BILINGUAL PUBLISHING CO.
Pioneer of Global Academics Since 1984

Journal of Geological Research
https://ojs.bilpublishing.com/index.php/jgr-a

ARTICLE

The Distribution of Surface Karst Features in the Bakony Region (Transdanubian Mountains, Hungary)

Márton VERESS[1*] Szilárd VETÉSI-FOITH[2]

1. Department of Geography, Eötvös Lóránd University, Szombathely, Hungary
2. Department of Physical Geography, University of Pécs, Pécs, Hungary

ARTICLE INFO

Article history
Received:13 March 2019
Revised: 16 April 2019
Accepted: 16 April 2019
Published Online: 30 April 2019

Keywords:
Block type
Karst type
Subsidence doline
Caprock doline
Ponor
gorge

ABSTRACT

The surface karst of the Bakony Region is described. VES measurements were applied to study the cover and the morphology of the bedrock. A karstmorphological mapping was also performed. A relation was established between the karst types and block types in the mountains. The karstification of the mountains was affected by the block structure of the mountains, the mounds of the uneven bedrock, the presence of superficial deposits and their young denudation. As a result of the above mentioned facts, the karst of the mountains is varied. Soil-covered karst is widespread in the mountains, but the specific features of this type (solution dolines) only occur on threshold surfaces at the margin of the mountains and on dolomite. The concealed karst was mainly formed on horsts elevated to summit position, but it can also be found on threshold surfaces and on horsts in summit position. Its features are subsidence dolines and depressions of superficial deposit. Cryptokarst and buried karst can be created by gravelly cover or basalt. Where the cover is gravel, epigenetic valleys develop with opened-up phreatic cavities. Where the cover is basalt, ponors develop at its margin, while inside, where the basalt thins out, caprock dolines are formed.

1. Introduction

1.1 A General Description of the Bakony Region

In this study, the surface karst of the Bakony Region, the morphological and genetic characteristics of the karst types as well as their occurrence related to block types are described.

The Bakony Region (its elevation is 150m-700m, its expansion is 4300 km^2) is constituted by the Bakony Mountains (its area is 2200 km^2) and the surrounding environs with a lower elevation. The Bakony Region is a meso region, which is separated into five micro region groups (Keszthely Mountains, Balaton Uplands, Southern Bakony, Northern Bakony, Bakonyalja Figs. 1, 2). The Bakony Region is situated in the Carpathian Basin. A mantle plume developed under the Carpathian Basin which thinned out the lower crust and this resulted in isostatic subsidence and created a sialic basin [1]. The sialic basin separated into partial basins by further subsidence. Such partial basins (structures) also surround the Transdanubian Mountains that bear the Bakony Region: in NW the Little Hungarian Plain and in SE the Great Hungarian Plain. Karst phenomena are present to some extent in all

*Corresponding Author:
Márton VERESS,
Department of Geography, Eötvös Lóránd University, Szombathely, Hungary;
E-mail: veress.marton@sek.elte.hu.*

 DOI: https://doi.org/10.30564/jgr.v1i1.622

micro region groups (Northern Bakony is the richest in karst features).

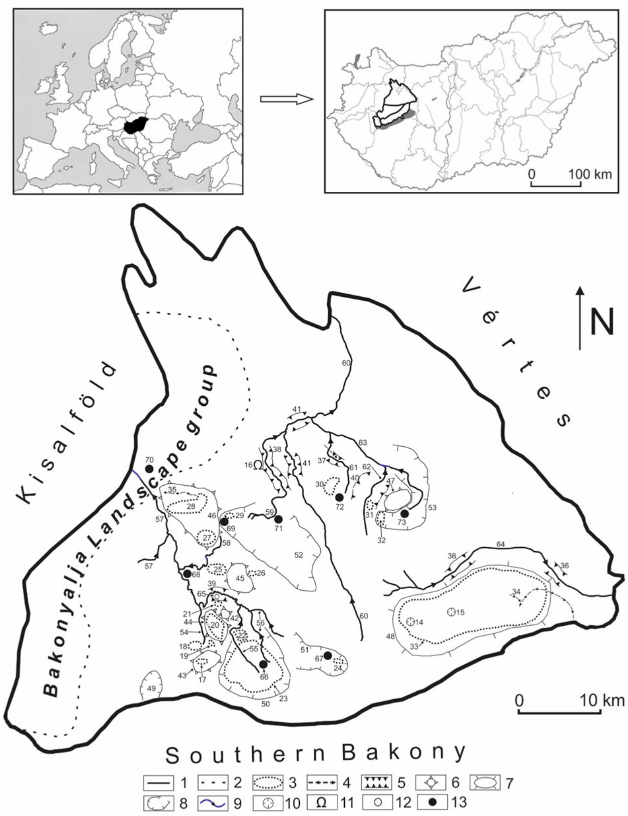

Fig. 1: The karstic features of the northern part of the Bakony Region

Legend: 1. boundary of the Northern Bakony, 2. boundary of micro region group, 3. concealed karst, 4. dry valley, 5. gorge, 6. block roof, 7. plateau, 8. basin, 9. stream and its valley, 10. karst depression, 11. cave opening, 12. spring, 13. settlement, 14. depression of Csengő shaft (marked I-51), 15. depression of Háromkürtő shaft (marked I-12), 16. Hódos-éri Likas-kő cave, concealed karst areas: 17. on the Középső-Hajag, 18. on the Felső-Hajag, 19. near Fehér-kő Valley, 20. on the Mester-Hajag, 21. between the Iharos block and Judit Spring, 22. on the Égett block, 23. in the Hárskút Basin, 24. in the Lókút Basin, 25. between the Som Mountain and Száraz-Gerence Stream, 26. doline group at Ősbükkös, 27. doline group by Eleven-förtés, 28. by the Márvány Valley, 29. near Újszépalmapuszta, 30. between the Cuha Stream and Gézaházapuszta, 31. on the Sűrű Mountain, 32. near Dudar, 33. on the Tési Plateau, 34. Tábla Valley, 35. Márvány Valley, 36. Gaja gorge, 37. Kőmosó gorge, 38. gorge of Hódos stream, 39. Kerteskői gorge, 40. gorges of Ördög Valley, 41. Cuha gorges, 42. Iharos block, 43. Középső-Hajag block, 44. Mester-Hajag block, 45. Som block, 46. Kőris block, 47. Magos block, 48. Tési Plateau, 49. Csehbánya Basin, 50. Hárskút Basin, 51. Lókút Basin, 52. Porvai Basin, 53. Dudari Basin, 54. the stream of Fehér-kő Valley, 55. Öreg Stream, 56. Gerence Stream, 57. Vörös János Stream, 58. Száraz-Gerence Stream, 59. Hódos Stream, 60. Cuha Stream, 61. the stream of Kő Valley, 62. the stream of Ördög Valley, 63. Dudar Stream, 64. Gaja Stream, 65. Judit Spring, 66. Hárskút, 67. Lókút, 68. Bakonybél, 69. Újszépalmapuszta, 70. Bakonykoppány, 71. Porva, 72. Gézaházapuszta, 73. Dudar

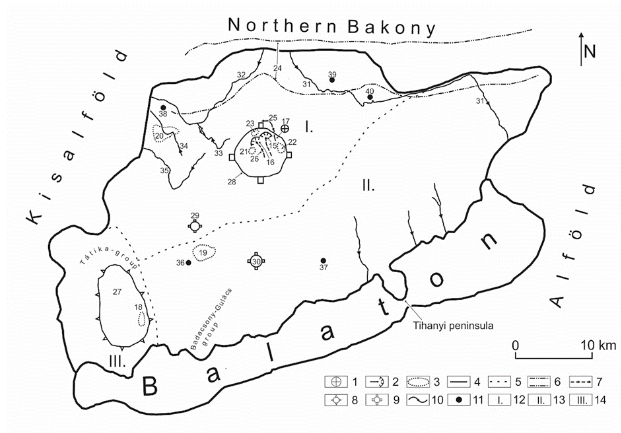

Fig. 2: The karstic features of the southern part of the Bakony Region

Legend:1. ponor, 2. blind valley, 3. concealed karst, 4. boundary of the southern part of the Bakony Region, 5. boundary of micro region group, 6. tectonic graben, 7. dry valley, 8. block roof, 9. block with basalt cap, 10. stream and its valley, 11. settlement, 12. Southern Bakony micro region group, 13. Balaton Uplands micro region group, 14. Keszthelyi Mountains micro region group, 15. Öreg-köves ponor, 16. Macskalik ponor, 17. Tönkölyös ponor, concealed karst areas: 18. on the Szabadhegyi Plateau, 19. Tapolcai Karst, 20. nearby Devecser, 21-23. on the Kab Mountain, 24. Veszprém-Devecser Graben, 25-26. dry valleys on Kab Mountain, 27. Keszthelyi Mountains, 28. Kab Mountain, 29. Agár block, 30. Fekete Mountain, 31. Séd Stream, 32. Torna Stream, 33. Padragi Stream, 34. Egres Stream, 35. Kígyós Stream, 36. Tapolca, 37. Dörgicse, 38. Devecser, 39. Márkó, 40. Veszprém

