STUDY OF CAVERN TERRACES ON THE AGGTELEK KARST

G. MEZŐSI

This paper summarizes the results of the literature and our own examinations into an area of karst morphology on which barely any research has been made: cavern terraces and their alluvia. The cavern researches are connected with surface observations and measurements. Our investigations were carried out mainly in the Béke and Baradla caves of the Aggtelek karst, these being typical stream-erosion (allogenic) caves.

Attention has already been drawn to the usefulness of research of such a nature by CHOLNOKY (1935), BALÁZS (1962) and L. JAKUCS (1964, 1971), since the resulting new evidence facilitates an understanding not only of the given cave, but of the history of the development of the area involved; this may also promote the solution of general karst-genetic questions. The present paper contains the results of the relevant grain-composition, mineralogical, morphological, pollen, etc. studies, and a critical analysis of the views relating to these. As a consequence of the degree of complexity demanded by the studies, the detailed comparative data in part require further supplementation. Thus, it was unavoidable that certain questions (see pollen-analytical comparison) should remain open. By the analysis of a satisfactory number of samples, however, in the future we should like to evaluate the outstanding evidence too.

Let us first consider the main results that have been obtained to date in research into cavern terraces, and into the formation of caverns with more than one level, these two phenomena exhibiting a close genetic parallel. The correlation of caves and erosion river-terraces has long been known. To the best of our knowledge, this question was first dealt with by FALK in 1824 on the example of the Kungur cave, while CVIJIC (1909) also made a detailed examination of the development of multi-level caves.

CHOLNOKY (1917) was the first to arrange the formation of multilevel caves into a genetic system, but in accordance with the age (one and two ice-age theories) he could distinguish at most two levels. In spite of this, what he writes about transformation as a result of the subsidence of the baselevel of erosion of caves, and about the changes in the water catchment areas of caves, is very noteworthy, being the first exacting scientific work in Hungarian in this respect. In a later paper (1932) he examines the connection of terraced river-valleys and caves, with a result leading in the right direction, but with contradictions arising from his earlier views. Ha considers cavern terraces to have a dynamic corrosion origin (1935). In contrast, BOKOR (1925), who conducted detailed measurements and a morphological analysis of the

Abaliget cave, explains the formation of cavern terraces by erosion due to stream meandering.

KEREKES (1936) describes a terrace of corrosion origin from the Görömböly-tapolca Tavas cave. The levels of the cave are paralleled by the valley-bottom levels of the Hejő stream. BALÁZS (1962) also describes a number of terraces from the Szabadság cave, and explains theirformation by means of erosion and corrosion. In a later paper (1974) he deals with the formation of cavern meanders, and considers the cavern terraces to be produced by the meandering stream. In the cave-complex of the Damänova valley, DROPPA (1964) distinguished eight levels and drew a parallel between these and the Wurmian-Riss terraces of the Demänova stream and the Mindelian—Pliocene terraces of the Vág river. This is an excellent example that parallelism and correlation is one of the most exact geomorphological methods for the determination of the age of caves.

JASKÓ (1935) describes Pleistocene terrace formations from the environment of the Jósvafő entrance to the Baradla cave. He considers the sand and gravel sediments deposited in layers here to originate from the Baradla. The level of the gravel bed at 255 m (this can now be found only incertain patches) coincides exactly with the bottom-depth of the main branch of the Baradla. A Pleistocene terrace at an average depth of 250 m can be very readily followed in the Jósva valley. Gravel is not found on this, however; its surface is covered with brown clay.

LÁNG (1955) described two terraces from the valley of the Jósva; these are Middle and New Pleistocene terraces with average depths of 280 m and 250 m, respectively. In his view the karst water level was in the vicinity of the surface up to the Pleistocene, and only after this did the area become a high karst, the gravel layer covering it being worn away.

KESSLER (1938) distinguishes three levels in the Baradla; the Upper branch, the Main branch (with two terraces here) and the Lower cave; however, his genetic presentation of the cavern terraces and terrace indicators is at times incorrect or deficient. JAKUCS (1953) describes alluvium in the terrace troughs as the residue of the one-time gravel bed, cemented into a conglomeration. Ha goes beyond the attitude of DAVIS (1930), and is the first to interpret and define stream piracy by underground streambeds (bathycapture), and to point out the general importance of the process (1956/1). He recognizes that the passage-widths of the erosion caves are directly proportional to the extents of the non-karstic water catchment areas. He demonstrates (1956/2) that the cavern passage-widht is connected with the throughput of the floodwaters forming it.

According to MAKSIMOVICH (1957), the horizontal caves are best formed when the vertical water-turnover of the Earth's crust falls back or is absent (for example, in the case of a covered karst). The streaming karst waters give rise to horizontal passages (fitting perpendicularly onto the river) at a depth of 20—25 m below the bed of the river, in the zone of syphon circulation. He attributes great importance to the presence of these passage from the aspect of parallelism. As he expressed in detail later (1963), he conceives that the multilevel caves are formed in seven development stages. SZENTES (1965) carried out detailed comparative tectonic and petrographic investigations in the Béke and Baradla caves, but his conclusions relating to the genetic roles of these factors are a little exaggerated. In his book on karsts, which is of great scientific value, JAKUCS (1971) gives a detailed analysis of the development of multilevel caves. He presents a new genetic explanation for the formation of cavern terraces.

MIOTKE and PALMER (1972) deal with questions of parallelism regarding the passages of the Crystal cave and the terraces of the Green river in Kentucky (U. S. A.). They consider that the passage width is connected with changes in the karst water level, and that it is necessary ot examine, therefore, the possibility of whether the development of the larger passages coincides with the hypothetical fluviatile stages of the Pleistocene, when more "*karst water*" was definitely available in the interior of the limestone formations too.

From the above considerations, the overall conclusion emerges that a unified standpoint has not developed yet as regards many questions of detail in the interpretation of cavern terraces.

