ECOLOGICAL CHARACTERISTICS OF DOLINE TYPES IN AGGTELEK HILLS (NORTH HUNGARY)

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INTRODUCTION

In recent years, a number of proposals have been put forward to typify the repeatedly buried and exhumed surfaces of the Hungarian Mountains and distinguish their geomorphological surfaces (PÉCSI,M. 1984; PÉCSI,M. and MEZŐSI,G. 1985, etc.). This paper presents a survey of our karst morphological investigations in the Aggtelek Mountains, with a view to clarifying the disputed questions of surface development in Late Quaternary. We assume that conclusions can be drawn for the date of the final exhumation of the individual morphogenetic units from the complex system of forms that developed on their surfaces. The central feature of our studies was the karstic depressions in various lithologic, tectonic and orographic situations. Our analyses permitted the identification of the doline types belonging to the most important morphogenetic units and an estimation of their ecological state.

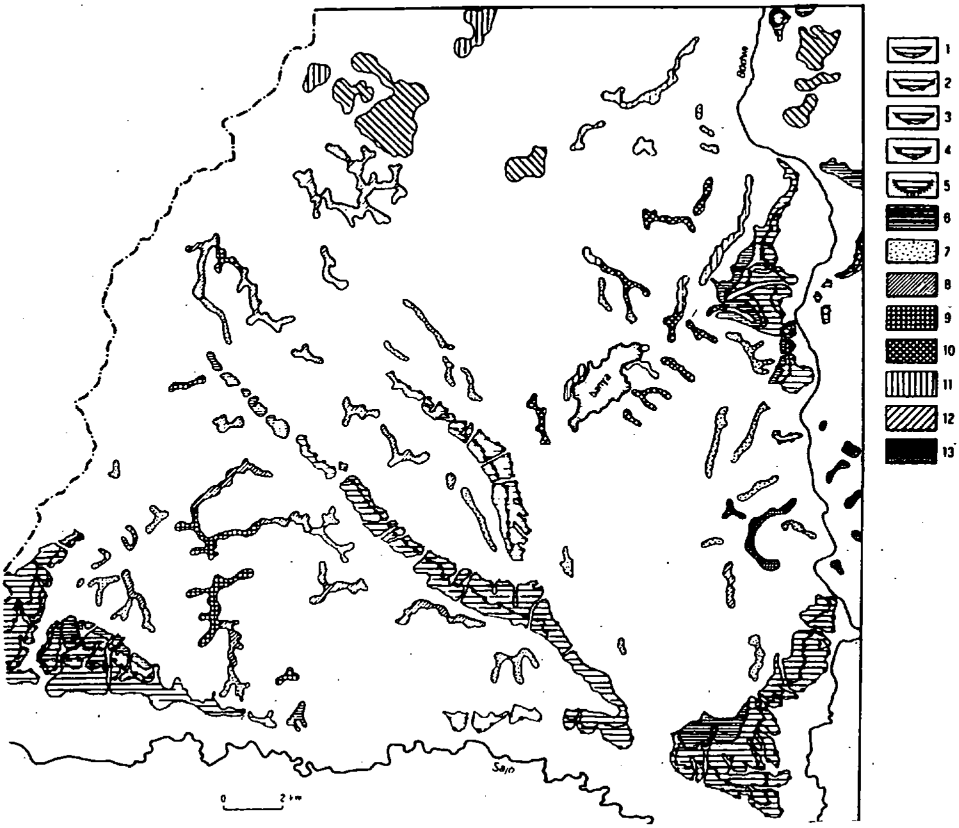
RESULTS

Geomorphological surfaces of the mesozoic horsts of the N-Hungarian Mountains

From a structural-morphological aspect, the Rudabánya-Aggtelek Mountains comprise a folded-faulted (some authors consider it to be covered) horst planated in the Mesozoic. The paleokarstic erosional surface was repeatedly buried and exhumed during the Tertiary (*Fig. 1*). In response to the Tertiary tectonic movements, it was dismembered into blocks undergoing independent development and eroding to various degrees. Because of their different geomorphic evolutions and positions, these mountains represent a relief subtype different from the previous ones. Orographically, they are now low mountains. The course of their general evolution may be summarized as follows:

The early Mesozoic areas of syncline type were transformed into mainland from the Upper Triassic, and up to the Middle Cretaceous planation prevailed under tropical subhumid climatic conditions. At the end of Mesozoic the low, "karstic", tropical erosional surface was dismembered by major faults. Although the climatic conditions would have permitted a further period of (regional) planation, extending to the entire Hungarian Mountains, active tectonism turned this region into a pediment zone of the higher, crystalline mountains to the north and south.

Geomorphologically, therefore, it may be assumed that peneplanation was followed by pediplanation in the Eocene.