As a part of the Transdanubian Mountains macro region (Alpaca Macrostructural Unit) the Bakony Region got into its present position from a southern alpine surroundings with a NE shift by the time of Miocene [1]. As a consequence, but also as a result of the changing of the position of the Eurasian Plate, its climate gradually became temperate from a tropical one. The Alpaca Macrostructural Unit is regarded as the uppermost, non-metamorphic member of the Austro-Alpine Nappe (Fig. 3a,[2]. Its main constituting rock is Triassic Main Dolomite (Main Dolomite Formation). The main dolomite is without impermeable intercalations, its thickness may exceed 1500 m in the Transdanubian Mountains [3], but it is reported to have a thickness of 1400 m in the Southern Bakony and 550-750 m in the Balaton Uplands [4]. Its bedrock is composed of Sándorhegy limestone (Sándorhegy Limestone Formation) with marl intercalations [5] then the bedrock of the latter is the Veszprém marl (Veszprém Marl Formation). The main dolomite is overlain by Triassic Dachstein limestone (Dachstein Limestone Formation), Jurassic, Cretaceous and Eocene limestones in patchy expansion mainly in small thickness (from some 10 m to some 100 m). (Fig. 3a). The main characteristic feature of its structure is given by its disproportionate development: in the

  DOI: https://doi.org/10.30564/jgr.v1i1.622

SE there are old Triassic, Palaeozoic, partially non-karstic rock, in NW there are also old (Triassic) Carboniferous rocks entirely on the surface, while in its middle part where the Triassic floor forms a depression [6, 2] limestones that developed in Jurassic, pelagic (Kardosrét Limestone Formation, Hierlatz Limestone Formation, Isztimer Limestone Formation, Tűzkövesárok Limestone Formation, Úrkút Manganese Formation, Lókút Radiolarite Formation), Cretaceous (Borzvár Limestone Formation, Sümeg Marl Formation, Alsópere Bauxite Formation, Tés Clay-Marl Formation, Zirc Limestone formation, Pénzeskút Marl Formation) and Eocene (Gánt Bauxite Formation, Szőc Limestone Formation, Csabrendek Marl Formation, Halimba Tuffite Formation, Iharkút Formation) shallow sea environment occur [7].

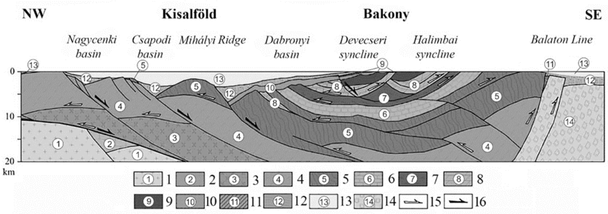

Fig. 3a: Geological profile of NW-SE direction from the mountains

Legend: 1. European Upper Crust, 2. European autochton Mesozoic, 3. Penninic, 4. Lower, Upper, Austroalpine Paleozic 5. Uppermost Austroalpine Palozoic, 6. Lower, Middle Triassic, 7. Veszprém Marl 8. Main Dolomite, 9. Dachstein and Kardosréti Limestones, 10. Gosau beds, 11. Paleogenic beds, 12. Lower, Middle Miocene beds, 13. Upper Miocene beds, 14. Paleo Mezozoic of dinaric type (Middle Hungarian Main Unit), 15. Mesozoic overthrusts, 16. Miocene dip faults

The tropical karstic peneplain of late Cretaceous age of the mountains[8-10] became already tectonically dissected from the Eocene [11] thus, the delta gravel of late Oligocene and Early Miocene (Csatka Gravel Formation, [12] covered a dissected surface. Younger, Middle-Miocene limestones (Lajta Limestone Formation, Tinnye Limestone Formation) and Pliocene freshwater limestones developed mainly at the marginal parts of the mountains [13]. However, Pannonian clay can also be found in small expansion [14] then, loess was formed in a wide expansion too. On some horsts of Southern Bakony, the volcanic activity of Pliocene age [15] created basalt cover (horst with basalt cap).

Karstification took place in the mountains several times. Thus, in the Upper Triassic [16], in the Jurassic [17] and in the Cretaceous [18]. The products of paleokarstification are mainly infilled and buried dolines [19, 9, 20].

The karst water of the mountains (main karst water) mainly developed in the main dolomite. (It was named after the reservoir rock, it extends to the whole area of the Transdanubian Mountains and it is located at the base level of erosion of the mountains.) Based on the elevation data of mountain marginal springs, karst marshes and lakes, its elevation was about 117-220 m at the margin of the mountain preceding artificial karst water lowering in the 20th century. At the northern margin of Northern Bakony it was situated at an elevation of 140-180 m, while in the south-eastern part of the mountains it was located above 200 m [21-23]. In case of impermeable intercalation, a karst water storey developed and develops in carboniferous rocks. (The karst water storey is a locally developing system above the main karst water level.)

The Bakony Region is separated into blocks (horst, mount) and block groups with different elevations. Leél-Őssy [24] claims the Northern Bakony and Southern Bakony to be a tectonically dissected, karstic peneplain section group. As a result of their oscillation movements, the blocks may be of various evolution. Taking this fact into consideration, classifying the horsts (the horst groups) of the mountains, Pécsi [11, 25] distinguished horst in summit position (its present elevation is above 600 m, on its surface with Triassic and Jurassic carboniferous rocks, possibly in patches with loess and reworked cover), horst elevated to summit position (its present altitude is 400-550 m, with Cretaceous and Eocene limestones on its surface with widespread loess cover and reworked deposit, possibly with gravel cover in patches). The above-mentioned author distinguishes an exhumed and semi-exhumed variety of this type. He also differentiated cryptopeneplain (its elevation is below 300-400 m and its surface is covered by Tertiary sediment) and threshold surface (its elevation is below 300-400 m and its surface is mainly constituted by Triassic carboniferous rocks), which lost its gravel cover by pedimentation, if it has a cover, it is reworked (Fig. 3b). All basins of the mountains, except Hárskút basin and the southern part of Lókút basin (which are horsts in summit position) are cryptopeneplains. However, the denuded nature of superficial deposits on cryptopeneplains, except loess (which is widespread in their area) is of various degree. In Lókút basin it is of greater extent, while in the areas of Porva Basin and Csehbánya basin it is of smaller degree. It is also of small extent in the area of Dudar basin and it can only be found at its margin.

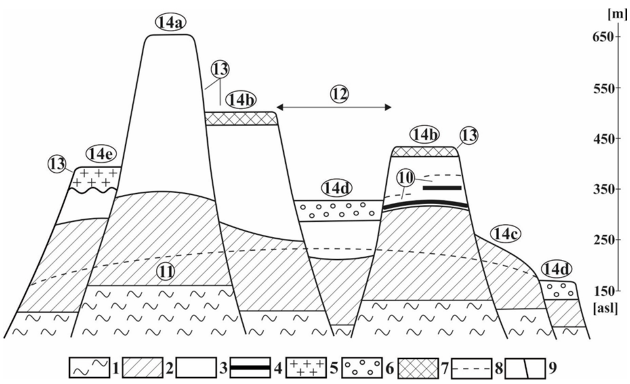

Fig. 3b: Block types from the mountains

Legend: 1. marl, 2. main dolomite, 3. Dachstein, Jurassic, Cretaceous, and Eocene limestones, 4. impermeable intercalation, clay, marly limestone, silica etc. 5. basalt, 6. gravel, 7. loess, 8. karst water table, 9. fault, 10. karst water storey, 11. main karst water, 12. basin, graben, 13. mount, 14a. horst in summit position, 14b. horst elevated to summit position, 14c. threshold surface, 14d. cryptopeneplain, 14e. block covered with basalt

(Fig a was prepared based on the data of BUDAI -KONRÁD 2011, and Fig. b was made using the data of CSÁSZÁR ET AL 1981 PÉCSI 1980.)

1.2 Karst Types and Their Features

Considering the coveredness of karst, various karst types can be distinguished [26-29]: thus, bare karst, soil-covered karst, covered karst and allogenic karst. Covered karst can be cryptokarst (the cover is impermeable), concealed karst (the cover is permeable) and buried karst (the cover is thick and impermeable). On bare karst or on soil-covered karst, solution dolines and collapse dolines are characteristic, on cryptokarst caprock dolines are specific, while subsidence dolines are typical karst features of concealed karst [30-31]. The features of allogenic karst are ponors [28, 32]. On buried karst no karstification takes place because of thick, non-karstic cover. Dropout dolines and suffosion dolines are varieties of subsidence dolines [33]. Subsidence dolines develop in the cover, a depression may also be present on the bedrock below them and there are always karstic passages (shaft) in the bedrock. Subsidence dolines may be syngenetic and postgenetic [34, 29]. In case of syngenetic dolines, the development of the passage of the bedrock (shaft) and the formation of the depression in the cover takes place simultaneously, while in case of postgenetic dolines, the passage of the bedrock (shaft) is older than the development of the depression of the cover (or at least than a part of it). Therefore, there are lenticular sediment structures in the cover below the postgenetic dolines [29], which developed during the infilling of the older depression.