I. Debated questions of cavern terraces

Essentially three standpoints may be distinguished in the debate on the development of cavern terraces. The first considers these formations to be produced by meandering streams (meander terraces) (BOKOR, BALÁZS, CHOLNOKY, etc.). The second view, which is rarer, is that the development of cavern terraces is explained by differences in water throughput due to climatic modifications (MAKSIMOVICH, KESSLER). The third viewpoint (JAKUCS) makes the following distinction: (1) the morphologically well-distinguishable flood-discharge terraces (symmetrical terraces), the formation of which is explained by changes in swallow-hole capacity, or in floodwater throughput for other reasons; (2) the meander terraces formed in periods of uniform maximum throughput (Fig. 1). In the case of the flood-discharge

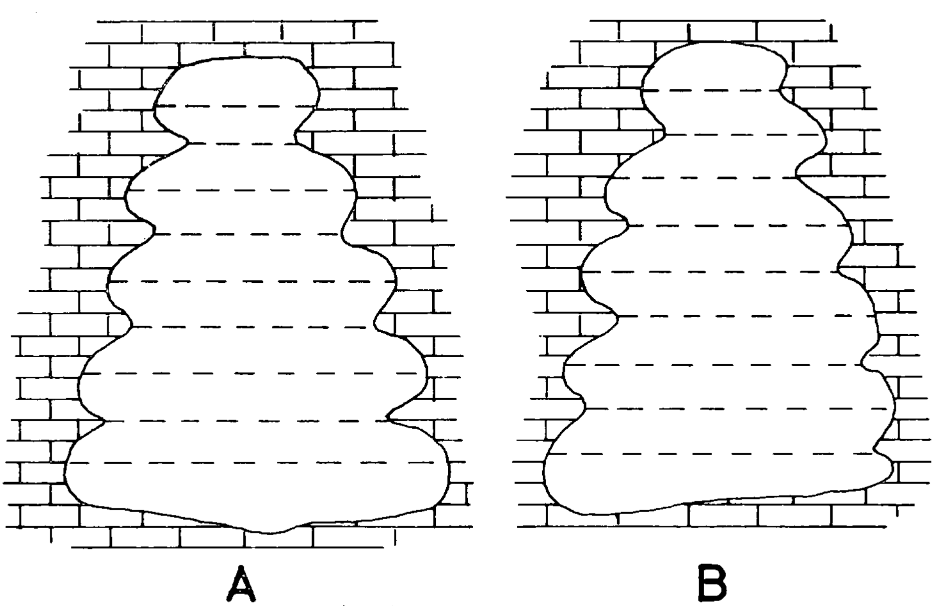

Fig. 1. Interpretation of A = flood-discharge terraces, and B = meander terraces, according to JAKUCS (1971.)

terraces there may be great differences in the widths of the passage sections formed, in contrast with the meander terraces, which have by and large unchanging widths throughout the entire scour.

In the course of our investigations, answers were sought of the following problems:

(1) What are the geneses of the terraces of the Béke cave? (2) Is there a flood-discharge terrace which also reflects a climatic change? If there is then from what age does it date? (3) What connection can be established between the cavern terraces and the related terraces of the surface swallow-hole valleys?

It is obvious, of course, that not only these selected genetic factors played a role in the development of the terrace formations, but that the forms are most frequently polygenetic. Accordingly, if a flood-discharge terrace is stated below to have a climatic origin, for instance, then this merely means that the climatic cause is regarded as the most important of the numerous factors.

II. Investigation of the underground formations

1. *Study of the grains of the alluvium of the terraces*

In order to decide whether the vertically separated, but morphologically similar terraces can be distinguished on the basis of their material, a detailed study was first made of the grains in the cavern stream alluvium. Based on preliminary morphological examinations in the central section of the Béke cave, three levels were distinguished, at 0, 150 and 250 cm. The vertical distances between these cavern levels decrease on proceeding from the swallow-hole section towards the spring. The relitive depths of the given terraces from the bed-bottom were 0, 170 and 290 cm at the first sampling site, and 0, 120 and 200 cm at the tenth sampling site. At all three levels samples were collected from ten sites in the cave (Fig 2).

From a study of the gravels at the individual levels, it turned out that, on average, those at any one level do not exhibit an essential difference in the extent of roll (examinations in a horizontal direction). This is not coincidence, for the short cavern route of only a few km is not able to alter the value of the extent of roll substantially. When the materials from gravel layers lying one above the other are examined with regard to the extent of roll, again no essential difference is observed. This means, among others, that the non-karstic water catchment area of the cave did not undergo any appreciable changes at the time of formation of the cave.

The calculations were performed with the SZÁDECZKY cpv method, on gravels 11—25 mm in diameter. Some characteristic data are presented in Table 1.

TABLE 1

Results of examinations on extent of roll

	2	4	6
I	5,6	5,3	5,5
II	5,7	5,8	5,4
III	6,0	5,5	5,8

2, 4 and 6: sampling sites.
I: soil level; II: 150 cm level; III: 250 cm level.

