic properties of the individual doline types occur in a mixed form. Against the erosional origin of dolines the following arguments can be cited.

– The walls of the chimneys are overwhelmingly characterised by solutional features (**Pict. 3**).

– The chimneys are narrowing downwards and becoming impassable or separate into passages of smaller diameter (primary chimney). If the chimneys were of erosional origin, they should be associated with through caves or continue in subhorizontal cave passages. This is not the case and it could be explained by the insufficient or ineffective exploration of caves. Chimneys would not narrow down in the enclosing rock (as it is often observed) but in the sediment fill.

– In the environs of covered karst depression not located on valley floors the cover sediment is loess. In case of intensive water movement (a precondition of erosion) loess could not have been preserved on these terrains or only remnants could have been observed now. Today and even more so in the past, it is first of all loess and soils that are removed from the environs of covered karst dewpressions. Such materials are not suitable for efficient mechanical corrasion.

– The covered karst depressions are almost always show deep fills. The transported sediment can only reach the chimneys if they are open for short intervals. From the flood ponds (see below) of covered karst depressions formed during activity the coarser sediment load, more prone to erosion, deposits and the already deposited sediments seal the chimney and hinder the movement of later transported sediment.

– To several covered karst depressions no channel leads. In lack of channels such depressions cannot collect considerable amounts of water.

– Covered karst landforms do not result from the bathycapture of surface water-courses. The lack of bathycapture is proved by the fact that depressions not located on the valley floor – even if they have channels – are neither crossed by channels nor associated with blind valleys. The channels of covered karst depressions are much younger than the depressions themselves. Since from the margin regressional channels are created, the development of channels is associated with that of the covered karst depressions.

– True bathycapture cannot happen either at covered karst depressions on the valley floor. Where it takes place in superimposed karst valleys, the retreat of valley rock boundary makes the site of bathycapture in the direction of the head valley (Jakucs 1971). The ponors of former sites of bathycapture develop into ponors (Jakucs 1971; Hevesi 1980, 1986) and only the ponor closest to the head valley is active.

The covered karst depressions aligned on the valley floors in the mountains this regularity is not observed. It often occurs that if there are several karst depressions on the valley floor, more than one or even all of them can be active. This also applies to the situation when inside the karst depressions there are accumulations of cover sediments of considerable depth. Mostly this does not mean fossilization proved by the generation of further partial depressions on the basement with cover sediments.

In some valleys all covered karst depressions are active, while in other valleys active and inactive fossilized depressions alternate. It is also common that fossilized karst depression occur right along the upper sections of valleys, while along the lower sections all karst features are active.

For their origin, the covered karst depressions of the mountains are different from all the mentioned covered karst doline types and, therefore, the introduction of a new terminology seems to be necessary.

The differences are summarized in the following:

– In the study area cover sediments play a decisive part in the development of chimneys.

– While in the case of subjacent dolines cavities of various shape cave in and in the case of subsidence dolines the surface of the carbonate rock is affected by solution, in the study area vertically developed chimneys open to the surface.

– Both for subsidence dolines and for subjacent dolines depressions form in the cover sediments and are hardly observed in the basement.

Syngenetic and postgenetic karstification and its forms

In the karstic rocks of the mountains there are numerous corrosional or even erosional passages formed at various dates. The reason for this is the abundance of paleokarsts and also the faulted structure and variable topography, which allowed multiple redeposition of cover sediments. The unconsolidated rock (loess) is also suitable from this respect. Thus, in the same site the conditions of chimney development (hidden rock boundary) could have existed in several subsequent periods.

Therefore, the ages of chimneys, passages or surface depressions in their prolongation are not the same. Accordingly, the surface karst features of the mountains are classified to syngenetic and postgenetic karst features. The processes producing them are called syngenetic and postgenetic karstification.

Syngenetic karstification takes place when the chimney and the associated depression form simultaneously. The surface karst landforms originates from the upward extension of the chimney in the karstic rock.

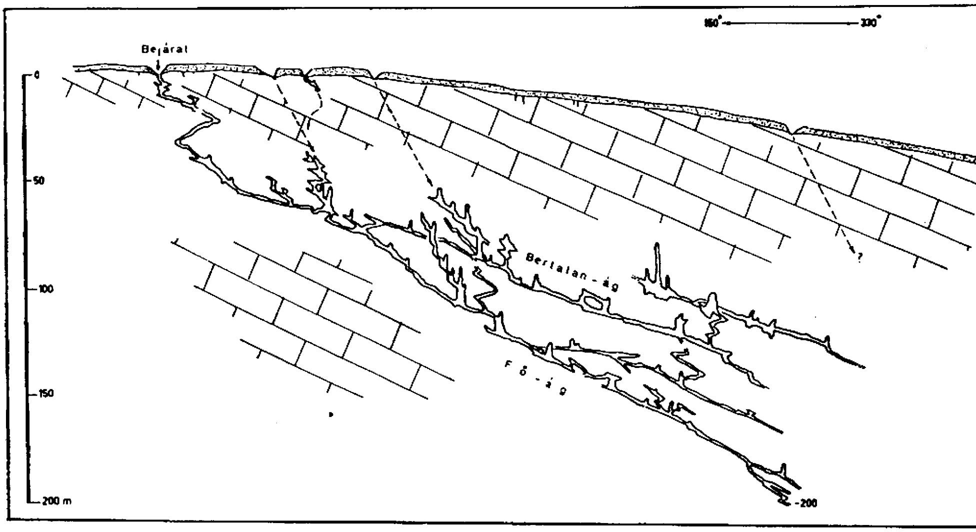


Fig. 12. Longitudinal section of the Alba Regia Cave (after KÁRPÁT 1982). Vertical sections of passages are probably chimneys formed by recent karstification and their extension is from the already existing main branch due to the effect of infiltrating water

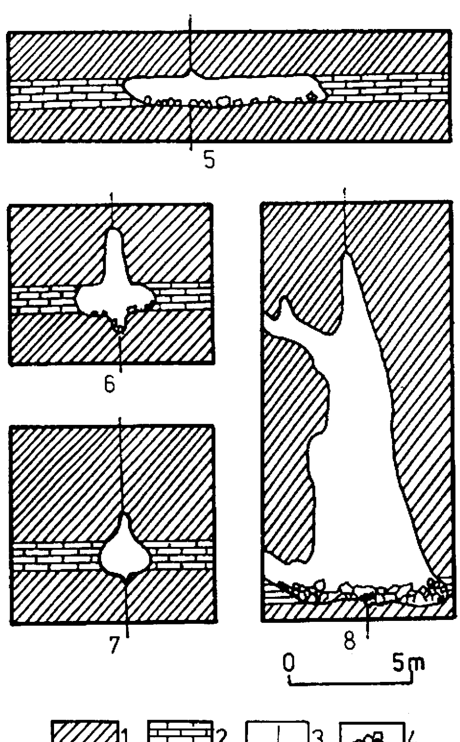


Fig. 13. Typical sections of the Alba Regia Cave (modified after ESZTERHÁS 1983)
Legend: 1. limestone; 2. calcareous marl; 3. joint; 4. collapsed material; 5. passage exclusively in calcareous marl; 6-7. passages formed both in calcareous marl and in limestone; 8. passage or chimney formed predominantly in limestone (sections 6-7 and particularly 8 may have formed during the present stage of karstification)

Postgenetic karstification denotes the situation when the chimney or the passage had formed before the associated depression. Postgenetic karstification is a local subsidence or caving in in cover sediments due to matter deficit which is caused by the removal of sediment fill from older passages. The surface depression forms partly (or entirely) in unconsolidated cover sediments.

The conditions of postgenetic karstification are particularly favourable on the Tés Plateau. The evidence are summarised below.

– Some of the covered karst landforms here developed in the cover sediments of valley floor sections without drainage, which were produced by the older stage of karstification (the resulting karst features were later buried). Therefore, those in their interior, in the sediment fill, must be products of more recent karstification.

– Part of the ponor-like passages of the plateau are at least partly of erosional origin. Erosional genesis is evidenced by the extraordinarily great dimensions of passages as well as the fact that some of them are found in calcareous marl (eg. Alba Regia Cave - **Figs. 12, 13**). Since present-day cavitation does not occur on the plateau (in lack of sufficient abrading material as carbonate rocks are directly overlain by loess), the passages must have formed under conditions different from the actual ones. Older karstification is indicated by the existence of a range of superimposed valleys on the plateau **(Pict. 18)**. By now they are lined with loess and there are a number of karst features, regarded postgenetic, on their floors.

At rock boundaries in the superimposing valleys ponors formed during bathycapture. (Postgenetic karst landforms in valley floor position came about in their sediment fills.) Ponor formation and the cover sediment (probably Csatka Gravel Formation), in which valleys deepened, favoured the development of relatively spacious passages of erosional origin **(Fig. 14)**.

The cover sediment in which postgenetic landforms develop may or may not grow thicker above the passage. In the first case, there is a karstic feature filled by sediment on the surface which is associated with the karst passage and of the same age (there is a genetic relationship between the karst passsage and the surface feature.) In the latter case, there is no depression above the karst passage. (The surface depression which contributed to the formation of the karst passage has been truncated or erosion exposed the underground cavity.) The postgenetic karst landform develops in the cover sediment in its entirety. This type may also occur on dissected surfaces but then surface landforms do not influence their genesis.

A surface postgenetic depression forms through the redeposition of the fill of the karst passages to the depth, into yet unfilled karst passages by processes of downward water percolation and collapses. For these reasons and possibly to the effect of the dissolution of lime and compaction, a matter deficit arises in the upper portion of the passage, from where sediments were removed. It is often a precondition of the clearing of the passage that the sediments covering it or filling the depression should thin out by way of surface erosion. (The degree of this thinning-out is not yet known.) Then more water can collect in the filled passage per time unit. The deficit can be further increased by the solution effect of infiltrating waters. Through further solution (and probably also by the collapses of solution remnants) the already existing passage can broaden. The opportunity for the partial or even complete removal of sediments from the upper section of the karst passage, close to the surface, increases.

The subsidence or caving of sediment fill of the old karst depression fills in the emptied space. In the case of subsidence the postgenetic depression in cover sediments will have

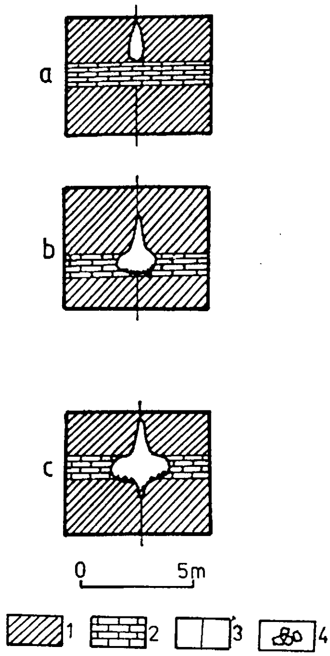


Fig. 14. Passage evolution in the Alba Regia Cave (modified after ESZTERHÁS 1983)
Legend: 1. limestone; 2. calcareous marl; 3. joint; 4. collapsed material; a. cavernation by corrosion in the zone of flowing karst water; b. passage formation by corrasion (during allogenic karstification); c. corrosional evolution: chimney formation on ceiling and channel development on floor (during postgenetic karstification)

gentle slopes, while in the case of caving steep sides. Since in the study area the filling sediments are fine-grained unconsolidated deposits (mostly loess and its reworked varieties), subsidence or caving depends on the rate of passage clearing. (Rapid removal of material results in caving, while a slow removal brings about subsidence.) The intensity of clearing is controlled by the development stage of the system of passages (filled to what extent and by what sediments) and the thickness of the sediment fill.

The above make it clear that postgenetic karstification is more complicated that syngenetic karstification.

The karst passages of postgenetic karstification can be of both corrosional and erosional origin. It is also probable that during postgenetic karstification the blocking and clearing of the same passage in the same place causes the repeated infilling and regeneration of the surface landform.

There are transitions between syngenetic and postgenetic karstification. A chimney under a filled depression without passage may activate (because of water infiltration the passage develops upwards) and this causes the rejuvenation of the depression. (The original depression and the karst passage could develop independent of each other. Their way and age of formation can be both different.) This type of covered karst formation is called pseudopostgenetic karstification.

On the covered karst terrains of the mountains during the inheritance of chimneys into the cover sediment a variety of surface landforms develop because of the variable topography (of both the present-day and the karstic basement surface), drainage network and the various stages of exhumation. The following syngenetic karstforms are identified (**Fig. 15, Table III**).

If during chimney formation a water-course suffers bathycapture (pseudobathycapture), a ponor with blind valley having an independent catchment is created. In the mountains

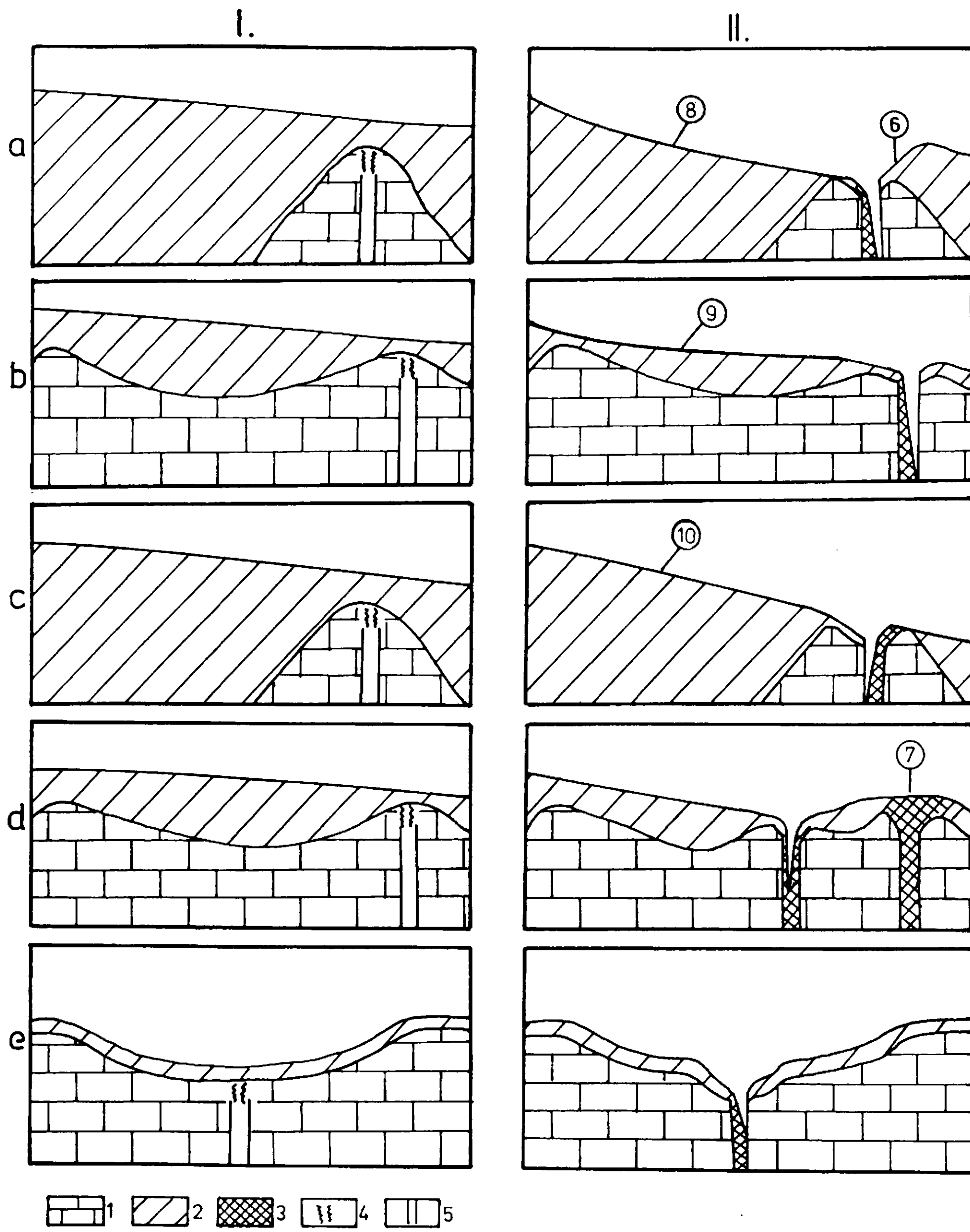
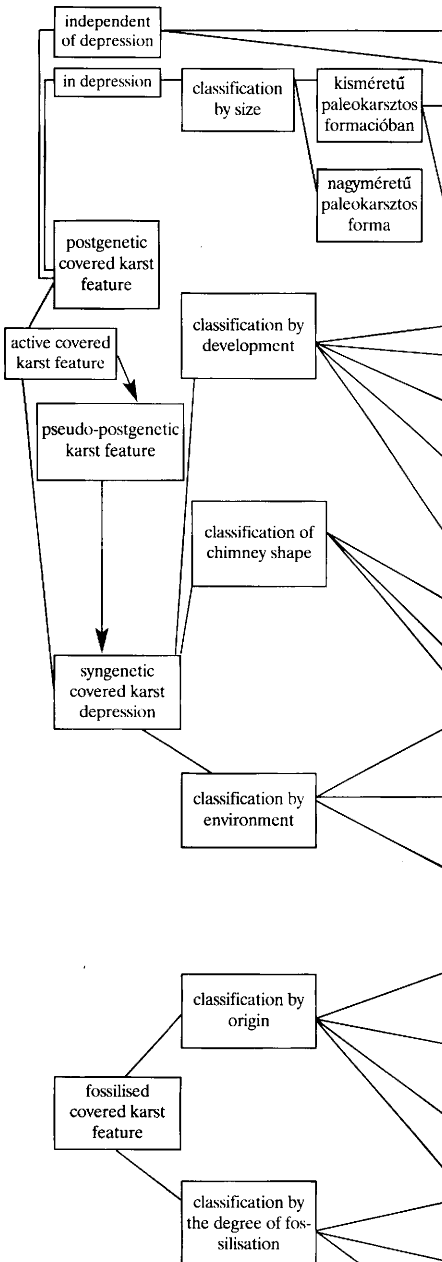


Fig. 15. Syngenetic karst depressions

Legend: 1. limestone; 2. cover sediments; 3. fill of reworked sediment; 4. primary chimney; 5. chimney; 6. front of blind valley; 7. fossilised doline-with-ponor; 8. thalweg of valley floor; 9. thalweg of channel floor retreating from the depression; 10. section of surface above doline-with-ponor (background area) I. initial stage; II. developed stage; a. covered karst ponor; b. pseudoponor; c. doline-with-ponor; d. depression; e. doline-with-ponor formed in fossilised doline

Table III.: A genetic classification of covered karst features (independent of karst water)



type of covered karst feature	covered karst feature and morphology of environment
doline-with-pseudoponor above passage	above paleokarst passage
pseudodoline above passage	above paleokarst passage
doline with pseudoponor	floor formed by subsidence, steep walls with terrace-like edge, with passage, in true depression
subsidence pseudodoline	like the previous one, but without passage
postgenetic sink doline	small-scale depression of steep walls, one or more erosional channels, in true depression
activating karst depression	no flat floor
equilibrium karst depression	flat floor, occasionally with partial depressions
inactivating karst depression	flat floor, infilling partial depressions
karst depression of complex development	slope segments of variable angle, passage outside the partial depression
fossilising karst depression	flat floor, shallow depth, no passage
simple, symmetrical doline-with-ponor	circular planform, steep walls
complex (twin) doline-with-ponor	interconnecting planforms
asymmetrical doline-with-ponor	elongated in planform, with slopes of various angle
covered karst ponor	on superimposed valley floor, at blind valley
pseudoponor	with cathment of its own, mostly associated with depressions
doline-with-ponor	no cathment of its own, with hinterland and conduit, on sloping terrain (in block side and top), exhuming residual terrain, floors and sides of superimposed valleys, fossil dolines
wallow of ponor type	on valley floors with blind valleys
wallow of doline-with-ponor type	on valley floors (mostly at head valleys) on block surfaces, in summit position, on exhumed terrain, in depressions
postgenetic wallow of doline-with-ponor type	in paleokarstic depression of superimposed valley floor
wallow of doline-with-pseudoponor type	like the previous
semifossilised karst feature	no depression, hinterland lost
completely fossilised feature (wallow)	secondary depression
eroding fossil karst feature	closed feature transformed into an open one through erosion, in summit position relative to its environs

studied recent bathycaptures happened on hidden rock boundaries. The thus created karst features are the covered karst ponors (**Pict. 11**).

If chimney exposure does not involve bathycapture, a doline-with-ponor (VERESS 1982a) develops. Dolines-with-ponor are surface karst landforms with no catchment but with water conduit (ie. the exposed chimney). The portion of sloping terrain around the dolines-with-ponor from which water reaches the depression and through passages the karst is the background area of the depression. They may occur on valley floors (**Pict. 13**), in valley sides (**Pict. 14**) or on a terrain non-dissected by valleys. Dolines-with-ponor are found in isolation or twinned (**Pict. 12**), without channels or with subsequently formed channels. Most of the covered karst depressions of the Northern Bakony are dolines-with-ponor.

Dolines-with-ponor form along symmetric or asymmetric rock boundaries or in old fossilized dolines. In the latter case the floor should be lined with permeable sediment. Chimney formation is generated by water collected in the fossilized doline and infiltrating from there. It is probable that the complete filling of the doline marks the end of chimney formation since then part of the rainwater runs off on the surface and partly reaches the karstic basement uniformly distributed over the area of the whole depression without concentration to a point. Within the fossilized doline one or more dolines-with-ponor can form. The karst landform is a composite one. The outer part is constituted by the slope and floor of the fossilized doline and the inner part by the doline-with-ponor developed on the floor. Morphologically, such dolines-with-ponor are similar to partial depressions.

In the background area surface erosion (sheet wash or stream erosion) cna be so effective that an independent catchment may took shape there. Such varieties of dolines-with-ponor are called dolines with dolines-with-ponor-like features or pseudoponors (**Pict. 15; Fig. 52**).

In cover sediments depressions of interior drainage form if cover sediments are transported through the older but cleared or just forming passages into the karst (VERESS 1998). The surface erosion of cover sediments (a precondition of karstification) lasts until the karstic rock, resistent to non-karstic ways of denudation, outcrops. The depressions of variable size and shape, which have interior drainage and form through material transport to depth from cover sediments between patches of carbonate outcrops are called exhumation depressions.

The existence of exhumation depressions in the mountains are evidenced by the following facts. (These properties allow the easy identification of depressions.)

– The uneven thickness of cover sediments points to the dissection of the carbonate basement. This is a direct evidence to the fact that lower-lying terrains with cover sediments are surrounded by carbonate outcrops. An indirect evidence is that the thickness of cover sediments is variable (as it appears in borehole data) and the changes do not correlate with the distribution of surface karst features (**Fig. 45**).

– Since the surface of the spot with cover sediment lies lower than the environs without cover sediments, this can only be the result of transport to depth. Transport to depth is indicated by the gradient of the floors of the depressions towards the partial depressions inside them, from where regressional channels deepen into the sediment.

– The one-time higher position of depression floors is proved by the now inactive karst depressions above the present-day floors. They were active recipients of sediment once. Their altitudinal position marks the elevation of the depression floor during its active stage. (Fossilization was due to the subsidence of the floor.)

The depression may form during syngenetic (**Figs. 16, 17**) or postgenetic karstification (**Fig. 18**).

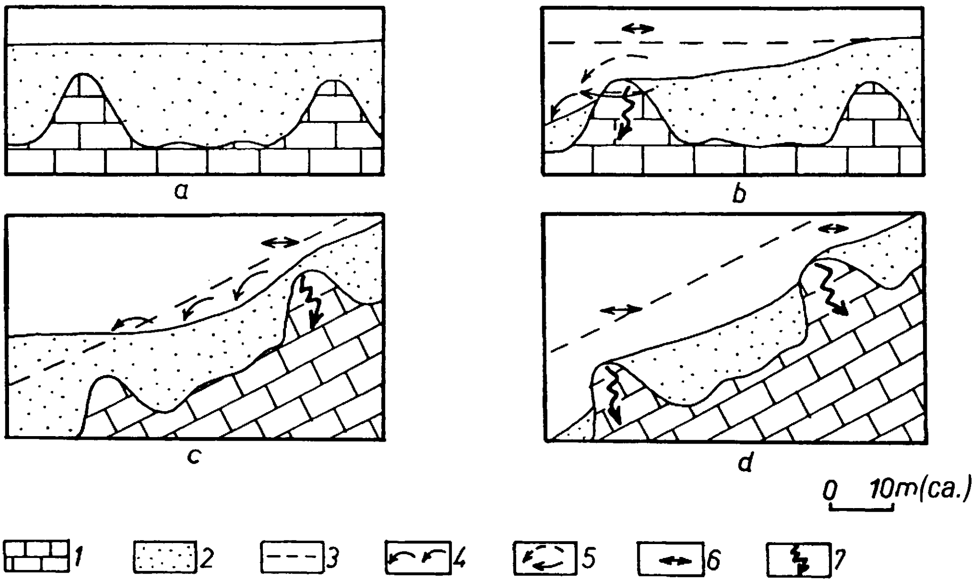


Fig. 16. Development and karstification of depressions
Legend: a. untilted carbonate basement, no denudation in broader environment, no depression, no karstification; b. untilted carbonate basement, denudation in broader environment, depression development, karstification on its edge on exhuming side; c. tilted carbonate basement, no denudation in broader environment, no depression, karstification on elevated cones because of the reworking of local sediment; d. tilted carbonate basement, exhumation in the broader environment, depression formation, karstification on its edge on exhuming side; 1. carbonate rock; 2. cover sediment; 3. original surface of cover sediment; 4. sheet wash undifferentiated; 5. sheet wash partly in intervals between cones; 6. karstification along hidden rock boundary; 7. material transport in depth

The depressions are referred to pseudodepressions (**Picts. 16, 17; Fig. 20**) and true depressions (**Picts. 19, 20, 22; Figs. 18, 55**). The basin of interior drainage is a pseudodepression if there are no landforms with interior drainage on the carbonate terrain under cover sediments or if the area of this landform is smaller than that of the pseudodepression. (The complete surface erosion of coversediment patches is hindered by the elevations of gradually exhuming carbonate rock around the pseudodepression.) A true depression is a closed basin with a landform of interior drainage (further: paleokarst depression) under the cover sediments. A preconditon to the development of both pseudodepressions and true depressions is that cover sediments should be removed from their environment by sheet wash or stream erosion (**Figs. 17, 18**). After the carbonate rock outcropped, further removal from the surface is prevented by the edge of the basin (for both types) or, in case of pseudodepressions, the joint base of cones or the frost-shattered debris between cones.

During material transport to depth, pseudodepressions reach various stages of development. Half-enclosed (**Fig. 19**) and then completely enclosed (**Picts. 16, 17; Fig. 20**) depressions are produced. Within enclosed depressions a growing proportion of karst features (dolines-with-ponor) are fossilized. A mature depression results (**Fig. 21**) with more and more covered karst depressions (**Fig. 22**). Because of material transport to depth at more and more sites of karstification, the immediate surroundings of the previously fossilized

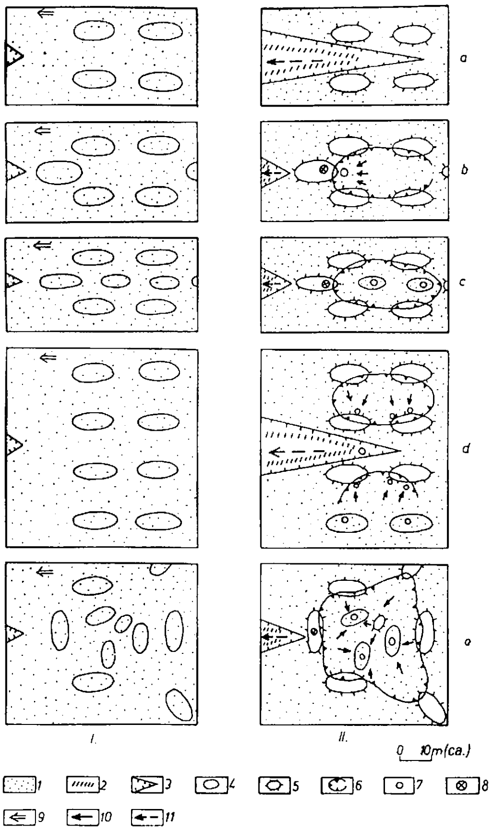


Fig. 17. Development of pseudodepressions of various morphology during exhumation of the broader environment through stream erosion
Legend: I. initial stage; II. later stage; a. no depression formation, the regressional valley retreats between the rows of cones; b-c. the retreat of the regressional valley is hindered by a row of cones, formation of elongated depression (b. with rows of depressions of variable activity; c. with rows of depressions of similar activity); d. the regressional valley is enclosed by several rows of cones, depressions on both sides of the valley, e. cones are not arranged in rows, irregular depression results. 1. cover sediment; 2. outcrop of carbonate rock in valley incising into cover sediment; 3. regressional valley; 4. buried cone; 5. row of semiexhumed cones; 6. depressions in various stages of development; 7. active karst landform of syngenetic karstification (doline-with-ponor); 8. non-active (fossilised) karst landform of syngenetic karstification; 9. slope of the broader environment; 10. slope of depression floor; 11. material transport in regressional valley

karst feature acquires a summit position within the depression. As cover sediments are thinning out, in the immediate surroundings of the karst feature renewed karstification begins. All these may result in the rearrangement of the paths of sediment removal and thus slope directions within the depression.

Depressions are similar to alluvial streamsink dolines. The main difference between the two types is that matter from the depression is removed into one or more passages formed within the depression and in the case of alluvial streamsink dolines the basin forms above the passage into which sediment is transported. In the latter case the surface of denudation (the basin) and of accumulation (the passage) are not distinct from each other as in the case of depressions.

Postgenetic karst features form in (true) depressions or independent of depressions. Postgenetic karst features form in fills of depressions which are of the same age with the karst passage. Postgenetic karstification and karst feature is independent of the depression if it develops in cover sediments which are not fills of surface karst depression. A pseudo-postgenetic karst fearture forms if a covered karst feature in the cover sediments of a karst depression to the influence of the exposure of an independently developed karst passage.

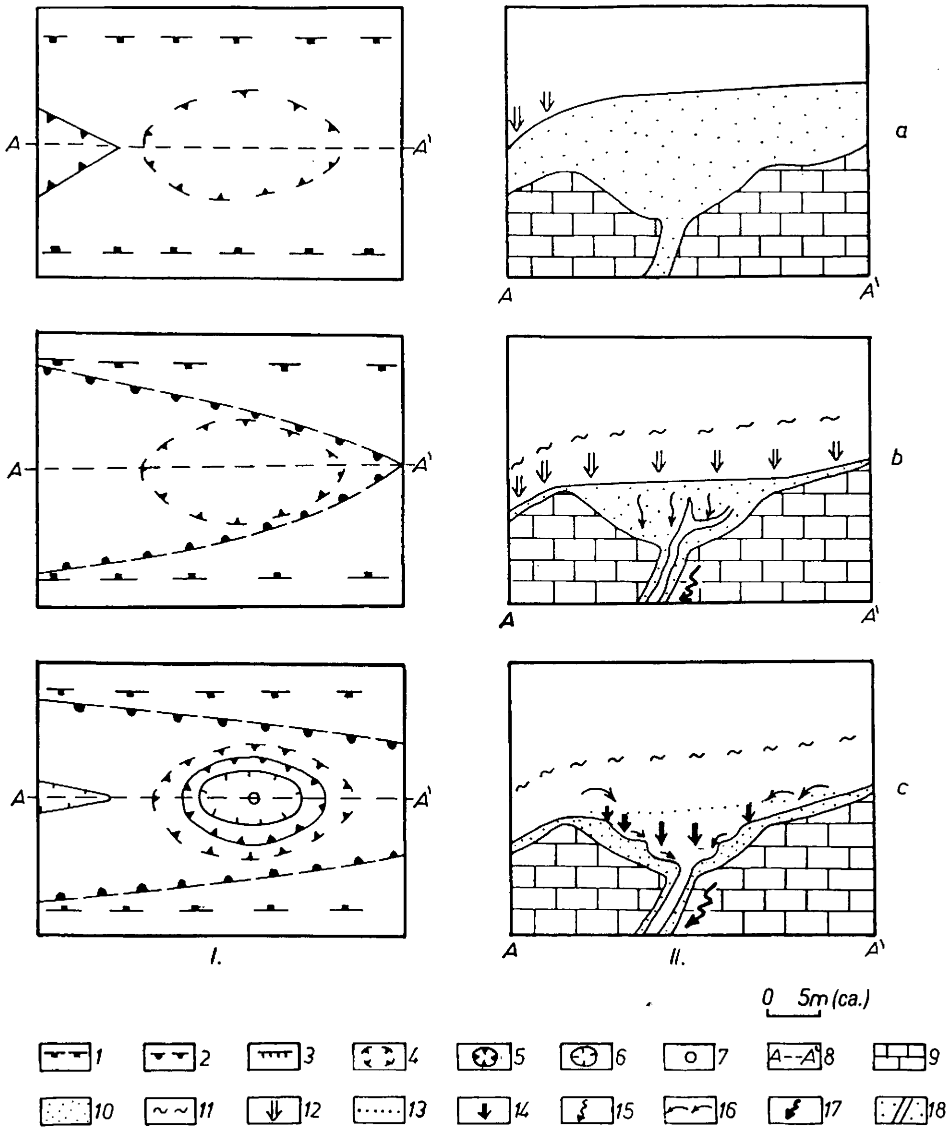


Fig. 18. Development of depression of postgenetic karstification

Legend: I. plan view; 1. filled well-developed superimposed valley; 2. **regressional developing superimposed** valley; 3. regressional channel; 4. buried paleokarst depression; 5. outer edge of doline-with-pseudoponor; 6. inner edge of doline-with-pseudoponor; 7. passage; 8. location of section; II. lateral view; 9. carbonate rock; 10. cover sediment; 11. surface before development of regressional developing superimposed valley; 12. removal of cover sediment by stream erosion; 13. surface before subsidence and caving; 14. subsidence **and caving;** 15. water seepage; 16. sheet wash; 17. material transport in depth; 18. passage in cover sediment

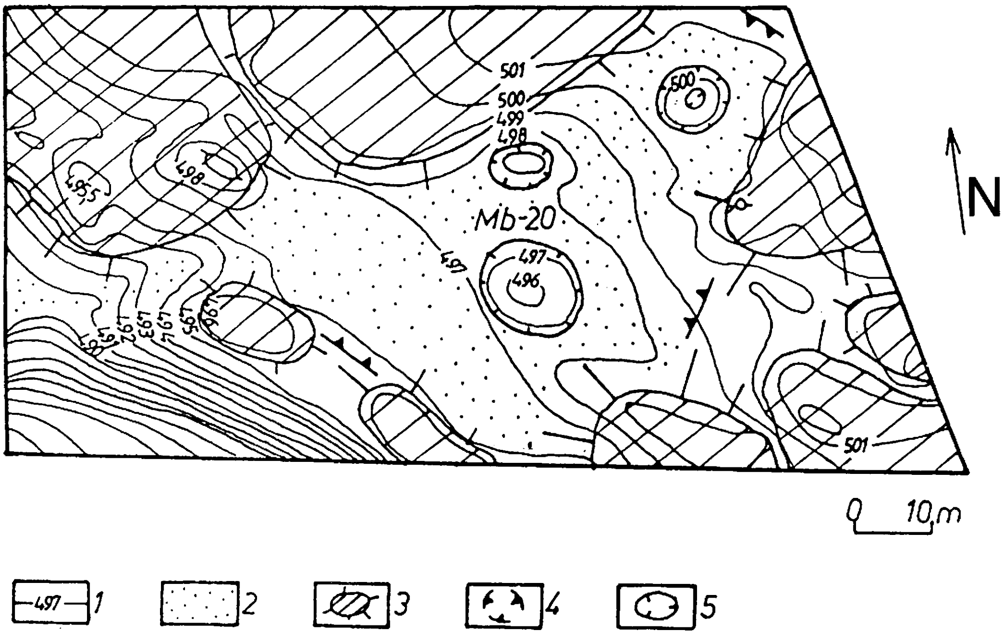


Fig. 19. Half-enclosed pseudodepression (environs of karst object Mb-20, Mester-Hajag)
Legened: 1. contour line; 2. cover sediment; 3. semiexhumed cone; 4. pseudodepression; 5. karst depression (doline-with-ponor)

The postgenetic karst featrures of depressions are the following (**Fig. 23**).