According to literary data, there is a relation between the number and frequency of subsidence dolines and the thickness of the cover. In China, 60 % of the investigated subsidence dolines develops on a cover thinner than 5 m, and 85 % of them are formed on a cover with a thickness smaller than 10 m [35-36]. According to Beggs and Ruth [37], in Florida, most dolines developed on a cover with a thickness smaller than 20 m. However, dolines can rarely develop in case of an extreme cover thickness for example in Italy a subsidence doline was formed in case of a 200-m cover thickness [31]. Its development is attributed to the role of the water rising to the effect of geothermal heat [38]. Large cover thickness does not favour doline development because the infiltrating water is stored in the cover thus, it does not reach the bedrock in addition to this, the larger the thickness of the cover, the greater the chance that the lack of material of the bedrock can be balanced by porosity growth without passage development [29]. The critical cover thickness (in case of which a doline can still develop) may vary even on the same karst because of the changes of the characteristics of the cover (for example grain size). The depression of superficial deposit (DSD) is also one of its concealed karst features. DSDs are large-sized features as compared to their depth. Their diameter can be several 100 m, while their depth is only some metres, especially in the Bakony Mountains. Their development is due to the local denudation of the cover, but its material is not transported on the surface, but it gets into the karst through subsidence dolines and ponors [39, 29]. According to the morphology of the bedrock, depressions of superficial deposit may be the following [34, 29].

(1). Pseudodepression, when there is no closed depression on the bedrock.

(2). True depression, when there is a closed depression on the bedrock.

2. Methods

Various karst types were distinguished in the mountains by the classification of the non-karstic cover and with the consideration of different karst features. Concealed karstic terrains are those where the cover is permeable (mainly loess) and there are subsidence dolines. Cryptokarst is where the cover is consolidated, impermeable rock and on which there are caprock dolines, buried karst where the cover is impermeable, non-karstic, unconsolidated rock, and there are gorges at its margin. Allogenic karst is where ponors occur at impermeable terminations.

Seventy-five blocks of the Northern Bakony were put into evolution types taking Pécsi's [11] classification into consideration.

The occurrence and frequency of concealed karst areas on the blocks of the Northern Bakony belonging to different types were studied.

A karstmorphological mapping was performed. Based

DOI: https://doi.org/10.30564/jgr.v1i1.622

on maps at 1:10000 scales, and on field studies the occurrence of significant surface karst phenomenon groups, their types and the number of the karst features of different groups were determined.

Large-scaled karstmorphological maps (1:500) were prepared of some parts of Tési plateau, of Mester-Hajag and of Kab Mountain.

VES (vertical electronic sounding) measurements were made along profiles (by the employees of Terratest Ltd) altogether in 43 subsidence dolines and in 11 depressions of superficial deposits bearing them in their environs on Tési plateau, in the area of Hárskút basin, (Homód valley), in the area of Eleven-förtési doline groups, on Mester-Hajag, in the environs of Fehérkő valley, as well as in some depressions located between Devecser and Nyirád, in the environs of Egres Stream, in the area surrounded by Kígyós, Torna and Padragi streams (hereinafter the environs of Devecser). The constructed geoelectric-geological profiles provided data on the morphology of the bedrock, the thickness, the composition, and the structure of the cover. Considering the structure of the superficial deposit, subsidence dolines were classified: the doline is postgenetic if below it, there are lenticular beds in the cover or an infilled depression on the bedrock, while the doline is syngenetic if these characteristics are absent.

The relation between the width of 29 interfluves around Márvány Valley and the subsidence dolines occurring on the interfluves was investigated. The width of the interfuves was determined in two ways: on the one hand, the distance between the margins of the valleys surrounding the interfluves was measured (perpendicular to the strike of the interfluve), on the other hand the distance between the channels of the surrounding valleys was taken into consideration.

We determined the host rocks of the caves occurring in the valley sides of gorges.

Table 1. The occurrence of subsidence doline groups in the mountains

Place of occurrence	elevation (m)	number (piece)	morphological environment	type of the bearing block
Tési plateau	400-500	137	plain terrain, valley floor, depression of superficial deposit	horst elevated to summit position
Mester-Hajag	440-500	122	on terrains between mounds and in their depressions of superficial deposit	horst elevated to summit position
environs of Márvány Valley (northern part of Kőris block)	410-600	120	on interfluves, in valleys	horst elevated to summit position
area between Som block and Száraz-Gerence	400-500	76	on plain terrain, on valley floor	horst elevated to summit position
Hárskút basin	420-500	60	plain terrain, valley floor, valley side	horst elevated to summit position
Égett block	440-470	25	on terrains between mounds and in their depressions of superficial deposit	horst elevated to summit position
Kab Mountain	400-450	20[1]	on valley floor, in caprock doline, in ponor, on plain terrain	horst with basalt cap
area between Iharos block and Judit spring (Kertes-kő)	390-410	21	on plain terrain	horst elevated to summit position
Felső-Hajag	440-500	20[1]	on terrain between mounds	horst elevated to summit position
area between Cuha és Gézaháza-puszta	450-470	14	on plain terrain, in depression of superficial deposit	horst elevated to summit position
Szabadhegyi plateau	400-420	13	on plain terrain	horst in summit position
near Devecser	160-230	10[1]	on plain terrain	threshold surface
near Tapolca	120-180	10[1]	on plain terrain	threshold surface
between Kőris block and Parajos block (Eleven Förtési Doline group)	670-680	9	on plain terrain, on valley floor	horst in summit position
near Dudar (marginal part of Dudar basin)	350-400	7	plain terrain	marginal part of cryptopeneplain
Középső-Hajag	580-600	6	on plain terrain	horst in summit position
near Tündér-major (Kő Mountain)	350-400	5	on plain terrain	horst elevated to summit position or the margin of cryptopeneplain
near Szépalma-puszta (at the marginal part of Porvai basin)	400-450	4	on valley floor	horst elevated to summit position
at the margin of Fehérkő Valley	340-360	4	in depression of superficial deposit between mounds	horst elevated to summit position
near Lókút (Lókút basin)	400-450	3	on valley floor (?)	horst elevated to summit position
Ősbükkösi doline group	400-450	3	on valley floor	horst elevated to summit position
Sűrű Mountain	400-440	2	on plain terrain	horst elevated to summit position

Notice: *[1] : estimated*

 DOI: https://doi.org/10.30564/jgr.v1i1.622

3. Results

It can be stated that on blocks of various types, different karst types developed. However, several karst types can also be present on some blocks. On horsts in summit position and on threshold surfaces, mainly the soil-covered karst type occurs, but this type can also be found on the surface of horsts elevated to summit position. In the area of cryptopeneplains, buried karst is present. The areas with gravel cover of Dudar basin, the northern part of Lókút basin and Porvai basin belong to this karst type. Cryptokarst and allogenic karst can be found on blocks with basalt cover (mainly on Kab Mountain). The occurrence of concealed karst terrains are summarized in Table 1.

It can be stated that 68.18% of all concealed karst areas are situated on horsts elevated to summit position. The majority of subsidence dolines occurs in these areas. Considering the number of dolines too (including some areas where the number is estimated), 616 out of 691 is located on horsts of this type. On low threshold surfaces there are only two concealed karst areas, while on horsts in summit position, three can be found, and one area occurs on cryptopeneplain and on block with basalt cover. The above-mentioned occurrence of larger degree of concealed karst cannot be explained by the larger frequency of horsts elevated to summit position. In the area of the Northern Bakony, where 50 horsts out of 75 belong to this type, concealed karst occurs on 32% of these horsts. While concealed karst occurs on 9,1% of horsts in summit position, and on 12,5% of cryptopeneplains and threshold surfaces do not have concealed karst (Table 2). If we look the proportion of horsts elevated to summit position as compared to all horsts, this is 66,67%, while 21,33% of the horsts of these block types bear concealed karst areas. The proportion of horsts in summit position is 14,67%, while that of cryptopeneplains is 10,67% as compared to all blocks in the Northern Bakony. However, concealed karst occurs on 1,33% of the blocks belonging to this block type. Thus, on horsts elevated to summit position there is a greater chance for the development of concealed karst than on other block types.

Table 2. The distribution of the concealed karst of Northern Bakony according to block type

block type	number of blocks	concealed karst		block type compared to all blocks	
		number	%	its proportion (%)	proportion of concealed karst (%)
horst in summit position	11	1	9.1	14.67	1.33
horst elevated to summit position	50	16	32	66.67	21.33
cryptopeneplain	8	1	12.5	10.67	1.33
threshold surface	6	0	0	8	0

Notice: *total number of blocks is 75*

Hárskút basin and Porvai basin were put into the type of horst elevated to summit position

With the help of karstmorphological mapping the following things can be established:

On the concealed karst terrains of the mountains, depressions of superficial deposit with a large diameter as well as subsidence dolines occurring in them can be distinguished (Figs. 4, 5, 6a).