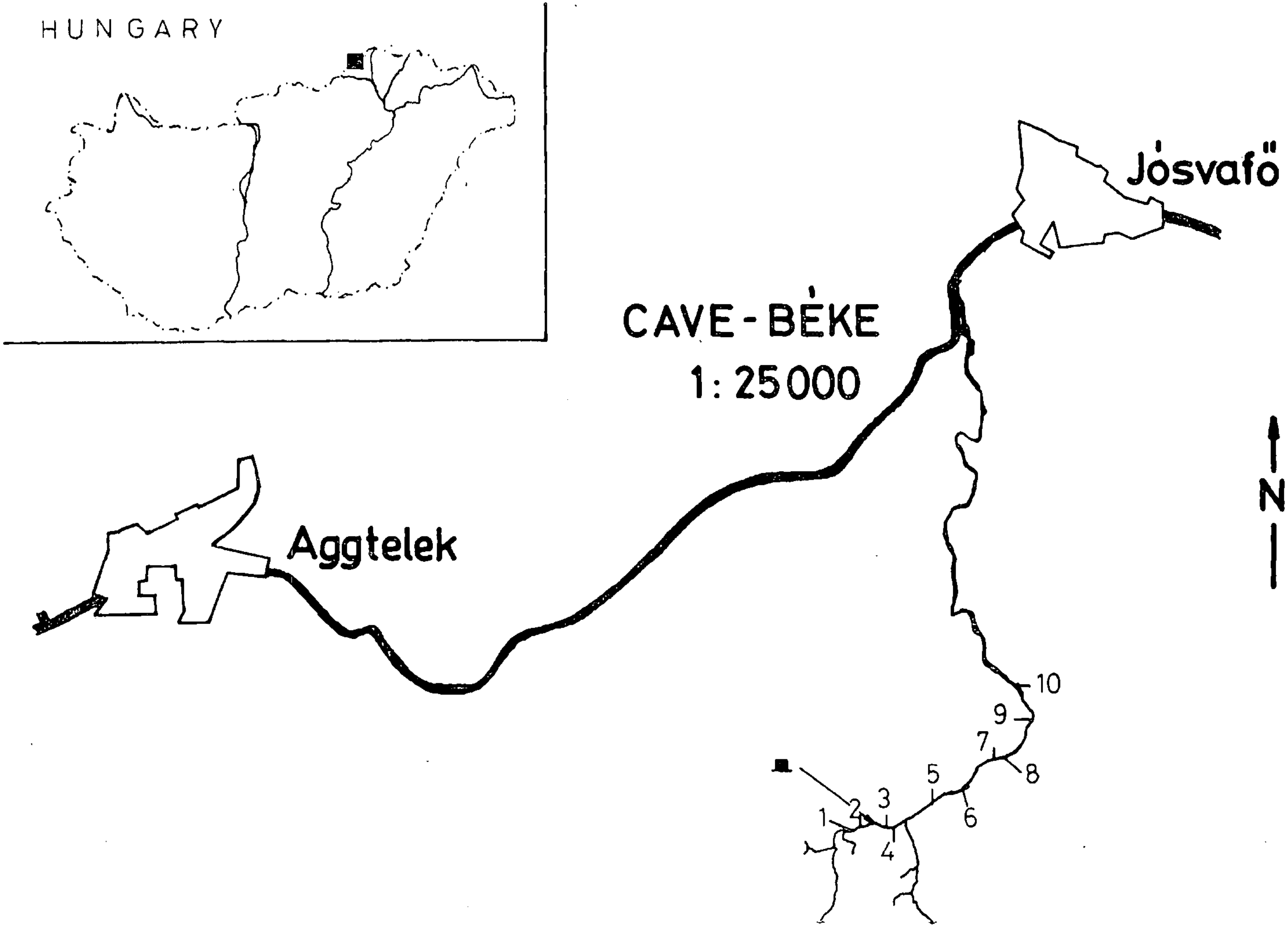

Fig. 2. Horizontal map of the Béke cave. Sampling sites 1—10.

In the subsequent stage of the research the samples were examined with regard to their grain compositions, with a view to distinguishing terraces situated one above the other. The results show that the grain-composition curves for alluvia at any one level exhibit a fairly large scatter (Fig. 3). This is caused by the different one-time and present gradient conditions, the possibility of tufa barriers, the mixing effect of high floods, and other local factors.

The different terrace levels are well distinguished at the individual examination points (Fig. 4 and 5). From the data, the average curve was constructed for every level, and these were plotted in one system (Fig. 6).

Since the curves are predominantly similar in shape, a difference existing only at lower grain diameters, instead of an individual analysis it is sufficient to consider the average curve. It can be seen in Fig. 6 that, on proceeding upwards in level, the grain composition is shifted towards a component proportion with higher grain diameter. The alluvium at the soil level is little-graded gravelly shingle. At the second and third levels, however, a better-graded gravel is to be found.

It emerges from all this that on the accumulation of the alluvium of the upper, third layer the cavern stream had a higher working capacity. This is an important fact, for if the accumulation was syngenetic with the development of the flood-discharge terraces, and with the deepening of the bed, then a higher degree of surface

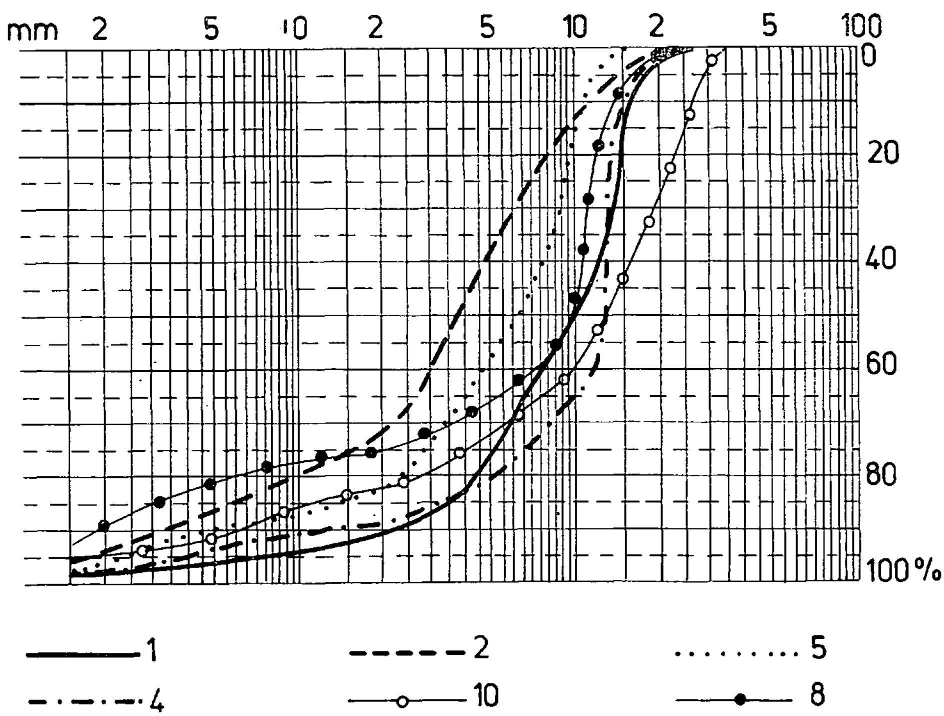

Fig. 3. Six characteristic grain-composition curves from second level 150 cm. 1, 2, ... =sampling sites.