If the paleokarst feature is of small dimension, over most of its area cover sediments acquire lower and lower positions. This way subsidence pseudodolines (with no water conduit on the floor) or dolines-with-pseudoponor (with water conduit on the floor) develop (**Pict. 18, 19, 20**).

The subsidence pseudodolines and dolines-with-pseudoponor do not have sharp edges. In their interiors, however, the internal depression formed by subsidence or caving is marked. The wall of the internal depression is of unconsolidated deposits. The floor is flat and rather extensive. After subsidence, the outer part of the depression is deepened by sheet wash. The karstic rock may outcrop locally. If the redeposition of sediment to the passage is limited, subsidence is restricted and slow. In this case the subsidence doline does not have a distinct internal part and a shallow and gently sloping depression ensues.

Such depressions are never similar to blind valleys. It is common that for the internal depression or from the passage exposed on the floor an erosional channel retreats to the edge of the outer part. In this channel small depressions can form in the sites of pseudobathycapture (**Pict. 21**). Probably, they can be both syngenetic and postgenetic. The edges of internal depressions are often dissected by arcuate and steep features. They are produced by mass movements (of rock and earth falls); some of them, however, could be resculpted by sheet wash. Subsidence pseudodolines and dolines-with-pseudoponor are the largest surface karst landforms in the mountains.

If the paleokarst landform is of great dimension, the filling sediments subside or cave in only partially. The clearing of an old passage is probably an indirect cause of the local caving of cover sediments. Because of the matter deficit in the passage another passage forms

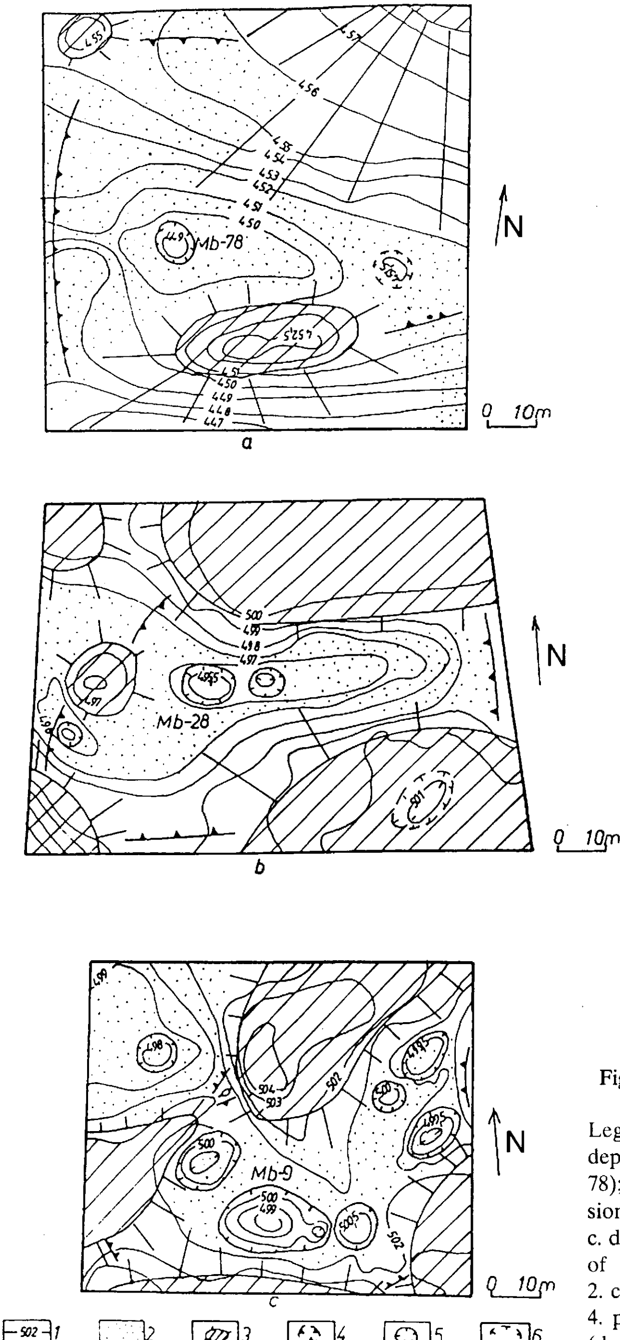


Fig. 20. Enclosed pseudodepressions of various shape on Mester-Hajag

Legend: a. elongated, less exhumed depression (environs of depression Mb-78); b. elongated, more exhumed depression (environs of depression Mb-28); c. depression of irregular shape (environs of depression Mb-9), 1. contour line; 2. cover sediment; 3. semiexhumed cone; 4. pseudodepression; 5. karst depression (doline-with-ponor); 6. fossilised karst depression

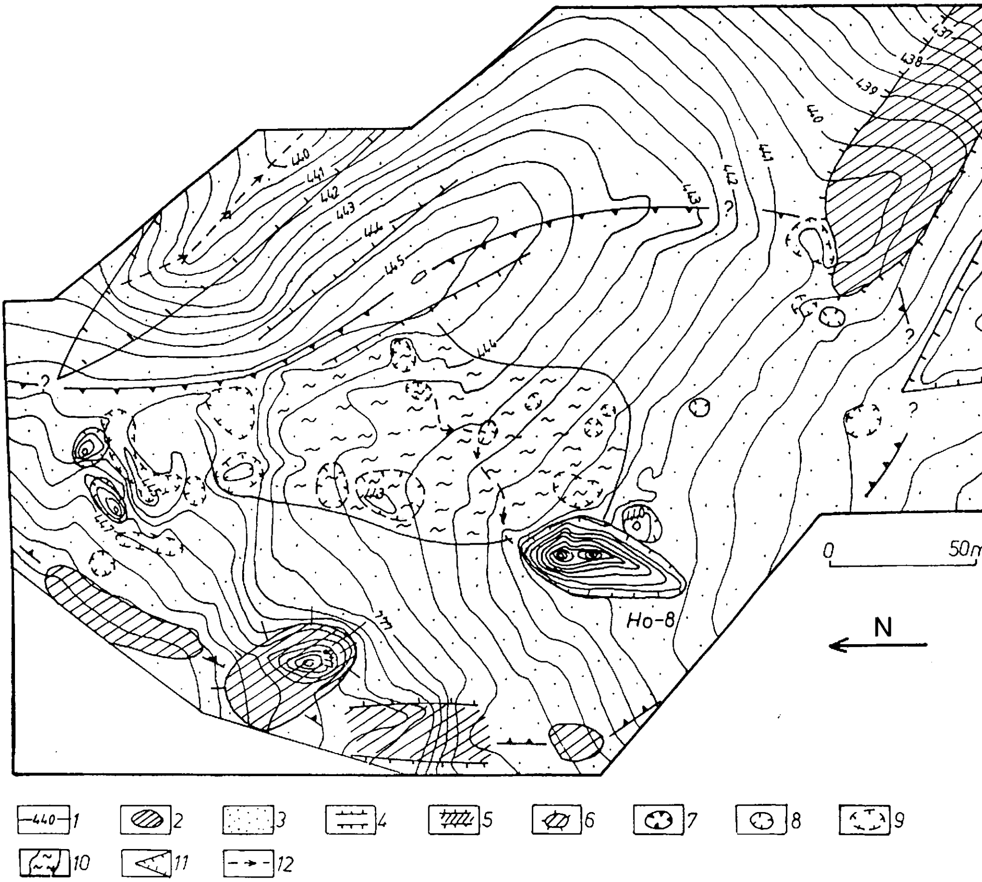


Fig. 21. Mature pseudodepression near karst object Ho-8, karst terrain around Homód-árok (the probably postgenetic karst object Ho-8 is fed by the overflowing water from the neighbouring fossilised depressions; some fossilised karst features – wallows – have an altitude of 447 m, indicating remarkable deepening of the depression floor)

Legend: 1. contour line; 2. outcrop of Middle Eocene limestone undifferentiated; 3. cover sediment (delimation is approximate); 4. covered, exhuming cone; 5. exhuming cone; 6. semiexhumed cone; 7. pseudodepression; 8. karst depression (doline-with-ponor); 9. fossilised karst depression (wallow); 10. recharge area of karst object Ho-8; 11. regressional developing superimposed valley; 12. channel

in the cover sediments and they cave in. Features of interior drainage, postgenetic dolines-with-ponor develop (**Picts. 22, 23**). Also in this case the catchment of the depressions forms over part of the sediments filling the paleokarst depression.

The upper part of the cover sediments of the filled paleokarst depression has undergone repeated redeposition. Locally the neighbouring fossilized ponors represent a single buried landform. The valley floor slopes towards the centre of the depression from all directions. These are essentially double depressions. The gentle outer slope gradually smoothes into neighbouring valley floors and sides. The internal part is not necessarily the postgenetic dolines-with-ponor in the geometrical centre. The outer zone is partly erosional, partly

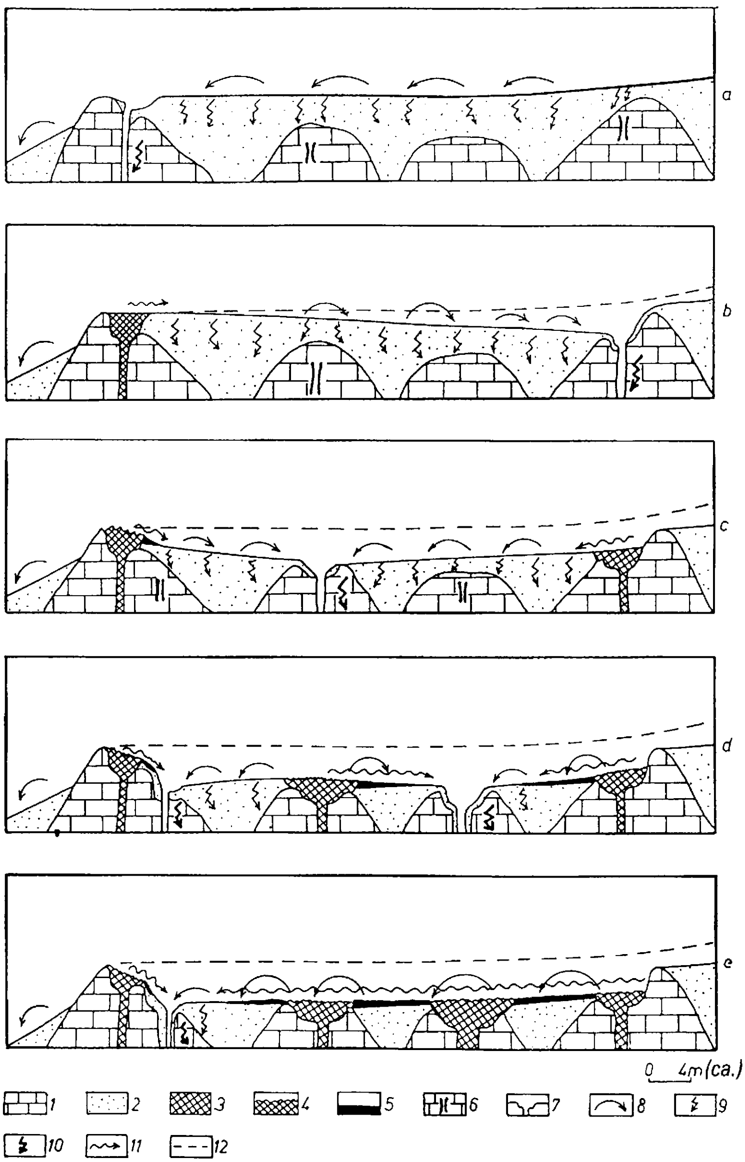


Fig. 22. Development of depression of syngenetic karstification

Legend: a. half-enclosed depression; b-d. enclosed depression (compared to the previous, karstification of the opposite edge, then formation of sites of karstification in the interior of the depression, consequently division of the depression into compartments, spreading of impermeable character over increasing portion of floor); e. mature depression (floor almost completely impermeable); 1. carbonate rock; 2. cover sediment; 3. impermeable sediment fill of syngenetic fossilised karst depression; 4. partially truncated sediment fill of fossilised karst depression; 5. impermeable sediment formed during truncation; 6. karst passage; 7. syngenetic active karst depression; 8. sheet wash; 9. water seepage; 10. material transport in depth; 11. surface runoff; 12. original surface of cover sediment

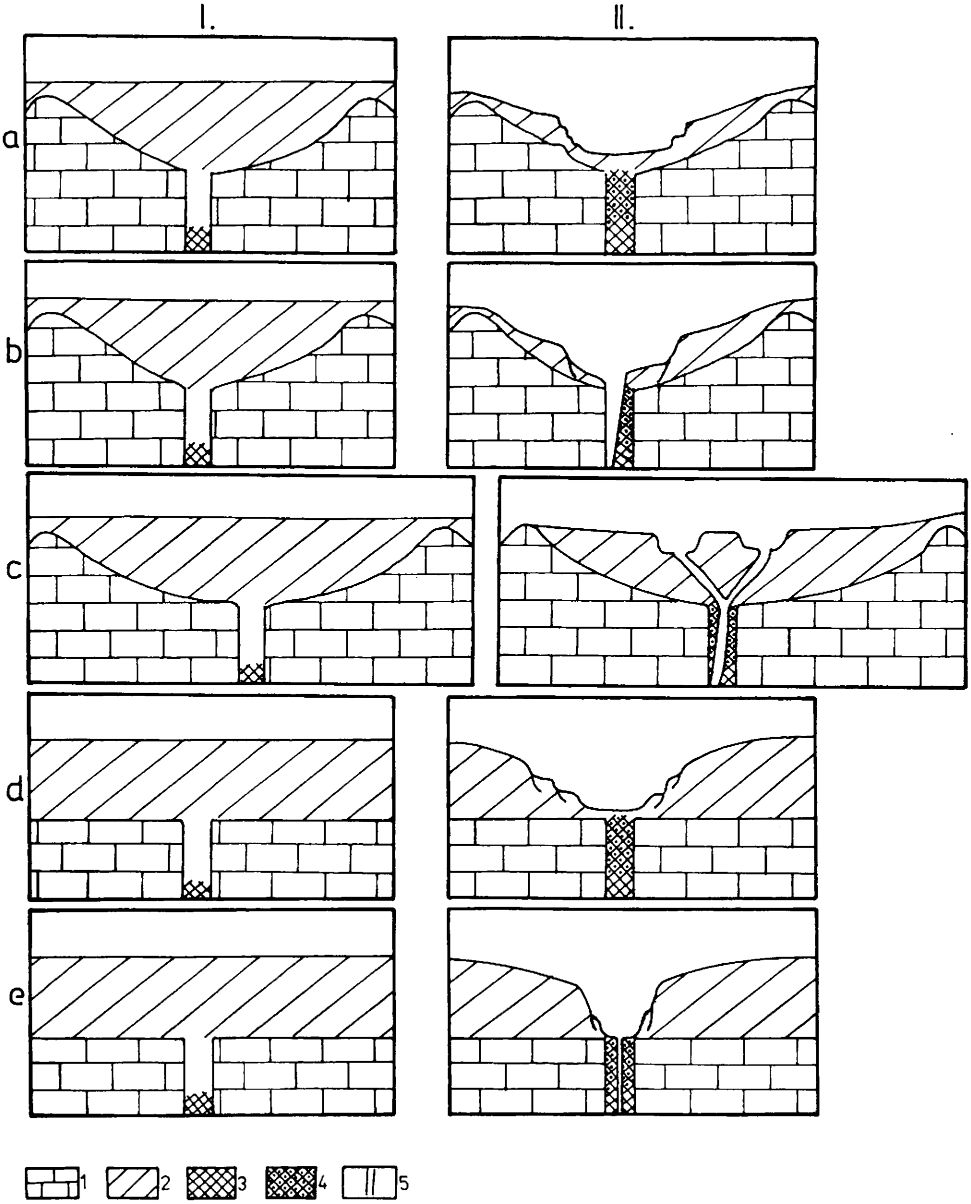


Fig. 23. Postgenetic karst depressions

Legend: 1. limestone; 2. cover sediment; 3. fill of reworked sediment; 4. sediment caved in or subsided into passage; 5. karst passage; I. initial stage; II. developed stage; a. subsidence pseudodoline; b. doline-with-pseudoponor; c. postgenetic doline-with-ponor; d. pseudodoline above passage; e. doline-with-pseudoponor above passage accumulational surface. The here accumulating sediments derive from the neighbouring valley sides and floors. At the same time, the sediments were reworked by sheet wash and streams into postgenetic ponors and transported further to depth.

The walls of postgenetic dolines-with-ponor are steep surfaces in unconsolidated sediments with collapses. Where there are more postgenetic dolines-with-ponor in the depressions, several old conduit passages may activate. They may develop through the formation of branches in the unconsolidated cover sediment and their exposure to the surface in various sites.

Postgenetic dolines-with-ponor may lack a channel or may have regressional channels (streams). The channels may meander (indicating the low energy of their water) or sometimes reach over the edge of the internal part of the depression. Mostly, however, their catchment is restricted to some part of the depression area. They may acquire a blind valley character.

Bedrock may outcrop on the channel and doline floors of postgenetic dolines-with-ponor and channels. Sites of pseudobathycapture may occur.

Postgenetic landforms without depression are small basins of steep walls (outer an inner parts are not distinguishable) with no or hardly any background. The carbonate basement does not lie deeper than the surroundings. Such basins may lack a conduit passage (pseudodoline above passage) or have a passage. In the unconsolidated sediments of the floor erosion exposes secondary passages and partial depressions of variabled life-time may form (doline-with-pseudoponor above passage).

On terrains where cover sediments are sufficiently thin or entirely removed chimney formation is replaced by the surface corrosion of carbonate rock. On terrains with a thin veneer subsidence dolines, while on terrains with only soil cover solution dolines may also come about.

Fossilized covered karst features

Fossilization begans if sediment transport from a karst depression to the karst stops or falls remarkably below the amount of sediment influx (VERESS 1995a). The conditions are favourable for fossilization if the water conduit is poorly developed and fine-grained material arrives from the background. (The grain size of sediments in the background area should be fine and the slopes of the background or the catchment area should be gentle.) The reduction of water influx also favours fossilization (although it involves the drop of sediment influx). It can be caused, for instance, by the loss of part of the background area. In the area of the infilled and fossilized karst landform a secondary depression may form through the compaction of sediments. The transport of some material to the depth in solution may also contribute to this process. A further factor is that the void ratio of precipitated matter is lower than before dissolution. The interior of such depressions is waterlogged and swampy for most of the year („wallow").

The permanently waterlogged ponds are locally called „kálistó", „förtés" or „wallow". Such localities are regarded karst features by HUNFALVY (1864). Waterlogged places probably do not only form in sites of impounded fossilized covered karst landforms. The evidence for the karst origin of wallows is summarized below.

– One of the basins of some twinned karst depressions contains a wallow, while the other is still an active karst feature.

– There are enclosed types of wallow of basin character.

– In some explored wallows filling sediments dip from the edges towards the centre.

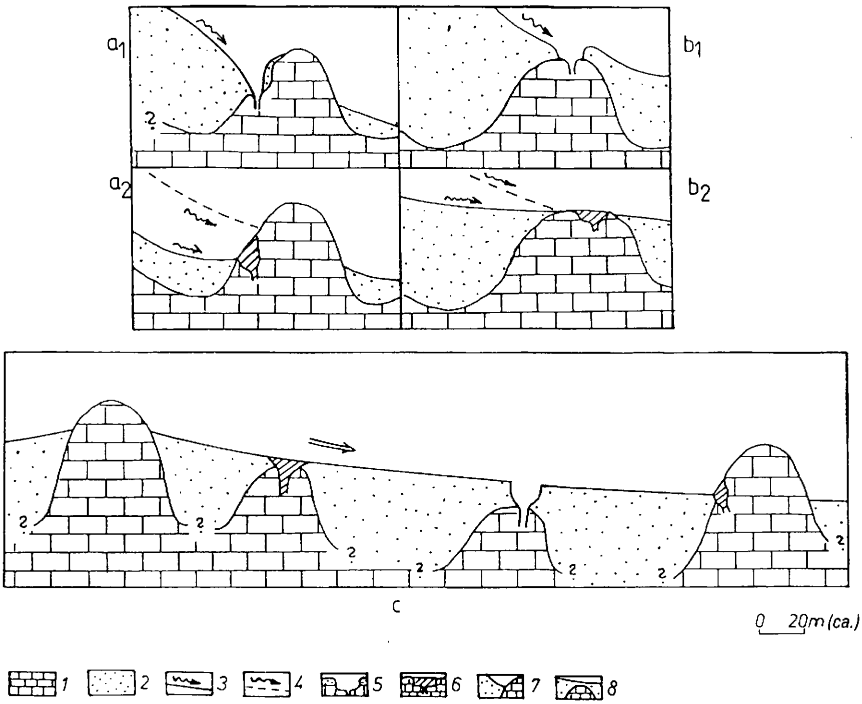


Fig. 24. Types of wallow (modified after VERESS 1998)
Legend: 1. limestone; 2. unconsolidated cover sediment; 3. present-day valley floor; 4. previous valley floor; 5. surface karst feature with water conduit; 6. wallow; 7. asymmetric hidden rock boundary; 8. symmetric hidden rock boundary; a. development of ponor-type wallow in blind valley (a_1. initial stage; a_2. present stage); b. development of ponor-type wallow in valley (b_1. initial stage; b_2. present stage); c. development wallow of doline-with-ponor type within pseudodepression

The wallow is regarded an inactive and completely fossilized karst feature with the formation of a secondary basin in the sediment fill, to the effect of various geochemical processes. The conditions of these processes are created by the buried karst feature.

Wallows may evolve from syngenetic covered karst ponor (ponor-type wallow) but also from postgenetic karst features **(Fig. 24)**. The wallows of doline-with-ponor type are the most common **(Picts. 24, 25)**, which include wallows of pseudoponor type.

Phenomena of karst depression activity

The further evolution, sediment transport and thus fossilization and environmental impact of covered karst depressions primarily depends on their water budget. The phenomena related with the water budget of depressions are called phenomena of activity (VERESS 1987a).

During its activity the karst depression receives water recharge from the background area from a stream or by sheet wash. The latter occurs during prolonged rainfalls or snowmelt if the surface is bare or frozen and the soil is saturated. The two ways of water recharge may alternate even during a single phase of activity. External sediment influx particularly happens during phases of activity.

The percolating waters of the background area flow over the clay series of the cover sediments towards the depression. Seepage is mostly expected during the summer half-year in background areas of vegetation cover and less impermeable sediments. Intermittent springs may form in depressions where channels incising into the cover sediments expose impermeable series. In the case of hidden activity infiltrated water reach karst passages without coming to the surface. Intermittent springs and particularly hidden activity prolong corrosional development. While inflow from the surface is restricted to some minutes' time, water recharge from unconsolidated sediments may last for several days or weeks. The dissolving power of solutions passing through unconsolidated sediments and enriching in biogenic CO_2 is higher than that of surface runoff.

A phase of activity is the time interval during which activity is observed. During an activity period – a rainy or snowmelt period – one or more phases of activity may take place.

The amount of water input of the depression depends on the size of the catchment (background area) and on the runoff coefficient. It is also influenced, for instance, by the vegetation of the background area. (In treeless areas with wind of favourable speed and direction, snow accumulates in the depression.) The sediment accumulation from waters flowing towards the depression as well as of the lithology of cover sediments may modify water input. The water input of the conduit may differ from that of the surface depression. While the overflow from flood ponds reduces the water input of the passage, during hidden activity water from the background may reach the conduit in an increasing amount.

In addition to water from activity, the amount of actual activity also includes water from intermittent springs and from hidden activity. The duration of activity (mostly accumulation) and of hidden activity (corrosion) may be different or vary from year to year for the same depression. The evolution of the individual depressions is specific and its rhythm is variable.

If in a covered karst depression the rate of water recharge exceeds the rate of water conduction to depth, flood ponds develop. Their diameters and depths are some metres. The intermittent ponds influence karstification on the covered karst in two ways. The pond may cause the covering and plugging of the chimney and triggers infilling of the depression. (In the infilling depression the pond survives for longer periods and more sediments are deposited.) On the other hand, the deepening fill increases the intensity of solution (more biogenic CO_2 is produced) since it takes longer to transfer water into the karst. Consequently, the sediments reaching the covered karst depression through flood ponds do not increase erosion but maintain or even increase corrosional development. By the duration of their existence the ponds are referred into the following types:

– Short-term ponds form in depressions with open conduit. Water transfer into the karst takes place through conduction. The dropping of their water table is rapid (the pond formed during one phase of activity does not survive until the next) and continuous. Water flow in conduits is probably turbulent.

– The sediments of ponds of longer existence **(Picts. 26, 27)** partly accumulate in depressions with impounded conduits. They are slowly drained partly by seepage and partly by flow. If they are not emptied before the next phase of activity, the rate of dropping water table may reduce in the wake of repeated water recharge. (The dropping of water table may stop and even a rise may follow for the same pond.)

– Long-term ponds **(Pict. 28)** form in depressions with filled conduits. The ponds loose part of their water by seepage and another part by evaporation. The life-time of such ponds may be longer than an activity period.

Sedimentation in karst depressions

The sediments of covered karst depressions indicate the relationship between the depression and the background area, the events occurred in these areas and the stage of development of the depression.

The sediments of covered karst depressions are original cover sediments or those produced by karst processes. The latter are either locally deposited or transported into the depression. Transport takes place by water, mass movements, eolian porcesses or by human activities. Sediments deposited by water derive directly from water inflow or indirectly from flood ponds.

Sedimentation from flood ponds

From a given pond only those sediments deposit the grains of which have a higher speed of subsidence than the rate of dropping of the pond water table. Grains with a lower speed are transported to the karst with the outflowing water of the pond. The dip of the beds of accumulation is adjusted to the slope of the floor during sedimentation. With permanent conditions of sediment influx the sequence produced by an activity phase thickens towards the centre of the depression if water table dropping is reducing.

With reducing water table dropping finer grains also deposit. Therefore, the sequences with poorer sorting in thicker parts were deposited fro ponds with reducing rate of water table dropping during emptying. At the same time, it is to be noted that a thickening of the sequence (in exposures decreasing dips on series boundaries) may be caused – independent of the rate of water table dropping – by increased sediment influx. It may also occur that the dip of series is growing upwards. It indicates that the subsidence of the floor due to karstification exceeded the rate of accumulation.

The main characteristics of recent pond sedimentation in covered karst depressions are the following (Veress 1987a, **Fig. 25**).

– In short-term ponds the dropping of water table may be so rapid that even the coarsest grained sediment is partly or completely transported into the karst. The finer sediment and the plant detritus may accumulate – as a consequence of the slow outflow of the emptying pond – on the floor or in its environs **(Pict. 29)** or even on the uneven surrface of the conduit.

– In ponds of longer existence fine-grained sediments may accumulate. In depressions where such ponds develop, a series of or with plant detritus (plant detritus coated or mixed with sediment) is deposited **(Pict. 30)**. The accumulation of a sediment series with plant detritus is explained by the rate of subsidence of plant detritus exceeding that of water table dropping in the intermittent pond. (The subsidence of plant detritus is mainly caused by the adhesion of sediment grains on detritus fragments.) If on the margins of the pond a zone of plant detritus takes shape **(Pict. 31)**, while towards the centre a series of plant detritus forms, the dropping of water table may be interrupted for a time. (Along the pond margins plant detritus adheres to the floor without subsiding, while in areas with deeper water it happens after subsiding.) In the resulting series with plant detritus the amount of plant detritus may decrease laterally or even disappear completely if temporarily the dropping rate of water table increases. The series with plant detritus may be of variable composition. The zonal appearance of the series with plant detritus is typical in depressions where the rate of water table droping fluctuates. In case of a uniform series with plant detritus, the water table of the pond is reduced at a uniform and slow rate **(Pict. 30)**. Variation in plant

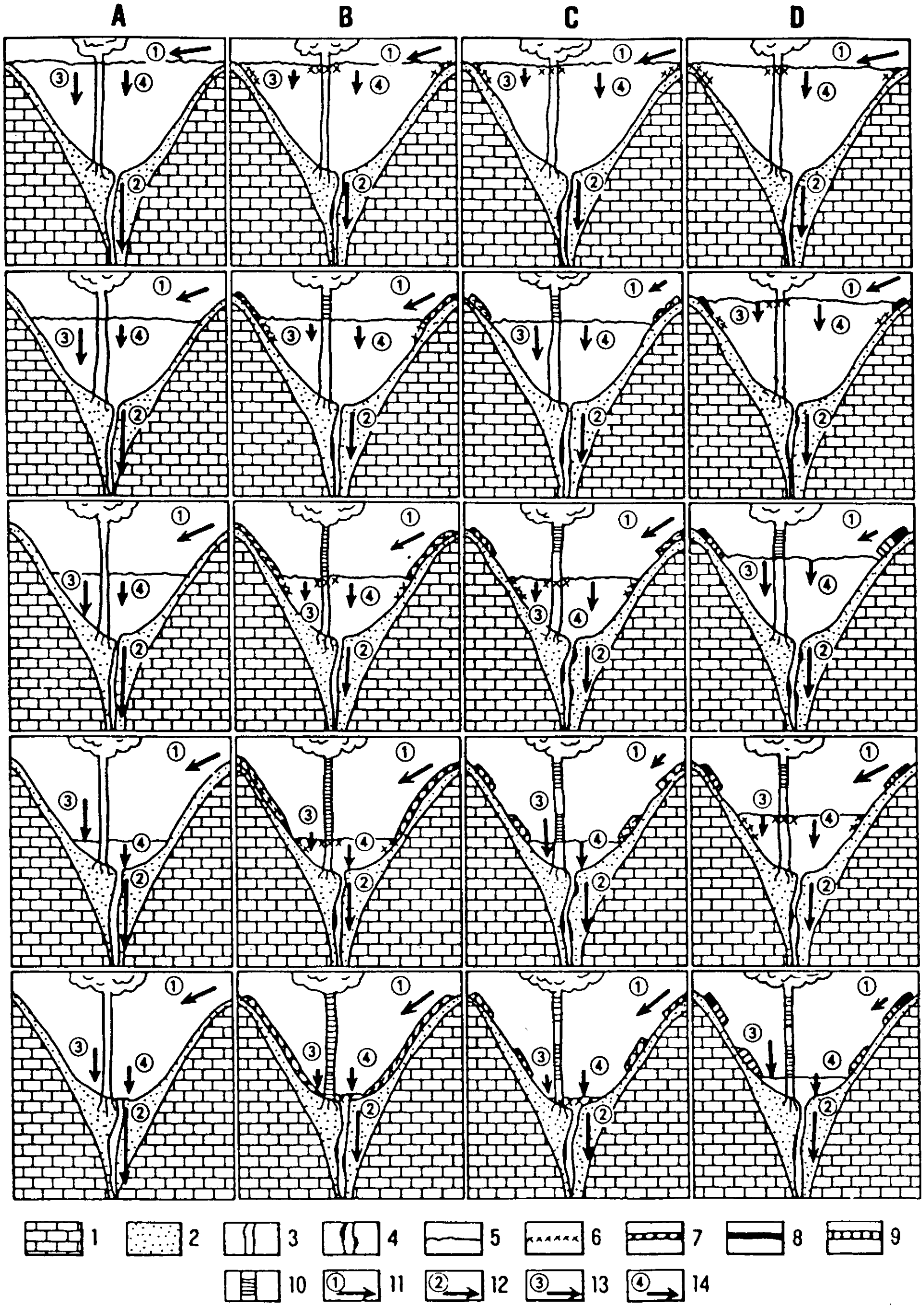

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Fig. 25. Deposition in long-term ponds (modified after VERESS 1987a)
Legend: 1. limestone; 2. unconsolidated sediment; 3. water conduit; 4. partially plugged conduit; 5. water table of intermittent pond at any date; 6. deposition; 7. plant detritus sequence of uniform appearance; 8. plant detritus rings with colloid coatings; 9. sequence of plant detritus rings; 10. colloid coating or plant detritus coating on tree trunk; 11. inflow into karst depression (length of arrow proportional to amount of water inflow per unit time); 12. water conducting (length of arrow proportional to amount of conducted water per unit time); 13. water table dropping (length of arrow proportional to sediment subsidence per unit time); 14. subsidence rate of plant detritus; A. water table dropping always exceeds subsidence of plant detritus; B. water table dropping always slower than subsidence of plant detritus; C. water table dropping sometimes exceeds subsidence of plant detritus; D. water table dropping 0 and then sometimes exceeds subsidence of plant detritus

detritus in the same pond (reflecting the fluctuation of water table and its droping rate) does not point to the fluctuation of conduit capacity but of water recharge (during repeated rainfalls or snow-melt of variable intensity). A series with plant detritus, however, forms if water transfer into the karst is retarded, large sections of the conduit are partly filled or short sections are totally plugged.

From ponds of longer existence colloids also deposit. The colloids from pond water adhere to tree-trunks and herbaceous plants in the karst depression. The colloid coating is also uniform if the rate of water table dropping is uniform and of annular form **(Pict. 32)** if the rate of water table dropping fluctuates. The upper margin of colloid rings is markedly distinct from the surface on which they formed (slow dropping) then it is gradually fading downwards because of the increasing speed of water table dropping.

The various colloid rings and plant detritus zones are in the same level for a given depression. The uppermost colloid rings and the plant detritus or the series with plant detritus marks the maximum water table of the pond.

– The sediment coarser than the colloids transported into long-term ponds is deposited, while the colloids are retained – after the evaporation of water – as gel. From every intermittent pond a pair of sediment strings (laminite) form. The occurrence of laminitic series indicates the plugging of conduits and water transfer into karst only through seepage.

Sedimentation accompanying fossilization

The complete fossilization of a karstic feature (VERESS 1995) results in the complete infilling of the depression. (On the floor of the depression waterlogging becomes ever more enduring.) The plant detritus transported in are gradually buried. In an environment without oxygen, a fill of high organic matter content with fragments variably carbonized accumulates (carbonic series with plant detritus). From the upper, soil-filled parts of the depression, infiltrating water carries iron to the lower levels. Iron precipitates in oxidic or limonite form. Fe-oxides precipitate at high pH in the presence of charcoal (which binds organic acids). Limonite precipitates in oxygen-free environment, resulting from the occurrence of groundwater. Consequently, the limone produced may point to the occurrence of groundwater and to the a complete cessation of water transfer, even by seepage, into the karst. Because of the transport of iron, a secondary depression may form. Therefore, the accumulation of the series with charcoal and plant detritus may continue or be repeated. The lime concretions in the fill of the fossilized depression originate when the pH of seeping water is reduced and CO_2 is released by the system. Acidity increases when the accumulation of the series with charcoal and plant detritus stops. The appearance of lime concretions may indicate input of calcareous sediments or the lack of favourable conditions for carbonization (the depression is filled in or the influx of plant detritus stops).

Evolution of karst depressions

Covered karst depressions evolve from their development to their destruction. If the grain size distribution of sedimentinflux, the stages of their evolution is best reflected by the sediments produced (VERESS 1986, 1987b). From the actual morphological conditions the stage of evolution can also be estimated. Depressions in different stages, however, may present similar morphologies. The phases of evolution are the following (VERESS 1986, **Fig. 26**).

With stable rate of sediment influx, the grain size of the fill of activating karst depression tends to grow coarser upwards since the life-time of ponds above the broadening passage (chimney) is ever shorter and thus the dropping of water table is more and more rapid. If beds are increasingly thicker upwards (their dip decreases), it can happen with increased sediment influx.