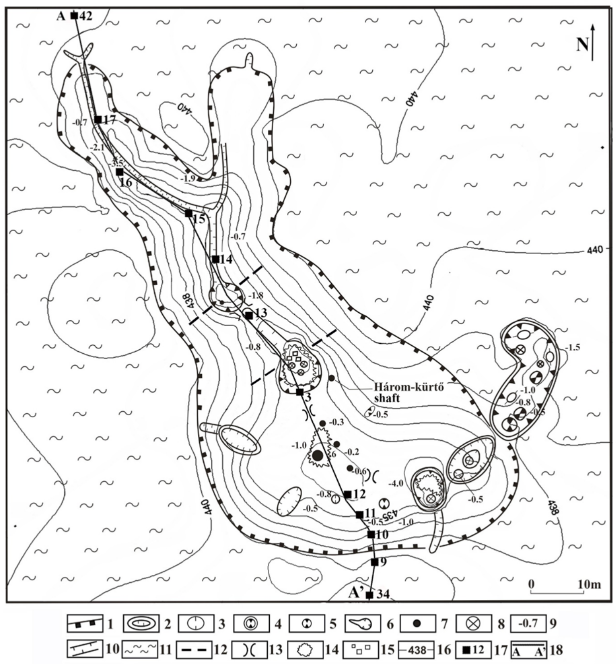

Fig. 4: The morphological map of the depression of superficial deposit (marked I-12) bearing Háromkürt**ő**-shaft (VERESS 2016 modified)

Legend: 1. margin of the depression of superficial deposit, 2. suffosion doline (diameter is larger than 2 m), 3. suffosion doline (diameter is smaller than 2 m), 4. dropout doline (diameter is larger than 2 m), 5. dropout doline (diameter smaller than 2 m), 6. ponor, 7. chimney, shaft, 8. passage in the cover, 9. depth of the feature, 10. gully, channel, 11. surrounding terrain, 12. rock boundary, 13. col, 14. outcrop, 15. rock debris, 16. contour line, 17. site of VES measurement, 18. line of VES measurement profile

DOI: https://doi.org/10.30564/jgr.v1i1.622

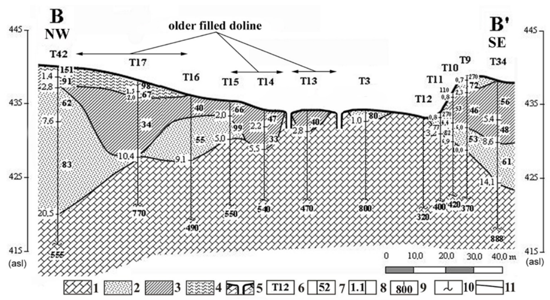

Fig. 5: The geoelectric-geological profile of the depression of superficial deposit presented in Fig. 4 along is longitudinal axis (VERESS 2016 modified)

Legend: 1. limestone, 2. loess (sandy or with limestone debris), 3, loess (clayey or silty) or clay with limestone debris, 4 (clayey) limestone debris, 5, chimney, shaft 6, code of VES measurement, 7, geoelectric resistivity of series (Ohmm), 8, base depth of geoelectric series (m), 9, geoelectric resistivity of bedrock (Ohmm), 10, approximate penetration depth of VES measurement, 11, boundary of geoelectric series

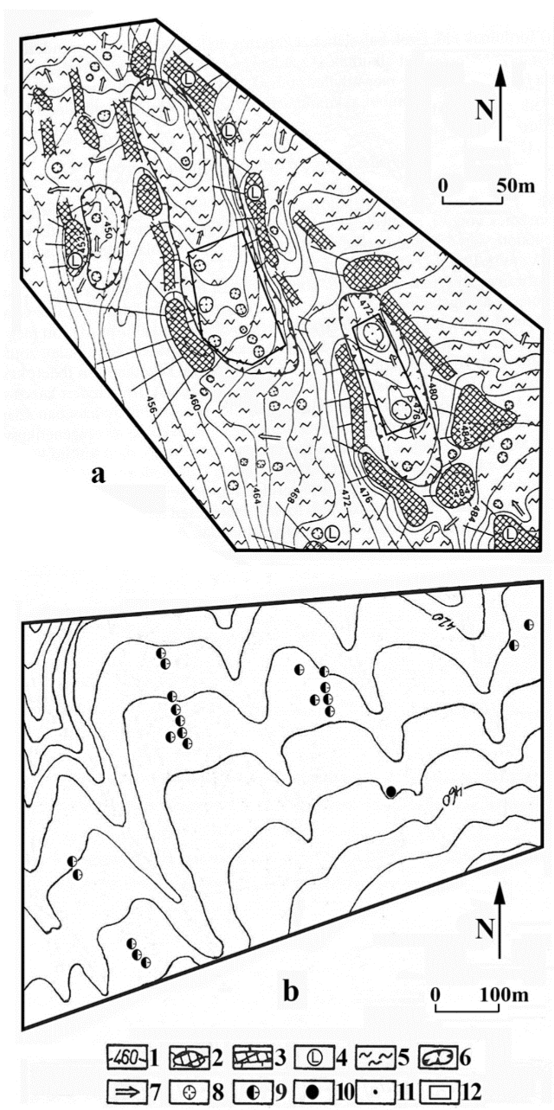

Fig. 6: Concealed karst: a. of a section between exhumed limestone mounds from Mester-Hajag, b. of a section from interfluves from the environs of Márvány valley

Legend: 1. contour line, 2. exhumed mound 3. semi-exhumed feature (it is ridge-like, but it does not constitute a mound), 4. limestone outcrop, 5. karstifying terrain with superficial deposit that developed by exhumation, 6. depression of superficial deposit, 7. material redeposition, 8. suffosion doline between mounds, 9. suffosion doline on interfluve, 10. suffosion doline on valley floor, 11. water drainage passage in a karstic depression, 12. area of VES measurements

On blocks built up of Middle-Cretaceous limestone (Zirc Limestone Formation) (Mester-Hajag, Égett block), exhumed limestone mounds are aligned in large density (Fig. 6a). These blocks are of small expansion and they are surrounded by valleys. Therefore the denudation of the cover was of large degree. The covered limestone mounds became and become partially exhumed, which is also favoured by the tilted position of the blocks. The inclination of the surface is larger than 9° on Mester-Hajag and larger than 2° on Égett block as a result of exhumation and tilting. No karstification takes place on exhumed mounds. (Karstification only occurred when the mounds were covered with superficial deposit which is proved by the here occurring truncated shafts.) If the density of mounds is large, the remnants of the cover cannot be transported from the terrains surrounding the already exhumed mounds into the valleys surrounding the blocks which results in the survival of patches of superficial deposit there. Therefore a concealed karstification takes place on terrains with cover (which is only of some metres thick) between the mounds. However, on blocks with a larger area (for example Tési Plateau), the denudation of the cover and thus, the exhumation of the mounds of the bedrock does not happen. The lack of surface denudation is indicated by the uniform expansion of loess and for example that the inclination of the surface is smaller than 1° in the environs of the depression (marked I-12) bearing Háromkürtő shaft. As a result of this, concealed karstification takes place on the plain surface above the thinly covered mound of the bedrock (Figs. 4. 5.).

Limestone patches (mounds) cropping out of the basalt cover (Kab Mountain) can be recognised, which are sites of local karstification. Here karstification is contributed by basalt barriers surrounding limestone patches and built up of basalt debris. Since these increase the areic nature of the terrains around these limestone patches (Fig. 7).

 DOI: https://doi.org/10.30564/jgr.v1i1.622

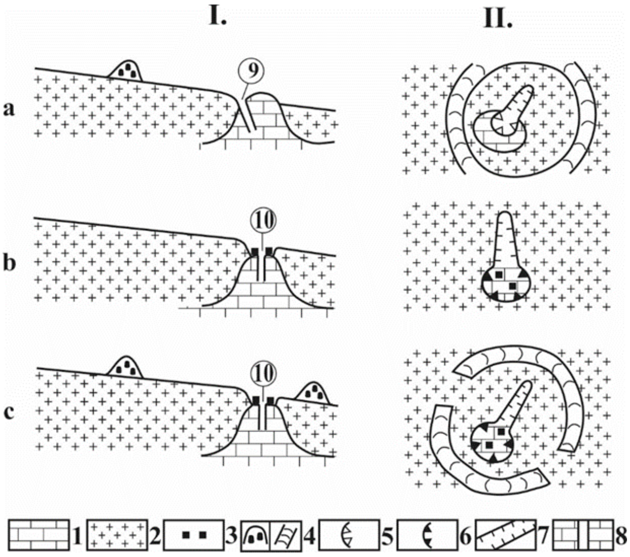

Fig. 7: Karst depressions at karst windows on Kab Mountain (Veress 2016, modified)

Legend: 1. limestone, 2. basalt, 3. basalt block that developed by collapse, 4. basalt barrier in plan view and in lateral view, 5. and 9. ponor, 6. and 10. caprock doline, 7. valley, 8. shaft, a. the ponor and its environs in lateral view and in plan view, b-c. caprock dolines and their environs in lateral view and in plan view

Based on the data of VES measurements and on the geoelectric-geological profiles made with their help, the following things can be established:

The cover bearing subsidence dolines may be loess, clayey-silty loess, clay, clayey limestone debris, clay with limestone debris and loess with sand or with limestone debris.