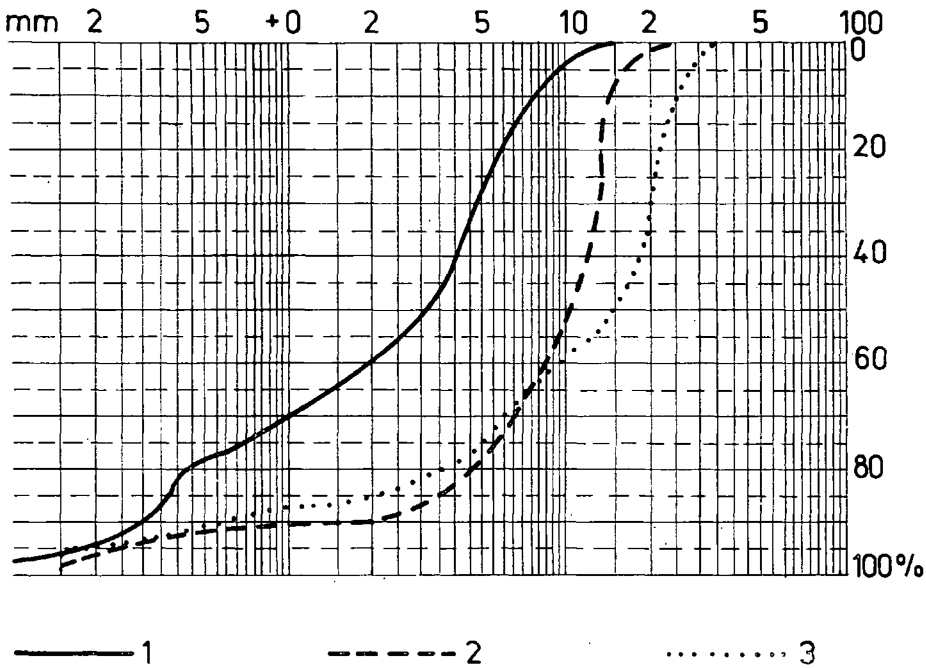

Fig. 4. Grain-composition curves from sampling site 2.
1 = soil level; 2 = 150 cm level; 3 = 250 cm level.

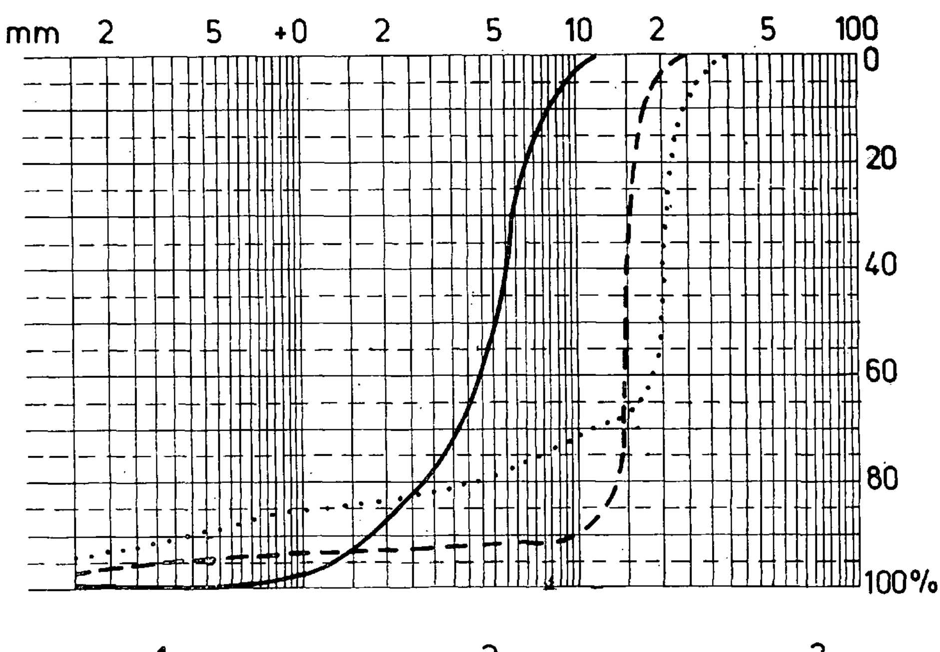

Fig. 5. Grain-composition curves from sampling site 6.
1 = soil level; 2 = 150 cm level; 3 = 250 cm level.

erosion too may be concluded from it. If, on the other hand, the accumulation occurred later, then it is not possible to draw such a conclusion.

When this question was examined, it was found that the coarse gravels of the third layer were situated mainly on meander terraces at a similar depth, in the layering

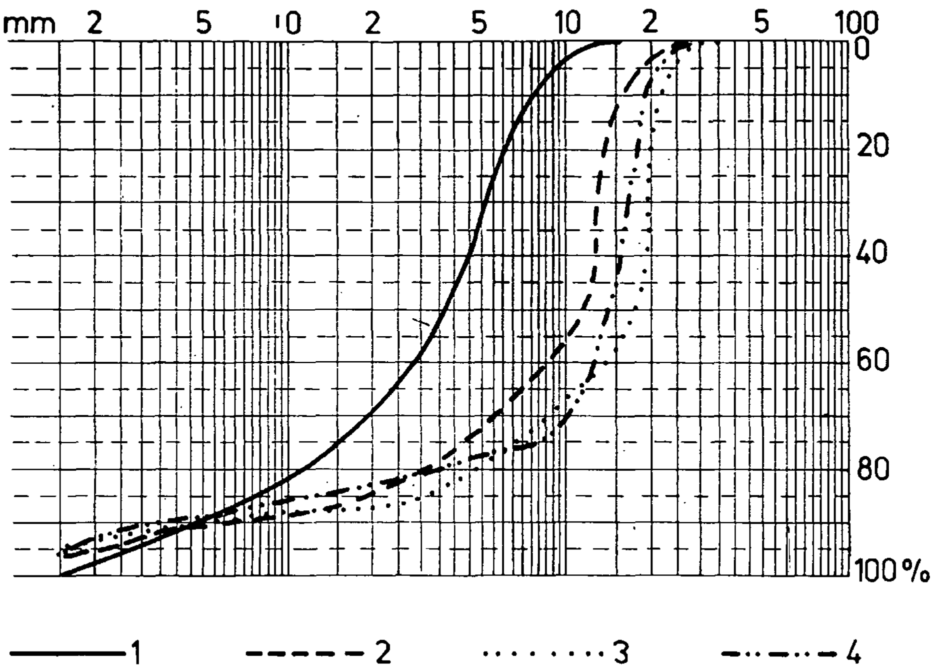

Fig. 6. Grain-distribution average curves from the levels studied.
1 = soil level; 2 = 150 cm level; 3 = 250 cm level; 4 = 50 cm level.

profile shown in Fig. 7. This fact can be explained as follows. The main role in the formation of the meander terraces was played by the sideways erosion of the water. The finer, weakly-cemented gravelly material of the layer series was deposited in parallel with this. These cavern sections possessed wide passages even before the period of increased floodwater throughput; that is, they did not widen further, but were rather sites of accumulation. This automatically means that the rate of the current, and hence its energy too, decrease in the event of a given water throughput in a wider bed. In other words, during streaming the current cross-section and the rate of flow are inversely proportional. The coarser gravels were therefore deposited in the period of formation of the flood-discharge terrace, and for a short time after this.