With unchanged rate of sediment influx, the gain size of the fill of equilibrium karst depression shows no alteration. If the rate of sediment influx grows, the series also tend to become thicker in the centre of the fill at an increasing rate.

In the fill of the inactivating karst depression (**Fig. 27**) an upward enrichment of finer sediment is observed as with the filling of the passage the water table dropping in intermittent ponds tends to slow down.

Karst depressions of complex evolution (**Fig. 28**) with changeable activity may also occur. In their fill grain size may change rhythmically.

From fossilized karst depressions (**Fig. 29**) no transfer of sediment and water into the karst takes place. The depression becomes inactive as ever finer sediments arrive from the background area of ever gentler slope. Depositing this sediment increases the life-time of the intermittent pond and thus causes the accumulation of more and finer sediments; the depression is filled in (VERESS 1995). At first semifossilized depressions develop. Here the original landform is almost completely filled but its remnants are still visible. (The depression may be completely filled but still detectable from the darker tone caused by the accumulated plant detritus.) Of the completely fossilized depression the development of a secondary depression is typical. Finally, in the area of destroying fossilized depressions erosion starts. Channels formed by rainwater or intermittent water-courses fed by groundwater develop in their area. As a consequence of erosion (indicated by surfaces of erosional unconformities in the fill), the destroyed depression may reactivate (postgenetic karstification).

COVERED KARSTIFICATION DEPENDENT ON FLOWING KARST WATER

This type of karstification is associated with cavernation in the zone of flowing karst water. Cavernation is through mixing corrosion evidenced by spherical cauldrons occurring in caves and on rock walls which remain after cave destruction. Cavitation is also influenced by non-karstic rocks. On the one hand, the process takes place under impermeable rocks (hidden karstification). On the other, cavity formation is also promoted by the water seeping from water-courses which arrive onto the carbonate rocks of the valley floor from non-karstic terrains.

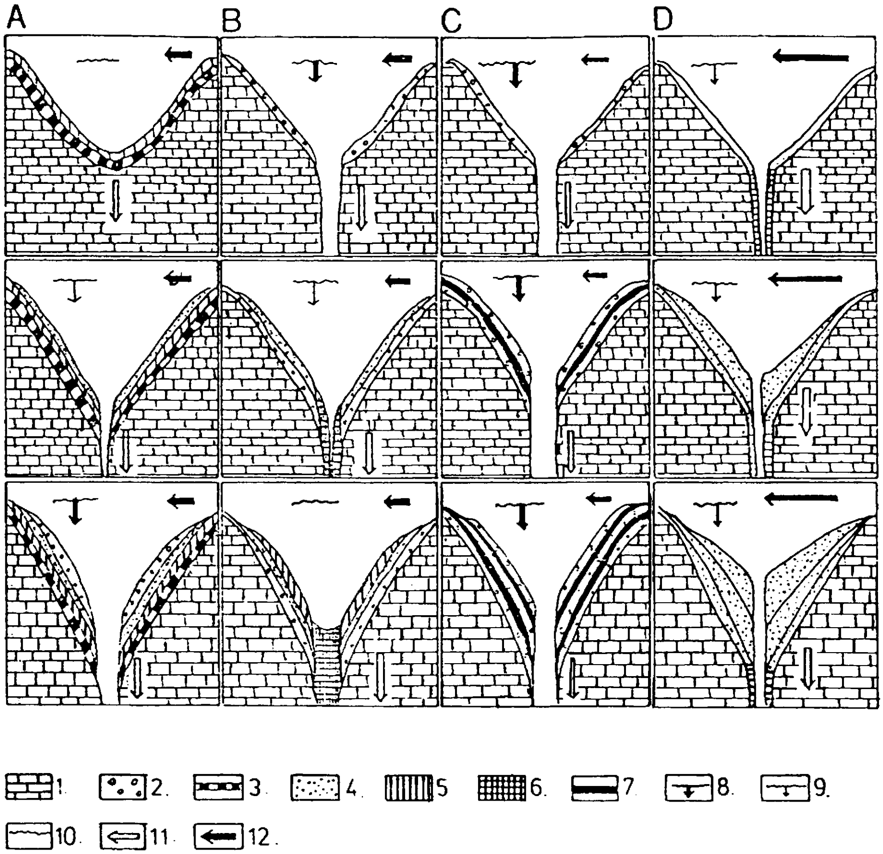


Fig. 26. Development of sediment fills of karst depressions in various types of development (VERESS 1986) Legend: 1. limestone; 2. redeposited loess; 3. clay (formed in situ); 4. clay sequence resulting from influx (beds of various colour); 5. laminitic series (perhaps overlying plant detritus sequence); 6. fill in the water conduit; 7. soil; 8. short-term intermittent pond; 9. intermittent pond of longer life-time; 10. long-term intermittent pond; 11. rate of deepening of karst depression; 12. rate of material influx into karst depression - A. type of activating karst depression; B. type of inactivating karst depression; C. type of equilibrium state karst depression; D. type of equilibrium state karst depression with increasing material influx

The caverns not recently bur earlier formed lie above the present-day karst water level. One-time cavity formation stages can be studied in valley sides (the here opening caves) or in quarry walls. The characteritic features of cavitation associated with flowing karst water are summarized below.

– Locally one can recognize that cavities formed by the merging of parts of caves and spherical cauldrons through solution (VERESS–PÉNTEK–HORVÁTH 1992a,b). They are complex secondary cavities. Other cavities of 1-2 dm diameter which did not formed by merging are also common (primary cavities).

– Cavitation is horizontal with regard to the spatial pattern of caves. Vertical (chimney-type) cavities rarely develop in the zone of flowing karst water (eg. Kerteskő Gorge).

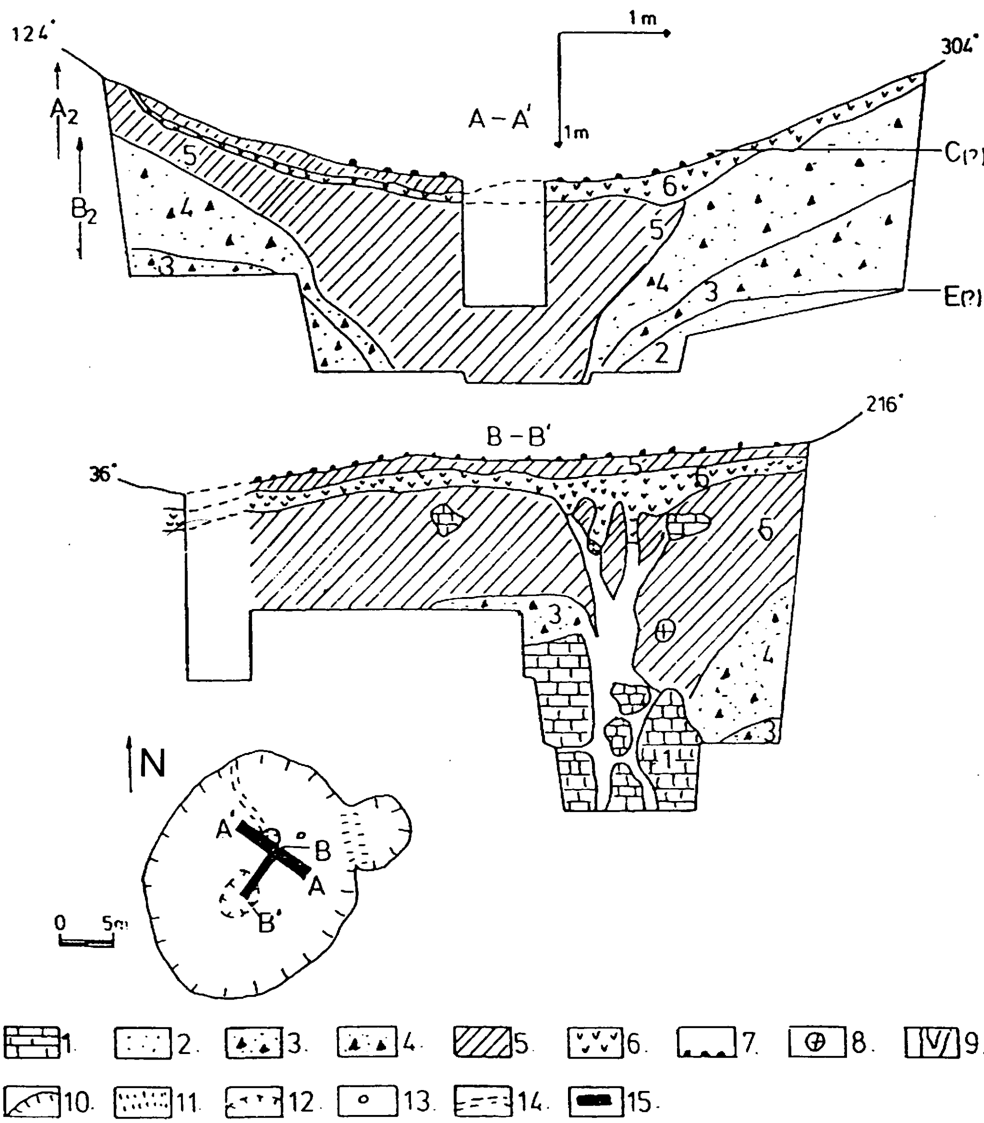


Fig. 27. Type of inactivating karst depression (doline-with-ponor Gy-9, central Hárskút Plateau – VERESS 1986, 1987b, sections drawn by FUTÓ 1980a)

Legend: 1. limestone; 2. reddich yellow clay without flint; 3. reddish yellow clay with flint; 4. greenish yellow clay with flint; 5. loess mixed with soil; 6. sequence with plant detritus; 7. grayish brown recent colloid (?); 8. recent bone and tooth remnant; 9. water conduit in lateral view; 10. edge of karst depression; 11. karst threshold; 12. partial depression; 13. water conduit in plan view; 14. channel; 15. exploration pit –A_2. inactivation with increasing sediment influx (impact of arable farming); B_2. equilibrium state at karst depression deepening; C. plugging of water conduit; E. opening of water conduit

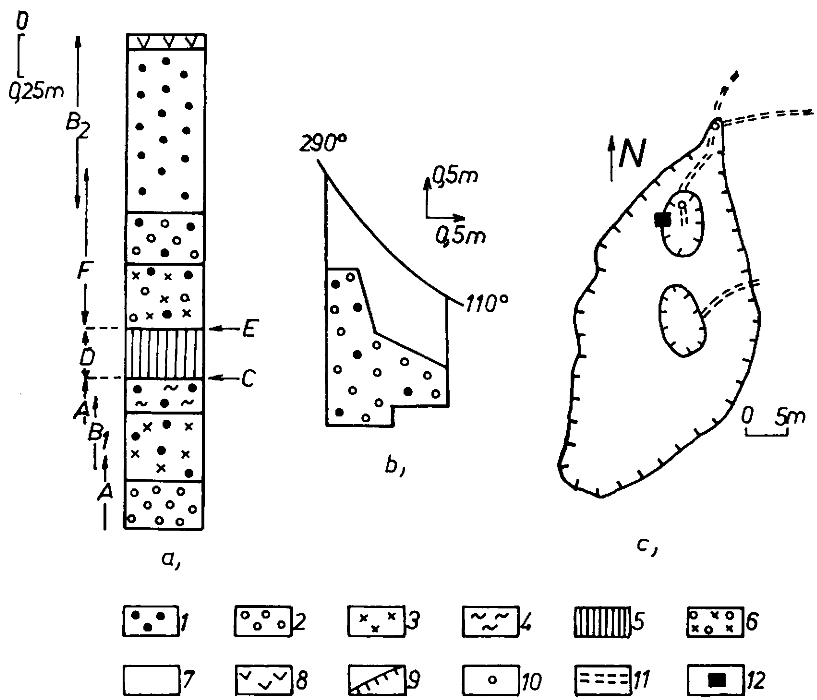


Fig. 28. Profile across the sediment fill of a karst depression of complex development (streamsink doline Ho-8, karst terrain around the Homód-árok) (modified after VERESS 1987b, sections drawn by FUTÓ 1980a)

Legend: a. cross-section of the explorationpit of the karst depression; b. longitudinal section; c. groundplan of karst depression - 1. scattered gravels in fill; 2. yellow silt; 3. dark gray clay; 4. greenish gray clay; 5. laminite (laminae of clay and silt); 6. slightly clayey silt; 7. brownish yellow soil; 8. humus; 9. edge of karst depression; 10. water conduit; 11. channel; 12. exploration pit - A. inactivation; B_1. state of equilibrium at deepening of karst depression; B_2. state of equilibrium with increasing sediment influx (forest clearing); C. plugging of water conduit; D. inactive state; E. opening of water conduit; F. activation

– The position of the zone of cavitation may be rahter variable related to the surface. The upper boundary may be close to the surface of carbonate rock (such cavities are exposed, for instance, in the stone quarry near Dudar) or in greater depth. The zone may be of limited thickness or of greater vertical extension. In the latter case, zones with and without cavities alternate. It is explained by the cyclical uplift od the enclosing block or by non-karstic or poorly karstifying intercalations in the karstic rock.

– A relatively large-scale cavity formation is observed in nummulitic limestone, particularly if it overlies „Hauptdolomit".

– The cavities of the flowing karst water zone contribute to the visible assemblage of landforms in the mountains in function of teh manner they evolved to their present shape. Caving of ceiling (collapse doline formation) or exposure (cave remnant formation) are distinguished.

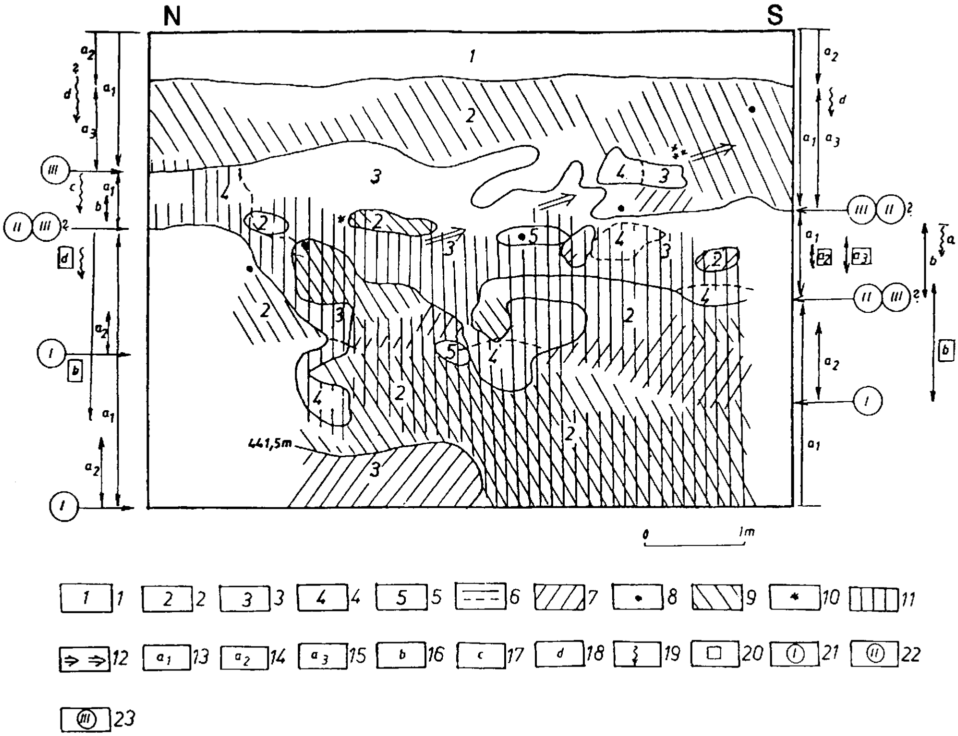


Fig. 29. Sediments in the exploration pit of wallow D-14 (karst terrain around the **Homód-árok**) (VERESS 1998)

Legend: recent sediment and soil fill in wallow; 2. gray clay; 3. gray-yellow mixed clay; 4. slightly yellow clay; 5. variegated mixed clay; 6. boundary of material; 7. series with charcoal; 8. nodular charcoal; 9. iron-oxide; 10. limonite; 11. calcareous series; 12. probable shift of water conduit site during accumulation; 13. accumulation undistinguished; 14. slow accumulation (wallow state); 15. rapid accumulation (burial); 16. redeposition with depression, deposition within partial depression; 17. calcareous precipitation (seepage from terrain without wallow); 18. complete inactivation (limonite formation, groundwater); 19. beginning of sign approximately shows the surface of infiltration; 20. process localised within fossilising depression; 21. plugging of water conduit; 22. opening, water conduction; 23. denudation (erosional unconformity)

Collapse dolines

Particularly on surfaces of Middle Eocene nummulitic limestone (Szőc Formation) elongated depressions of several metre diameter, irregular planform and shallow (sometimes only several dm) depth are common; they are collapse dolines. The varieties distinguished are circular **(Pict. 33)**, elongated wide and elongated narrow collapse dolines **(Pict. 34)**. Circular collapse dolines have gentler slopes, less elongated and definitively withour drainage. The wide and narrow varieties have steep sides and the latter are less markedly without drainage. Collapse dolines form through the caving of cavities developed in the zone of flowing karst water.

Their origin by caving is proved by the ceiling remnants found on their walls when the floors are excavated. The fill of the floor is composed partly of flat stone fragments deriving from the caved-in roof. Another piece of evidence is the traces of rockfalls on their margins. In numerous places in the continuation of cave remnants of valley sides collapse dolines follow beyond the valley margin. The only explanation to this is the exposure of underground cavities by the valley in valley sides, while beyond the valley margin (or the continuations of those in the valley sides) cave in and loose their cavity character.

Collapse origin is confirmed by their arrangement and morphology similar to depressions of the Dohányos Hill (Kab Hill), formed by the caving of the ceilings of mine galleries.

The origin of the solution origin of the cavities from which collapse dolines develop is evidenced by the following observations.

– In the sidee walls of collapse dolines solution features are common (eg. ruins of chimneys).

– Collapse dolines are of small dimensions; could have developed from cavities of some metres' length, 1-2 dm or at most 1 m depth and width and occur in great density in an area. These properties contradict an erosional origin as well as the summit position of depressions on terrains between valleys and the lack of erosional channels, even of blind valleys.

– It was mentioned that collapse dolines are typical of terrains of Middle Eocene nummulitic limestone. If they were of erosional origin, some collapse dolines would extend over the neighbouring Triassic carbonate rocks. In the case of erosional origin there would be no reason why the cavities resulting in collapse doline formation should be restricted to Eocene limestone.

– Their fill is a mixture of stone fragments, soil and reworked loess. Their appearance and composition also denies origin by erosion.

Cave remnants

Cavities formed in the zone of flowing karst water and exposed subsequently through the erosion of the enclosing rock are called cave remnants (VERESS 1980a, 1981a).

Valley cave remnants are formed during valley development (**Figs. 30, 31**). Those in summit position are exposed by frost shattering or mass movements on the summit levels (**Figs. 32, 33**) and those on the margins of plateaus through similar porcesses on the scarps of blocks. An example for a cave remnant in summit position is the Likas-kő of Hódos-ér and cave remnants on margins of plateaus are the caves of Magos Hill, Tönkölös Hill and Kőrisgyőr Hill.

The development of cavities later exposed as cave remnants in the zone of flowing karst water is proved by features like spherical cauldrons on the cave walls (**Pict. 35**), which attest to mixing corrosion. (In the percolating karst water zone there is no or not much opportunity for mixing corrosion but conditions in the zone of flowing karst water are much more favourable.)

In the zone of flowing karst water conditions do not only favour cave remnant development but also that of spring caves. In the mountains studied, however, caves are not of spring cave character but cave remnants as it is proved below.

– The superimposed valleys in the mountains could develop during uplift, which resulted in the subsidence of the main karst water level. The regressional incision of valley floors follows the subsidence of the karst water table only belatedly.

Parallel to incision, valley floors reach lower positions at a slower rate than that of uplift of blocks. In an opposite case valley floors would subside below the neighbouring surfaces (of the Little Hungarian Plain).

This statement is confirmed by the present-day conditons in the mountains. The floors of superimposed valleys are in a hanging position above the main karst water level (even more so at scarps or summit levels of uplifted blocks). The water-courses in superimposed valleys do not drain but feed now and have fed the main karst water. Superimposed valleys could only tap karst water storeys as observed in many places including the Mester Hajag, where water from a karst water storey issues in several places in the side of the Szekrényes-kő-árok. The karst springs fed by karst water storeys, however, are of too low yield to produce spring caves.

– The caves of the Ördög-árok developed by the solution activity of water flowing parallel to dip, ie. from the direction of the present entrances. It is only possible if the enclosing rock mass, the place of origin of karst water, have been removed by now.

– Caves with a completely dead end are typical of the mountains (**Fig. 31**). It is impossible in the case of a spring cave but possible in a cave remnant formed through the exposure of a cavity.

– Ruins of spherical cauldrons are common on rock walls, particularly on valley sides (**Picts. 36, 37, 38**). The presence of spherical cauldrons indicates that previously numerous cavities had existed which were subsequently destroyed and rock-walls were produced on which (now mostly ruined) spherical cauldrons of mixing corrosion origin are preserved.

The distinction between corrosional spring caves and cave remnants is not always easy to make. On the one hand, the lengths of cave remnants may even exceed those of spring caves and, on the other, losing parts of their ceiling, the latter may be dissected into ruined features. In order to distinguish between the two types of cave, the following properties (**Fig. 34**) have to be looked for. (When describing spring caves, the results of Jakucs 1971 are used and for cave remnants Veress 1980 is relied upon.)

– Spring caves occur at heads of superimposed valleys or along margins of karst plateaus (rarely in sides of superimposed valleys), while valley cave remnants are found in the sides of superimposed valleys.

– In the foreground of spring caves mostly travertine occurs, while in the case of cave remnant foregrounds, where no karst water issues over a longer period of time, travertines are absent.

– The fills of spring caves are composed of weathering residues, while in cave remnants weathering residues (if it develops at all) may be overlain by fluvial and other redeposited sediments.

Spring caves are larger formations which occur at several levels and in isolation. Cave remnants are shorter (of some metres' length). The valley cave remnants occur in a hanging position (because of incision) at variable height (**Fig. 35**) since a number of cavities could form in the zone of flowing karst water (**Pict. 39**). In fact, the various valley cave remnants are grouped at some specific levels and this indicates that their solution was due to a prolonged stage of karst water. The deviation between the mentioned levels, however, could be rather remarkable and explained by the formation of cavities at various depths parallelly at a given stage of the karst water. The cave remnants of plateaus are in summit positions but those on plateau margins may show a variety of altitude.

– Spring caves mostly have only one entrance and the passage from the entrance may branch repeatedly. Cave remnants often have several entrances as the exposure (and destruction) of cavities often takes place in sites where they branch.

– The enclosing rocks above spring caves are rather thick and thus dissection into ruined caves hardly takes place. Above the cave remnants, however, thin enclosing rock is found and the ceiling may cave in often and in several places. (Thus, ruined caves without ceiling, gateways and arches develop.) Remnants of solution features (ruins of spherical cauldrons or chimneys) are common on rock walls.

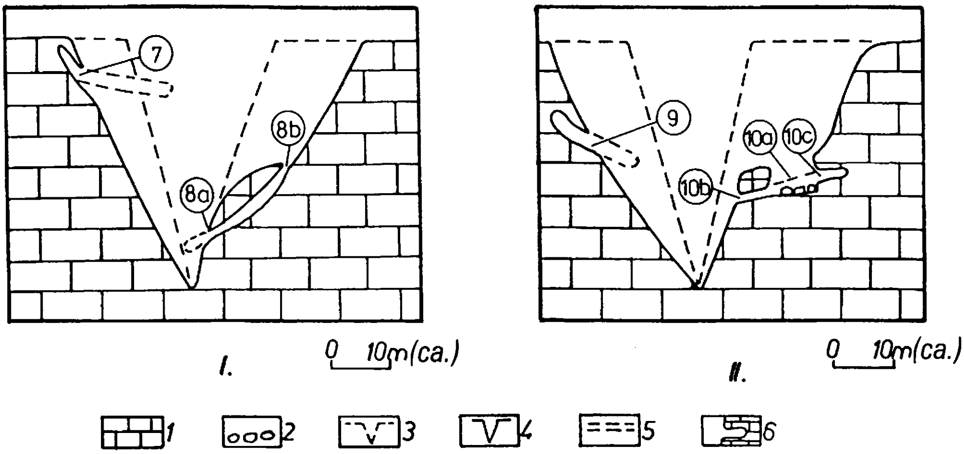


Fig. 30. Cave remnants exposed by erosion and further evolved by denudation of the valley side (I) and exposed and further evolved by the denudation of the valley side (II)
Legend: 1. karstic rock; 2. collapsed ceiling; 3. older valley; 4. present valley; 5. destroyed cavity section; 6. cave remnant; 7. ruined cave remnant exposed by stream erosion and truncated by the denudation of the valley side; 8. cave remnant exposed by stream erosion (8a) and further developed by the denudation of the valley side into a ruined cave remnant (8b); 9. ruined cave remnant exposed and truncated by the denudation of the valley side; 10. ruined cave exposed by the denudation of the valley side and ceiling caved in (10a), ruined cave remnant isolated by caving in (10b) and truncated cave (10c)

– Moving away from the entrance of a spring cave, the floor is getting ever deeper and the slope of cave remnant floors and the relief between their floors and the entrance may be highly variable **(Figs. 31, 34)**.

The gorges and gorge-like narrow valley sections in the mountains **(Pict. 40)** are of karstic origin since cavities of flowing karst water also contributed to their development. The water-courses of incising valleys (eg. Cuha, Ördög-árok, Kő-árok, Kőmosó-szurdok etc.) expose these cavities (Fig. 35). Exposed cavities promote incision and increase its rate. The density of cave remnants of valley type is greater since the water percolating from surface water-courses can increase the rate of cavernation and thus probably also the frequency of cavities.

There are two varieties of cave remnants developed parallel with valley incision: those exposed directly by stream erosion and those exposed by the erosion of valley sides.

The caves exposed by stream erosion are located in the vicinity of the channel and open in steep rock walls **(Pict. 41; Fig. 31)**. The caves formed earlier, by the erosion of valley sides, are further shortened (truncated cave remnants) or dissected (ruined cave remnants) or new cavities are exposed **(Pict. 42; Figs. 30, 31, 36)**. The cave remnants further sculpted by the erosion of valley walls and particularly those which are exposed by this process are further away from the channel and their relative elevation above the channel is often remarkable. The valley slopes in their environs are not particularly steep.

As a consequence of the erosion of valley walls, windows may open on the ceilings of cave remnants or of their ruins. Further destruction leads to the development of rock ar-

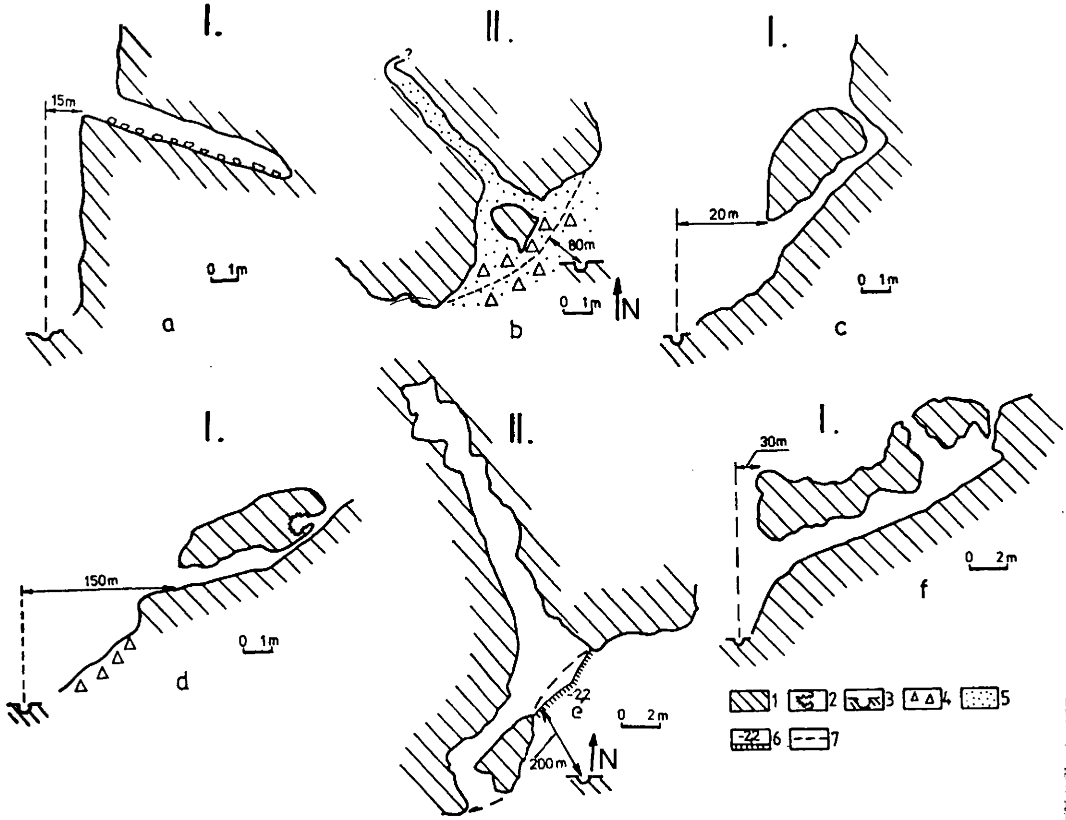


Fig. 31. Cross-sections (I) and plan views (II) of some characteristic cave remnants
Legend: 1. enclosing rock; 2. spherical cauldron; 3. channel; 4. debris; 5. soil, weathering residue; 6. rock wall with depth; 7. slope of entrance; a. cave remnant exposed by stream erosion (C-3 or Rejtett-fülke, Cuha Valley); b. cave remnant with several entrances exposed by the denudation of the valley side (K-8 or Kő-völgy-sziklaüreg); c. cave remntant exposed by denudation of valley side and eroded into ruined cave remnant (Km-1 or Átjáró Cave, Csesznek); d. cave remnant exposed by denudation of valley side and eroded into ruined cave remnant (M-4 or Likas-kő, Magos Hill); e. cave remnant exposed by the denudation of fault scarp and divided into ruined and truncated cave remnants (M-5 or „Csapóné konyhája"); f. cave remnant exposed by denudation of the valley side and divided into ruined cave remnants (C-4 or Remete-lik). Cave maps from reports of the Cholnoky Caving Group for 1977 and 1978

ches or ceiling remnants (**Pict. 43; Fig. 36**). Truncated or ruined cave remnants of some metres' length will come about.

The cave remnants which lose their ceilings entirely became cave ruins (**Picts. 44, 45**), bordered by steep rock walls on all sides. They are common features and there are hundreds or even a thousand of them in the valley walls of the Ördög-árok. According to their groundplan they are of corridor or chamber nature. Cave ruins also originate from caved-in subsurface cavities which do not form a feature without drainage, ie. a collapse doline (VERESS–FUTÓ 1987, **Figs. 32, 33**).

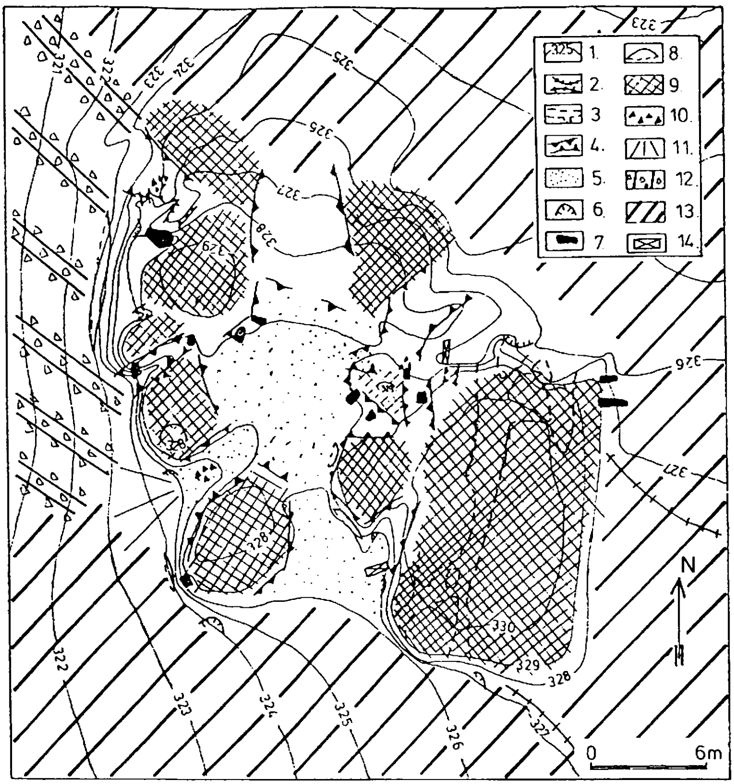


Fig. 32. Morphological map of Likas-kő, Hódos-ér (VERESS-FUTÓ 1987)
Legend: 1. contour line; 2. col; 3. ruined cave remnant; 4. cave ruin; 5. fill; 6. ruined spherical cauldron; 7. chimney remnant; 8. rock overhang (partly filled spherical cauldron); 9. rock block; 10. collapsed material; 11. debris fan; 12. debris slope; 13. terrain covered by unconsolidated and reworked sediment; 14. exploration pit

In the walls of gorges or gorge-like valley section in sites where caves are frequent, an arcuate rock wall of several metres' length develops on the slope. The reason why this happens is the caving of the steep slope here as a consequence of intensive cavity destruction. Other slope processes are repressed in these places and, therefore, the downwearing of slopes is moderate.

In the walls of gorges ruined caves of vertical axes **(Pict. 46)**, which are partly destroyed former chimneys originally developed in the karst water zone. They are similar to cave remnants of stream erosion origin and located close to the channel. Chimneys may also contribute to the destruction of valley sides as the erosion of the narrow dividing walls between chimneys produce depressions of 5-10 m width and wedge out towards to upper end of the valley side. They may be still dissected by remnants of dividing walls **(Pict. 47)**.

The cavities exposed by stream erosion promote valley incision (the gorge character is strengthened) and those exposed by the destruction of valley walls result in valley widening. The whole process is called valley evolution through cavity exposure, which is a particular but common form of karstification.