Out of the 43 studied subsidence dolines, 24 dolines are syngenetic and 19 dolines are postgenetic. According to bedrock morphology, 30 dolines developed above a covered, paleokarstic mound (11 were formed over the infilled, paleokarstic depression of the bedrock and 2 dolines are situated above a flat, slightly-inclined bedrock surface). A covered mound can be seen in Fig. 5. As regards syngenetic dolines, in case of 9 dolines the thickness of the cover is smaller than 3.5 m at their margin, in case of 11 dolines it is between 3.51 m and 6.0 m and in case of 4 dolines, it is larger than 6.01 m. They develop with a greater and greater chance on a thinner and thinner cover because the infiltrating water has a greater and greater chance to reach the bedrock and arriving there it still has a solution capacity in case of a thin cover. In case of postgenetic subsidence dolines, the cover thickness is more varied: in case of 2 doline it is smaller than 3.5 m, in case of 6 dolines, it is between 3.51 m and 6.0 m and in case of 11 dolines it is larger than 6.01 m. The reason for this is that postgenetic subsidence dolines can also develop if the cover is of larger thickness since the material of the cover can also be transported into the karst through the already existing shaft [34, 29]. All in all, it can be established that in harmony with literary data, there is a relation between cover thickness and the frequency of doline development. Syngenetic subsidence dolines (but partly postgenetic dolines too) have an increasingly greater chance to develop in case of a thinner and thinner cover.

According to the morphology of the bearing surface, out of the 43 studied dolines, 18 dolines can be found on a flat surface, 15 dolines on valley floor (some of them above a covered mound) and 10 dolines are located on terrains between exhumed mounds (for example Mester-Hajag). On these latter terrains the degree of denudation is similar to that of subsidence dolines of valley floor position since the average cover thickness is 3.85 m in case of syngentic dolines with a valley floor position, it is 3.95 m on terrains between the mounds, while in case of postgenetic dolines it is 6.18 m and 8.24 m. As a result of the thinning out of the cover, syngenetic subsidence dolines also develop above flat, slightly-inclined bedrock on Mester-Hajag (2 dolines).

● Hollows can also be detected on the bedrock under the depressions located in the environs of Devecser. This refers to the fact that under the cover the depressions of the bedrock are solution dolines which became partially infilled with reworked cover subsequently (Fig. 8).

  DOI: https://doi.org/10.30564/jgr.v1i1.622

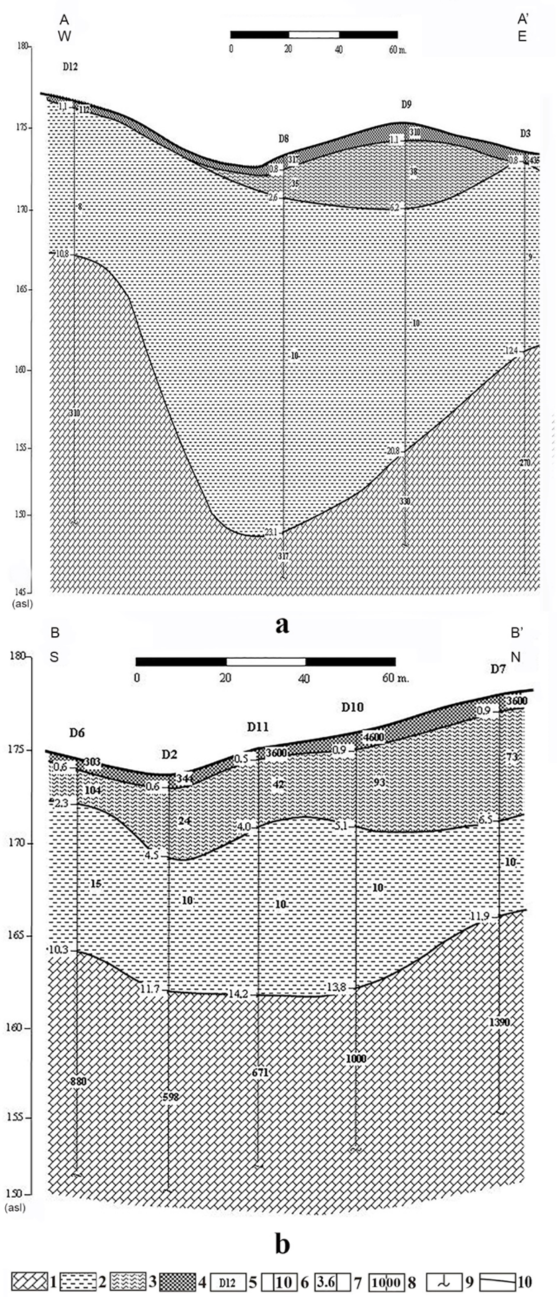

Fig. 8: The geoelectric-geological profiles A-A' and B-B' perpendicular to each other of a solution doline (Devecser); Source: colleagues of Terratest Ltd.

Legend: 1- limestone, 2- clay, 3- clay with limestone debris, 4- clayey limestone debris, 5- VES measurement site, 6- geoelectric resitivity of series (Ohmm), 7- base depth of geoelectric series (m), 8- geoelectric resistivity of bedrock (Ohmm), 9- approximate penetration of VES measurement, 10- boundary of geoelectric series

Forty-six subsidence dolines out of 120 occur on valley floor in the area surrounding Márvány Valley. The valleys are epigenetic, but their upper parts are filled with the sediment originating from the interfluves. The subsidence dolines that are situated on the valley floor occur on those upper parts of the valleys which are shorter than 200 m. Seventy-four subsidence dolines can be found on the interfluves. It can be stated that here the dolines occur on the upper part of the interfluves, on interfluve parts which are surrounded by filled upper valley sections (Fig. 6b). Thus, on those parts from where the superficial deposit accumulated into the valleys. There is a relation between the distance of the channels of the valleys surrounding the interfluves and the occurrence and frequency of subsidence dolines, as well as between the distance of valley margins and the occurrence and frequency of the dolines. There are no dolines on 9 out of 29 interfluves. Among these, the distance between the channels of the valleys is smaller than 300 m in case of three interfluves and larger than this value in case of 6 interfluves. However, the majority of subsidence dolines (n=66) occur on such interfluves where the distance between the surrounding valleys is 100-300m. If we take the distance between valley margins into consideration, 48 dolines occur on such interfluves where the distance between the valley margins is 0-200 m and only 18 dolines occur at places where this value is 200-300 m (Table 3).

Table 3. The relation between the width of interfluves and the distribution and frequency of subsidence dolines around Márvány Valley

width of interfluve (m)	**The number of subsidence dolines when the width of the interfluves is given by the distance of the channels of the valleys**	**The number of subsidence dolines when the width of the interfluve is given by the distance between the margin of the surrounding valleys**
0-100	-	10
100.1-200	33	39
200.1-300	34	19
300.1-400	1	-
400.1-500	-	6
500.1-600	-	-
600.1-700	6	-

The horizontal caves with various elevation of the gorges in the mountains developed above impermeable beds (Table 4). This is proved by the fact that their development took place at local water flow places of different elevation.