In contrast, the reason why less gravel is found on the symmetrical terraces is that these developed under just those cavern stream energy conditions that corresponded to the alluvium-transport energy requirements of the stream with increased throughput. The symmetrical terraces are therefore rather erosion formations. The fact that gravels are nevertheless found on them at times might have been caused by floodwaters after the development of the terraces. However, there could not have

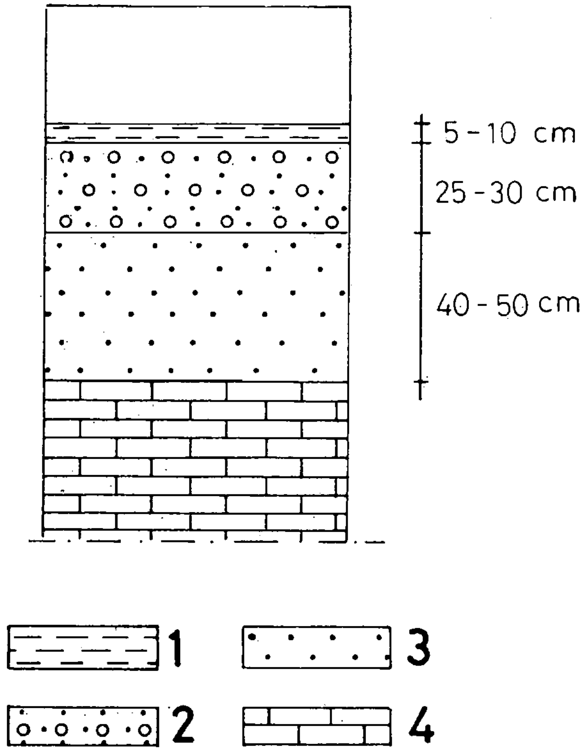

Fig. 7. Alluvium layering found on meander terraces of third level. 1=clay; 2=coarse gravelly formation; 3=fine gravelly formation; 4=Wetterstein limestone.

been a substantial phase difference in time between to two processes, for the deepening of the cavern bottom limits this. Even floodwaters of extreme magnitude (occurring every 8000—10000 years), such as that of the Baradla in 1955 (JAKUCS, 1956/2), do not display sufficient energy to transport such coarse-grained gravels by lifting them in great mass to accumulate high above the present stream bed.

To summarize, therefore, it may be stated that not even the accumulation of the gravels on the third level is separated in time from the development of the terraces, and the high floodwaters could have played a role in the accumulation only when the bed of the stream had not yet scoured substantially deeper below the terrace in question.

Although a complete series of samples is not available from the 50 cm level, it is nevertheless clear-cut that general alluvium refinement can not be counted on towards the cavern bottom. In Fig. 6 the average curves have been supplemented with the average curve for the 50 cm level. The Figure well illustrates the levels of different genesis. At the 50 cm level the alluvia with larger grain diameters may be indicative of a newer erosion terrace, possibly of Recent origin. In connection with this, however, definite conclusions can be reached only after evaluation of the results of the current investigations.

2. *Mineralogical examinations*

Only during the analyses did it prove that mineralogical examinations may be suitable for distinguishing between the levels. It was observed that, on the action of hydrochloric acid, the 0.63—1.4 mm fraction of some samples disaggregated to an average grain size of 0.01—0.08 mm. This was particularly appreciable on the third level. We thus obtain an answer to the inversion of the grain-composition curve of Fig. 6 with regard to the small fractions.

From the mineralogical characteristics of the individual levels it is to be emphasized that the sediment of the third level is comprised predominantly of quartz and muscovite mica, which generally disintegrates to a grain size of 0.01—0.08 mm in the course of excavation. The grains are not carbonatic, but are most frequently cemented together with a clayey binding. The samples of the second and third sampling sites often contained rounded sandstone concretions with clayey binding. The small number of calcite grains, measuring only a few microns, adhere to a central quartz grain.

Of the samples from the first and second levels, few disintegrated to smaller fractions, but in every case these involved carbonatic binding. Their compositions were by and large similar. Rounded quartz grains 50—70 microns in size predominated; feldspars, sandstone debris and concretions could also be found.

The samples collected from the 50 cm level had particle sizes of 50—70 microns, but 150 micron quartz grains too sometimes occurred. Their surfaces were well rounded, and they displayed a loose calciferous binding.

A study was also made of the black coating found on the surface of the quartz gravels. Similarly to BALOGH (1934), we found this manganese hydroxide coating, which is formed at the sites of highest oxygen potential, to be manganese wad. An explanation was obtained (in the permanent water permeation of the limestone) for the fact that this coating does not appear on the carbonatic rocks. JAKUCS (1952) also describes gravels with a similar blackish coating from the Baradla too, but he stresses the secretory role of manganese bacteria.

3. *Morphometric examinations*

It appeared necessary to carry out an exact survey of at least a smaller section of the cave, with a view to investigating the relative positions, displacements and vertical profiles of the terraces. Accordingly, a detailed map was prepared of the approximately 20 m cavern section indicated in Fig. 2 (Fig. 8), and profiles with an accuracy of 10 cm were established in it at 1 m intervals. The horizontal sections at distances of 1 m are plotted together in Fig. 9.

The development of a cavern meander can be readily followed in the Figure. The meander development to be found here belongs in the half-cone meander type (BRETZ, 1942); that is, the developing meanders strive to follow the surface of this form. It can be seen in the Figure that the 3 m level line determines a much wider passage than any other. According to the results obtained in point 1, therefore, this is evidence of the higher water throughput.