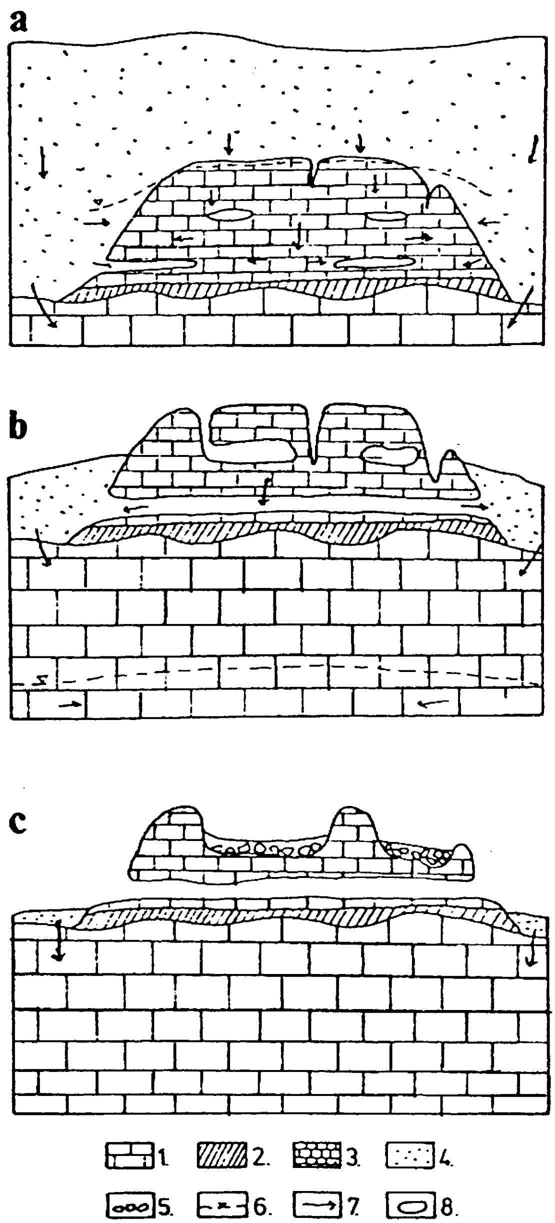


Fig. 33. Evolution of karstic cavities of Likas-kő (Veress-Futó 1987) a. carbonate rock covered and below karst water table; b. partly exhumed and above karst water table; c. karstic cavities are destroyed following further exhumation

Legend: 1. Triassic carbonate rock; 2. abraded base conglomerate; 3. Eocene limestone; 4. gravel (Csatka Gravel Formation); 5. collapsed material; 6. karst water table; 7. direction of flow; 8. karstic cavity

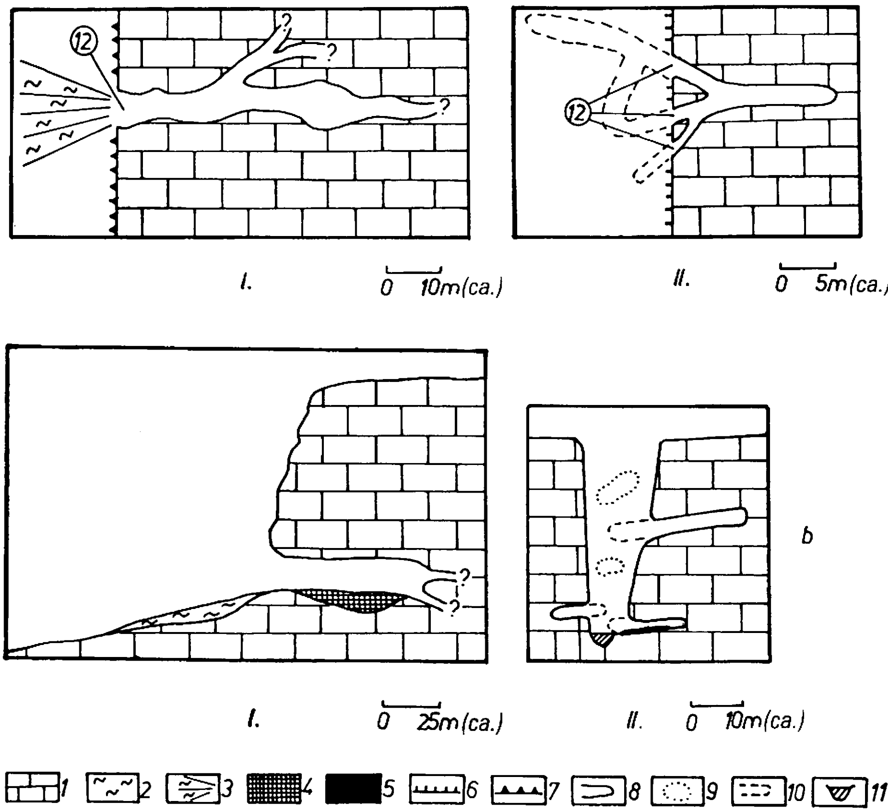


Fig. 34. Some morphological parameters of spring caves (I) and valley cave remnants (II)
Legend: 1. carbonate rock; 2. travertine; 3. travertine cone; 4. cave clay; 5. fluvial deposits; 6. margin of karst; 7. margin of superimposed valley; 8. solution cave; 9. cavity completely destroyed by erosion; 10. destroyed part of eroded cavity; 11. channel flow; 12. cave entrance; a. plan view; b. lateral view

TYPES OF KARSTIFICATION

The karstic features on the blocks of the mountains can be referred into various types of karstification. Karstification in a particular terrain may belong to a single or to several types. The following factors are influential in the formation of types of karstification.

– Whether the morphology of the carbonate basement is dissected or undissected? In the former case, is this morphology of tectonic or paleokarst origin?

– Whether there is a well-developed system of passages and if yes, what is the density of passages, what kind of sediments fill them and to what extent?

– The depth and nature of cover sediments, whether the denudation or accumulation of the surface with cover sediments continues further or what processes (sheet wash or stream erosion) dominate denudation.

– Surface morphology (eg. presence or absence of valleys).

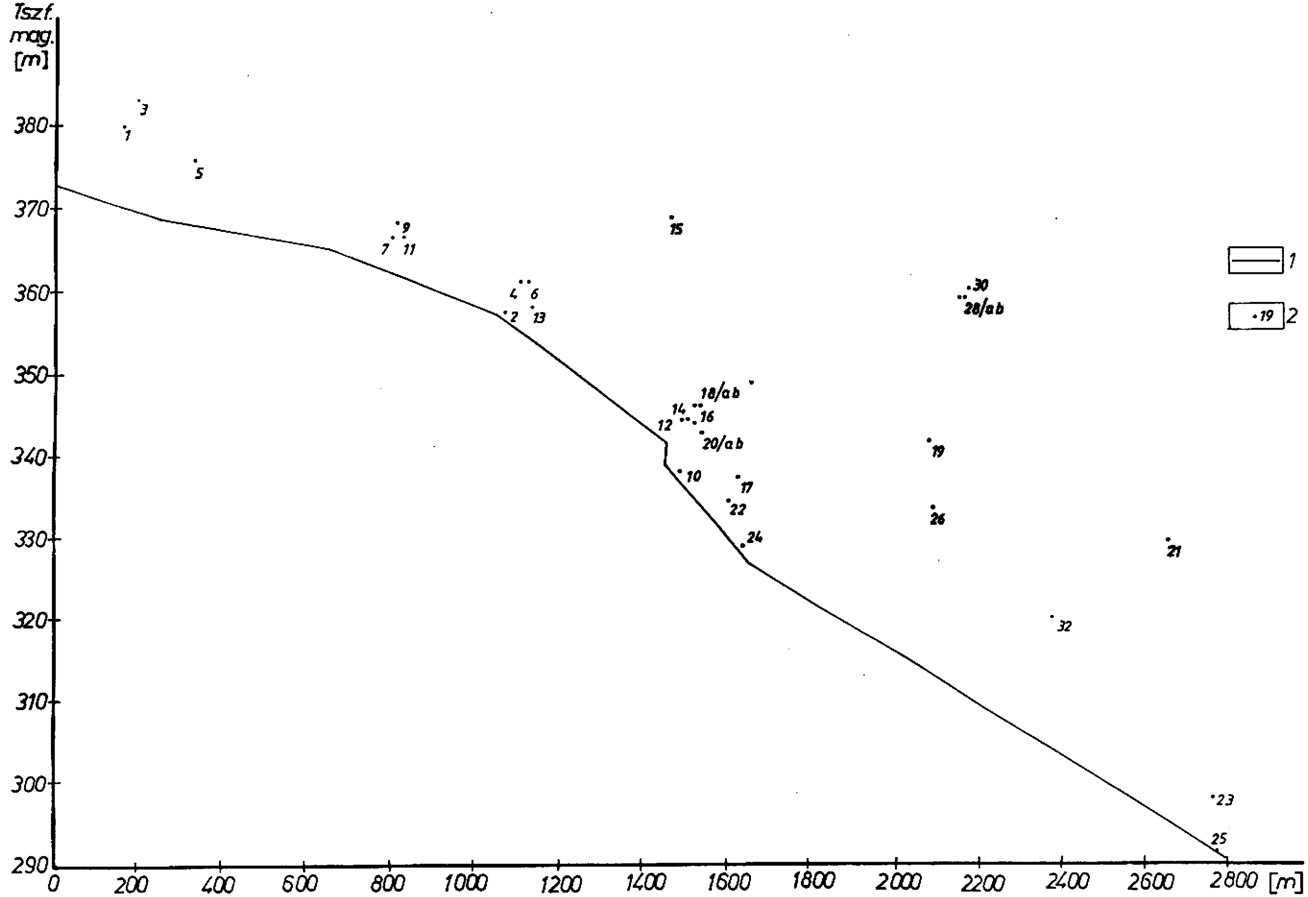


Fig. 35. Thalweg of the Ördög-árok channel and location of caves in valley side. Legend: 1. channel; 2. cave entrance

– Where do sites of valley development occur related to the paleokarst features.
– What kind of karstic rocks occur on the enclosing block and in what distribution?
– The altitude and relative evolution and extension of the enclosing block.
– The rate and nature of Quaternary uplift (cyclic or gradual), the way of uplift (uniform or tilted).
– The date of the beginning and the end of valley superimposition (when did they occur related to block uplift, loess formation and karst water accumulation).
– The position of flowing karst water related to the carbonate basement during the formation of karst water level. How uniform and deep is the cavity system of the zone of flowing karst water.

An overview of the types of karstification outlined below is provided in **Table IV.** and **Fig. 37.**

Types of karstification independent of flowing karst water

The karstification independent of flowing karst water takes place blocks or on groups of blocks which had been uplifted by the time the zone of flowing karst water (main karst water or karst water storeys).

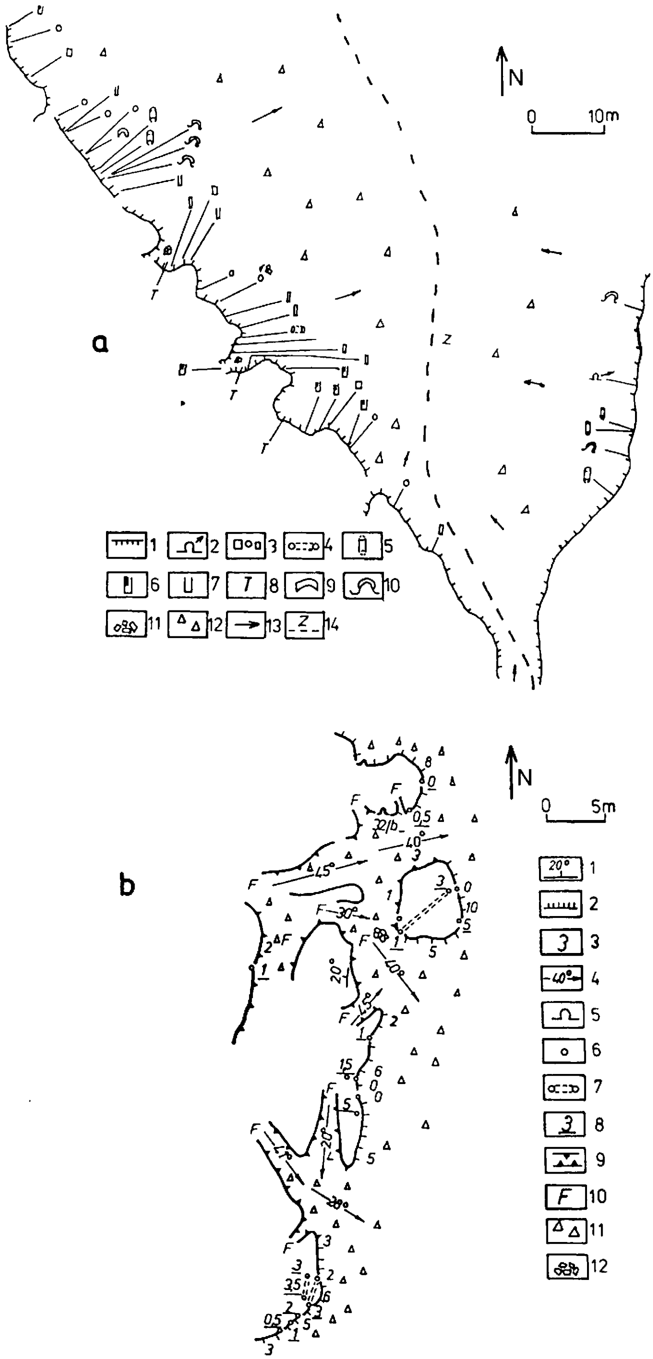
By the time of cavernation, in such blocks the karst water table was in a deeper position related to the surface of the carbonate basement or no valleys developed the floors of which could incise down to the karst water table. It may have occurred that the still developing superimposed valleys reached and exposed cavities above the karst water table. Subsequently, however, their development came to a halt since the denudation of cover sediments from their environs left them without a water-course (inactive well-developed superimposed valley). On such blocks no valley evolution by cavity exposure could or can happen. In the sides of inactive well-developed superimposed valleys cavities of smaller size (some tens of centimeters diameter) can occur. These features are remnants of the zone of cavernation of moderate vertical extension formed before the inheritance of the valley.

The karstification here is affected by rainwater infiltrated into the permeable cover (loess). Karst water or the cavities formed by karst water exert no influence on karstification.

The denudation (or accumulation) of cover sediments may take place in carbonate terrain dissected by fault scarps, elevations (cones) and paleokarst depressions. Cover sediments may be eroded (thinned out) by sheet wash, stream erosion and matter transport in depth. The different types of karstification produce different densities, distributions, sizes, types, positions and geomorphological environs of karst features (or relative frequencies of various karst feature types). In addition to the above factors, the character of exhumation and thus the type of karstification also depends on the dimensions of blocks or groups of blocks, their altitudes and relative heights and the preceeding geomorphic history. Thus subtypes and varieties can be indentified. As a consequence of numerous factors and of a limited number of karstic terrain, karstification on the individual blocks or groups of blocks is of individual nature. Karstic microregions, however, could not form in the mountains since karst features are of small size and low density and karstification is unable to determine the face of blocks or groups of blocks. The following types of exhumation are distinguished (**Table IV**).

Karstification in terrain with covered fault scarps

In carbonate terrains dismembered by fault scarps, hidden rock boundary can develop on the edges of fault scarps, particularly, if scarps are also tilted (**Fig. 38**). Dolines-with-


a
N
0
10m
b
N
0
5m

← Fig. 36. Remnant features predominantly formed by stream erosion (below Pápalátó-kő) (a) and by sheet wash (around Cave Ö-32) (b) (a: after VERESS 1981a; b: see Annual Report of Cholnoky Caving Group for 1981)

Legend: a: 1. rock wall; 2. truncated cave remnant; 3. vertically elongated, impassable truncated cave remnants of circular irregular cross-section; 4. ruined cave remnant; 5. chimney ruin; 6. cave ruins with ceiling remnants; 7. cave ruin of corridor-like appearance; 8. cave ruin of chamber-like appearance; 9. rock arch; 10. spherical cauldron on rock wall; 11. collapsed material; 12. debris, soil; 13. slope; 14. walking path b: 1. dip and dip direction of bed; 2. rock wall; 3. height of rock wall (m); 4. slope angle and direction; 5. entrance to passable cave remnant; 6. impassable cave remnant; 7. impassable ruined cave remnant; 8. height of karst passage in rock wall (m); 9. cave ruin; 10. caved-in ceiling (cave remnant with damaged ceiling); 11. debris; 12. collapsed material from ceiling

ponor of small size and without channel are formed in rows. Where exhumation is due to sheet wash, the alignment of rows can be adjusted to the strike of faults (karstification takes place along a single scarp edge) or rectilinear to the strike (karstification takes place in certain sites along the scarp edge). Where exhumation is due to stream erosion, rows of depressions are associated with valleys. Here the surface with fault scarps is dissected by superimposed valleys older than the faults (inactive well-developed superimposed valley type) and the valleys are subsequently filled by redeposited loess. Now younger valleys are incising into the old valley fills (developing superimposed valley type – **Fig. 48**). The cover sediments in the upper ends of older superimposed valleys are redeposited into the younger valleys and, thus, the cover sediments there have thinned out **(Fig. 39a)**. Rows of karst depression can also develop in the sides of inactive well-developed superimposed valleys since during the regression of developing superimposed valleys cover sediments may also thin out on the valley sides of the former through sheet wash. In this case the rows of depressions meet the valleys at low angles since along the lower valley sections the evolution of the developing superimposed valley is of earlier date and, thus, sheet wash may extend over the upper segments of the wall of the older superimposed valley. Along the upper valley sections sheet wash could make cover sediments thin out only on the lower valley sides since along these sections, due to the headward incision of developing superimposed valley, sheet wash could start at a later date **(Fig. 39)**. Karstification can also take place where channels retreat from the younger developing superimposed valley towards the upper part of the older, well-developed superimposed valley where the latter is is still filled (buried) **(Pict. 49; Fig. 40)**. In both sites the edges of fault-scarps experience karstification. Exhumation types by sheet wash and by stream erosion are not distinct from each other spatially. In the area of the Márvány-árok (N slope of Kőris Hill) exhumation and accompanying karstification are caused by stream erosion in the superimposed valleys and on interfluvial ridges by sheet wash **(Fig. 41)**.

Karstification of terrains with cones

In considerable parts of the mountains the carbonate surface is uneven and dissected by cones (VERESS 1991). This morphology is primarily typical of Middle Cretaceous limestones but also occurs on „Hauptdolomit", Jurassic limestones and Middle Eocene limestones. Cones are sometimes found in rows and in other places arranged irregularly. This assemblage of features can be regarded as remnants of a tropical fengzong type of inselberg karst, exhumed to various degrees. On the summit levels of buried cones (hidden rock boundary) or on the sides of semiexhumed cones (asymmetric hidden rock boundary or no

Table IV.:

Karstification types in the Northern Bakony (independent of flowing karst water, only in case of exhumation)

exhumed feature	type of erosion	exhuming terrain		feature formed during exhumation	morphology of developing covered karst feature		
					type of karst feature	distribution of karst features	geomorphological position of karst feature
escarpment	sheet wash	side of block with scarps		block side	doline-with-ponor	in rows	gently sloping plane
	linear erosion	superimposed valley		double valley or channel in the fill of superimposed valley	doline-with-ponor	in rows	side of superimposed valley
cone	sheet wash	block of small area, non-tilted		flat block surface	doline-with-ponor	in irregular groups	on block surface in summit position
		block of small area, tilted	block tilted in a single direction	crests of downslope direction with exhumed residual terrain in between	doline-with-ponor	in short rows	on block surface on exhuming terrain
			block tilted in two directions	cone series of downslope direction with exhumed residual terrain in between	doline-with-ponor	in short rows	on block surface on exhuming terrain
	linear erosion	transversal exposure on block of large area		superimposed valley	covered karst ponor	isolated	
					solution doline	in irregular groups	
		longitudinal exposure on block of large area	on cones	ridge between superimposed valleys	passage without depression	isolated	on ridge between superimposed valleys
			among cones	superimposed valley	doline-with-pseudoponor, doline-with-ponor	in rows	on sides of superimposed valleys
					subsidence doline	in groups	
	linear erosion and/or sheet wash and transport at depth	block surface		pseudo-depression	doline-with-ponor	in short rows (sometimes along arcs), in groups	on block surface in summit position
paleokarst depression	sheet wash	exposure of valley floor with paleokarst depression		superimposed valley	doline-with-ponor	in short rows	on floor remnants of summit position superimposed valleys
	sheet wash or linear erosion and transport at depth	exposure of portion of block surface with paleokarst depressions		true depression on flat block surface	pseudoponor	isolated	in true depressions
					doline-with-ponor	in groups	
		exposure of superimposed valley		true depressions on epigenetic valley floor	postgenetic doline-with-ponor	isolated or in irregular groups	on superimposed valley floors
					doline-with-pseudoponor, subsidence doline	in rows	

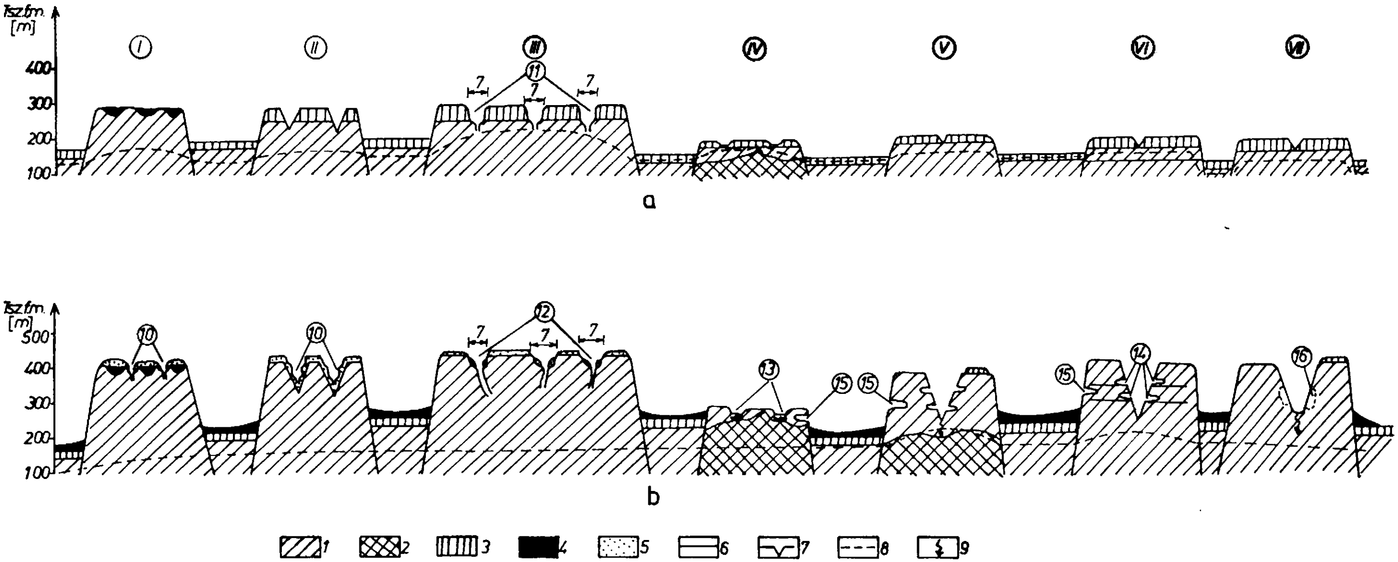


Fig. 37. Covered karst types and subtypes of blocks of various structure and uplift (dimensions are not proportional)
Legend: 1. limestone; 2. dolomite; 3. Csatka Gravel Formation; 4. reworked cover sediment; 5. loess; 6. impermeable intercalation in carbonate rock; 7. superimposed valley; 8. karst water table; 9. seepage from valley floor into the main karst water; 10. syngenetic karst features (dolines-with-ponor); 11. ponors on floor of superimposed valley; 12. postgenetic karst features (eg. postgenetic doline-with-ponor); 13. collapse doline; 14. cave remnant in valley side; 15. cave remnant in block side; 16. chimney ruin (remnant of old cavity formed below the karst water table); I. valley formation (if present) on block of high position even initially stops for the time of inheritance and syngenetic karstification follows below the cover sediments overlying the uneven basement (type with cones and fault scarps); II. on block of high position even initially syngenetic karstification on floors of superimposed valleys, later filled up; III. on block of high position even initially valley formation continues after inheritance and slow incision favours bathycaptures and postgenetic karstification in filled ponors after loess formation; IV. initially low block, slow uplift, cavities below karst water table are not exposed in lack of valleys and cave in at an early date; V-VI-VII. initially low block, because of cyclic uplift (V) or presence of impermeable series (VI) cave remnants form in sides of superimposed-regressional valleys or slow continuous uplift produces chimney ruins in the sides of superimposed-antecedent valley sections (VII); a. initial stage; b. present stage

hidden rock boundary) karstification takes place. The (fragment of) block of covered surface with cones may have various size. On small blocks no surface drainage could or can develop on cover sediments.

Karstification on a small block with cones

The exhumation by sheet wash can take place on tilted or untilted small blocks (VERESS 1991).

– If the block is untilted, the denudation of cover sediments is more or less uniform over the whole surface. The summit level of still buried cones may undergo karstic processes. Karst depressions are dolines-with-ponor of small size arranged irregularly. Fossilisation is common since the border areas and slopes of depressions are limited. (The reason for the former is the great density of depressions and for the latter is that exhuming cones hinder sheet wash.) This subtype of karstification is characteristic of the eastern portion of the Mester-Hajag (Pénzesgyőr) and the area above Judit spring.

– The tilt of the block before and during exhumation cna be unidirectional (eg. on Égett Hill near Pénzesgyőr) or bidirectional (Mester-Hajag). In the former case, matter transport takes place in one, while in the latter, in two directions. While in the first case ridge-like features **(Fig. 42)** are exhumed (from among the cones of cone rows the unconsolidated material is hardly removed), in the second, cones are exhumed if the cones are aligned in rows **(Fig. 43)**. Cone exhumation becomes possible since the surface of blocks do not only slope towards the cone rows but also in more or less rectangular direction. Therefore, cover sediments may be removed from the intervals of cones. Between the ridges and cone rows there are exhuming remnant terrrains buried under unconsolidated sediments. Here under cover sediments heavily truncated cones and maze-like dolines shape the basement morphology. As it has been mentioned above, karstification occurs on the summit levels of buried conesd (hidden rock boundary) or in the sides of semiexhumed cones **(Figs. 44, 45)**. During exhumation rock boundaries are bound and acquire lower positions. Over cones karstification is shifted, new features develop and those of higher position are mostly truncated **(Fig. 46)**. As a consequence of exhumation, an equilibrium state is produced. Another intensive exhumation stage and the accompanying rearrangement of karstification sites occurs if uplift or valley incision in the environs ensues. Exhumation may also intensify to the effect of forest clearing. The exhumed terrains with cones may be buried. In this case, the rock boundary and karstification shifts upwards in the sides of cones. The previously formed karst depressions are buried. The karstic features on the slopes of cones, destroyed, fossilised or buried by now indicate the directions of sediment transport. Thus, it is reconstructed that during exhumation karstification occured on the sides of cones in the direction of sediment transport and during accumulation the opposite side karstified. The length and direction of karst depression rows is in accordance with the length and direction of exhumed remnant terrains or cone rows. The border areas of dolines-with-ponor with or without channels are constituted by exhumed remnant terrains, which wear down during exhumation and this favours the fossilisation of karst depressions.

On both the untilted and tilted blocks pseudodepressions also occur **(Figs. 42, 43, 44, 45)**.

– On terrains with cones depressions may completely replace exhumed remnant terrains (VERESS 1998). This is typical mostly of block surfaces where tilt is limited and cones are arranged irregularly (cockpit terrain), sheet wash is predominant but of insignificant extent. Those block details are particularly prone to such processes which are far from terrains of

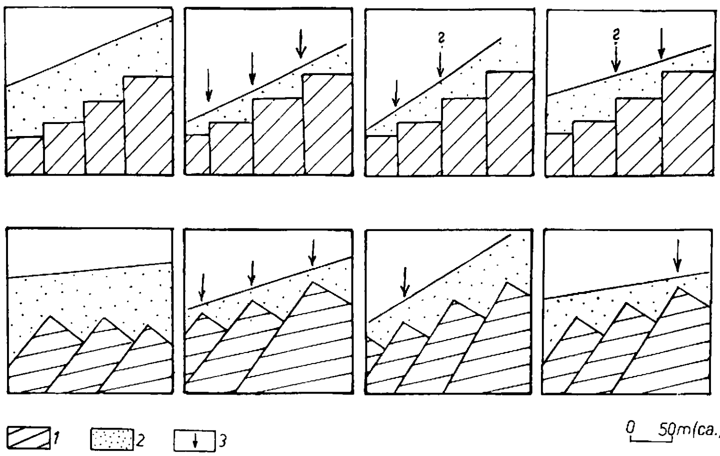


Fig. 38. Hidden rock boundaries in cases of various assemblages of fault scarps and various thicknesses of cover sediments
Legend: 1. carbonate rock; 2. loess; 3. hidden rock boundary

stream erosion (**Figs. 17, 47**). Terrains of similar karstification are found in the SE of Mester-Hajag (**Picts. 16, 17; Figs. 19, 20**), in the vicinity of the Augusztintanya and in karst terrains around Homód-árok (**Fig. 21**). In their interior karst depressions are arranged in rows or occur irregularly. In the area of pseudodepressions matter transport in depth is coupled with the related redeposition of cover sediments. The background to resulting karst features is the previous accumualtion terrains of depressions (with fossilising karst features) (**Fig. 22**).

Karstification on a large block with cones

On the surfaces of larger blocks a drainage network develops and exhumation takes place by the process of stream erosion. Valleys in such terrains, where karstification occurs on floors and side walls, are active or inactive well-developed or developing superimposed valleys. Exposure is either transversal or longitudinal (VERESS 1991).

– In case of transversal exposure (**Fig. 48**) the directions of the cone row and of the valley are different. On the floor of the valley incised into the Csatka Gravel Formation karstic and non-karstic zones alternate. (In the latter sites the incision of the valley reached the summit level of the cone.) Karstification occurs where the valley floor reaches the carbonate rock. It takes place on valley floors covered by loess or redeposited cover sediments and covered karst ponor may be created on a hidden rock boundary (pseudobathycapture and blind valley development – eg. the covered karst ponor no K-1 near the Kleintanya, Hárskút). Mostly, however, rows symmetric dolines-with-ponor formed on hidden rock boundary follow the floors of superimposed valleys (also including pseudoponors). During incision or the redeposition of the loess fill the cover sediment thins out over more and more cones and, thus, further dolines-with-ponor develop. The background areas of dolines-with-ponor are constituted by the floor of the superimposed valley and its side slopes. In pseudoponors or dolines-with-ponor deep fills accumulate since they function as traps for sediments removed from upstream valley floor sections. The exhumation of buried

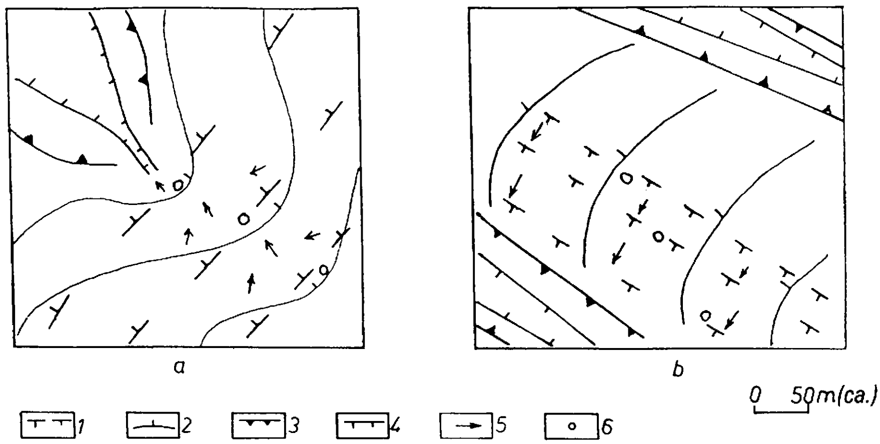


Fig. 39. Karstification of transversal and longitudinal fault scarps with channels retreating over a broad ridge (a) and inregressional developing superimposed valleys in superimposed valley (b)

Legend: 1. fault scarp; 2. contour line (approximate); 3. margin of well-developed superimposed valley; 4. margin of developing superimposed valley or channel; 5. zone and direction of sheet wash; 6. karst depression

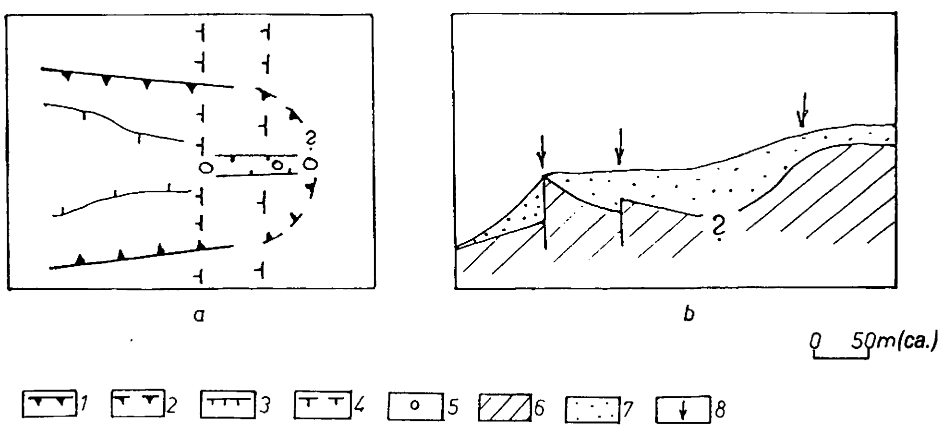


Fig. 40. Karstification of the upper end of superimposed valley **exposed by regressional channel,**
a. plan view; b. lateral view

Legend: 1. well-developed superimposed valley partly filled with loess; 2. well-developed superimposed valley filled with loess; 3. regressional developing superimposed valley or channel in superimposed valley; 4. edge of fault scarp; 5. karst feature; 6. limestone; 7. loess; 8. hidden rock boundary

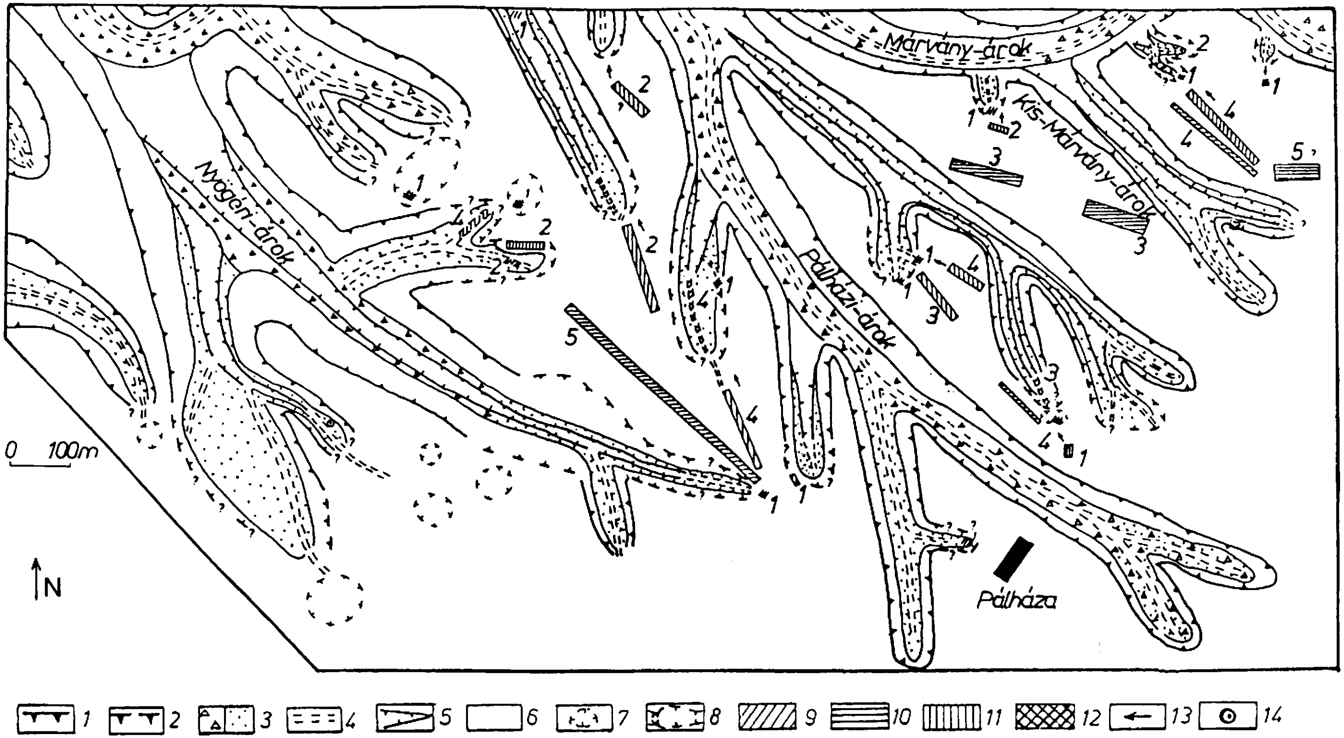


Fig. 41. Karst morphological map of the area S of Márvány-árok

Legend: 1. margin of well-developed, older superimposed valley; 2. margin of well-developed buried superimposed valley; 3. floor of well-developed superimposed valley with slope deposit and reworked loess accumulation; 4. regressional developing superimposed channel; 5. regressional, partly developed superimposed valley; 6. planated surface dissected into interfluvial ridges; 7. buried paleokarst landform; 8. paleokarst feature exposed by superimposed valley; 9. valley or channel section with karstification; 10. karstification zone on interfluvial ridge along transversal scarps (number of karst depressions in zone); 11. zone of karstification along longitudinal scarps (number of karst depressions in zone); 12. karstification associated with buried paleokarst feature; 13. sheet wash towards ends of regressional channels; 14. karstification in side of well-developed superimposed valley

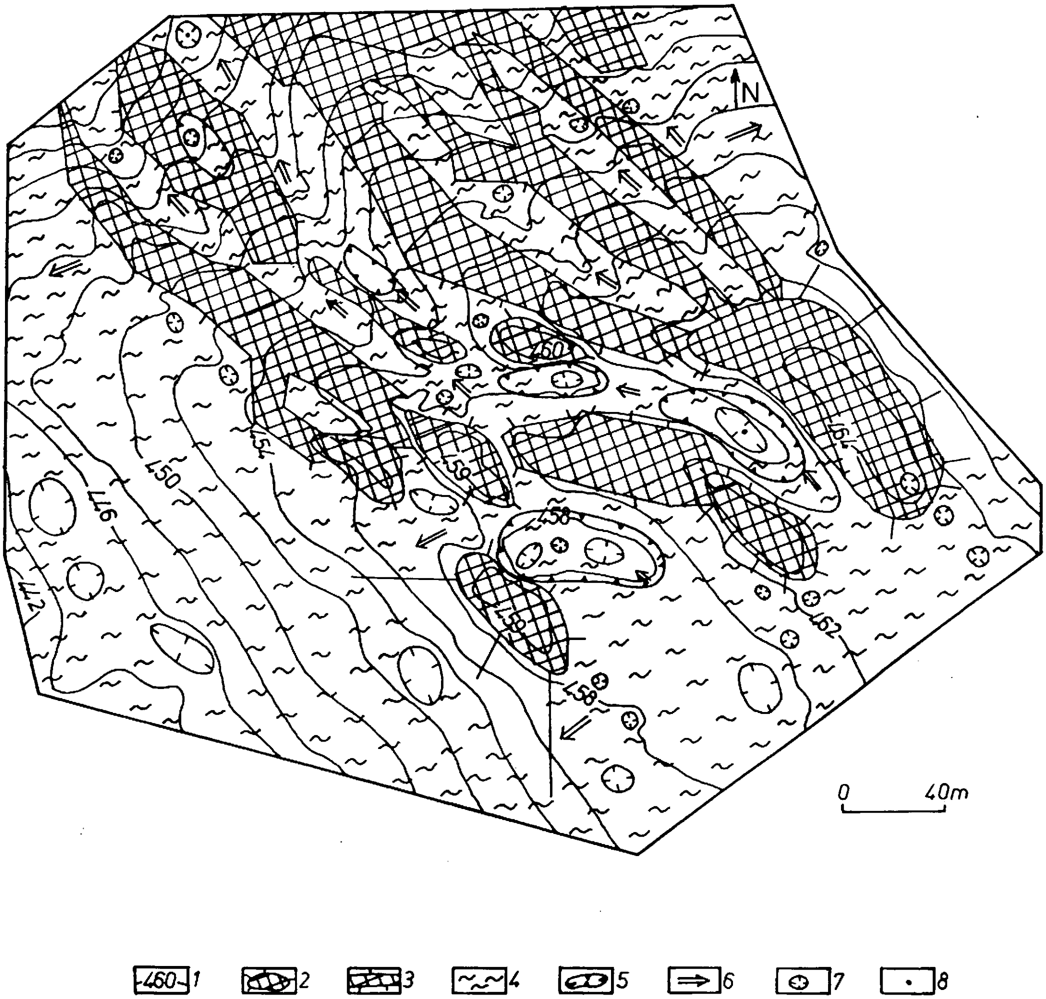


Fig. 42. Morphology of block with row of cones, tilted unidirectionally (Égett Hill, VERESS 1991)
Legend: 1. contour line; 2. semiexhumed cone; 3. exhuming cone; 4. exhuming relict terrain; 5. pseudodepression; 6. reworking; 7. karst depression; 8. water conduit in karst depression

cones is of moderate scale since only small amounts of sediment from valley floors above the sites of karstification are transported beyond the cone (by overflow) and also because karst depressions are only able to store small amounts of sediment. On the summit level of the exhumed cone subsidence dolines sometimes also occur. This subtype of karstification is typical of eg. the Szilfakő Valley in the central Hárskút Plateau **(Pict. 13)**.