Table 4. The host rocks of some cave openings (Determination of rocks was performed in the Geological Institute of Hungary)

Cave	**Host rock**		**Sample site**	**Material of the sample**
	material	**age**		
Ö-12	limestone	Upper Eocene	entrance	marly limestone
Ö-15 (Ördöglik)	limestone	Upper Eocene	above entrance	marly limestone

 DOI: https://doi.org/10.30564/jgr.v1i1.622

Ö-15	limestone	Upper Eocene	entrance	marly limestone
Ö-15	limestone	Upper Eocene	above entrance	marly limestone, fossils
Ö-16	limestone	Upper Eocene	below entrance	sligthly marly limestone, foraminifera
Ö-20/b (Ördög-árki Róka lyuk)	limestone	Lutetian	at the northern part of the entrance	limonitic, marly limestone, with nummulites and sea urchin stings
M-2	limestone	Eocene	entrance	marl, marly limestone
caves marked M-5, M-6, M-7, M-8	limestone	Lutetian	beds below caves	slightly marly limestone with fossil
Törkő-likak	limestone	Jurassic	at and below the caves	silica intercalations with a thickness of 1-2 dm
Likas-kő of Hódos-ér	limestone	Middle Eocene	below entrance	abrasional breccа1

Notice: Cave names starting with '*Ö*' are in *Ö*rd*ö*g Valley of Dudar, while those beginning with M are in the cliff wall of Magos Mountain situated in the valley side of one of the tributary streams of Dudar stream

[1(]*Source:* Veress, (Futó 1987), T*ö*rkü-likak on K*özépső*-Hajag

4. Discussion

In the mountains, the following karst types can be found: soil-covered karst, concealed karst, cryptokarst and buried karst. In the soil-covered karst of karst areas in addition to solution dolines subsoil karren are also specific [30]. The soil-covered karst of the Bakony Region occurs on the following block types thus, on low threshold surfaces (1) and on horsts in summit position (2):

(1): On low threshold surfaces, where solution dolines occur. Here, the cover became denuded during the pedimentation of the block area. The development of dolines was favoured not only by this fact, but also by the low inclination of the surface in the area of threshold surfaces. Lippmann et al [40]. indicated the relation between low inclination and doline development in the Mecsek Mountains (Hungary) where the proportion of surfaces with dolines is the greatest on surfaces with an inclination of 2°-7°. According to Telbisz et al [41], 89% of dolines occur on surfaces with a dip smaller than 12° in the Miroč Mountains (Serbia). Soil-covered karst occurs near Devecser and Tapolca. The dolomite surfaces of the eastern part of the Veszprém-Devecser graben also belong to this variety. Here, the development of solution dolines was favoured by the fact that the surface is dissected by mounds since they hindered surface run-off partially or totally.

(2) Soil-covered karst occurs on horsts in summit position and in a smaller expansion horsts elevated to summit position. On the latter concealed karst is the most widespread as a result of the greater distribution of superficial deposit (see below). However, on horsts in summit position, solution dolines are absent, but subsoil karren (grikes, kamenitza) are widespread. This can be attributed to the fact that on the blocks of such types the roof level is either absent or if there is any, it is of small expansion and of relatively large inclination. Thus, for example in the area of Kőris Hill, apart fom the area of Eleven Förtési doline group (these are subsidence dolines) there is no surface with an inclination smaller than 8°. However, the lack of solution dolines may also have contributed by the fact that the denudation of the impermeable material of the Csatka Gravel Formation took place relatively late. This is proved by the fact that gravel patches still exists on horsts elevated to summit position.

The concealed karst of the Bakony Region primarily developed on horsts elevated to summit position (Tables 1, 2). However, they only developed on 32% of the blocks and not on all of them in the Northern Bakony. The fact that the occurrence of concealed karst is significant on blocks of this type is due to the presence of superficial deposit (mainly loess) and the suitable morphological environment. Concealed karst is less widespread on horsts in summit position (the permeable cover was denuded from their surface as a result of their elevated position) and on cryptopeneplains. On the latter where gravel was denuded from their more elevated sections, but loess survived. The concealed karst features of the mountains are mainly the suffosion dolines (Fig. 9A, C) and depressions of superficial deposit (Fig. 6a).

Fig. 9: Karstic depressions: suffosion doline (A), dropout doline (B), subsidence doline that developed by the collapse of ceiling of Csengő shaft (C), Macska-lik ponor (D)

Notice: A: from Hárskút basin, B-C: from Tész plateau, D. from Kab Mountain 1. depression section that developed before July 2010, 2. doline section that developed after July 2010, 3. wall of the feature with collapse origin, 4. vegetation fallen by collapse, 5. blocks of the cover with collapse origin

Concealed karst may develop on several karst areas of

DOI: https://doi.org/10.30564/jgr.v1i1.622

the Earth [30, 29]. It develops at places where the morphological environment ensures the (thin) thickness of the cover that is suitable for karstification. A thin cover can be formed in the area of depressions (valley, karst depression), and at the mounds of the bedrock. However, the morphological environment also contributes to the arheism of the surface and thus, indirectly to covered karstification.

Regarding morphological environment, concealed karst may develop on river terraces [42], in poljes [30], in glacier valleys [32, 29, 43], in river valleys [44, 29], in depressions of glacial origin [45, 43], and in the area of karst depressions of various types [46, 31, 29], on interfluves [47], on intermountain plains [31], abrasion platform [48]. In the Bakony Region, the concealed karst terrains develop in a specific way due to paleokarstic bedrock, blocky structure and epigenetic valleys. As a result of this, it is unique and shows a great diversity within short distances.

In the mountains concealed karst occurs in five morphological environments: on the floor of epigenetic valleys with superficial deposit or on the floor of valleys that deepened into superficial deposit (1), on plain surfaces above the covered mounds of the uneven bedrock (2), on the terrains between the exhumed mounds of the uneven bedrock (3) and at sites where the density of epigenetic valleys is large on the blocks (4), and in karstic depressions (5).

(1): On valley floors either the sediment cover is thin (in case of epigenetic valleys) or the cover was thinned out by channel erosion at gullies and creeks that deepen into superficial deposit. Tábla valley (Tési plateau) is an example for the former, while some tributary valleys of Márvány valley are instances for the latter.

(2): Above mounds, subsidence dolines can develop as a result of former (at the time of accumulation) local thin character of the cover and thus, without the denudation of the cover for example at the already mentioned Háromkürtő shaft (Figs. 4. 5). On Tési Plateau, the survival of the cover and thus, the development of covered karst features on the cover above buried mounds are favoured by the relatively large expansion of the plateau. (Its expansion is 8 km in NS direction and 16 km in EW direction.) As a result of this, the marginal valleys or their tributary valleys do not extend onto the area of the plateau and thus, loess does not become denuded.

(3): On bedrock terrains dissected by mounds the denudation of the cover may be of such degree that as it has already been mentioned the mounds become exhumed and the cover becomes so thin between them that subsidence dolines (suffosion dolines) and thus, concealed karst develop on the surviving cover patches (Fig. 6a). Such areas are Mester-Hajag and Égett Hill. The exposure of block surfaces is favoured by the small size of the blocks (for example the distance of the streams of the valleys surrounding Mester-Hajag is 1.3 km, while the width of its roof level, which coincides with the shortest distance between the valleys, is 300-500m.) and by the fact that the blocks are often surrounded by epigenetic valleys. As a result of the former, surface denudation (mainly if the inclination of the block is significant) also expands to the inner part of the block.) As a result of the latter, the elevation difference is large indepently of the elevation of the block. This and the streams of the valleys favour intensive material transport.

(4): Narrow interfluves also favour the development of concealed karst (the smaller the width of the interfluve, the more subsidence dolines occur there). The smaller is the width of interfluves, the larger the valley density or in case of the same valley density, the larger the valleys are. Smaller valley margin distances favour the denudation of the cover from the interfluves into the valleys and thus, the thinning out of the cover. Small channel distance favours the transport of the cover from the valleys and the permanence of the process. The small width of the interfluves ensures a thin cover and thus, a favourable condition to the development of concealed karst.

(5): In the area of karstic depressions, covered karstification may develop in the area of depressions of superficial deposit and that of infilled paleokarstic depressions. Although the formerly developed subsidence dolines play a role in the development of depressions of superficial deposit, if they are formed, newer and newer subsidence dolines may develop on their floor. In the mountains, depressions of superficial deposit with subsidence dolines on their floor often occur on Tési Plateau and on Middle Cretaceous limestone blocks (Mester-Hajag, Égett Hill and Felső Hajag). In the Bakony Region there are subsidence dolines which developed in the fill of paleokarstic depressions. Thus, according to the data of VES measurements [49], under one of the subsidence dolines of Tési Plateau in a filled karstic depression. The development of the former may have been caused by the activisation of the shaft of the filled depression. However, the Eleven-Förtés doline group may also be mentioned where the cover patch bearing the subsidence dolines is surrounded by limestone outcrops. This is only possible if there is a closed depression on the limestone surface below the cover patch bearing the doline group. Here, the development of subsidence dolines was contributed by the fact that surface streams were hindered by limestone outcrops.

Its cryptokarst can be associated basalt cover. Karstification occurs not only at the margin (allogenic karst) of terrains with basalt cover, but also inside them [50, 29]. Inside the basalt cover, at the mounds of the limestone bedrock where the limestone crops out, allogenic karst may also develop (Fig. 7a). Features of allogenic karst are ponors with blind valley (Fig. 9D). Inside the basalt cover, karstification also occurs at places (the karst features are caprock dolines) where the limestone does not crop out onto the surface (Figs. 7b, c), and also further from the limestone outcrop on the basalt. These are the cryptokarst patches of the basalt cover which develop at places where the bedrock constitutes a limestone mound since the basalt is locally thin at these places.

No karstification occurs in the area of (cryptopeneplain) terrains covered with Oligocene-Miocene gravel, but fluvial geomorphic activity exerts its effect (see below). Streams emerging from gravelly terrains inheriting to the limestone formed gorges which can be regarded as the karstic manifestations of these terrains in a broader sense.