Via the detailed mapping of a 35 m section of the Szabadság cave, BALÁZS prepared its horizontal sections, on which the development of the meanders can similarly be well followed. In his view, from the enclosure of the meanders conclusions can be drawn regarding the stepping of the entire cave into an erosion cycle.

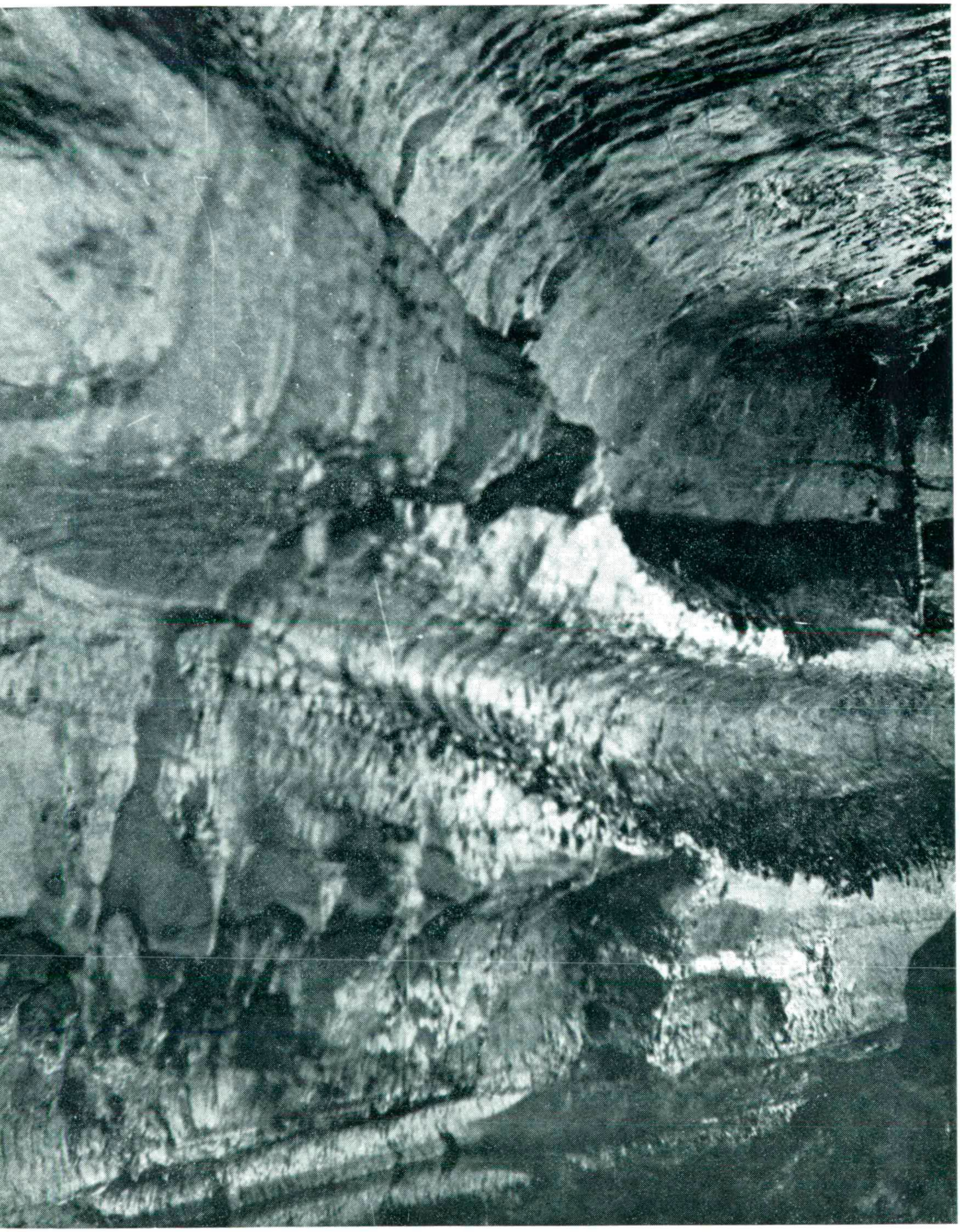

Fig. 8. Detail of the cavern section examined. Terraces covered with a gravel conglomeration can be seen on the left side of the cavern passage.