– During longitudinal exposure the valley forms either above or between cones. In the former case, the sides of inactive well-developed superimposed valleys formed in unconsolidated deposits erode rapidly. Thus, the background area for karst depressions on the valley floor is destroyed and, therefore, the depressions are truncated **(Fig. 49)**, their water conduit may be occasionally preserved. A truncated feature is the Gyenespuszta Cave in the area of Hárskút (**Pict. 2**). The side slopes of the valley incising between cone rows (developing superimposed valley) are sometimes covered by loess (**Fig. 50**). Where loess is washed down and thins out, a hidden rock boundary develops and dolines with ponor and pseudoponors come about. The karst depressions are aligned in the valley sides in rows parallel with the valley axis. As a consequence of the removal of cover sediments, the hidden rock boundary and, thus, karstification shift upstream and solution dolines can also develop in valley sides without cover sediment. This variety of karstification is characteristic for the Öregfolyás Valley in the central Hárskút Plateau (**Picts. 12, 14**).

Paleokarst depressions and karstification in their environs

Karstification also results from the exhumation of paleokarst depressions of various size, shape and origin. They are eg. dolines formed before the present stage of karstification (allogenic type of karstification) and ponors formed at the beginning of the present stage of karstification (authigenic type of karstification). Ponors developed on valley rock boundaries in now inactive superimposed valleys. In this case, the valley was superimposed on a covered limestone terrain where the zone of flowing karst water lay close to the surface. On valley floors of this kind the uplift of the area resulted in true bathycaptures.

Syngenetic karstification

Karstification affects the thresholds between paleokarst depressions. The conditions are favourable for this process where the ponors formed (along a rock boundary) on the floor of the superimposed valley were buried before the present denudation. As a result of the removal or redeposition of sediments covering the valley floor, the valley floor remnants between former ponors karstified (**Fig. 51**). A row of dolines-with-ponor develops in the direction of the inactive superimposed valley. the background area of dolines-with-ponor are the filled paleokarst depressions. (The sediments on the sides of superimposed valleys in which valley formation once began are missing by now.) It is a common phenomenon that even recent karstic features on valley floor remnants have been fossilised by now.) This subtype of karstification is clearly detected on the floors of superimposed valleys of uplifted blocks (Középső-Hajag, Som Hill and Papod-Borzás).

The removal of cover sediments from the paleokarst through sheet wash can be so intensive that on the edges (mostly on symmetric hidden rock boundary) syngenetic karstification begins (VERESS–FUTÓ 1990). Pseudoponors or groups of pseudoponors are often generated. Because of matter transport in depth pseudoponors generate clearly delimited catchments in the area of the paleokarst feature (**Pict. 15; Fig. 52**). In the well-developed regressional channels leading to pseudoponors a series of bathycaptures is detectable. The areas of this subtype of karstification occur in isolation (the Eleven-Förtés group of dolines on Kőris Hill and the pseudoponor G-6/b near Gombáspuszta in the central Hárskút Plateau).

This karstification is typical of fossil dolines. During karst processes dolines-with-ponor develop in fossil dolines. This type does not occur independently. The resulting features appear in low density and mixed with landforms of other types of karstification. Features of such origin probably occur on the Tés Plateau and in the western Sűrű Mountain Group.

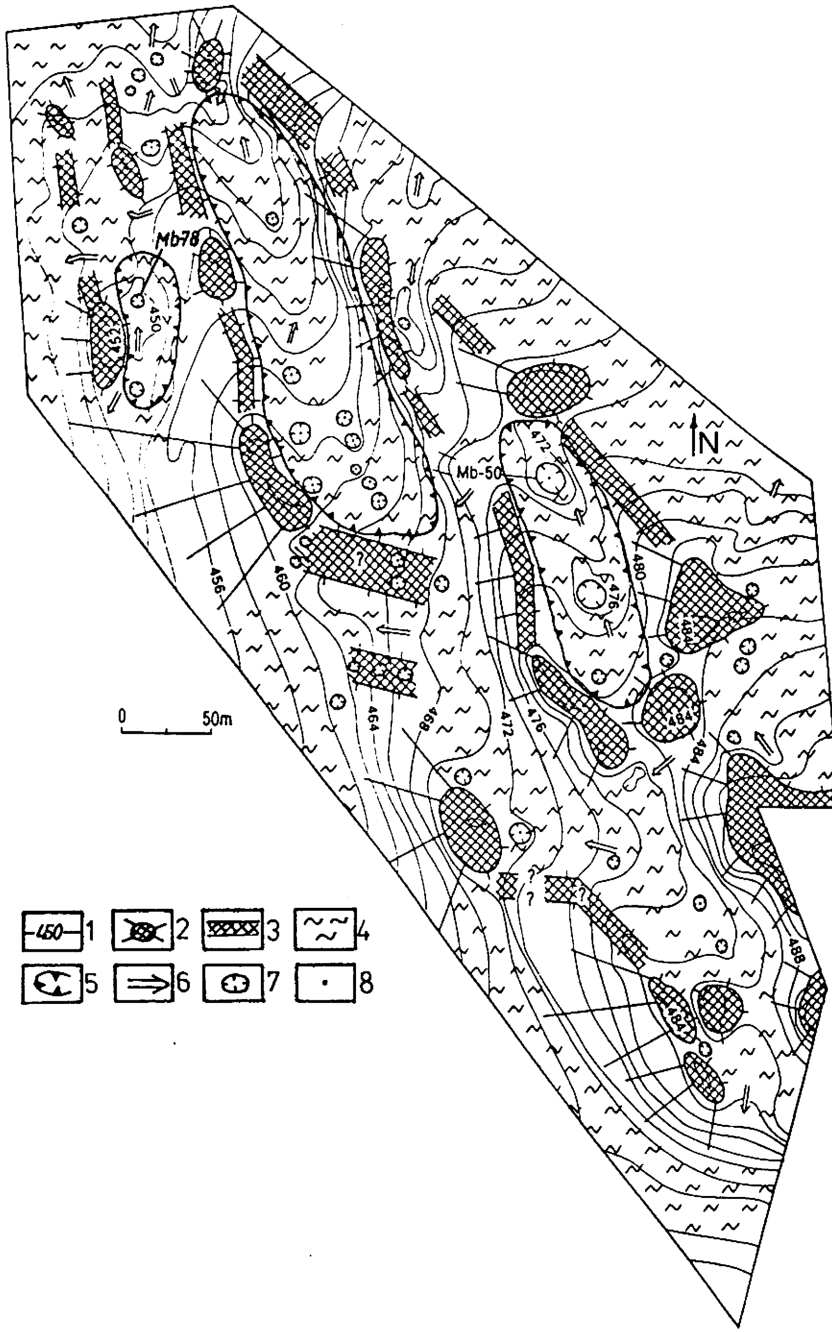


Fig. 43. Morphology of detail of block with row of cones, tilted bidirectionally (Mester-Hajag, VERESS 1991)

Legend: 1. contour line; 2. semiexhumed cone; 3. exhuming cone; 4. exhuming residual terrain; 5. pseudo-depression; 6. reworking; 7. karst depression; 8. water conduit in karst depression

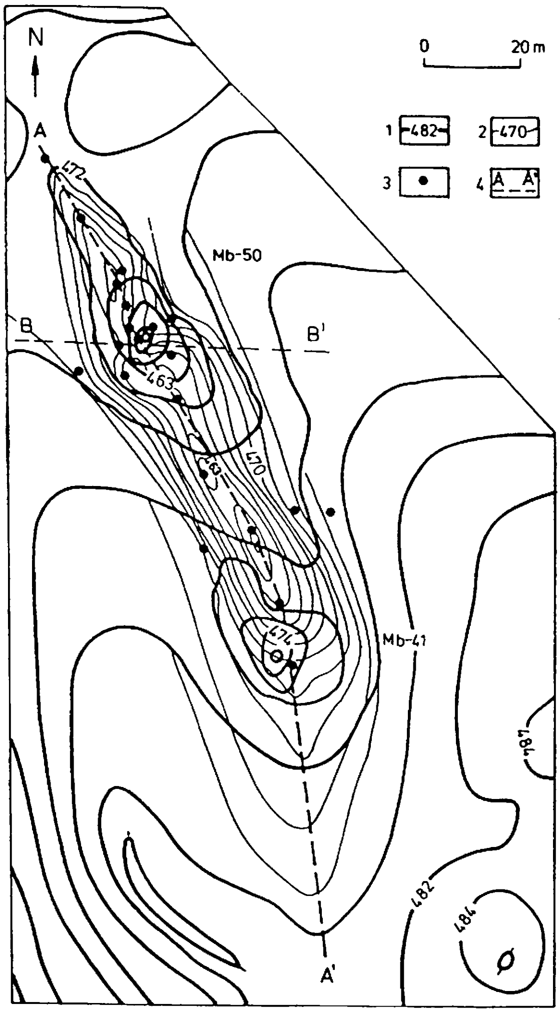


Fig. 44. Topographic map of the basement and the surface around the pseudodepression (see Fig. 43) of karst object Mb-50 (Mester-Hajag) (VERESS-FUTÓ-HÁMOS 1986) Legend: 1. contour line; 2. contour line of limestone basement; 3. borehole site; 4. section (see Fig. 45)

Postgenetic karstification

If over paleokarst depressions of the floors of superimposed valleys (former ponors formed along a rock boundary) cover sediments thin out, mostly postgenetic karstification is induced. Thinning out can derive from sheet wash or from stream erosion **(Fig. 18)**. As a result of subsequent clearing of passages, postgenetic karst depressions are produced **(Picts. 19, 20, 21, 22)**. Postgenetic depressions develop in the area of paleokarst features. Postgenetic depressions are aligned along the floors of superimposed valleys. In the rows there occur pseudodolines, dolines-with-pseudoponor and depressions with postgenetic dolines-with-ponors. It is common that although the landforms are arranged in rows but do not follow the superimposed valleys along their whole length. Frequently, postgenetic features appear at the confluences of tributaries or in the bends of the enclosing valley.

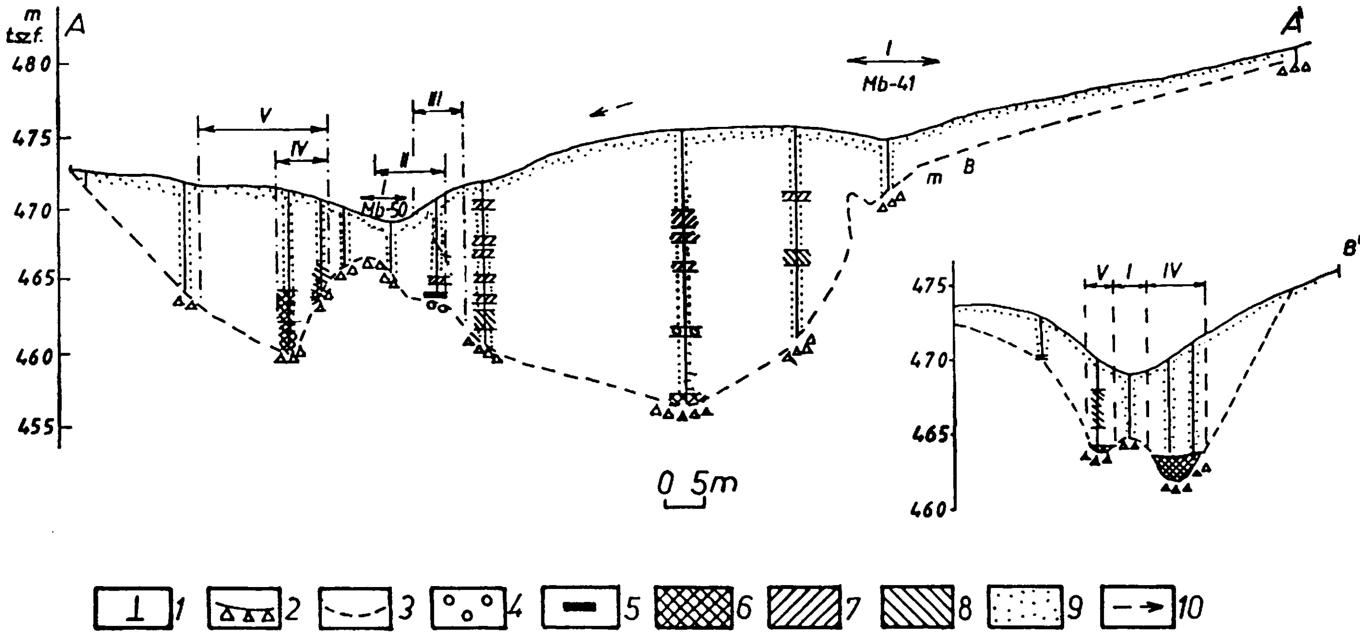


Fig. 45. Structure of carbonate basement and cover sediments in the area of the pseudodepression near karst object Mb-50 (Mester-Hajag) (Veress-Futó 1990)

Legend: 1. borehole site; 2. limestone basement reached by borehole; 3. assumed one-time and present limestone basement; 4. gravel; 5. brown clay; 6. reddish brown clay; 7. laminite; 8. buried soil; 9. silt, clayey silt; 10. former transport; I. syngenetic dolines-with-ponor formed above hidden rock boundary (Mb-50: on elevation destroyed by karstification; Mb-41: in side of elevation); II. elevation destroyed by karstification (lack of reddish brown clay indicates a former denudation terrain raising above its environs); III. the side of the elevation with former karstification (laminite series indicate pond levels, ie. the shift of rock boundary); IV. reddish brown clay on the slopes of elevation and of increased thickness by redeposition in depressions; V. assumed fossil depression (filled with reddish brown clay, silt and soil of great thickness)

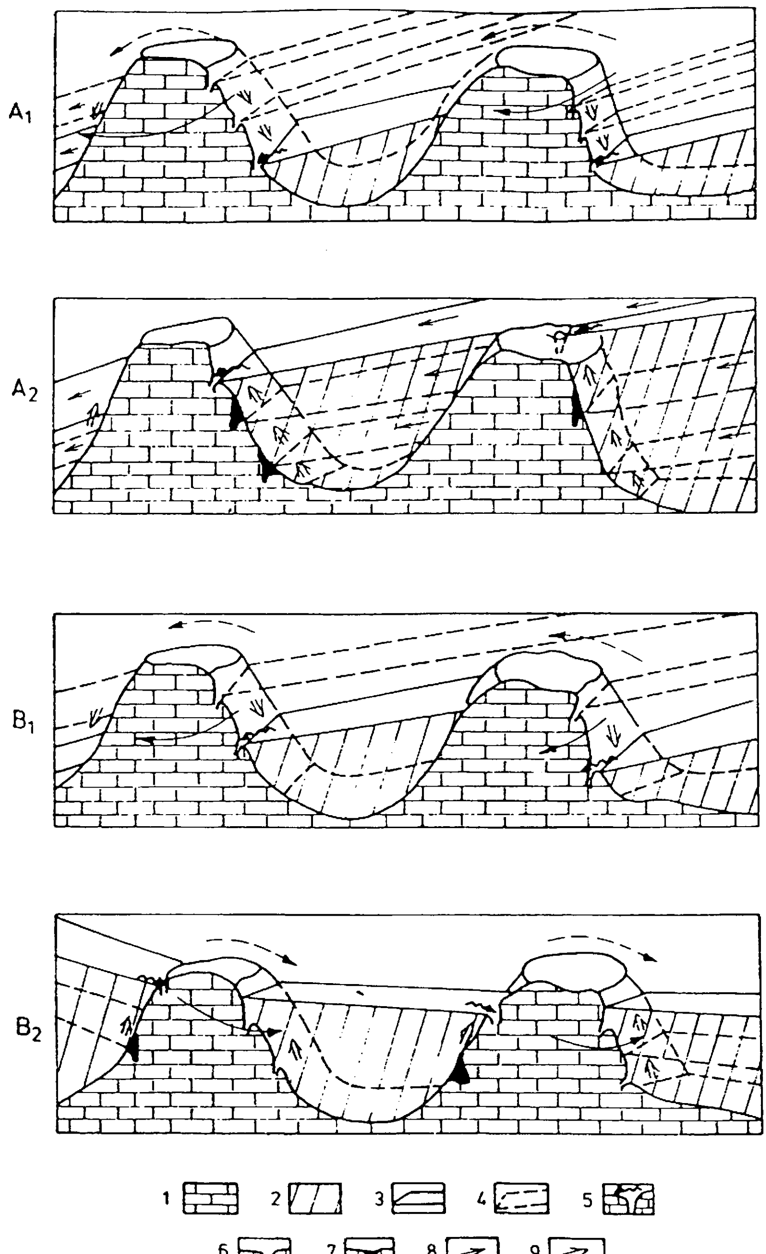


Fig. 46. Karstification of paleokarst elevations during exhumation (A_1 and B_1) and burial (A_2 and B_2) Legend: 1. limestone; 2. cover sediment; 3. present surface; 4. old surfaces; 5. active karst depression; 6. inactive karstic feature; 7. inactive filled karstic feature; 8. direction of material removal; 9. shift of rock boundary. A. karstification on one side of the elevation, no change in direction of transport; B. karstification on both sides of elevation, changing direction of transport

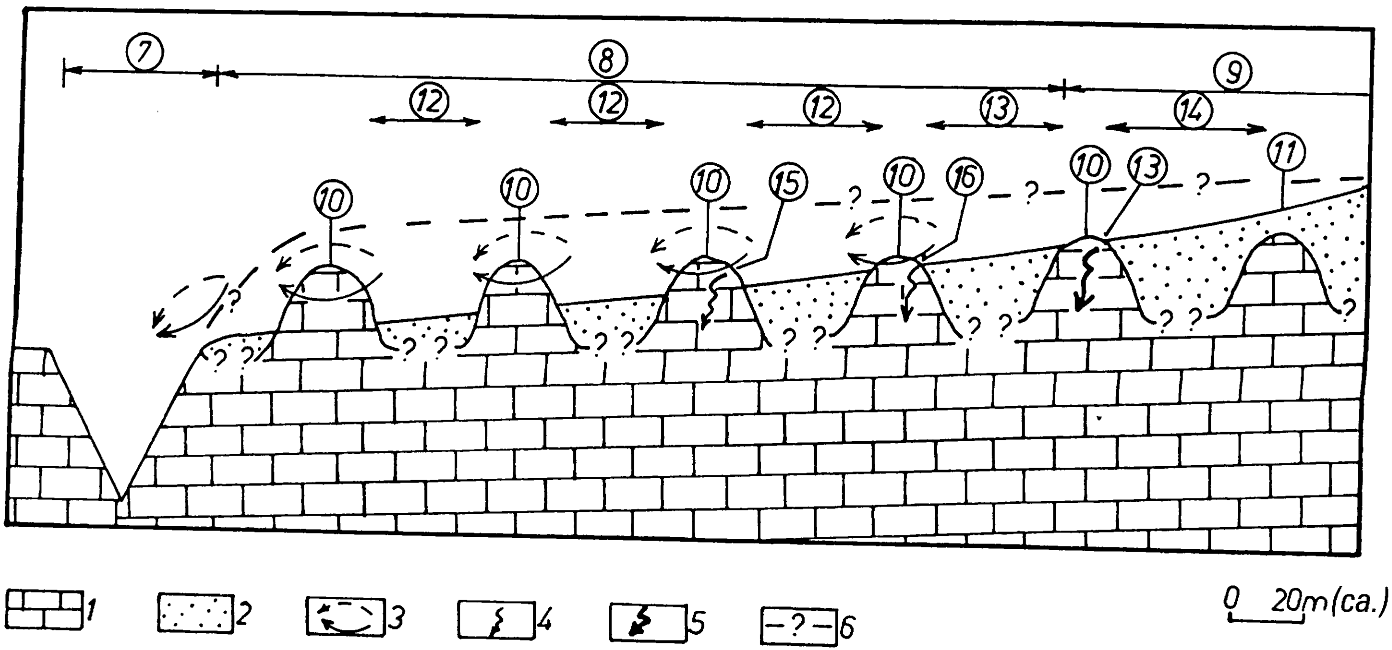


Fig. 47. Denudation of slightly tilted block through sheet wash (the greater is the extent of tilting, the more intensive the removal of cover sediment is, even in lack of a marginal valley)

Legend: 1. carbonate rock; 2. cover sediment; 3. sheet wash (partly between cones); 4. partial transport in depth; 5. transport in depth; 6. (assumed) original surface of cover sediment; 7. superimposed valley; 8. zone of exhumation and accumulation; 9. zone of exhumation; 10. cones exhumed to various extent; 11. buried cone; 12. exhuming residual terrain; 13. residual terrain partly formed by transport in depth; 14. depression; 15. syngenetic, now inactive karst feature; 16. syngenetic active karst feature

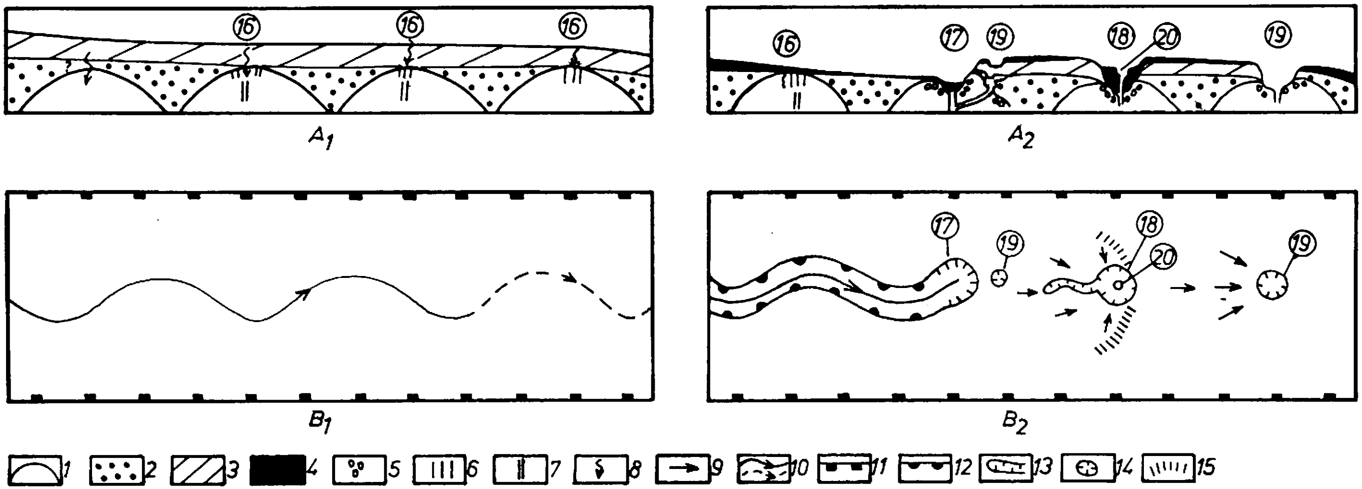


Fig. 48. Karstification on exhuming limestone ridges rectangular to the valley axis (examples of the valley of ponor K-1 and of the Szilfakő Valley, modified after VERESS 1991)

Legend: 1. limestone; 2. gravel; 4. loess; 4. fluvially reworked series (on valley floor and in karst depression); 5. collapsed material; 6. primary chimneys; 7. secondary chimney; 8. water seepage; 9. surface runoff; 10. permanent and intermittent water-courses; 11. well-developed superimposed valley; 12. developing superimposed valley (blind valley); 13. channel; 14. covered karst depression; 15. section with opposite slope on cover sediments of the valley floor; 16. hidden rock boundary; 17. covered karst ponor; 18. pseudoponor; 19. doline-with-ponor; 20. partial depression. A_1. lateral view initially and at present (A_2); B_1 plan view initially and at present (B_2)

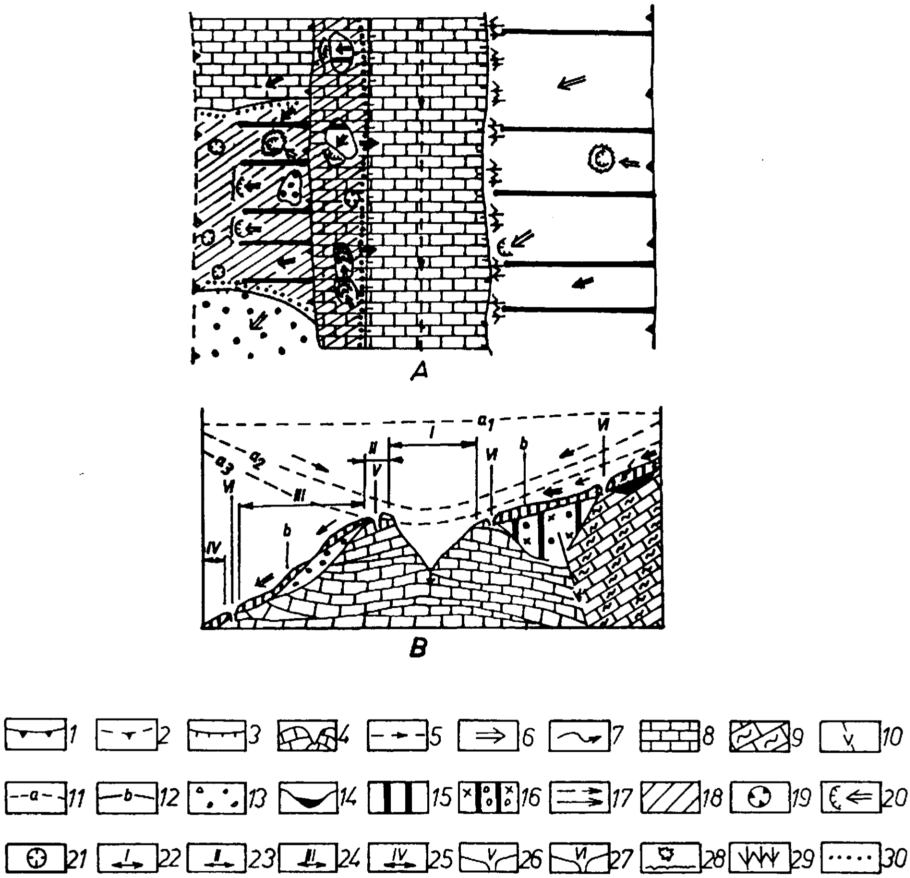


Fig. 49. Karstification on cones aligned along the valley axis and buried under the valley (example of Hidegaszó Valley, modified after VERESS 1991)

Legend: 1. valley side inn unconsolidated sediments; 2. former valley side in unconsolidated sediments; 3. valley side in limestone; 4. valley formed on anticline structure in lateral view; 5. intermittent water-course; 6. water flow on surface and above aquiclude; 7. seepage; 8. Upper Jurassic limestone; 9. Middle Cretaceous limestone; 10. assumed fault; 11. former levels of gravel mantle (a_1, a_2 and a_3); 12. present surface; 13. gravel; 14. clay; 15. loess and clayey loess; 16. reworked, mixed gravel, clay and silt; 17. former and present reworking of cover sediments; 18. zone of karstification; 19. inactive chimney ruin (cave) in plan view; 20. doline-with-ponor in plan view; 21. subsidence doline; 22. zone of covered karst ponors completely destroyed; 23. zone of inactive covered karst ponors and dolines-with-ponors; 24. zone of dolines-with-ponors; 25. zone of subsidence dolines; 26. inactive chimney ruin (cave) in lateral view; 27. active doline-with-ponor in lateral view; 28. symmetrical hidden rock boundary; 29. asymmetrical hidden rock boundary; 30. inactive boundary; A. plan view; B. lateral view

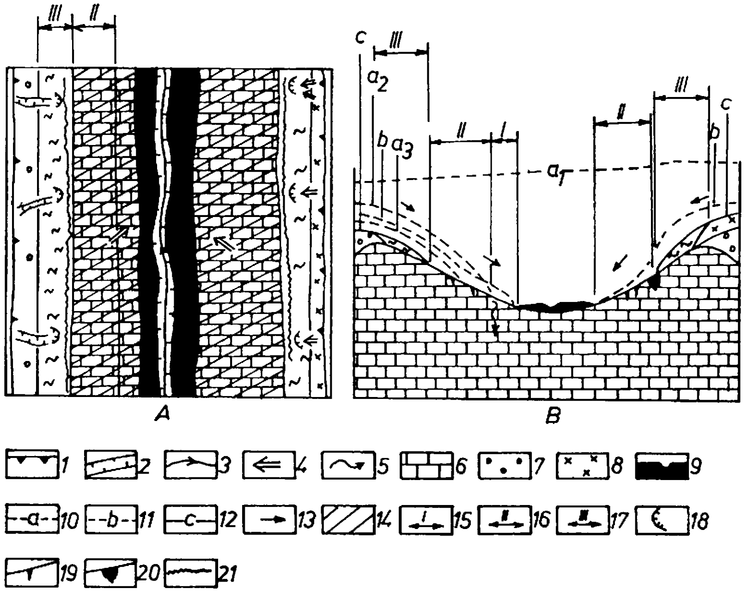


Fig. 50. Karstification on limestone cones along the valley axis (example of Öregfolyás Valley, modified after VERESS 1991)

Legend: 1. valley side; 2. channel; 3. water-course; 4. flow on the surface and above aquiclude; 5. seepage; 6. limestone; 7. gravel; 8. loess; 9. stream deposit with channel; 10. levels of former gravel mantle (a_1, a_2 and a_3); 11. levels of former loess mantle; 12. present surface; 13. reworking of cover sediments; 14. karstic zone in plan view; 15. zone of subsidence dolines; 16. zone of inactive dolines-with-ponor; 17. zone of active dolines-with-ponor; 18. doline-with-ponor in plan view; 19. plugged water conduit in lateral view; 20. fossil filled karst depression in lateral view; 21. hidden rock boundary; A. plan view; B. lateral view

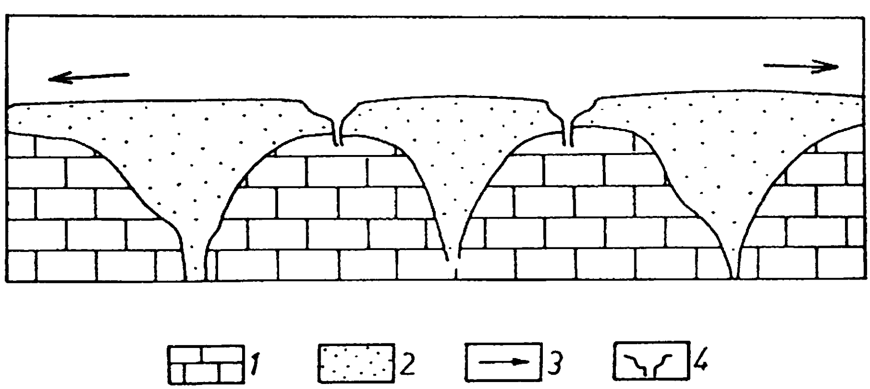


Fig. 51. Karstification of thresholds between paleokarst depressions on floor of superimposed valley

Legend: 1. limestone; 2. cover sediment; 3. sheet wash; 4. syngenetic karst depression

Such a type of karstification is common on the Tés Plateau **(Figs. 53, 54, 55)**. Here several stages of karstification must have occurred with interruptions when non-karstic geomorphic evolution prevailed. (The non-karstic stages were modified by the products of the previous phase of karstification, while non-karstic evolution, denudation or accumulation, also had an effect on the following stage of karstification.) The probable stages of geomorphic evolution are the following **(Fig. 56)**.

- Ponor development through bathycapture (true capture) on the floors of superimposed valleys along rock boundaries (allogenic karstification). The retreat of captures produced doline rows.
- The subsequent uplift of the plateau resulted in the complete removal of teh Csatka Gravel Formation, probably through pedimentation. The superimposed valleys were partially truncated.
- In the area of interfluvial ridges (or in terrains without valleys) authigenic karstification was active (probably with doline formation).
- As a consequence of loess formation and the subsequent sheet wash (removing eg. matter from the neighbouring valley slopes), swallow dolines fill in and become covered. Dolines formed during authigenic karstification fill in only partially since those formed on interfluvial ridges or in terrains without valleys hardly any sediment could accumulate.
- In the fossilised features postgenetic (in fossil ponors) or syngenetic (in fossilised dolines) karstification begins.