Epigenetic valleys may also have permanent streams if their streams are fed by springs issuing from gravel or the streams tap karst water storey. The seeping water of the inherited valleys fed and feeds not only the main karst water, but also created karst water storeys. An active, current karst water storey is referred by karst springs situated over an altitude of 300 m inside the mountains. Non-active, former karst water storeys are represented by the horizontal caves of valley sides which are situated above impermeable intercalations (silica, marl) (Table 4). On the slopes of the gorges of the Bakony Region (mainly the epigenetic-antecedent valley sections) such caves occur. These caves developed in a phreatic environment (in karst water storey) (which is also proved by their spherical cavities) where the seeping water of epigenetic valleys contributed to the development of karst water storey. During valley development, the valley downcut the rock bearing the karst water storey and by thus, it opened up the phreatic cavities. The opened-up cavities became separated into sections by the collapse of their ceilings. The remnants were transformed into cliff corridors (cave parts that lost their ceilings). As a result of this, the walls of gorges are dissected by cave remnants and cliff corridors with a larger and smaller length.

A striking peculiar feature of Bakony karst is that in karstic valleys and valley sections no ponors and no connecting blind valleys develop either. Its possible causes may be the following:

(1): Drainage takes place in the total length of the sections with gorges.

(2): The floor of the gorge intensively deepens in an erosional way which hinders the development of a depression on the floor.

(3): The cavities under the valley floor are destroyed by erosion thus, no stabile, permanent drainage system can develop.

5. The Comparison of the Karst of the Bakony Region with Other karst Areas

The surface karst of the Bakony Region differs from the surface karst of other typical karst areas. (Such karsts occur in other parts of the Transdanubian Mountains.) While dolines and ponors are prevailing in typical karst areas, these features are absent in the Bakony Region or their occurrence is subordinate. However, covered karst is widespread in the mountains. Since surface karstification takes place in separate blocks with small expansion in the Bakony Mountains, the expansion of their karstic patches is significantly smaller than in karsts where surface karstification occurs in the whole area of the karst or on its plateaus.

Covered (concealed) karst is widespread in different types of karsts on the Earth. When comparing the covered karst of the Bakony Region with other karsts we focus on morphological environment, type of its features, the expansion of this karst type and the dominant cover thickness.

Concealed karst may occur in all karst areas where the superficial deposit survives long-lastingly, but not in a large thicknesss or it redevelops. The cover is reformed where there is a lot of weathering residue (mediterranean and tropical karst). However, the superficial deposit of the Bakony Region, the loess is young, its denudation does not take place at all because of its surface morphology or if it does, it happens only partially.

In the majority of karst areas, solution dolines and concealed karst features occur together alternating each other. In contrast, in the Bakony Region, concealed karst is specific apart from some lower, marginal karst areas. Regarding the morphological environment (mentioned in this study), not all environments are present in the Bakony Mountains. Concealed karst occurs on interfluves and on valley floors similarly to other karst areas. Concealed karst patches between exposing mounds are characteristic of the Bakony Region as a result of small block size and the dissected bedrock. Such morphological environment – to a larger extent – occur on fenglin karst where concealed karst may develop on intermountain plains. As compared to other karst areas, in the Bakony Region there are no concealed karst areas on the terraces and alluvial cones of the mountains, and their occurrence is only subordinate in karst depressions.

The expansion of concealed karst terrains of the Ba-

DOI: https://doi.org/10.30564/jgr.v1i1.622

kony Region rarely exceed 1-2 square kilometres (Tési Plateau), they mainly have an expansion of some hundred square metres. In contrast, in other karst areas (tropical karst, glacial karst or on Padis among temperate karst areas), the expansion of concealed karst may be larger than 1-2 square kilometres. However, in several karst areas (depressions of glaciokarst, poljes of mediterranean karst) the expansion of concealed karst is not larger than some hundred square metres too.

There is a difference in the types of concealed karst features. In the Bakony Region, suffosion dolines are predominant and there are only some dropout dolines. In contrast, dropout dolines are widespread (common) on glaciokarsts and on intermountain plains. Pseudo DSDs are also characteristic in the Bakony Region. Among DSDs, those are widespread in other karst areas which developed during the transport of former karstic fill (real DSD). However, these latter are rare in the Bakony Region.

Regarding the development site of subsidence dolines and the thickness of superficial deposit there, there is no difference between the Bakony Mountains and other karst areas. For example in China, subsidence dolines occur on a cover with a thickness smaller than 5 m and 10 m [35,36], while in the Bakony Mountains on a cover with a thickness smaller than 6 m [29]. The cause of the similarity is that the superficial deposit has an optimal size (an upper value) at which dolines (still) develop.

It is difficult to compare the size and frequency of dolines. The issue of size is hard because on concealed karst, dolines develop fast, as regards frequency because they are formed continuously and determining the limit of concealed karst terrains is subjective. However, if we make a comparison it can be stated with a great probability that in the Bakony Region smaller sized dolines are dominant and their density is smaller than in other karst areas.

6. Conclusions

It can be stated that the surface karst of the Bakony Region is diversified, but the karstic terrains are of small expansion, they are situated far from each other and the karst features are small-sized too. Its karstification is island-like and predominantly it is in an initial phase, but the start of the karstification of some blocks is different because the cover thins out in various degree and in different time and bedrock is exposed to a various extent and at a different pace. The karstification of its blocks (block groups) is often unique and differs from the karstification of the surrounding blocks. Its recent karstification was determined by the blocky structure, the oscillation of the blocks, the covered bedrock dissected by depressions and mounds, the distribution of the dolomite, the presence and young (ongoing at present too) denudation of the superficial deposits.

Soil-covered karst occurs on threshold surfaces and on horsts in summit position (on the blocks of the latter type solution dolines are absent because of the small expansion of surfaces with small inclination). Concealed karst with subsidence dolines is specific of horsts elevated to summit position where the cover is thin enough as a result of its denudation or the mound of the bedrock. Cryptokarst can be found on blocks with basalt cover. On blocks with basalt cover, allogenic karst developed with ponors, while at limestone mounds inside the basalt cover, allogenic karst or cryptokarst with caprock dolines developed. At the margin of the gravel cover of cryptopeneplains gorges (cave openings) developed.

References

[1] Stegena L, Géczy B, Horváth F (1975). Late Cenozoic evolution of the Pannonian Basin. Tectonophysics, 26: 71-90.

[2] Budai T, Konrád Gy (2011). Magyarország földtana (Geology of Hungary). Pécsi Tudományegyetem, Pécs (in Hungarian).

[3] Haas J (1993). A Budaörsi Dolomit Formáció, Fődolomit Formáció, Kösseni Formáció (Budaörs Dolomite Formation, Main Dolomite Formation, Kössen Formation) – In: Haas J. (szerk): Magyarország litosztratigráfiai alapegységei. Triász, Földtani Intézet kiadványa, Budapest (in Hungarian).

[4] Budai T, Császár G, Csillag G, Budka A, Koloszár L, Majoros GY (1999). A Balaton-felvidék földtana, Magyarázó a Balaton-felvidék földtani térképéhez, 1:50000 (The geology of Balaton Highlands, An interpretation to the geological map of Balaton Highlands, 1:50000). Magyar Állami Földtani Intézet, Budapest (in Hungarian).

[5] Gyalog L (2005). Magyarázó Magyarország fedett földtani térképéhez (az egységek rövid leírása) 1:100000 (An interpretation to the covered geological map of Hungary, a short description of the units). Magyar Állami Földtani Intézet Budapest (in Hungary).

[6] Láng S (1962). A Bakony geomorfológiai vázlata (A geomorphological outline of the Bakony Mountains). Karszt és Barlangkut. Táj. 7: 86-91. (in Hungarian).

[7] Bence G, Bernhardt B, Bihari D, Bálint Cs, Császár G, Gyalog L, Haas J, Horváth I, Jámbor Á, Kaiser M, Kéri J, Kókay J, Konda J, Lelkesné Felvári Gy, Majoros Gy, Peregi Zs, Raincsák Gy, Solti G, Tóth Á, Tóth Gy (1990). A Bakony hegység földtani képződményei

(Geology of Bakony Mountains, Hungary). Magyar Állami Földtani Intézet, Budapest 119.

[8] Szabó PZ (1956). Magyarországi karsztformák klímatörténeti vonatkozásai (Relations between climate and karst formation in Hungary). Dunántúli Tud. Gyűjtemény: 183-189. (in Hungarian).

[9] Szabó PZ (1968). A magyarországi karsztosodás fejlődéstörténeti vázlata (The History of the Development of Hungarian Karstification). Dunántúli Tud. Gyűjtemény: 13-25. (in Hungarian).

[10] Bulla B (1968). A magyar föld domborzata fejlődésének ritmusai, az újharmadkor óta a korszerű geomorfológiai szemlélet megvilágításában (The phases of the Terrain Development of Hungary since the Lower Tertiary in perspective of the modern geomorphological view). Válogatott természeti földrajzi tanulmányok, Akadémia Kiadó, Budapest (in Hungarian).