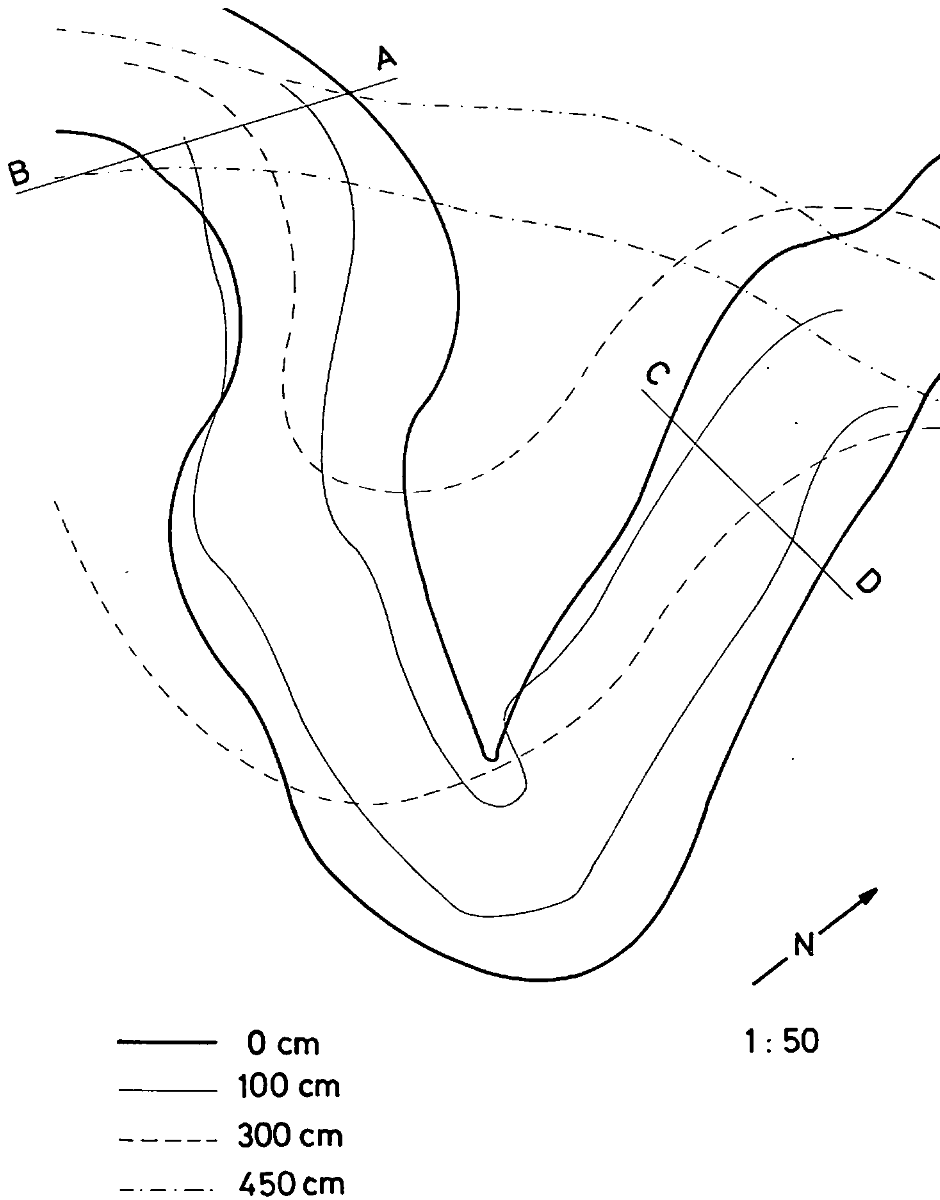

Fig. 9. Horizontal sections from the cavern section surveyed.

In our, opinion, however, such a finding can be made only by a wide-ranging geomorphological analysis of the whole cave. An effect observed at a given place is not necessarily manifested throughout the complete length of the cave, since individual tendencies may be displayed in the various sections. For example, in the knowledge of the bare rock-bottoms, beds and cut-through tufa barriers of the Retek branch of the Baradla cave, and of the meander-development conditions constructed from the other places, we can speak with high probability of a present, new, erosion stage of the cavern branch. The new erosion cycle of the Szabadság cave (according to BALÁZS), and similar developmental stages of the whole of the Baradla and the Béke caves, however, have not yet been satisfactorily proved by the research results to date.

Figure 10 depicts two cross-sections from Fig. 9, where the flood-discharge terrace character of the third level, and the meander terrace character of the second level, are well exhibited.

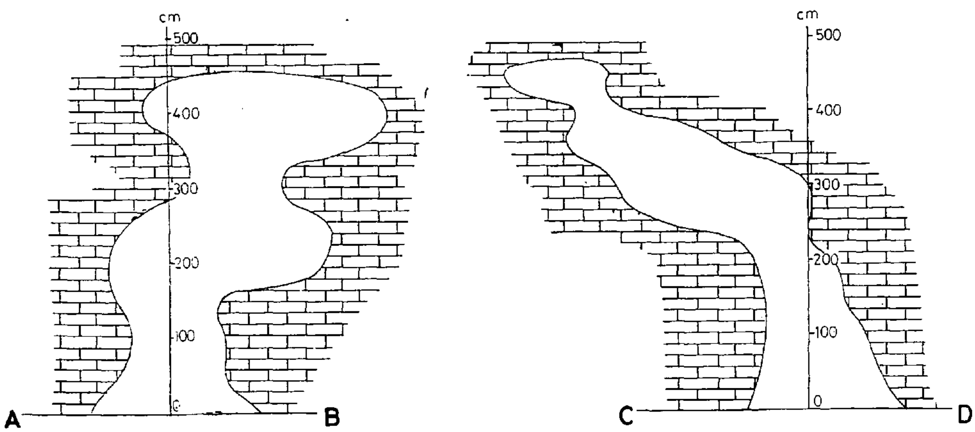

Fig. 10. Cross-section from the cavern section surveyed.

Mention must be made of another factor of meander formation which has as yet received no, or only very little attention in the literature. This is the dragging-away of the meanders according to the line of dip direction. MIOTKE and PALMER (1972) raise this question in the caves of covered karsts (Fig. 11). Of course, the

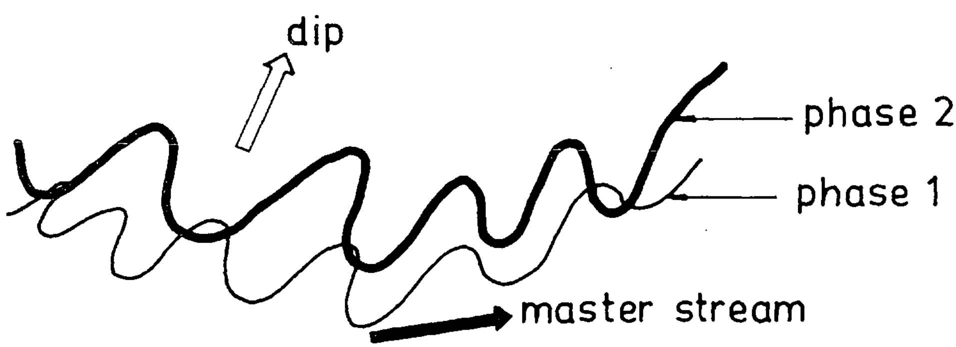

Fig. 11. Two stages of the dragging-away of the meanders in the line of dip direction (after MIOTKE).

role of the petrographic (stratification) conditions may be considerable in places, but this process is generally not manifested in the entire cave. We too have demonstrated its effect in the case of certain meanders of the Béke and Szabadság caves.

4. *Pollen analysis*

The question also arises of the determination of the absolute age of the cavern terraces. An attempt was made to obtain the answer via pollen examinations. However, the samples studied were poor in pollen. On the basis of the little residue, therefore, a classification in time was somewhat dubious and difficult.

The 0.5 m level featured a relatively rich association. The Salix, Alnus, and members of the Compositae, appearing with Pinus, as well as Polypodiacea, Licopodium and Selaginella, may indicate the wet period at the end of the Wurmian. Just because of its outstanding pollen richness, it may be assumed that the sediment of this layer was washed into the cave not too long ago.