1 - terrace II/a; 2 - terrace II/b; 3 - terrace III, travertine horizon; 4 - terrace IV, travertine horizon; 5 - terrace V; 6 - Upper Pliocene pediment (locally red clay formation); 7 lower interfluvial ridges, derasional terrace steps, remnants of older pediment surfaces; 8 - higher hill-summit surfaces, or interfluvial ridges (initial phases of Quaternary valley formation); 9 - Neogene pediplain remnants; 10 - semiexhumed planated horst surface transformed by pedimentation (covered by Paleogene sediments); 11 - moderately elevated planated horst surfaces (exhumed in Tertiary and Quaternary); 12 - bare planated horst surface in summit position, completely exhumed and intensely karstified; 13 - repeatedly buried and exhumed peneplain remnants built up from Paleozoic sediments; 14 - mine area

Figure 1 *Main geomorphological levels in the Aggtelek-Rudabánya Mountains and their environment*

Subsequently, during the Paleogene and particularly the Neogene, the surface was covered by sediments of varying thicknesses and kinds.As a result of these tectonic movements, which lasted from the end of the Miocene up to the Pleistocene and affected only certain zones, and also as a result of the oncoming erosional activity, this region was transformed into partially or completely exhumed low mountains with a horstgraben structure. Accordingly, the true horst surfaces lost their young Tertiary sediment mantles and underwent mountain margin pedimentation at the end of the Pliocene.

The investigations by LÁNG, S. (1973) and JAKUCS, L. (1964) indicated that neither the climatic nor the karst-hydrological conditions (the latter because of the hiqh karst-water table) of the formerly assumed Pliocene karstic planation were present.

By taking into consideration the orography and the differences in evolution too, we distinguished the following horst types (sometimes in combination).

(a) Exhumed planated horsts in summit position: including the completely exhumed plateaux of the Aggtelek and Martony Mountains, which underwent intensive karstification during the Quarternary.

(b) Moderately elevated planated horsts: the central part of the Rudabánya Mountains (preserved with ore indications), from which the original Paleogene cover was totally degraded during the Late Tertiary and the Quaternary.

(c) Semi-exhumed planated horst transformed by pedimentation: these elevated horsts are covered by spots of Oligocene or Miocene sediments of various depths (e.g. the margin of the Rudabánya Mountains).

These relief subtypes frequently differ in orographic position, but this does not mean morphogenetic variation (i.e. a higher position does not necessarily mean an older geomorphological surface). Accordingly, it would have been a mistake to identify the horst levels with geomorphological surfaces merely on the basis of their present position.

Doline types of Aggtelek Hills

The process of karst formation, which can be measured in geological periods, took place in the karst of Aggtelek Hills without being overlapped by non-karstic rock, thus typical karstic phenomena and varying karstic surface forms could take shape in this area. Accordingly, recent karst formation processes can be primarily studied on the latter karsts. We can find **solution dolines** here, which we consider to be characteristic forms of temperate zone karsts. Solution dolines occur as unique dolines, especially on the surface of karst plateaus. The appearance of row dolines is quite frequent in the valleys inherited from the planted karsts which are dry today.

Besides dolines, bare karr surface occurs less rarely, for example, the karr field on the shore of the lake in Aggtelek, whose rounded-off surface coloured by root-arms obviously refers to subterranean corrosion processes.

The formation and the development of solution dolines are influenced by several exogenic ecological factors. According to our concept, the climate and the microclimate play the most important part among them, with which the soil covering the rock the biological processes taking place in the soil and the vegetation settling on it will be developing in close interaction, and the dynamics of the subterranean corrosion denudation develop in connection with them. Besides the emphasis on the determining role of the climate, the soil and the biogenic factors, karst formation is not independent of the relief and neither of the structural and microtectonic endowments of the rock-bed and the forms largely show the period of the influence of the processes, too.