The streamsink caves or alluvial streamsink caves and avens in the mountains developed during allogenic karstification. It is indicated by the large dimensions of caves, the erosional sections in caves and the partial or entire absence of collapse material in the upper part of aven-like features. Indirect evidence is supplied by the gravels or red clay in some fossilised karst features. (The latter points to the existence of these landforms even between the pedimentation and loess deposition stages.). The relict karstification in the recent past and in the present generates cavernation, which is, in fact, chimney formation. Chimney formation is largely affected by the cavities and passages developed during allogenic karstification. It means that chimneys originate under surface depressions but develop from below, fromm the previously formed passages towards the surface. Syngenetic karstification probably occurs in fossil dolines where the chimneys, developing from cavities to the influence of infiltration, rise close to the surface of the carbonate rock if the depression nature is preserved (water from the environs collects here) and if the sediment fill is permeable **(Fig. 12, 56)**.

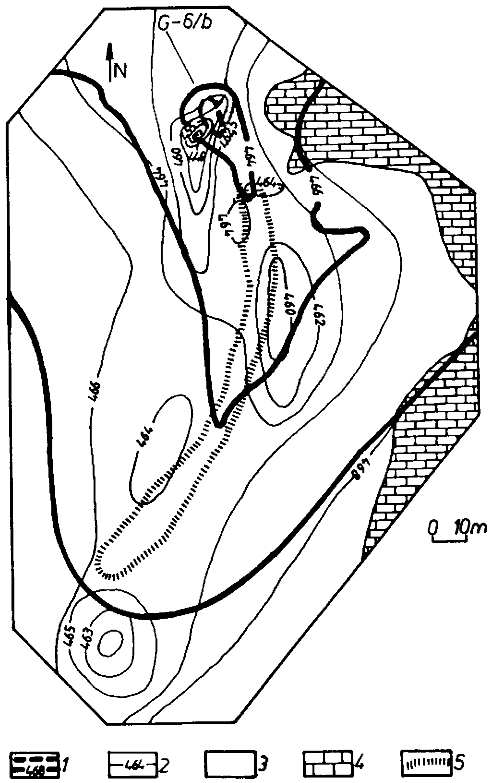


Fig. 52. Topographic map of the surface and the limestone basement in the catchment of pseudoponor G-6/b (VERESS-FUTÓ 1990)
Legend: 1. surface contour line; 2. contourline of limestone basement; 3. unconsolidated cover sediments on the surface; 4. limestone on the surface; 5. channel

Karstification above paleokarst passages

The features of postgenetic karstification without depression mostly occur in very low density and fully irregular arrangement on mostly undissected basement. This is the least known type of karstification.

It does not occur independently but, in principle, in combination with any other type. It is probably present on the Tés Plateau, in the W part of the Sűrű Mountain Group, between Kőris Hill and Som Hill.

Types of karstification dependent on flowing karst water

In certain areas of the mountains the removal of the Csatka Gravel Formation took place at a very late date because of the minimal and belated uplift of the enclosing blocks. The resulting assemblage of landforms is largely influenced by that fact that valley superimposition succeeded cavity formation or they were parallel processes.

This type of karstification is primarily characteristic of blocks where the Triassic carbonates (Triassic „Hauptdolomit" and Dachstein Limestone) are overlain by Middle Eocene Limestone.

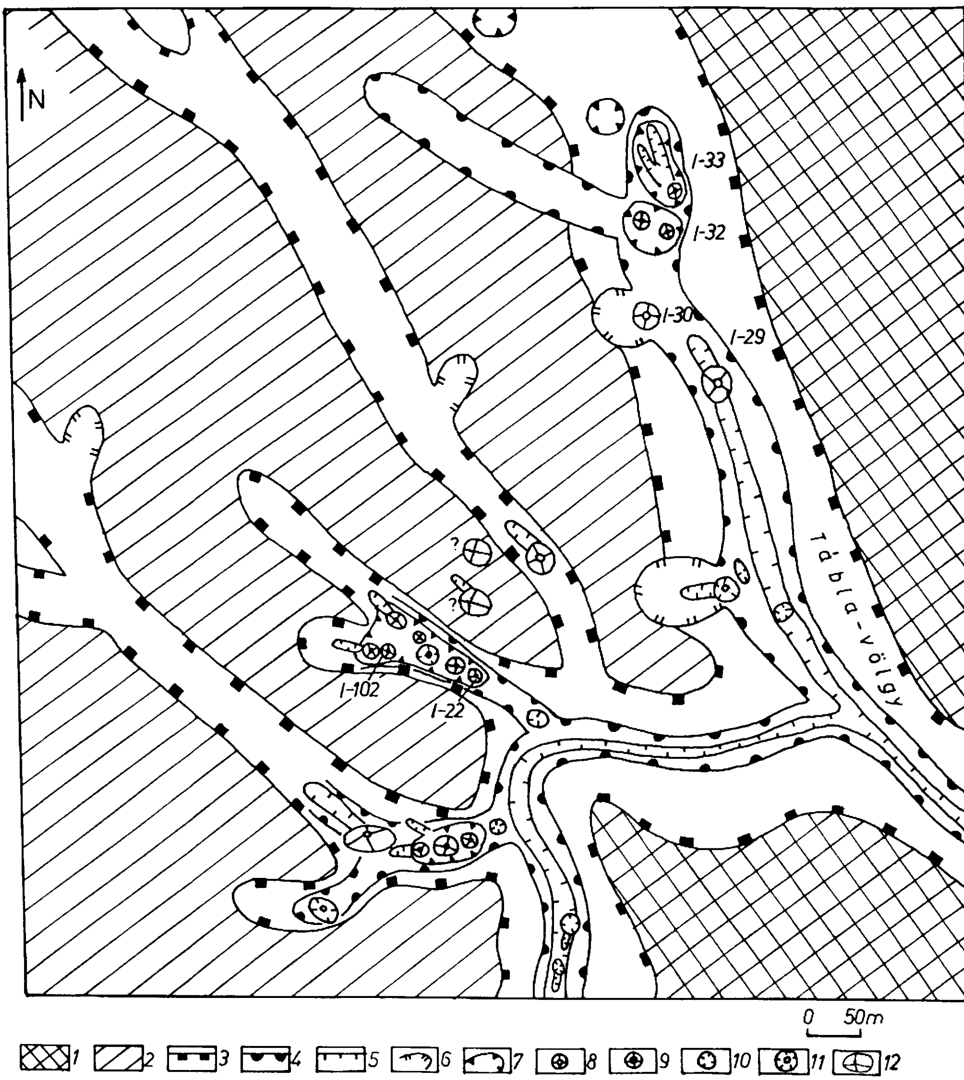


Fig. 53. Karst morphological map of the Tábla Valley (Tés Plateau) and environs
Legend: 1. exhumed remnant of planated surface; 2. interfluvial ridge; 3. well-developed superimposed valley; 4. developing regressional-superimposed valley; 5. developing regressional-superimposed channel; 6. derasional valley; 7. large depression; 8. doline-with-pseudoponor; 9. postgenetic doline-with-ponor; 10. pseuodoponor above passage; 11. doline-with-pseudoponor above passage; 12. doline-with-ponor formed in fossil doline

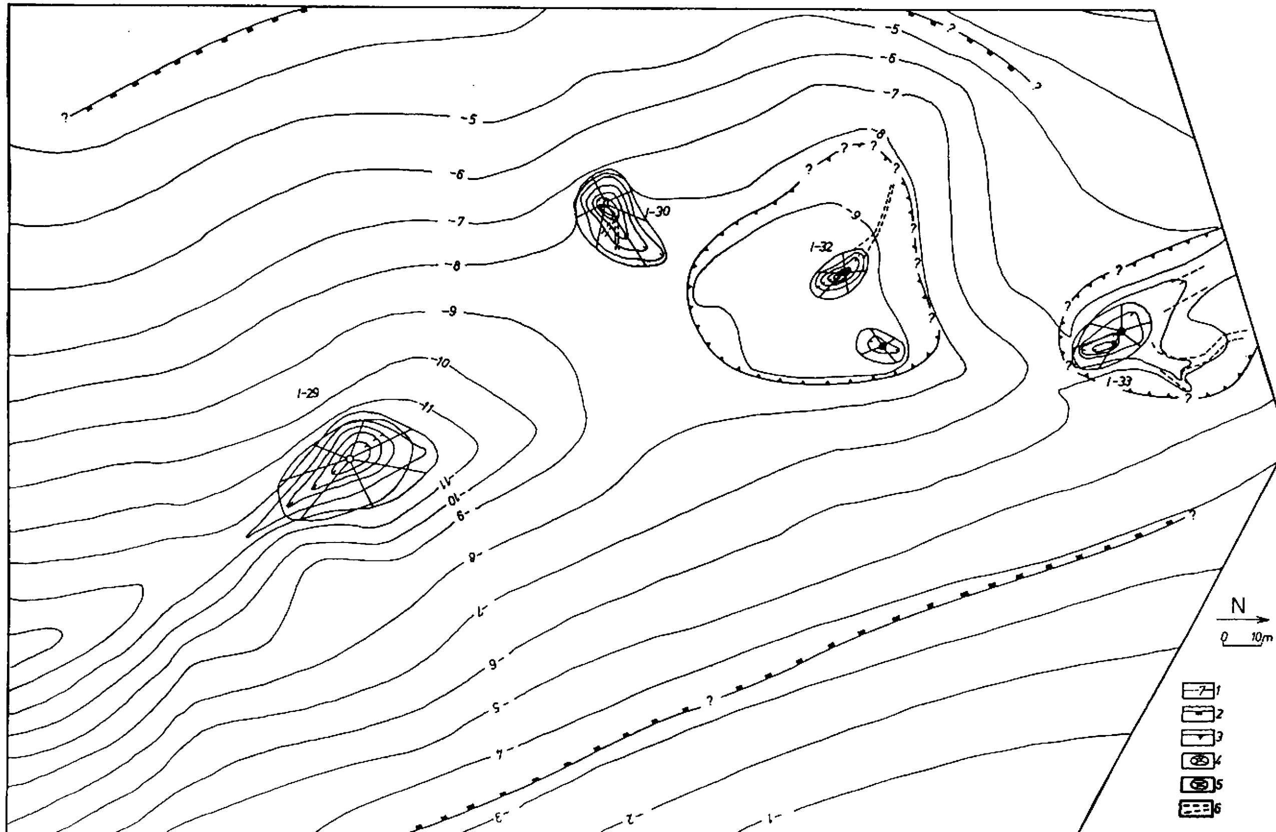


Fig. 54. Topographic map of part of the Tábla Hill

Legend: 1. contour in local system; 2. margin of developing superimposed valley; 3. large depression; 4. doline-with-pseudoponor; 5. postgenetic doline-with-ponor; 6. erosional channel

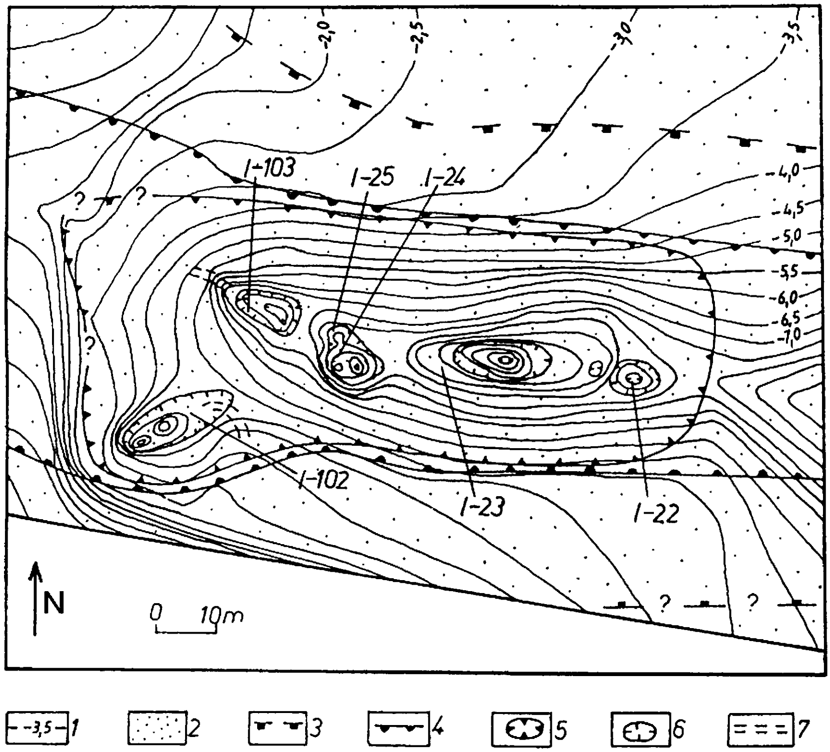


Fig. 55. Postgenetic karstification in the interior of true depression (tributary of Tábla Valley at postgenetic dolines-with-ponor I-22 and I-102)

Legend: 1. contour in local system; 2. cover sediment; 3. assumed margin of well-developed superimposed valley; 4. assumed margin of developing regressional-superimposed valley; 5. large depression; 6. postgenetic doline-with-ponor; 7. erosional channel

Karstification of terrains with valley formation after cavernation

On block or groups of blocks which remained in low positions for a longer time, karst water table was located on the boundary between cover sediments and the carbonate rock (**Fig. 57**). An evidence for this is eg. the gravel fill of the solution chimney on the ceiling of cave no M-7 and the gravels found in passages opening onto the surface. Cover sediments forced karst water to flow laterally. The water deriving from cover sediments also contributed to solution and cavernation (buried karst). In the karst water zone karst water moves in two basic directions. A predominantly horizontal movement occurs in abraded conglomerates, marl series and in a thinned-out Eocene limestone overlying dolomite. Further away from these sites, particularly if the enclosing block is uplifted, water flow becomes increasingly vertical. In the previously mentioned sites cavities develop in diverse horizontal directions, in accordance with flow, while in the latter sites directions are less diverse and mostly vertical cavities form. During the further uplift of the enclosing block cover sediments are removed. The incising regressional-superimposed valleys (postgenetic valleys) partly destroy and partly expose cavities. If the ceilings of subsurface cavities

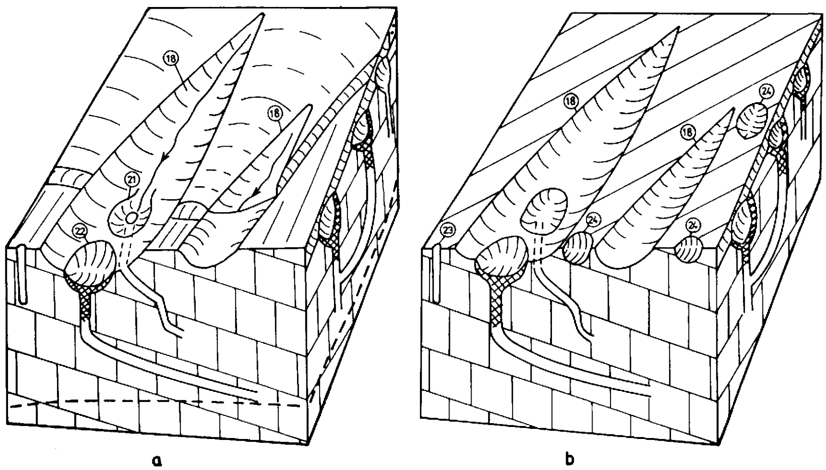
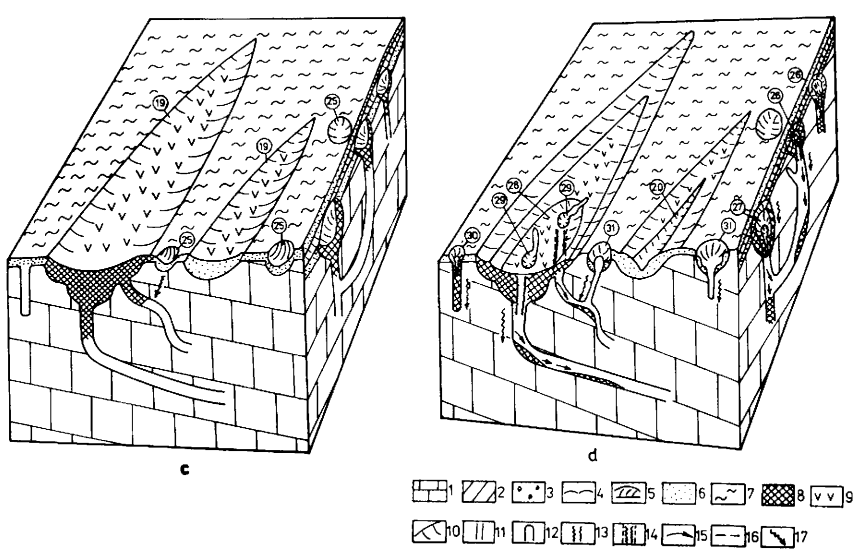


Fig. 56. Probable phases of karstification on the Tés Plateau

Legend: 1. limestone; 2. limestone surface; 3. impermeable cover sediment; 4. surface of impermeable cover sediment; 5. scarp formed during the removal of impermeable cover sediment; 6. permeable cover sediment (loess); 7. surface of permeable cover sediment; 8. deposits from fluvial transport (weathering residue, fluvial clay and loess); 9. accumulation surface (with sheet wash and fluvial transport); 10. slope bordering on valley and karst depression; 11. karst passage; 12. blind chimney; 13. passage formed in sediment fill; 14. passage not visible in section; 15. reworking within passage; 16. karst water table; 17. seepage; 18. superimposed valley; 19. filled inactive superimposed valley; 20. inner valley formed in the fill of a superimposed valley; 21. ponor developed on rock boundary; 22. streamsink (fossil) doline; 23. former conduit preserved after truncation; 24. solution doline; 25. fossil doline; 26. small depression with subsidence pseudodoline; 27. small depression with subsidence-doline-with-pseudoponor; 28. large depression; 29. postgenetic doline-with-ponor; 30. doline-with-pseudoponor above passage; 31. doline-with-ponor formed in fossil doline; a. allogenic karstification; b. authigenic karstification; c. burial; d. partial exhumation



formed on interfluvial ridges cave in, collapse dolines are produced. (Some collapse dolines are inherited over loess cover sediments.) As a consequence, circular collapse dolines occur where the Eocene limestone is thinner (on the boundary between Middle Eocene limestone and „Hauptdolomit") and elongated and wide or elongated and narrow collapse dolines develop where it is thicker.

This subtype of karstification is typical of terrains W of Hódos-ér (eg. around Dörgő Hill and on Szent László-erdő).

Karstification of terrains with valley development simultaneous with cavernation

With relatively early uplift of the block, valley incision and superimposition may take place at an early stage. However, karst water table lowers before superimposition (**Fig. 58**). Increasingly rapid valley incision into the karstic rock follows the subsidence of karst water table. No bathycapture takes place since - although percolating waters increase the rate of cavernation under the valleys - incision destroys the potential water conduits. Cavernation is concentrated under the floors of incising valleys as the percolating waters from the water-course are mixed with flowing karst water. Valley evolution is promoted by the already existing and exposing cavities (valley evolution through cavity exposure). The here outlined evolution of a superimposed valley may be prolonged by the catchment of considerable size on covered surfaces beyond the block (examples are the Cuha, the Gerence and the Ördög-árok streams). As a consequence, the process is still active in the valleys.

The above suggest that valley evolution through cavity exposure is characteristic of syngenetic valleys. Postgenetic valleys only expose cavities, their water-courses do not contribute to the evolution. Therefore, with valley evolution through cavity exposure, the rate of mixing corrosion is highest under valley floors. The frequency of spherical cauldrons and cavity size are highest there. Moving laterally from the valley floors the frequency of spherical cauldrons and cavity size decrease.

Incising postgenetic valleys may reach down to the zone of cavernation and cavities may be exposed. In this case, moving away from the valley axis, the assemblage of solution landforms (eg. the frequency of spherical cauldrons) remains the same. (Mixing corrosion was not limited to the zone under the channel.) It may occur that the water percolating from water-courses dissolves rocks. The resulting vertical cavities are virtually the same as the chimneys described under the heading surface karstification. The percolation may cause mixing corrosion in deeper levels and, thus, valley evolution through cavity exposure may gradually develop also for postgenetic valleys. If the valley is active for a sufficiently long time, cavities formed in greater depths may also be exposed. In the case of similar valleys, moving towards the valley floor, the frequency of spherical cauldrons may increase in the exposed cavities and cavity dimensions may also grow.

Valley evolution through cavity exposure (VERESS 1980a,b, 1981a, 1982b) may accompany both superimposed-regressional and superimposed-antecedent valley evolution. In the sides of gorge sections of superimposed-antecedent valleys, cave ruins of vertical position may also occurs (eg. Kerteskő Gorge). The reason behind this is that antecedent valley evolution more probably takes place if block uplift is slow but continuous, accompanied by a similar trend in karst water table. If block uplift is rapid but cyclical, horizontal cavernation or cavity formation at several levels result also in antecedent valley sections (but more typically in superimposed valleys) and with impermeable (marl) intercalations.

Valley evolution through cavity exposure gradually stops. This is cause by the decreasing rate of valley incision with the removal of cover sediments. Thus, cavity formation and, as a result, valley evolution slows down.

Cavity exposure is sometimes only typical of some sections of superimposed-regressional valleys instead of their whole length. Such sections are indicated by groups of cave remnants. The branching of these caves in various directions points to the one-time groups of cavities. The position of the group of cave remnants related to the channel is an evidence of the influence of stream erosion, whether the latter affected the margin or the interior of the former group of cavities (**Fig. 59**). This subtype of karstification is characteristic of the valleys incising in the area of the Sűrű Mountain Group.

The valley evolution subtypes with collapse dolines and through cavity exposure are usually not distinct spatially. Thus, for instance, in the area of the Sűrű Hill, Dudar, landforms of cavity exposure and collapse doline origin appear next to each other and it shows that the subtypes alternated. (Here human intervention has changed the morphology of collapse dolines in many sites.) All these allow that on blocks originally in low positions karstification resulting in collapse dolines was replaced – as a consequence of uplift – karstification with valley evolution through cavity exposure if patches of cover sediments were preserved in the catchments of valleys. Valley evolution exclusively through cavity exposure is only possible if the karst water table was in low position related to the carbonate basement even in the initial stage of development.

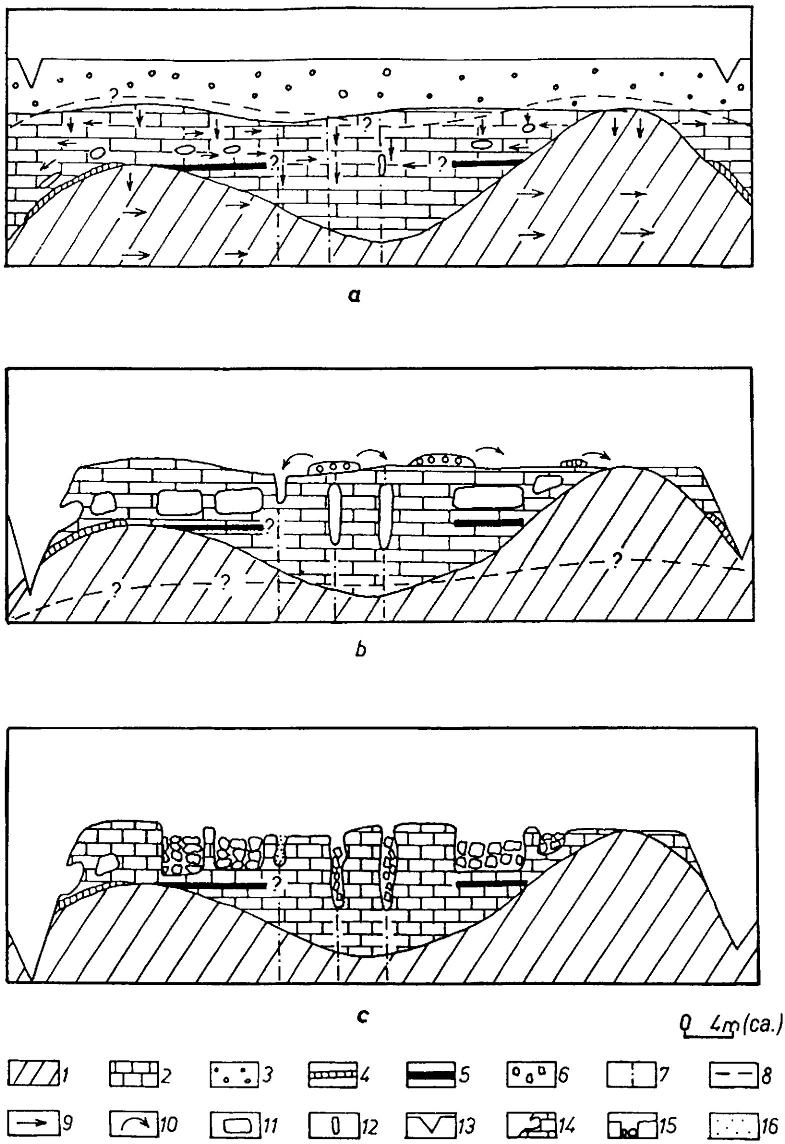


Fig. 57. Development of collapse dolines

Legend: a. forced karst water table under the Csatka Gravel Formation; b. cavernation with mixing corrosion in karst water zone; c. the ceilings of cavities cave in and others are exposed by superimposed valleys; 1. Dachstein limestone and dolomite (Fenyőfő Formation); 2. Middle Eocene nummulitic limestone (Szőc Formation); 3. gravel (Csatka Gravel Formation); 4. abrasion breccia; 5. marl; 6. collapsed material; 7. fracture and fault; 8. karst water table; 9. flow direction of karst water; 10. removal of cover sediment by sheet wash; 11. cavity with horizontal axis; 12. cavity with vertical axis; 13. valley; 14. exposed cavity; 15. collapse doline; 16. fill derived from cover sediment

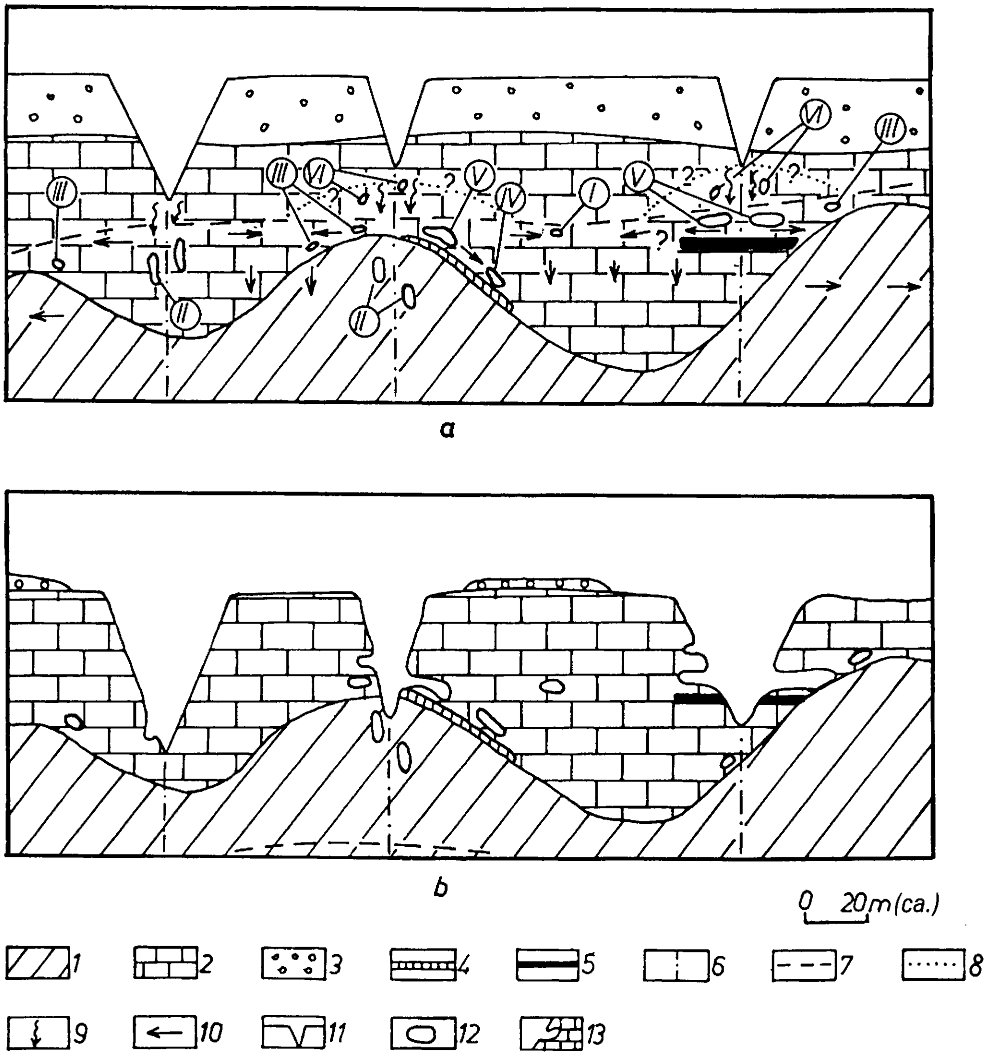


Fig. 58. Development of cave remnants (modified after VERESS 1980)

Legend: a. valley and cavity formation; b. cavity destruction and exposure; 1. Triassic carbonate rock; 2. Middle Eocene limestone (Szőc Formation); 3. gravel (Csatka Gravel Formation); 4. abrasion breccia; 5. marl; 6. fracture and fault; 7. karst water table; 8. local elevation in karst water table from seepage; 9. seeping water from floors of superimposed valleys; 10. karst water flow; 11. superimposed valley; 12. cavity; 13. exposed cavity (cave remnant); I. cavernation below karst water table; II. cavernation along fractures and faults; III. cavernation above dolomite; IV. cavernation above local impermeable (or partially impermeable) series; V. cavernation above local impermeable series intensified by seepage from valley; VI. cavernation below karst water table temporarily elevated

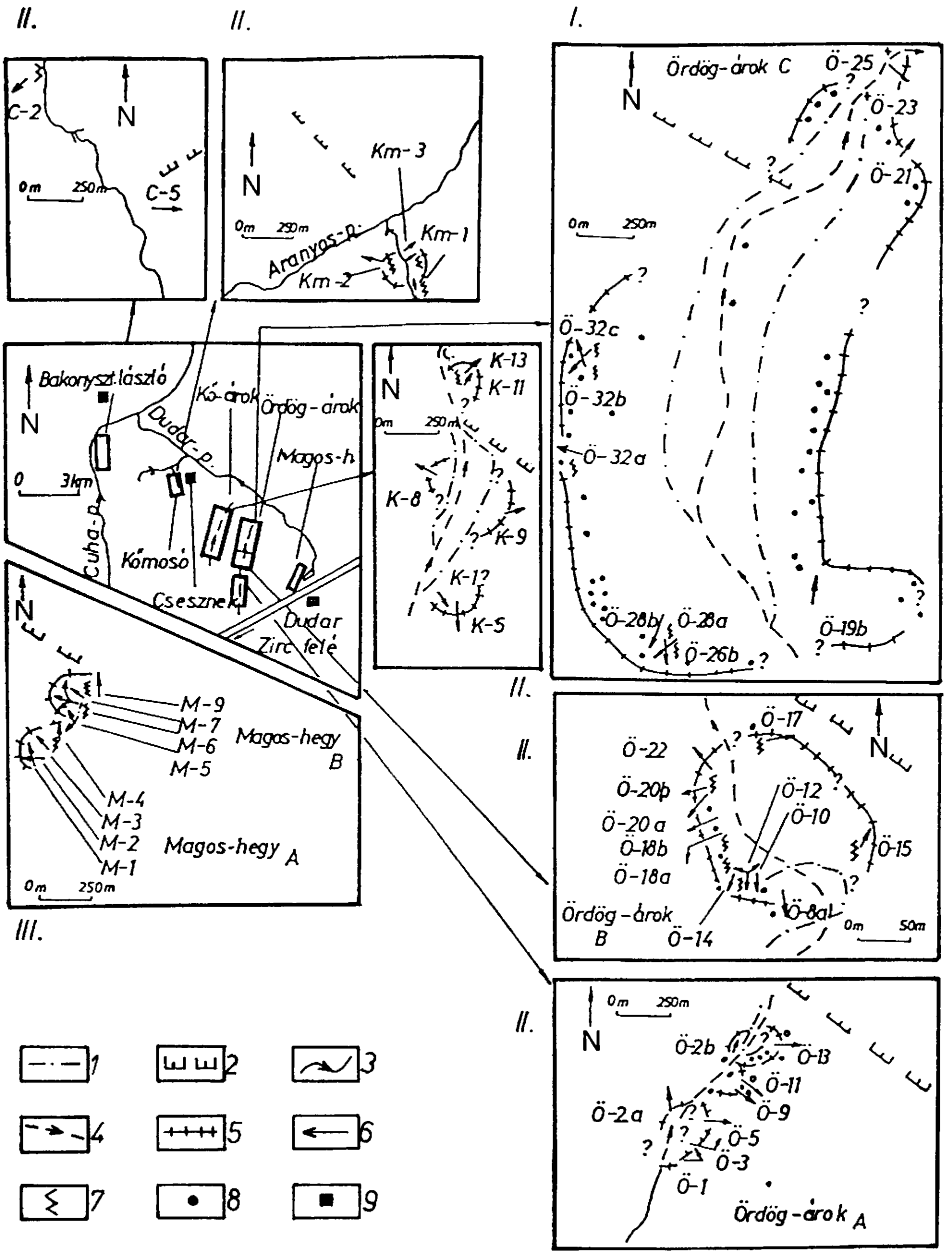


Fig. 59. Reconstruction of former cavity groups from the distribution of cave remnants

Legend: 1. boundary between Eocene limestone and Triassic dolomite; 2. fault; 3. permanent water-course; 4. intermittent water-course; 5. boundary of cavernation zone; 6. axis of karstic cave (arrow is not proportional); 7. cauldron in cave; 8. cavity with caved-in ceiling; 9. settlement. I. at superimposed-regressional valleys; II. at superimposed-antecedent valleys; III. in scarp

CONCLUSIONS

1. The main types of karstification are controlled by the date, extent and rate of uplift, the position of the cavernation zone related to the surface, its width and date of origin and the date of valley inheritance. Since the mountains are constituted of blocks of highly variable geological history, composition and morphology, karstification involves diverse processes. Because of the loose network, low density and small size of karstic features, karstification is not a dominant process in the geomorphic evolution of the mountains.

2. Karstification independent of flowing water (surface karstification) occurs on blocks of the following properties:

– Built up of (at least, partly) of well-karstifying limestone of uneven surface and only covered by permeable cover sediments.

– Because of rapid uplift, the cavernation zone developed in great depth or reached a great depth by the time of valley superimposition. On these blocks syngenetic karstification is typical and, if occurs on valley floors, involves pseudobathycapture. On blocks where the cavernation zone is close to the surface and slow valley incision prolonged after superimposition, allogenic karstification is observed. During the present exhumation of the mountains, allogenic karstification could only take place in few sites, in the first stage of the present karstification. Today these sites show postgenetic karstification. Independent of the presence or absence of cavernation zone, pseudopostgenetic karstification may also be present on blocks where autogenic karstification occurred for a shorter or longer period and fossilised dolines with partial permeable fill developed.

– Among block types, the most favourable for syngenetic karstification are horsts uplifted to summit position and exhumed or cryptopeneplains (landforms similar to semiexhumed horsts in summit position) of relatively high position from which non-karstic, impermeable cover sediments have been partly removed.