On the other levels the pollens and spores are essentially poorer in numbers of individuals. In the evaluable samples collected from both the second and the third layer the glacial character of the Wurmian is predominant. Evaluation was made difficult by the fact that examinations of such a nature had not previously been carried out in the area, merely JÁNOSSY (1969) and KORDOS (1974) having studied the remains of vertebrates in samples from the gallery of the Imre Vass Cave. The drawing of further conclusions, therefore, would be made possible mainly by a detailed paleoclimatological analysis of the area.

In the light of our investigations it appears that the allogenic formation stage of the Béke cave is not older than 150,000—170,000 years, i.e. its main development occurred in the Wurmian Period. Thus, a decrease of 4—6° in the average temperature can be reckoned with in the genetic phase, but without a cavern frost effect throughout the whole year.

An effort was therefore made to find an answer to the question of whether there is some trace indicative of a surface weathering difference between the materials of the second and third levels, which would point to differing temperature levels. An X-ray diffractoragm examination led to a negative result; it proved a crude method, and we could not establish a weathering difference between the materials of the terraces, although we strived to concentrate on samples more or less syngenetic with the terrace formation. As an interesting feature we refer to the presence of hydrargillite.

To summarize all the above, it may be said that climatic factors played an undoubted role in the development of the flood-discharge terrace on the third level of the Béke cave; indeed, these were decisive factors. The investigations revealed the absolute age of the cave and certain details of the relative age differences of the terraces. The samples examined did not appear to be remains of a uniform floodwater.

In our view the terraces in the Baradla are of similar origin. It may be generalized that the regional locations of the "climatic terraced" caves of the Pliocene-Pleistocene are closely connected to the periglacial areas. This may be illustrated with a single further example. The various developmental levels of the gypsum caves of the southern part of the Podolian Ridge can be brought into parallel with the Pleistocene terraces of the Dnyester, and these with the individual glacials (DUBLYANSKII, 1972).

REFERENCES

Balázs D. (1962): A Szabadság-barlang. (The Szabadság cave.) Karszt- és Barlangkutató, 1961/II, pp. 61—77.
Balázs D. (1974): A barlangi meander képződése. (Cavern meander formation.) Karszt és Barlang, 1971, II, pp. 75—81.
Balogh E. (1934): A komarniki barlang. (The Komarnik cave.) Erdélyi Museum, 1934, XXXIX/1—6, pp. 3—22.
Bokor E. (1925): Az Abaligeti-barlang. (The Abaliget cave.) Földr. Közl. *53*, pp. 105—141.
Bretz J. H. (1942): Vadose and freatich features of limestone caverns. J. of Geol. *50*, pp. 676—811.
Cholnoky J. (1917): Barlangtanulmányok. (Cavern studies.) Barlangkutatás, *5*, pp. 135—175.
Cholnoky J. (1932): A barlangok és a folyóvölgyek összefüggése. (The interconnection of caves and river valleys.) Barlangvilág, *2*, 1—2, pp. 3—10.
Cholnoky J. (1935): A barlangokról. (Caves.) Barlangvilág, *5*, 2, pp. 1—11.
Cvijic J. (1909): Bildung und Dislozierung der Dinarischen Gebirges. Rumpfläche Peterm. Mitteil. Bd. 55, VI, VII.
Davis, W. M. (1930): Origin of limestone caverns. Geol. Soc. Am. Bull. *41*, pp. 475—628.
Droppa A. (1964): Vyskum terás vachu v strednej casti lipovskij kotliny. Geogr. Ces. SAV r. 16, Bratislava.
Dublyanskii V. N.—Smolnyikov B. M. (1972): Karshtolovo-geofizicheskiye isledovanyiya karshtovich polshkey pridnyestorskoy Podolii i Pokutya. Simferopol, pp. 140.
Jaskó S. (1935): A Jósva-patak felső völgyének geológiai leírása. (Geological description of the upper valley of the Jósva stream.) Földtani Közl. pp. 291—300,
Jakucs L. (1953): A Béke-barlang felfedezése. (Discovery of the Béke cave.) Budapest.
Jakucs L. (1956/1): Adatok az Aggteleki-hegység és barlangjainak morfogenetikájához. (Data on the morphogenetics of the Aggtelek Hills and their caves.) Földr. Közl. 1956/1.
Jakucs L. (1956/2): A barlangi árvizekről. (Cavern floodwaters.) Földr. Közl. 1956/4.
Jakucs L. (1964): Geomorfológiai problémák az É-borsodi Karszt-vidéken. (Geomorphological problems on the North Borsod Karst area.) Borsodi Fölrdr. Évk. *5*. pp. 1—12.
Jakucs L. (1971): A karsztok morfogenetikája. (The morphogenetics of karsts.) Budapest.
Jánossy D. (1969): Gerinces őslénytani ásatás az Esztramoson. (Vertebrate paleontology excavations on the Estramos.) Karszt- és Barlang. 1969./II, p. 77.
Kerekes J. (1936): A Görömbölytapolcai tavasbarlang. (The Görömbölytapolca lake-cave.) Barlangvilág, 1—2, pp. 23—29.
Kessler H. (1938): Az aggteleki barlangrendszer hidrográfiája. (Hydrography of the Aggtelek cave system.) Doctoral dissertation, Budapest, p. 38.
Kordos L. (1974): Ősmaradványok a Vass Imre-barlang tárolójából. (Primordial remains from the gallery of the Imre Vass cave.) Karszt- és Barlang, 1971/II, p. 92.
Láng S. (1955): Geomorfológiai tanulmányok az Aggteleki-karsztvidéken. (Geomorphological studies on the Aggtelek karst area.) Földr. Ért. 1, pp. 1—21.
Maksimovich G. A. (1957): Korrelatsiya rechnih teras i horizontalnih karstovih peshcher. Trud Com. po izuch. chetv. perioda, *13*, pp. 243—253.
Maksimovich G. A. (1963): Asnovnih karstovedenyiya Perm.
Miotke F. D.—Palmer A. M. (1972): Genetic relationship between caves and landforms in the Mammoth cave national park area. Hannover, p. 69.
Szentes Gy. (1965): Földtani, tektonikai és genetikai vizsgálatok a Baradla- és Béke-barlangban. (Geological, tectonic and genetic studies in the Baradla and Béke caves.) Karszt és Barlang, 1965/II, pp. 71—78.