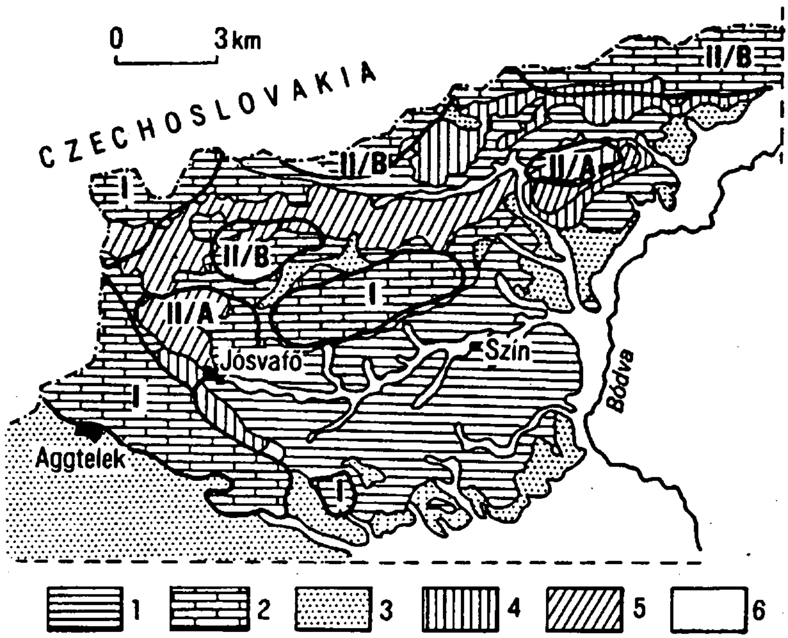
In accordance with the individual relief subtypes, we carried out detailed morphometric and litholoqical studies of the karstic depressions and their fills *(Fig. 2., Table 1)*. These revealed unambiguous correlations with the evolution of the zones of the depressions. On this basis, three main groups may be distinguished:

	Valley type	**Basin type**	**Plateau type**
relief ratio	0.08	0.14	0.12
elongation ratio	2.24	1.58	1.12
deep (m)	16.6	15.8	9
diameter (m)	207	113	75
average area of dolines/km²	0.01	0.02	0.016
total area of dolines as percentage of karst surface	23	32	31
doline density	11-13	32-36	7-9

Table 1 *Some morphometrical parameter of the different doline types in the Aggtelek region*

I. Dolines situated at a height of 310-350 m, with a diameter of 50-200 m and a depth of 15-40 m. Several large dolines frequently coalesced. Even disregarding the dolines, the terrain is strongly dismembered, with flat ridges of considerable extent where there are no, or only very few dolines, the peaks of these ridges even rise above 400 m. Most of the dolines are situated in rows and display N-S and W-E strikes. A typical fill is dark red terra rossa with a high iron oxide content (up to 14 %). This attains a layer thickness of 5-15 m on the doline bottoms. The doline sides and bottoms protected by the terra rossa exhibit definite tropical tower (?) karst microforms. Such forms are absent from the ridges and doline sides not covered by terra rossa, probably as a result of secondary, normal surface karst denudation processes shaping the relief. In the doline bottoms covered by red clay, the usual karren microforms are missing.

II.a. Dolines situated at a height of 270-280 m, with a diameter of 5-30 m and a depth generally not more than 2-8 m. The karstic terrain, rich in small dolines, has a fairly uniform height and a definite planation character. The material filling the depressions is yellowish-brown, and is primarily reminiscent of terra fusca, with a little terra rossa. The clay fill is 2-5 m thick, and is present not only on doline floors, but also on the ridges. The karstic limestone protrudes onto the surface at only a few sites, forming bare patches. The subsoil rock forms are primarily characterized by corrosional karren with the presence of fissure-karren.



1 - Lower Triassic (Campilian) limestone, shale; 2 - Lower Triassic (Gutenstein) limestone and dolomite; 3 - Wetterstein limestone; 4 - Wetterstein dolomite; 5 - Pliocene gravel, sandy gravel; 6 - extensive fluviatile sediment from Holocene; I - exhumed, intensely karstified karst; mainly "valley" type dolines; II/a - moderately elevated, weakly karstified, planated surface; mainly "basin" type doline; II/b - bare planated exhumed horst surface in summit position mainly "plateau" type doline

Figure 2 *Karst doline types in Aggtelek Mountains*

II.b. Dolines situated at a height of around 500 m and higher, with a diameter of 50-200 m and a depth of 20-50 m. These dolines generally have steeper sides than the dolines at intermediate heights; this may well be connected with the fact that they contain little fill which favours the expression of the morphology of the original rock surface. The terra rossa is almost completely missing; the fill is rather black humus, rendzina forest soil. We have not yet encountered with justified tropical tower karst forms; both on the surface and under the generally thin soil layer, the microforms merely display the features of root and precipitation corrosion and of cryofraction. As far as their positions are concerned, the dolines are not aligned in definite rows; the terrain is a uniplanar plateau, generally presenting a picture only of a karstic erosional surface.

The relative ages of the various horsts as geomorphological surfaces can be given on the basis of the related doline types, in the following manner:

By the end of the Pannonian (Late Miocene), the surface had progressively lost its pediment position. Of the surface segments along the earlier tectonic lines, II/b was exhumed first, followed by II/a (currently in a basin position). In our view, the exhumation of unit I can be regarded complete: the remnants of the Pannonian gravel mantle are to be found in a number of sites. At the same time, the karstic valleys that appeared on its surface in the Pleistocene have exposed the older karstic form complex, additionally including dolina row formation, which meant the starting phase of intense karstification. Here, therefore, "old" and "young" karstic forms are found side by side in the same orographic situation.