3. Syngenetic karstification is chimney development on hidden rock boundaries. Through inheritance surface landforms like covered karst ponors, pseudoponors, dolines-with-ponor and depressions are produced. The features of postgenetic karstification result from the subsidence induced by the transport in depth of unconsolidated sediments filling older karst features or passages. The landforms produced are subsidence pseudodoline, doline-with-pseudoponor, postgenetic doline-with-ponor, pseudodoline above passage and doline-with-pseudoponor above passage.

4. Recent surface karstic features form where the permeable cover sediment (loess) thins out. The precondition to this is an uneven and dissected carbonate basement and removal of cover sediments. The density of karstic landforms remains low even in zones potentially suitable for karstification. Karstification takes place if the basement is dismembered tectonically (on the edge of fault scarps) or dissected by paleokarst elevations (summit level of cone terrains) or paleokarst depressions (along their margins). The location, size and and shape of karstification zones and the frequency and type of karst features on a block are controlled by the way of exhumation (by sheet wash or stream erosion) and the sites of fluvial incision and the position of the latter related to the morphology of the underlying rock.

5. The influence of older, fossilised karst feature assemblage on recent karstification is manifested in the following.

– On the summit levels of paleokarst elevations and on the edges of paleokarst depressions hidden rock boundaries form.

– Postgenetic karstification may ensue in the fossilised ponors of the one-time authigenic karst, at older syngenetic chimneys or at older karstic passages or cavities exposed by denudation.

6. Unconsolidated cover sediments are of decisive influence on the formation of covered karst depressions (and on the nature of covered karst development) since they govern chimney formation and its stages. At the same time, unconsolidated cover sediments also favour the rapid removal of karstic landforms; partly through the plugging of chimneys with the large amounts of inwashed deposits and, thus, covered karst features fill up rapidly and partly through the truncation of depressions as a consequence of rapid denudation. (The latter process is favoured by the formation of chimneys in higher parts of the karstic basement.)

The small dimensions of karstic landforms in the mountains, however, is not caused by the young age of recent karstification but because the individual karst objects are young. Karstic features have fossilised and new features developed.

The karst depressions are neither dolines nor true ponors. Although they receive water from their background areas, they are not formed by true bathycapture. The chimneys cannot develop into erosion systems because they function for a short period and there are no water courses of proper competence on the surface and debris and gravels for corrasion are also missing. The background areas are small (because of the block structure, the nature of topography and because depressions develop in each other's immediate vicinity) and, thus, small amounts of water are collected in the passages.

Ponors cannot develop along the superimposed-antecedent valley sections either. Here intensive incision may destry or exposed the passages and cavities of flowing karst water.

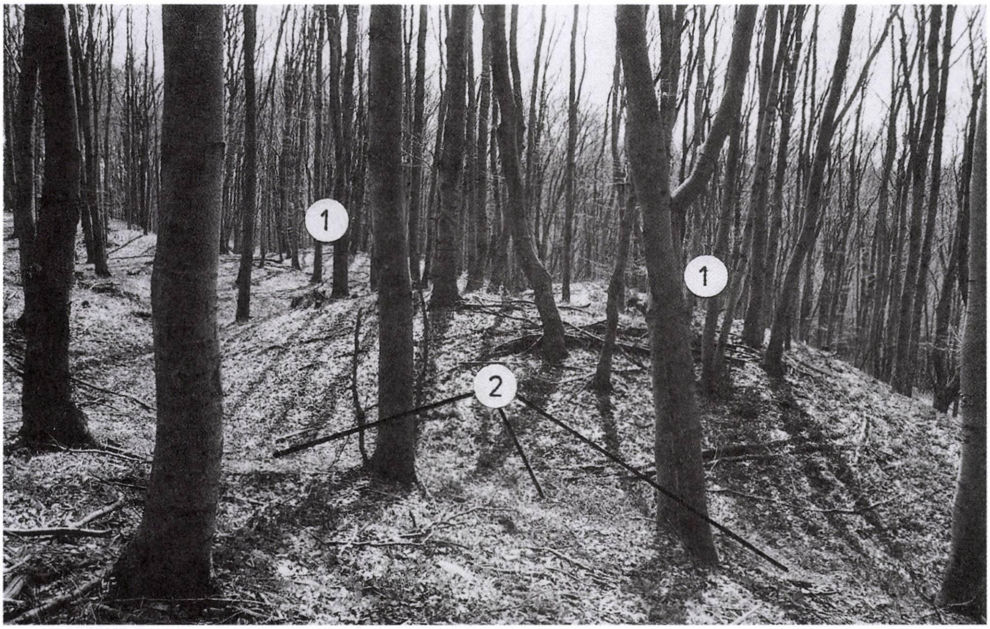
7. Caves and cavities of no ponor origin develop in the zone of flowing karst water. Cavernation occurs close to the surface of karstic rock (particularly in nummulitic limestone if it is underlain by a Triassic carbonate rock) with moderate or great thickness (particularly in dolomite) or at greater depth.

If the block is of low position, cavernation is at subsurface levels and the resulting valleys on the block are not superimposed or only at a later date (postgenetic valley) into the karstic rock (perhaps no valley develops). Cavities are not destroyed but cave in (collapse doline). Terrains like this are typical of buried horsts in summit position.

The superimposed valley may further incise and reach the zone of cavernation. If it is gradually inactivating or cuts through the cavernation zone of moderate thickness, no bathycapture happens; the cavities of the zone are partly destroyed and partly exposed in valley sides. With the exception of cryptopeneplains, any block type may have such a terrain.

If the inheritence of the valley on an isolated block occurs at an early stage (syngenetic valley) and is prolonged, valley evolution through cavity exposure takes place. A necessary condition to such an evolution is that the block should be enclosedd by non-karstic terrain and that cavernation should take place in a relatively great depth below the surface of the karstic rock or the cavernation zone should be continuous from the surface to a great depth. Cavernation and valley evolution are in a positive feedback relation and a gorge of karstic origin develops. The caves in the valley sides are not spring caves since no tapping of karst water occurred here; the water was conducted away instead. The exposure of cavities explains the small size and relatively high frequency as well as the location in valley sides of these caves. The distribution and three-dimensional shapes of cavities are controlled by the rate of uplift, the nature of uplift (cyclical or continuous) and possible intercalations in the karstic rock by impermeable strata.

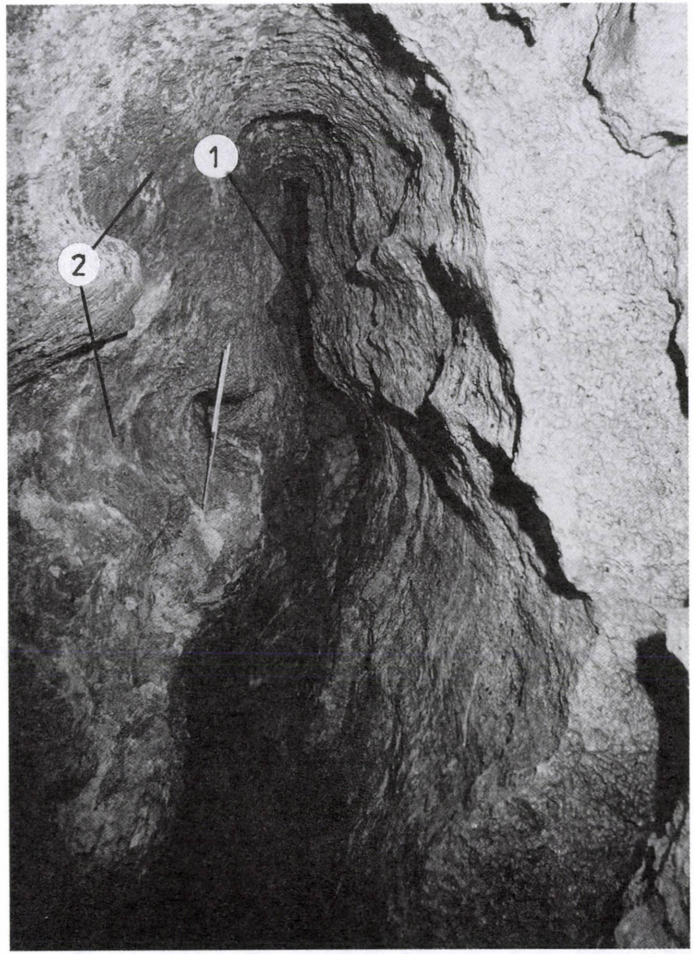
8. The caves in valley sides of the mountains have formed by the subsequent exposure of cavities originally formed in the zone of flowing karst water. In the mountains spring caves are not characteristic. Some small-scale spring may occur in the sides of blocks if karst storeys formed. At the outlets of main karst water small passages (eg. Tapolcafő) have not developed into spacious spring caves. No information is available on older spring caves formed higher than the present emergence level of main karst water.



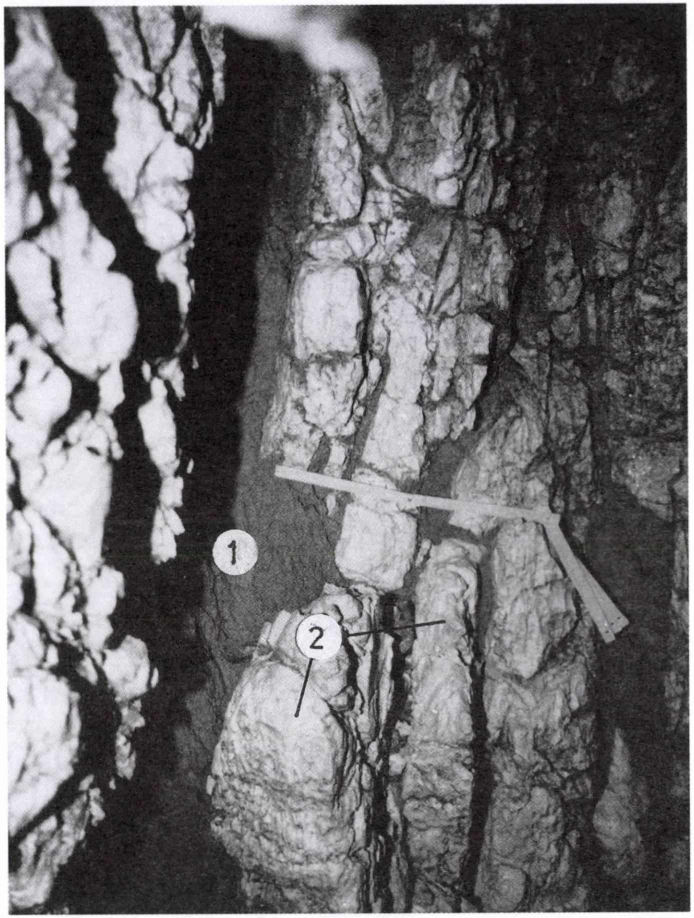
Pict. 1. Paleokarst terrain partially deprived of its cover sediment, Mester-Hajag
Legend: 1. exhumed cone; 2. irregular exhuming residual terrain formed between cones by sheet wash


Pict. 2. Truncated doline-with-ponor (entrance to Gyenespuszta Cave, Hárskút Plateau)

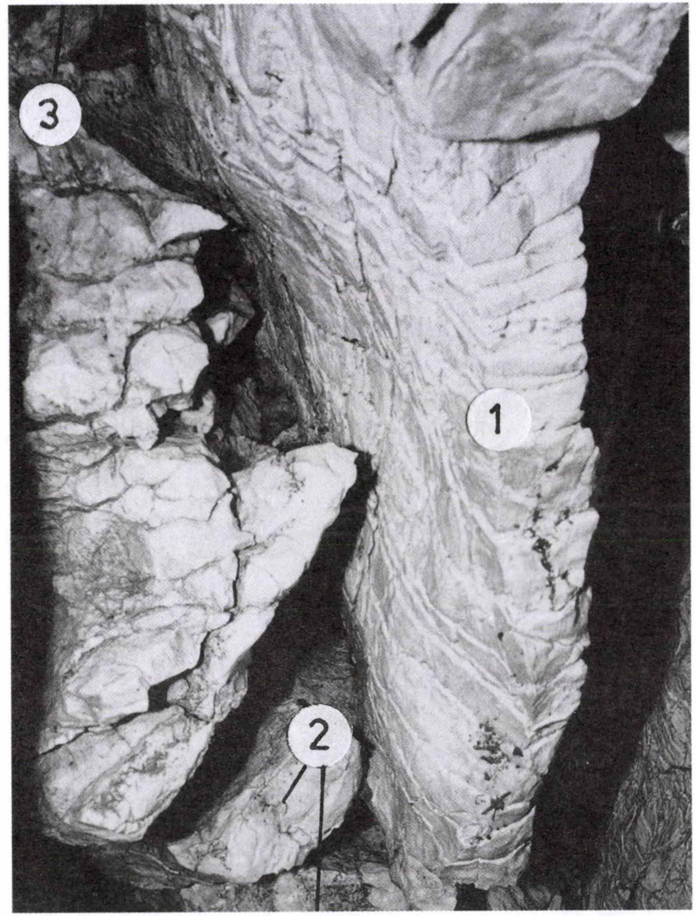
Pict. 3. Solutional rock surfaces from the wall of the main chimney of twin doline with ponor Gy-12
(side of Öregfolyás Valley, central Hárskút Plateau)



Pict. 4. Blind chimney in the passage of doline-with-ponor Gy-3 (Szilfakő Valley, central Hárskút Plateau)
Legend: 1. blind chimney; 2. ruin of primary chimney



Pict. 5. Ruins of primary chimneys (main chimney of twin doline with ponor Gy-12, A-A' cross-section in Fig. 6)
Legend: 1. chimney ruin with soil fill; 2. remnant of dividing wall between chimneys

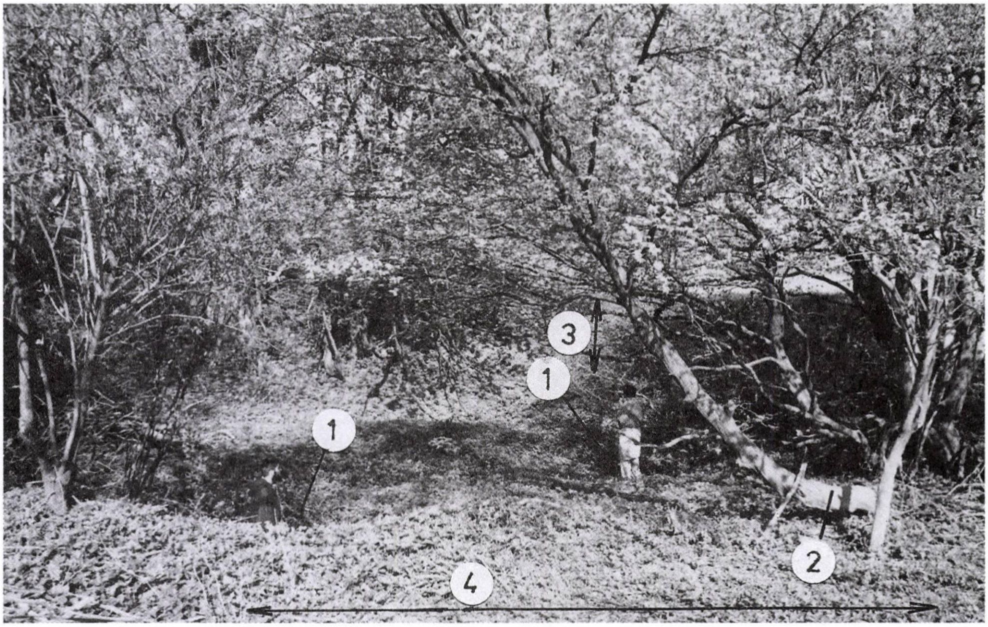


Pict. 6. Dividing wall remnants between ruins of primary chimneys (doline-with-ponor Gy-3, Szilfakő Valley)
Legend: 1. remnant of dividing wall between chimneys; 2. collapsed material; 3. soil fill in chimney ruin

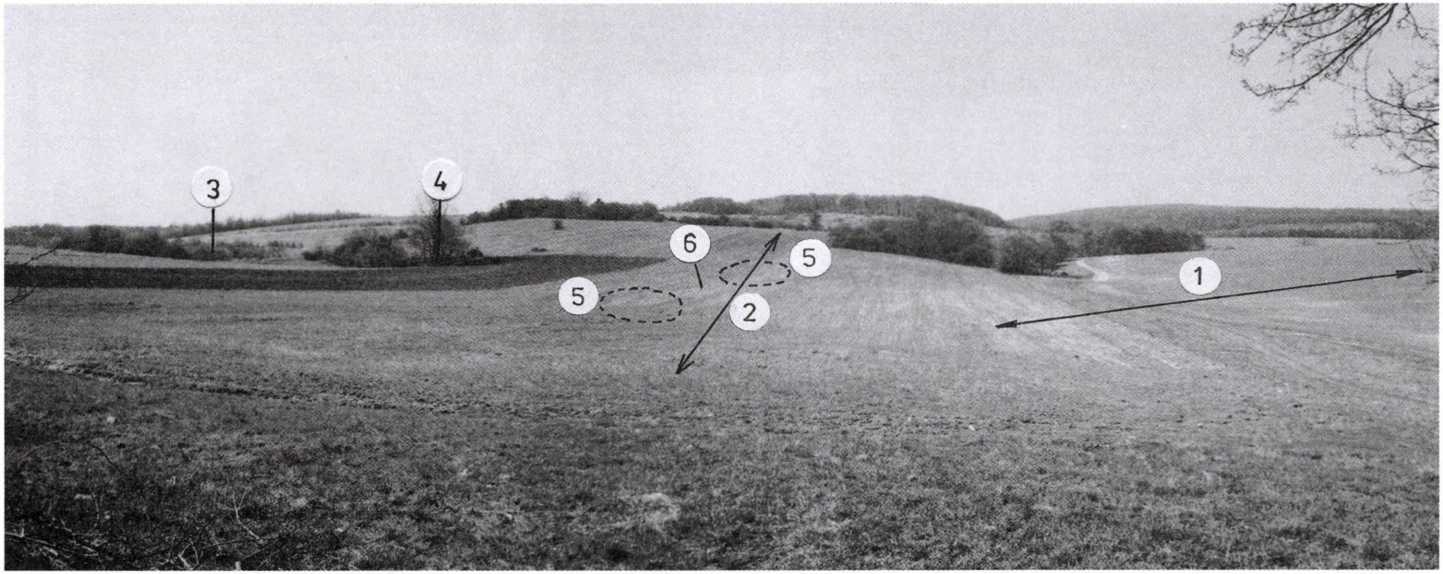
Pict. 7. Opening of cover sediments fro some day on May 20, 1998, 50-100 m from covered karst ponor K-1

Pict. 8. Openings inherited over cover sediments in pseudoponor Hu-10, 1985 (valley side of Öregfolyás)
Legend: 1. edge of depression; 2. floor of depression; 3. opening

Pict. 9. Curved tree indicating mass movement in doline-with-ponor Gy-9, 1979
(the roots also differ downslope and upslope from the trunk, adjusted to movement)

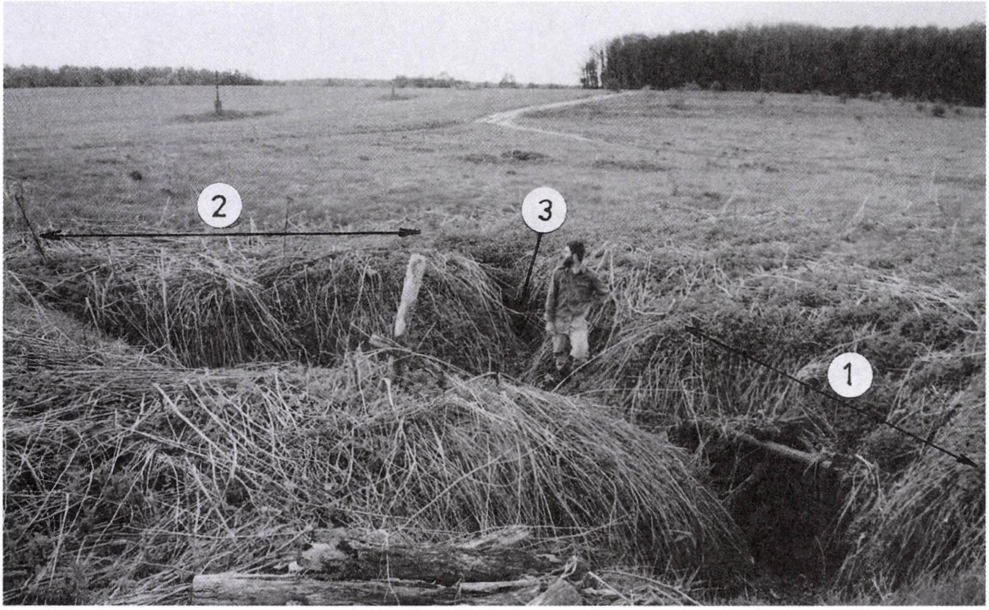


Pict. 10. Detail of covered karst ponor K-1 (central Hárskút Plateau)
Legend: 1. partial depressions; 2. buried tree; 3. filled W side of depression; 4. floor of depression almost smoothed by fill

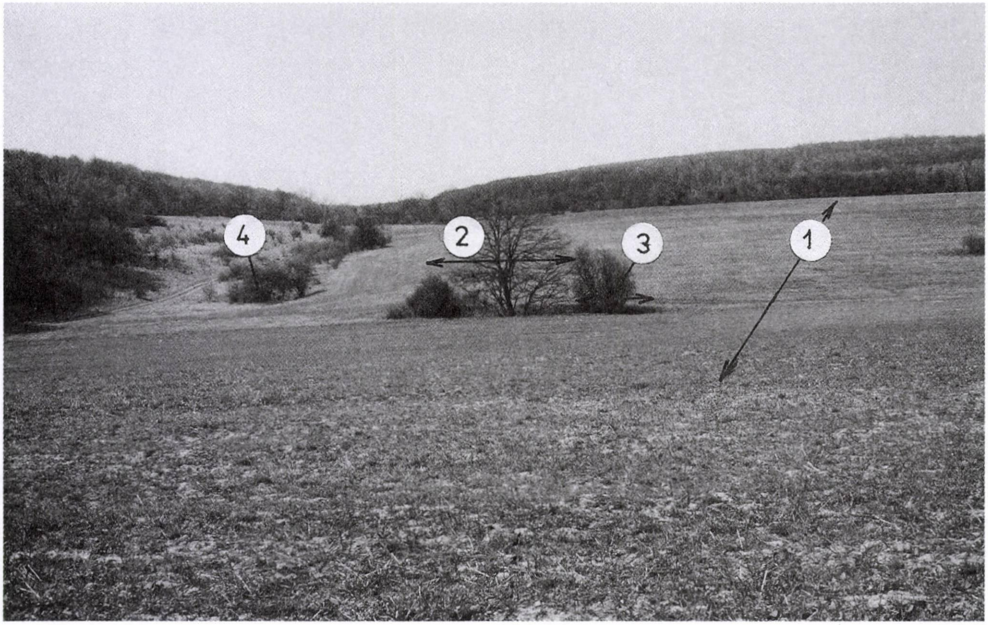


Pict. 11. Covered karst ponor K-1

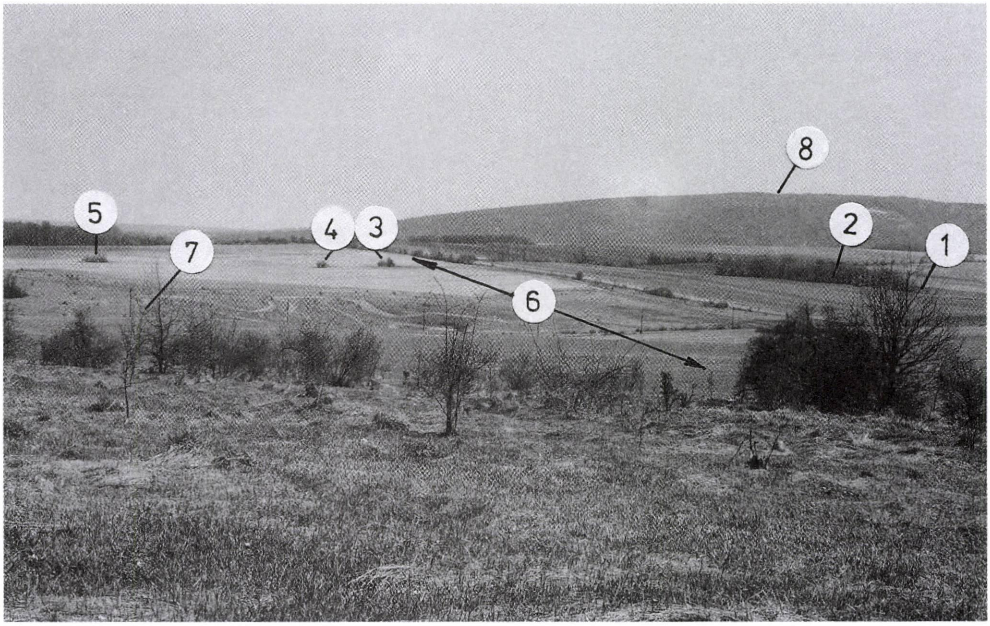
Legend: 1. Szilfakő Valley; 2. older valley; 3. younger, dead-end valley; 4. covered karst ponor; 5. covered karst depressions formed on older valley floor; 6. approximate site of opening shown in Pict. 7



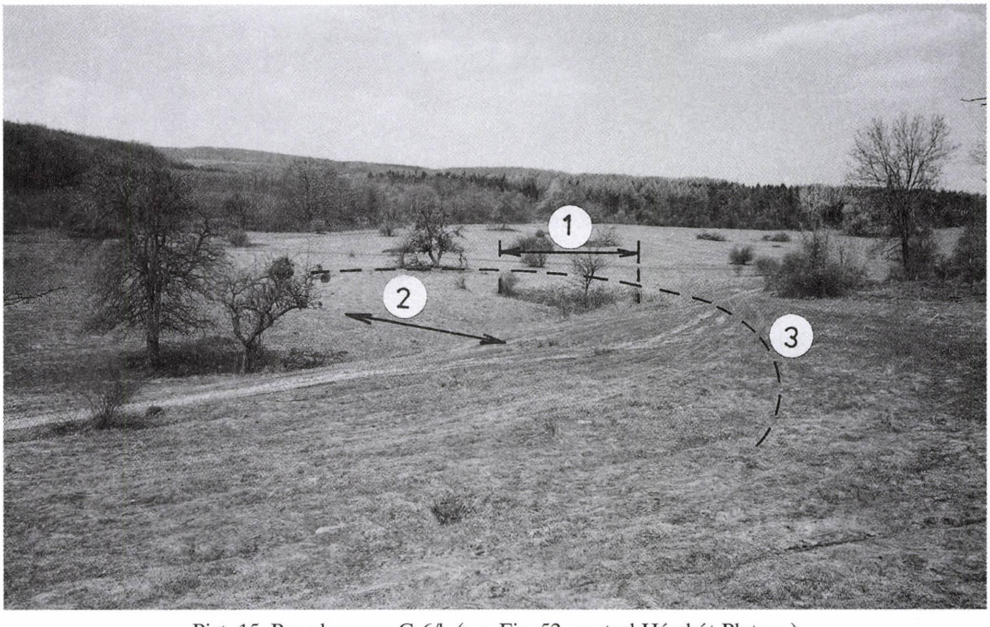
Pict. 12. Twin doline with ponor (Gy-12)
Legend: 1. partial depression of main chimney (no 10 in Fig. 6); 2. partial depression of subsidiary chimney (no 11 in Fig. 6); 3. recent opening (probably formed during the initial opening of chimney no 12 in Fig. 6 to the surface)



Pict. 13. Twin doline with ponor and doline with ponor on valley floor
Legend: 1. Szilfakő Valley; 2. partial depression K-2; 3. partial depression K-3; 4. doline with ponor G-9



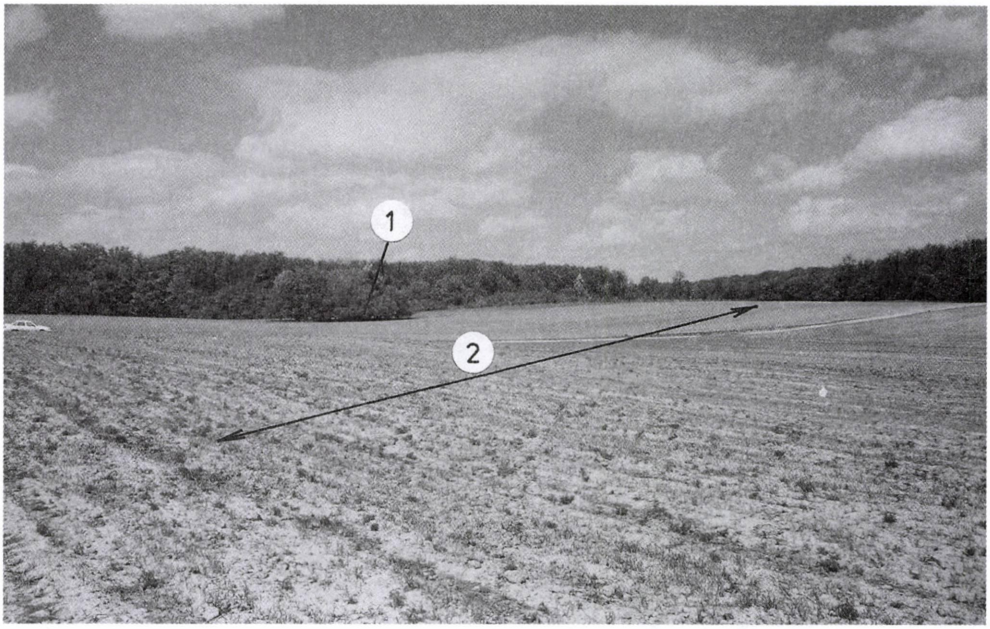
Pict. 14. Row of dolines-with-ponor in the right-hand valley side of Öregfolyás
Legend: 1. pseudoponor; 2. channel leading to the pseudoponor; 3. streamsink doline Hu-1; 4. doline-with-ponor Hu-2; 5. doline-with-ponor Hu-3; 6. Öregfolyás; 7. covered exhuming cone in valley side; 8. Kőris Hill of Hárskút



Pict. 15. Pseudoponor G-6/b (see Fig. 52, central Hárskút Plateau)
Legend: 1. pseudoponor; 2. channel of pseudoponor; 3. margin of true depression

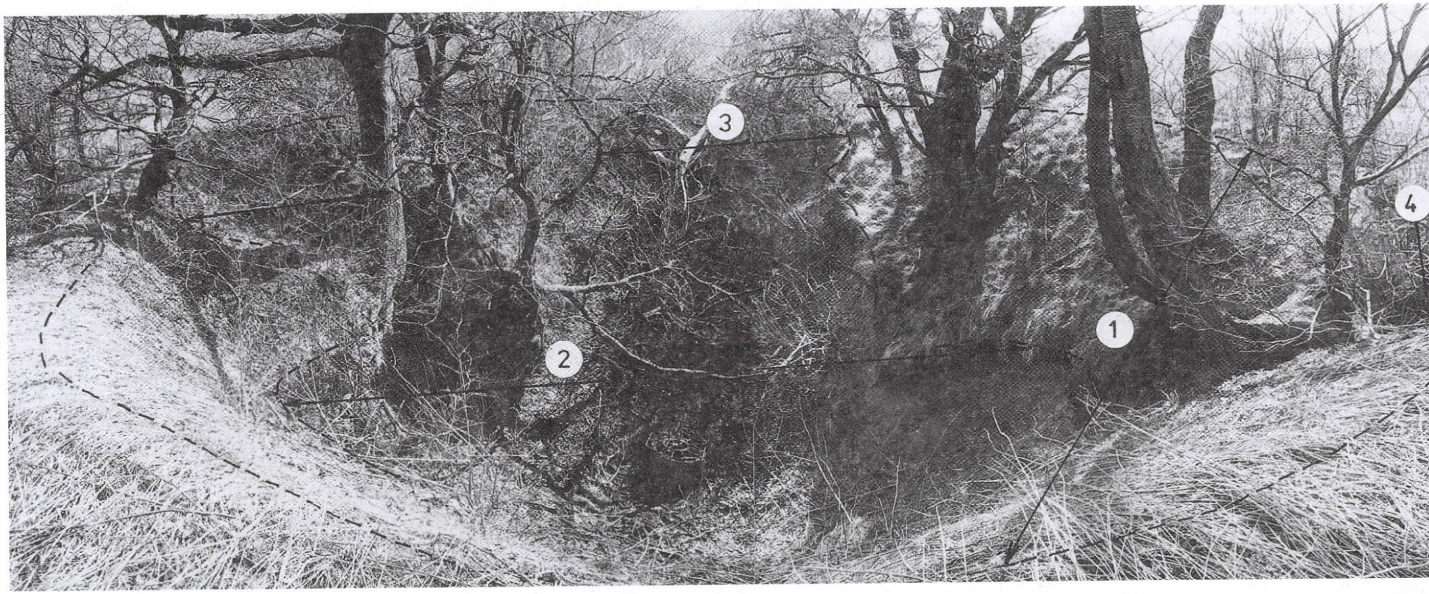
Pict. 16. Pseudodepression on Mester-Hajag (see Fig. 20)
Legend: 1. cone; 2. karst depression (syngenetic doline-with-ponor); 3. pseudodepression

Pict. 17. Pseudodepression on Mester-Hajag (see Fig. 20)
Legend: 1. cone; 2. covered karst depression (syngenetic doline-with-ponor); 3. pseudodepression



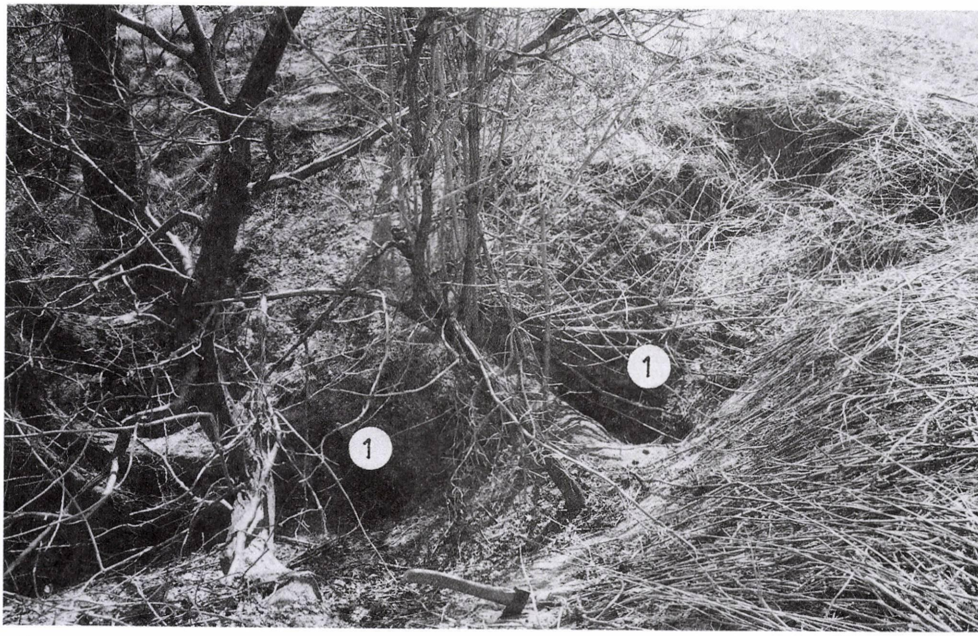
Pict. 18. Doline-with-pseudoponor (entrance to the Alba Regia Cave) on floor of filled superimposed valley
Legend: 1. doline-with-pseudoponor; 2. superimposed valley

Pict. 19. Doline-with-pseudoponor I–29.
Legend: 1. margin of depression and outer edge of doline-with-pseudoponor; 2. interior of doline-with-pseudoponor; 3. depression with arcuate margin shaped by mass movement