[11] Pécsi M (1980). A Pannóniai-medence morfogenetikája (The Morphogenesis of the Pannonian basin). Földrajzi Értesítő 29: 105-127. (in Hungarian).

[12] Korpás L (1981). A Dunántúli-középhegység oligocén-alsó-miocén képződményei (Oligocene-Lower Miocene Formations of the Transdanubian Central Mountains in Hungary). MÁFI Évkönyve, Budapest (in Hungarian).

[13] Császár G, Csereklei E, Gyalog L (1981). A Bakony-hegység földtani térképe (Geological map of the Bakony Mountains) (szerk.). Magyar Állami Földtani Intézet, Budapest (in Hungarian).

[14] Jaskó J (1961). A balatonfelvidéki és észak-bakonyi patakok vízhozamának kapcsolata a földtani felépítéssel (The relation of discharge of the streams of Balaton Highlands and Northern Bakony with geological structure). Hidrológiai Közlöny, 41.(1): 75-84. (in Hungarian).

[15] Lóczy L (1913). A Balaton környékének geológiai képződményei és ezeknek vidékek szerinti telepedése (The geological features of the surroundings of Lake Balaton and their regional distribution). A Balaton tudományos tanulmányozásának eredményei, I. K. Budapest (in Hungarian).

[16] Raincsák E (1980). A Várpalota – Iszkaszentgyörgy közötti triász vonulat szerkezete és felépítése (The Structure of the Triassic Ridge between Várpalota and Iskaszentgyörgy). Földtani Intézet Évi Jelentése 1978-ról: 187-196. Budapest (in Hungarian).

[17] Konda J (1970). A Bakony hegységi Jura időszaki képződmények üledékföldtani vizsgálata (Lithologishe und Fazies-Untersuchung der Jura – Ablagerungen des Bakony-Gebirges). Ann. Inst. Geol. Publ. Hung., 50 (2):161-260. (in Hungarian).

[18] Noszky J (1964). A Bakony-hegység északi részének földtani vizsgálata (A Geological Investigation of the northern part of the Bakony Mountains). Földtani Intézet Évi Jelentése 1961-ről, Budapest, 1:203-206. (in Hungarian).

[19] Pataki A (1983). Karsztmorfológiai megfigyelések a nyirádi és az iharkúti bauxit-előfordulás területén (Karstmorphological observations in the Bauxite occurrence area of Nyirád and Iharkút). MÁFI Évi Jelentés az 1983. évről: 121-133. (in Hungarian).

[20] Bárdossy Gy, Pataki A, Nándori Gy, (1983). Bányaföldtani térképsorozat módszertani kidolgozása és gyakorlati alkalmazása az iharkúti külfejtéses bauxitbányászatban (Methodological elaboration and practical application of a minegeological map series in the open cut bauxite mining of Iharkút). Földtani Kutatás 26: 3-10. (in Hungarian).

[21] Papp F (1942). Dunántúl karsztvizei és a feltárás lehetősége Budapesten (The karst waters of Transdanubia and the opportunity of exploration). Hidrológiai Közlöny 21: (7-12) 146-196. (in Hungarian).

[22] Szádeczky-Kardoss E (1941). A Dunántúli középhegység karsztvízének néhány problémájáról (On some problems of the karst water of the Transdanubian Mountains) Hidrológiai Közlöny 21 (7-12): 67-92. (in Hungarian).

[23] Szádeczky-Kardoss E (1948). A Dunántúli-középhegység karsztvíz térképe (The map of karstwater in the Transdanubian Mountains). Hidrológiai Közlöny 28 (1-4): 2-3. (in Hungarian).

[24] Leél-Őssy S (1960). Magyarország karsztvidékei (Karst regions of Hungary). Földrajzi Értesítő 9 (1-4): 480-494. (in Hungarian).

[25] Pécsi M (1991). Geomorfológia és domborzatminősítés (Geomorphology and relief classification). Földrajz Tudományi Kutató Intézet, Budapest (in Hungarian).

[26] Gvozdetskij NA (1965). Types of Karst in the U.S.S.R. Separatum, Prob. Speleol. Res. (Prague) 47-54.

[27] Hevesi A (1986). Hideg vizek létrehozta karsztok osztályozása (Classification of cold water karsts). Földr. Ért. XXXV (3-4): 231-254. (in Hungarian).

[28] Jakucs L (1977). Morphogenesis of karst regions. Adam Hilgar, Bristol.

[29] Veress M (2016). Covered karsts. Springer DOI10.1007/978-94-017-7518-2.

[30] Sweeting MM (1973). Karst Landforms. Columbia University Press, New York.

[31] Waltham T, Bell F, Culshaw M (2005). Sinkholes and Subsidence. Springer, Berlin – Heidelberg.

[32] Ford DC, Williams PW (2007). Karst Hydrogeology and Geomorphology. John Wiley & Sons, Chichester.

  DOI: https://doi.org/10.30564/jgr.v1i1.622

[33] Williams PW (2004). Dolines. – In: Gunn J (ed.), Encyclopedia of Caves and Karst Science, Fitzroy Dearborn, New York, London, 304–310.

[34] Veress M (2009). Investigation of covered karst form development using geophysical measurements. Zeits. f. Geomorph. 53 (4): 469-486.

[35] Yuan D (1987). Environmental and engineering problems of karst geology in China – In: Beck BF, Wilson WL (eds.) Karst Hydrogeology: Engineering and Environmental Applications, Balkema: Rotterdam 1-11.

[36] Chen J (1988). Karst collapses in cities and mining areas, China. Environmental Geology Water Science, 12:29-35.

[37] Beggs TF, Ruth BE (1984). Factors affecting the collapse of cavities. – In: Beck BF (ed.) Sinkholes: Their Geology, Engineering and Environmental Impact, Balkema: Rotterda.

[38] Beck F (2000). Report on Italian sinkhole conference. KWI Conduit, 8(1) www.karstwaters. org.m, pp. 183-188.

[39] Veress M (2000). Covered karst evolution Northern Bakony mountains, W-Hungary. A Bakony Természettud. Kut. Eredményei 23, Bakonyi Természettudományi Múzeum, Zirc.

[40] Lippmann L, Kiss K, Móga J (2008). Az Abaliget-Orfűi karszt karsztos felszínformáinak vizsgálata térinformatikai módszerekkel (GIS investigation of the karst landforms in the Abaliget-Orfű karst). Karsztfejlődés XIII: 151-166. (in Hungarian).

[41] Telbisz T, Mari L, Kohán B, Jelena C (2007). A szerbiai Miroč-hegység töbreinek térinformatikai GPS-es terepi vizsgálata (A spatial informatics GPS study of the dolines of the Serbian Miroč Mountains). Karsztfejlődés XII:71-90. (in Hungarian).

[42] Soriano MA, Simón JL (2001) Subsidence rates of alluvial dolines in the central Ebro basin, Northeastern Spain. In: Beck BF, Herring JG (eds) Geotechnical and environmental applications of karst geology and hydrology. Balkema, Lisse, pp 47–52.

[43] Veress M, Telbisz T, Tóth G, Lóczy D, A Ruban D, M Gutak, J (2019). Glaciokarsts. Springer, Cham, Switzerland, doi.org/10.1007/978-3-319-97292-3.

[44] Zhang Z (1980). Karst types in China. GeoJournal 4(6):541–570.

[45] Djurović P, Petrović AS, Simić S (2010). The overall impact of pleistocene glaciation on morphological diversity of uvalas at Durmitor and Žijovo. Serb Geogr Soc 90:17–34. https://doi.org/10.2298/GSGD1001017D.

[46] Waltham AC, Fookes PG (2003). Engineering classifi cation of karst ground conditions. Q J Eng G Hydrogeol 36:101–118.

[47] Korzhuev SS (1961). Merzlotnyi karst Srednego Prilen'ya i nekotorye osobennosti yego proyavleniya (The Middle-Lena frozen karst and its characteristics). In: Sokolov NI, Gvozdetskiy NA, Balashov LS (eds) Regionalnoe karstovedenie. Izdatelstvo AN SSSR, Moscow, pp 207–220.

[48] Lovász G (1971) Adatok az Abaligeti-karszt geomorfológiai és hidrológiai jellemzéséhez (Data for the description of the Abaligetien Karst). Földrajzi Értesítő XX(3):283–296 (in Hungarian).

[49] Veress M (2006). Adatok a Tési-fennsík két térszínrészletének fedett karsztosodásához (Survey/data on covered karstification of two surface parts of the Tési plateau). Karsztfejlődés XI:171–184 (in Hungarian).

[50] Móga J, Németh R, (2005). The morphological research of the basalt and loess covered plateaus in the Bakony Mts. (Transdanubian middle mts.-Hungary). Acta carsologica 34. (2): 397-414.