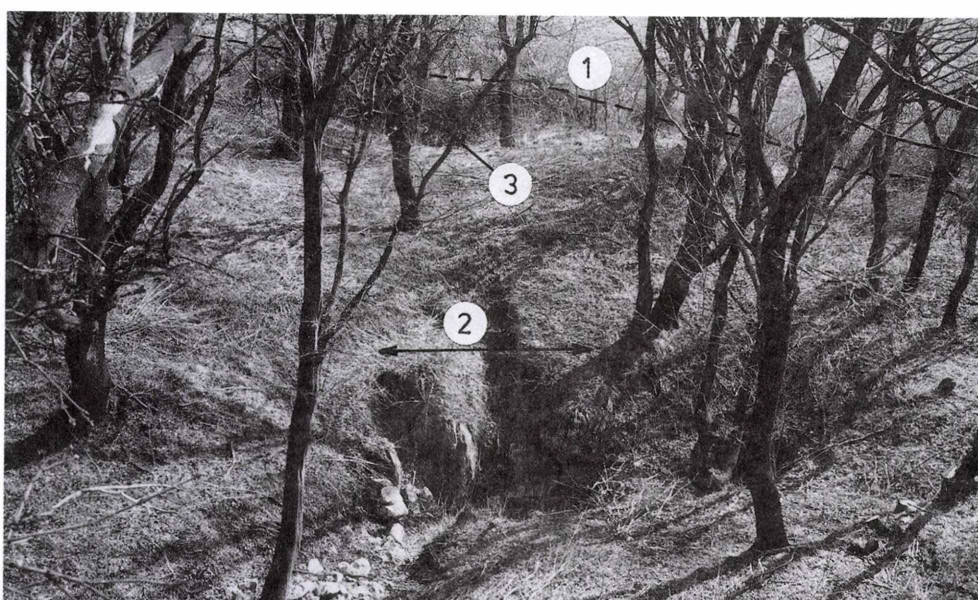


Pict. 20. Doline-with-pseudoponor I-30 (Tábla Valley, Tés Plateau)

Legend: 1. depression and doline-with-pseudoponor; 2. interior of doline-with-pseudoponor; 3. depression with arcuate margin shaped by mass movement; 4. erosional regressional channel



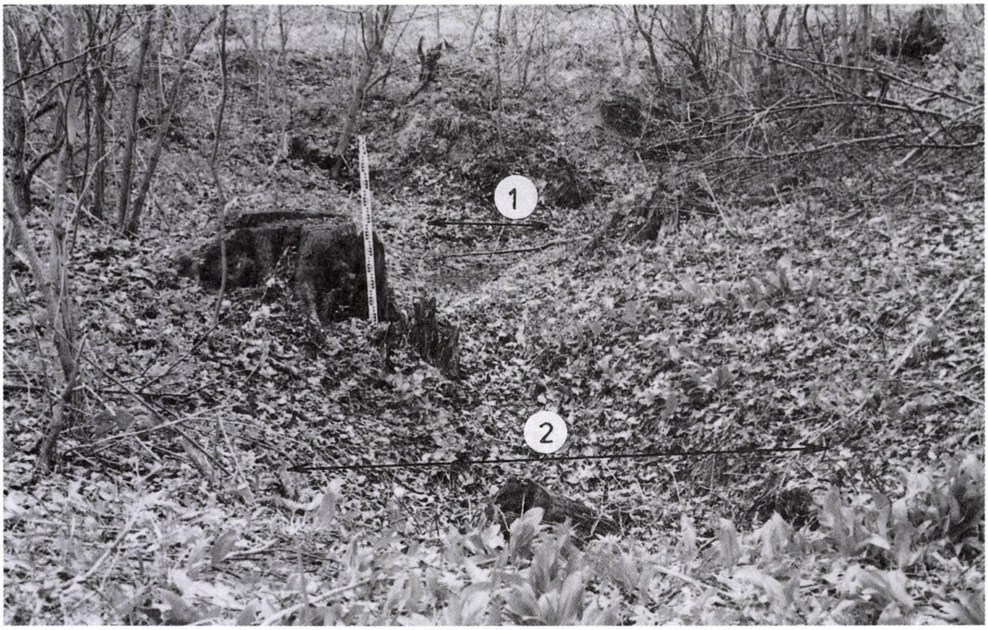
Pict. 21. Erosion regressional channel of doline-with-pseudoponor I-30 with sites of pseudobathycapture (1)



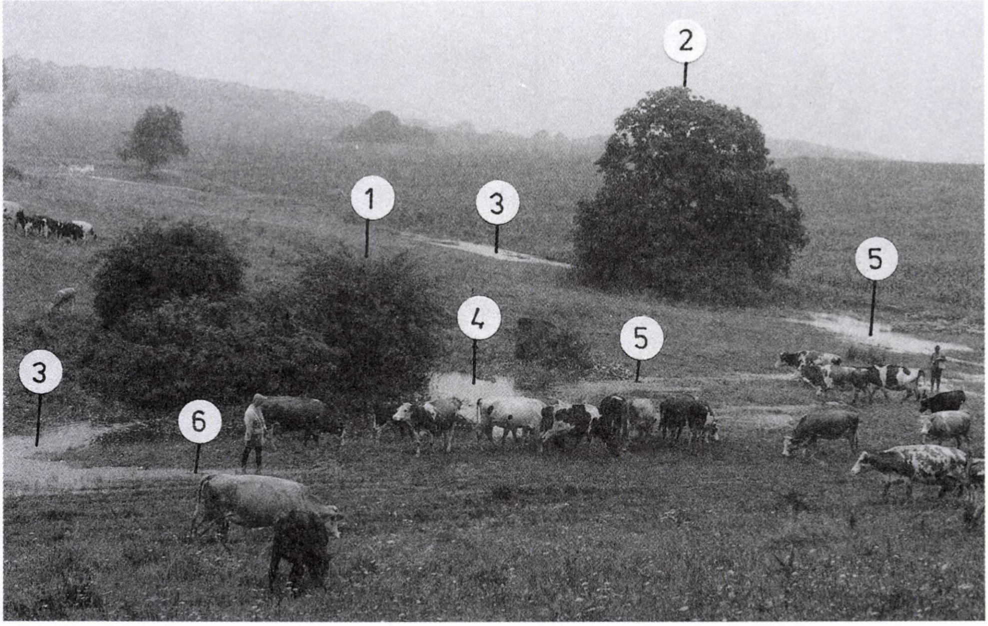
Pict. 22. Postgenetic doline-with-ponor of depression I-14
Legend: 1. margin of depression; 2. doline-with-pseudoponor and its channel (with outcrops of basement); 3. pseudodoline

Pict. 23. Postgenetic doline-with-ponor I-33 (Tábla Valley)

Pict. 24. Fossilised covered karst feature on the karst terrain around the Homód-árok



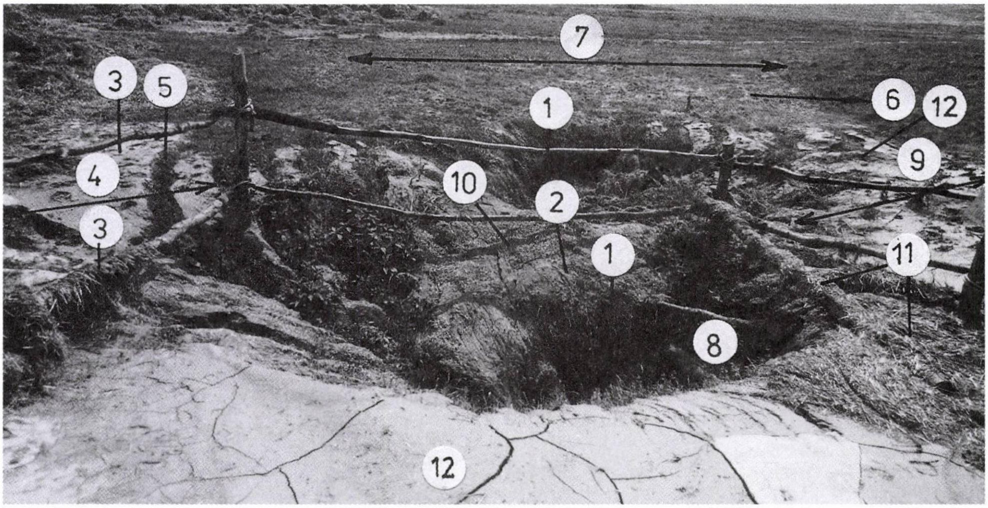
Pict. 25. Fossilised (1) and active (2) partial depression of twin doline-with-ponor near the Fehérkő-árok (the fossilised partial depression is recharge area for the active partial depression)



Pict. 26. Flood pond of longer life-time, 1984
Legend: 1. doline-with-ponor G-9; 2. twin dolines-with-ponor K-2 and K-3; 3. inflow on valley floor; 4. pond; 5. outlet; 6. flow by doline-with-ponor G-9

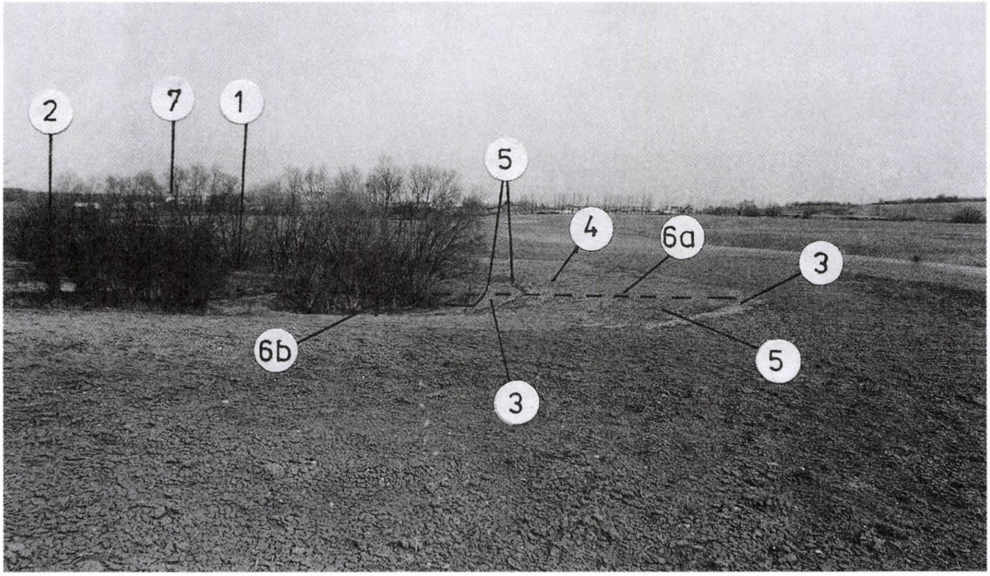

Pict. 27. Close view of a flood pond, 1984 (covered karst ponor K-1)


Pict. 28. Long-term flood pond. The enclosing depression is found near pseudoponor G-6/b (between 8 and 14 August 1984)

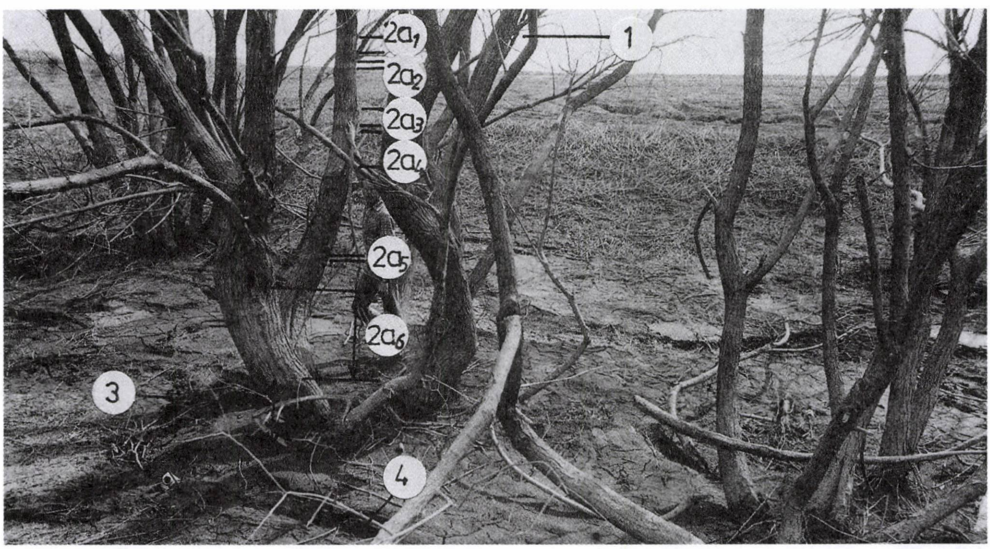


Pict. 29. Deposits of short-term flood pond at twin doline-with-ponor Gy-12 (activity on 9 May 1980) Legend: 1. partial depressions; 2. threshold; 3. coarser sediment or plant detritus accumulated along the margins during intensive inflow; 4. zone of intensive surface inflow; 5. erosion rills in sediment; 6. colloidal discolouring on vegetation, attesting to slow surface inflow; 7. zone of slow surface inflow; 8. short-term portion of fomer pond (intensive water flow and conduction); 9. part of the former pond of longer life-time (moderate flow and conduction); 10. plant detritus deposited on the threshold because of shallow water; 11. plant detritus accumulation allowing overflow; 12. sediment deposited in the long-term portion of pond or during overflow

Pict. 30. Sedimentation in a pond of longer life-time, 1980 (twin doline Gy-11, central Hárskút Plateau) Legend: 1. plant detritus series (uniform appearance due to low or stable rate of water table dropping in flood pond); 2. erosion rill (depth equals to thickness of sediment formed during the existence of the pond)



Pict. 31. Sedimentation from pond of longer life-time on the outer margin of a doline-with-ponor near Dudar
Legend: 1. karst depression; 2. water recharge; 3. plant detritus zone with sharp outer margin; 4. plant detritus series; 5. terrain free of plant detritus; 6. maximum horizontal (a) and vertical (b) extension of pond; 7. Dudar village (the zone of plant detritus indicates pond level and its wedging out points to accelerating subsidence of water level)



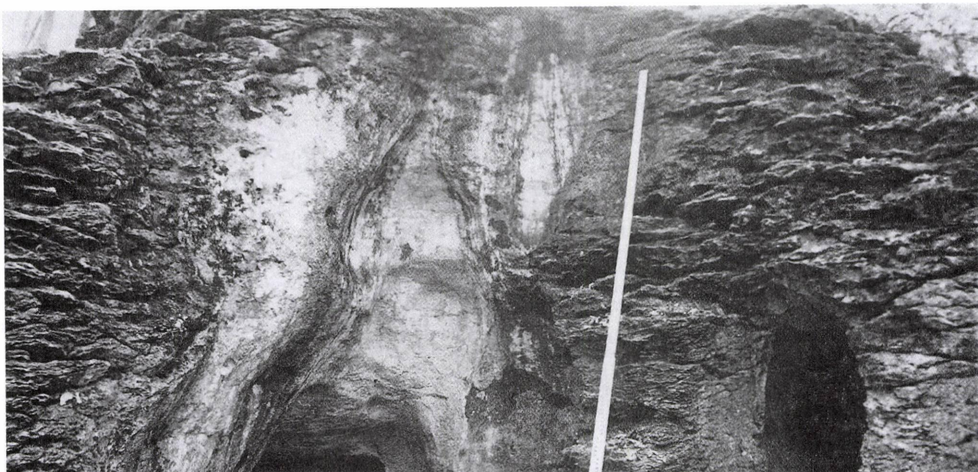
Pict. 32. Sedimentation in flood pond of longer life-time with recharge from meltwater, interior of doline-with-ponor shown on Pict. 31.

Legend: 1. maximum level of pond; 2. colloid rings indicating slower dropping of pond water table (a_1-a_6); 3. tree trunk detail free of colloids (the conduit opening at the tree roots results in local acceleration of flow); 4. erosion rills (colloid coating marks the influx of fine sediment, colloid rings point to water table subsidence at variable rate)

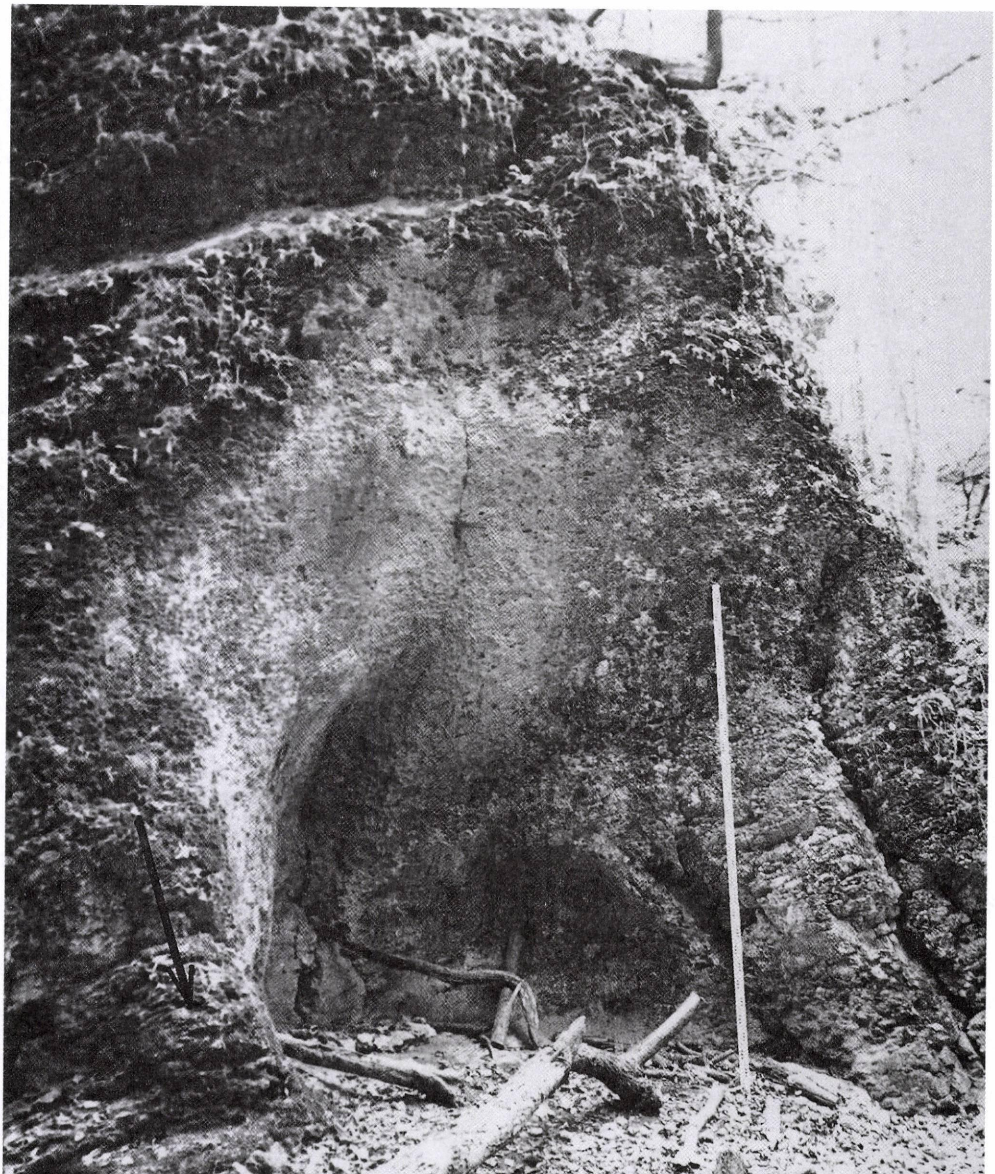
Pict. 33. Circular collapse doline (Durrogós-tető; near Hódos-ér). Uneven interior because of ceiling remnants

Pict. 34. Elongated-wide collapse doline (Durrogós-tető; near Hódos-ér)
Legend: 1. chimneys or spherical cauldrons on the steep N margin, 2. elongated-narrow collapse doline at subsidiary corridor

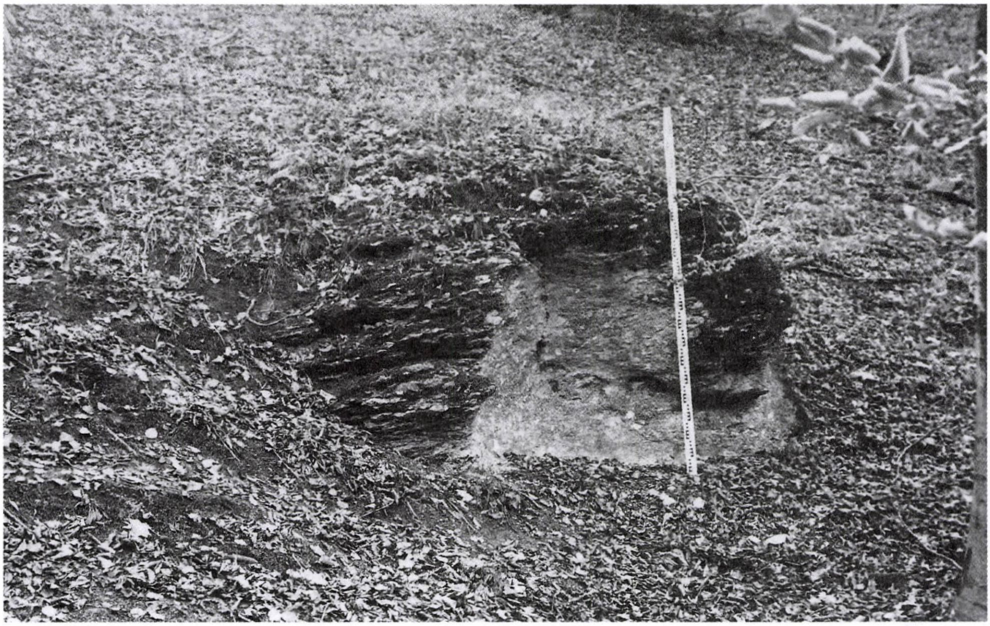
Pict. 35. Ruin of spherical cauldron in cave M-6 near Dudar village (Kő-lik 2 of Magos Hill) (its presence proves mixing corrosional origin in the zone of flowing karst water)



Pict. 36. N entrances to Likas-kő of Hódos-ér with ruins of spherical cauldrons over the E entrance



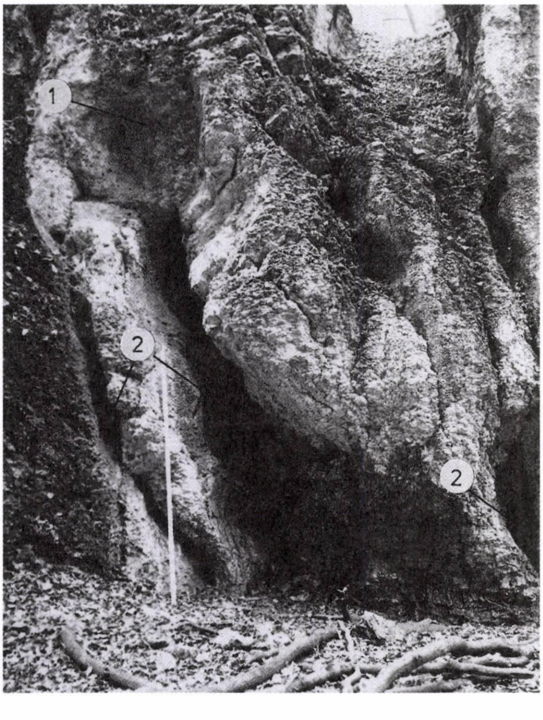
Pict. 37. Ruin of spherical cauldron on channel floor in Ördög-árok, below Gizella pass. Flow direction is from left to right. If the feature were an erosional cauldron, water flow must have destroyed the left-hand edge of the spherical cauldron (marked with arrow).



Pict. 38. Ruined spherical cauldron in the valley side of Ördög-árok at Gizella pass. Its presence indicates that the cavity or cavities formed in the vicinity have been destroyed completely by now

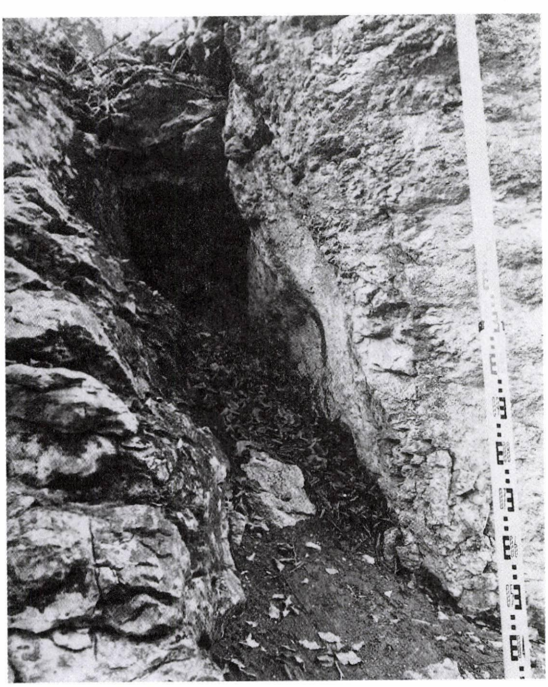
Pict. 39. Cave remnant of vertical position (Nagy Törkü-lik, Szilfakő Valley, Hajag)

Pict. 40. Superimposed-antecedent gorge: Kőmosó Gorge (the catchment of the stream which cuts through Vár Hill is a faulted graben in the foreground of the hill, filled by non-karstic rocks)



Pict. 41. Cavities formed by solution along faults and exposed by stream erosion (Ördög-árok at Gizella pass). Legend: 1. ruined spherical cauldron; 2. cave ruin

Pict. 42. Cave remnant transformed into cave ruin by valley side denudation with window on its ceiling (Gerencepuszta Cave, Gerence Valley)



Pict. 43. Cave ruin with ceiling remnant (Ördög-árok)

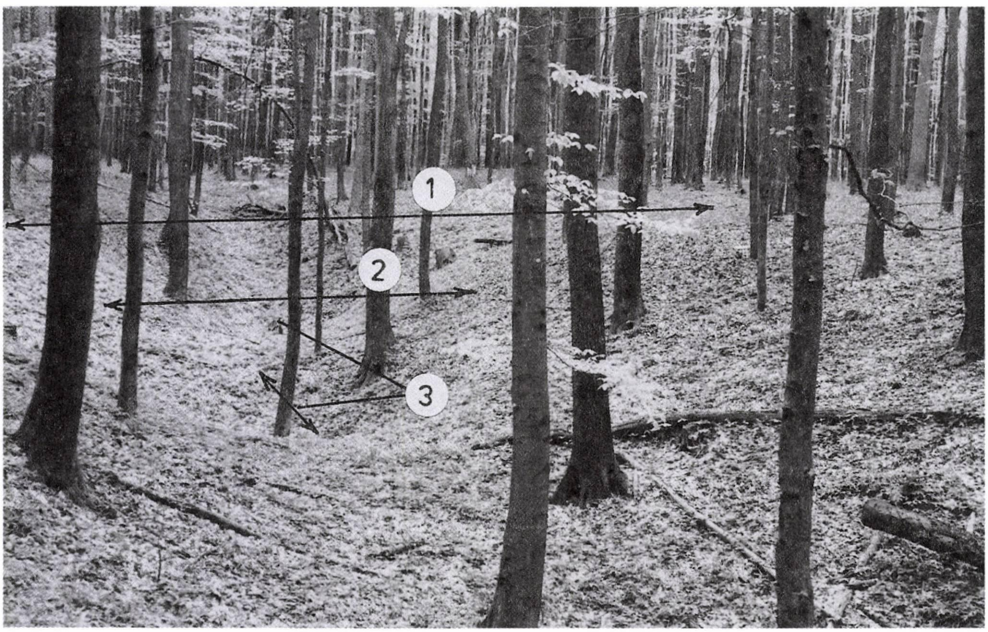
Pict. 44. Corridor-like (1) and chamber-like (2) cave ruins (in the terrain above the Likas-kő of Hódos-ér)

Pict. 45. Corridor-like cave ruin in Ördög-árok (with rills formed by solution along bedding planes on side walls)

Pict. 46. Ruins of exposed chimneys formed in the zone of flowing karst water in the side of Kerteskő Gorge (Gerence Valley)

Pict. 47. Denudation of gorge wall dissected by chimney ruins (Kerteskő Gorge)
Legend: 1. remnant of partially destroyed chimney; 2. completely destroyed chimney; 3. remnant of dividing wall between chimneys

Pict. 48. Double valley (tributary of the Nyögér-árok, a tributary of the Márvány-árok)
Legend: 1. old superimposed valley partially filled by reworked loess; 2. developing superimposed valley



Pict. 49. Karstification of developing superimposed valley (tributary of Pálházi-árok, a tributary of Márvány-árok)
Legend: 1. filled, old well-developed superimposed valley; 2. developing superimposed valley; 3. doline-with-ponor

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Explanation of frequently used concepts

Valleys

Regression valleys: Valley developing on non-karstic deposits on carbonate rock (further: cover sediment) in a direction opposite to slope.
Antecedent valley: Valley incision by the erosion of its water-course keeps pace with uplift along a section of the valley. As a result a gorge is created.
Superimposed valley: The water-course erodes through cover sediments and valley formation goes on in the underlying carbonate rock.
Regressional-superimposed valley: A retreating valley is inherited over from the cover sediments to the underlying carbonate rock.
Antecedent-superimposed valley: Along a section of the inherited valley, an antecedent valley section develops.
Developed superimposed valley: The water-course in the valley has cut through the cover sediment entirely. Along its total length the valley is incised into the carbonate rock. A developed superimposed valley can be active or inactive. An active superimposed valley has a water-course (although part of the water seeps away) and, thus, there is valley incision. An inactive superimposed valley – with the cover sediments removed from its catchment – has no water-course and, consequently, there is no incision.
Developing superimposed valley: The water-course of the valley has not yet cut through the cover sediments along the whole length of the valley.
Complex valley: In the mountains double or triple complex (terraced?) valleys are common. This shape is most typical of developed superimposed valleys. The internal valleys appear on the flat alluvial floors of developed superimposed valleys. In some cases the latter have already cut through the fills of older valleys locally (regressional developing superimposed valley).
Pregenetic valley: A superimposed valley which had been inherited over the carbonate rock earlier than the zone of flowing karst water formed.
Syngenetic valley: A superimposed valley, which was inherited over the carbonate rock at the same time as the zone of flowing karst water formed under the valley.
Postgenetic valley: A superimposed valley which was inherited over the carbonate rock after the zone of flowing karst water had been formed.
Valley evolved through cavity exposure: A superimposed valley the incision of which was partly due to cavities formed through dissolution by water seeping away from the water-course. Below these valleys or valley sections local solution intensifies as a consequence of influx of large amounts of water from non-karstic catchments. This type of valley evolution is particularly common along superimposed-antecedent valley sections, which are gorge-like and have many caves in their sides.

Karst features

Syngenetic covered karst features

The chimney developed in the karstic rock is inherited over the surface, where an undrained landform with passage (later covered or filled in) is produced. The following syngenetic karst features are identified:
Covered karst ponor: The chimney develops on a valley floor with water-course. The

ponor is located at the end of a blind valley. As part of the catchment of the watercourse is retained, the ponor has a catchment.
Doline-with-ponor: The chimney is exposed on a slope (eg. in the side of a valley). Although part of the slope runoff is collected in the resulting depression, the doline-with-ponor has no markedly delimited catchment. Dolines-with-ponor are not larger some metres in diameter and their slopes are mostly formed on cover sediment. Particularly in the case of smaller ones, side-slopes are steep or even subvertical.
Doline with ponor-like feature (pseudoponor): A doline-with-ponor which involved intensive erosion (gullies, valleys in cover sediment) induced by its development and, thus, a catchment can be identified.
Depression: An undrained feature of uneven floor some tens of centimetres across and of several tens of metres outer diameter, developed in the cover sediments of the carbonate rock. The lack of drainage is often caused by a ring of exhuming or semiexhumed cones around them. In the areas of depressions there may be several recent karst features (doline-with-ponor).
Half-enclosed depression: A depression with drainage.
Mature depression: Impervious deposits on the depression floor.
Pseudodepression: The carbonate basement has a dissected surface, however, with no undrained feature below the depression.
True depression: Below the depression, on the carbonate basement surface, an undrained feature had developed before the cover sediments accumulated.

Postgenetic covered karst features

As a consequence of the removal of the fill of a karst passage older than present-day karstification, a karst feature develops in the cover sediment. The older paleokarst passage may or may not be associated with a paleokarst depression. In the first case, postgenetic karstification is accompanied by depression formation (karstification dependent on depression) and, in the latter, it does not happen (karstification independent of depression).

Karst landforms dependent on depression

Subsidence pseudodoline: A landform without passage in the fill of old paleokarst depression. The depression is a complex one: its external part (the depression) has been eroded by sheet-wash, while the side-slope of its internal part has a steep wall in cover sediments and spotted with landforms of mass movement origin. Its diameter may reach 10 m and its depth may be more than 5 m.
Doline-with-pseudoponor: It has a shape similar to the previous form but there is a water conduit in depressions of such origin.
Postgenetic doline-with-ponor: A feature smaller than the paleokarst form and only occupies part of it. The cover sediment surface of the depression represents the catchment of this feature.

Postgenetic karstification independent of depression

Pseudodoline above passage: A feature without passage or catchment developed in cover sediments above the paleokarst passage.

Doline-with-pseudoponor above passage: It has a shape similar to the previous feature but there is a water conduit in the depression.

Fossilised covered karst features

Water recharge from the one-time karst landform into the karst has ceased. Partly due to imperviousness and partly to the fact that these sites are mostly without drainage, rainwater accumulated here for longer periods. The landforms have diameters of some metres and depth of some tens of centimetres.
Wallow of ponor type: A syngenetic covered karst ponor fossilised.
Wallow of doline-with-ponor type: Syngenetic or postgenetic dolines-with-ponor fossilised.

Caves died development forms

Collapse doline: A mostly undrained landform of some tens of centimetres depth, developed from the caved-in ceilings of cavities in the zone of flowing karst water. According to groudplan form, circular, elongated and broad and elongated and narrow collapse dolines are distinguished. They are distinct in their environment. The elongated and broad collapse doline has steep walls (of bedrock) and 10-20 cm width.
Cave remnant: A cavity formed in the zone of flowing karst water and exposed by the erosion of the enclosing rock.
Cave remnant in valley: In valley side, exposed by a water-course.
Cave remnant on plateau margin: Exposed by frost shattering and mass movements and opens onto escarpment.
Cave remnant in summit position: Also exposed by frost shattering and mass movements but opens onto block summit surface.
Corrosional residual feature: A minor feature which is not joined by other solutional cavities during its development but also exposed with the erosion of the enclosing rock.
Truncated cave remnant: The cave exposed by the water-course is shortened as the valley side is being eroded.
Ruined cave remnant: After the ceiling of the cave is destroyed in several places, the cave is divided into several shorter through caves. The through caves are mostly of some metres' length and have two or more entrances.
Cave ruin: The cave remnant loses its ceiling. Cave ruins are some metre long and some tens of centimetres deep features with vertical rock walls.

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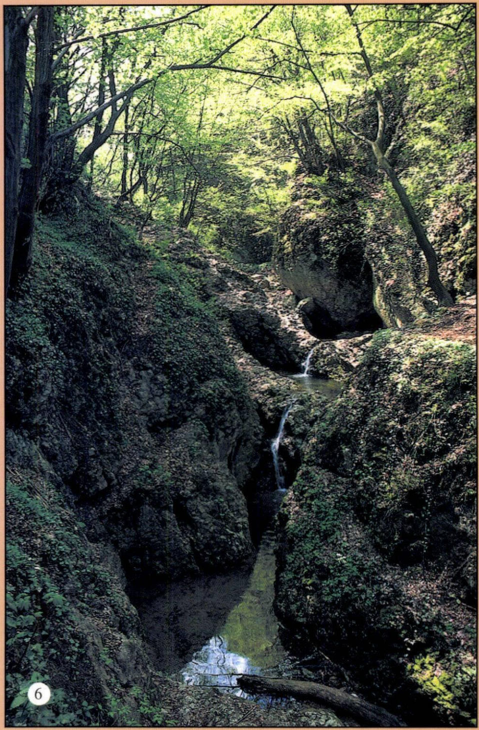

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