Microclimatological characteristics of the dolina types

As we have mentioned it above, the determining exogenic factor in the development of dolines is the climate, which roughly defines the effect-mechanism of the ecological factors. The dolines modify the radiation effects within the local climate of the mountain and the valley respectively, thus creating an independent microclimatic system. The different slopes further dissect the microclimate of the doline within the microclimatic area resulted from the closedness of the karst depression.

The air-space of dolines is filled up by a cold airlake at night and by the high-temperature air by day stuck in the depression. In the heat-absorption and emission processes of the slopes, temporal difference and a difference of order are shown in compliance with the changes in the irradiation conditions. The shadow effect also plays an important part in the heat economy of dolines as a result of horizon limitedness. The symmetry axis of the air temperature in the North-South segment shifts in the direction of the slope facing South. The minimum temperatures shift in the direction of the slopes at night in case of fog (*Fig. 3*).

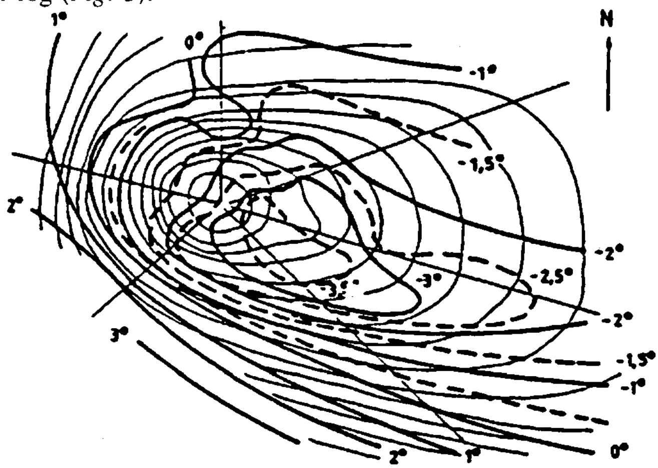


Figure 3 *Isotherms in a doline in Aggtelek Hills at night (17. 8. 1992)*

The soil temperature, which is important from the viewpoint of the processes in the soil, alters according to the changes of air temperature but with considerable phase-shift. The course of the sun influences the alternation of soil temperature, too. The soil layer close to the surface is the warmest on the North-Western slope by day (southern exposition), while the deeper layers of the soil are the warmest on the northern slope. The southern slope is the coldest (northern exposition) the biggest phase-shift can be experienced here moving toward the deeper layers. The expositional differences of soil temperature is considerable until the depth of 20 centimetres. This is significant as the biological processes of the soil take place here most intensively.

The expositional differences make it possible that the snow cover in winter remains for different periods; on the southern slope (northern exposition), the snow cover remains for a longer period because of the early occurrence of self-shadow and the low efficiency level of radiation arriving at a low angle, and the corrosion is faster under it than in places where snow does not remain for a long time. Consequently, the amplitudes of soil temperature are significantly smaller in the southern parts than in the northern ones.

Most important characteristics of doline-soils

In the Aggtelek Mountains, remnants of Mediterranean red soil (terra rossa), reddish brown soil, rendzina and brown forest soil are alternating in the dolines.The thickness of the soil on the slopes is of several 10 centimetres, while at the bottom of the dolines it can be of several meters even. The doline soils are usually strongly bound, they have high humus content (crude humus usually), their pH is weakly acidic or neutral. The pH has been showing some changes on the Aggtelek karst primarily (BÁRÁNY, I. 1987), which we demonstrated by means of the differences between the pH figures (in aqueous and potassium-chlorided solution). Presumably, the acidic depositions as well as the herding live-stock farming have contributed to forming the unfavourable tendency. In lower strata of the doline soils, a level of Fe accumulation can be detected, which is the result of matter transcumulation. The doline soils are deficient in ionic constituents just at the bottom of the dolines owing to the stronger leaching, while on higher levels and on the edge of the dolines, both the anion and the cation contents are higher. (*Fig. 4*).

The changing of humidity conditions of doline soils is quite important from the viewpoint of the life of the soil and that of.the subterranean corrosion as well. The section close to the surface, which is richer in organic matter is usually wetter than the lower strata of the soil. The daily occurrence of convectional precipitation due to the drastic rise in temperature at midday is indispensable for the life of the soil, which is characteristic of the summer period. The soil humidity is higher in the southern part of the dolines. This figure is usually higher in afforested dolines than in those covered by soft-stemmed, grassy vegetation. The life of the soil is more intensive in the latter type.

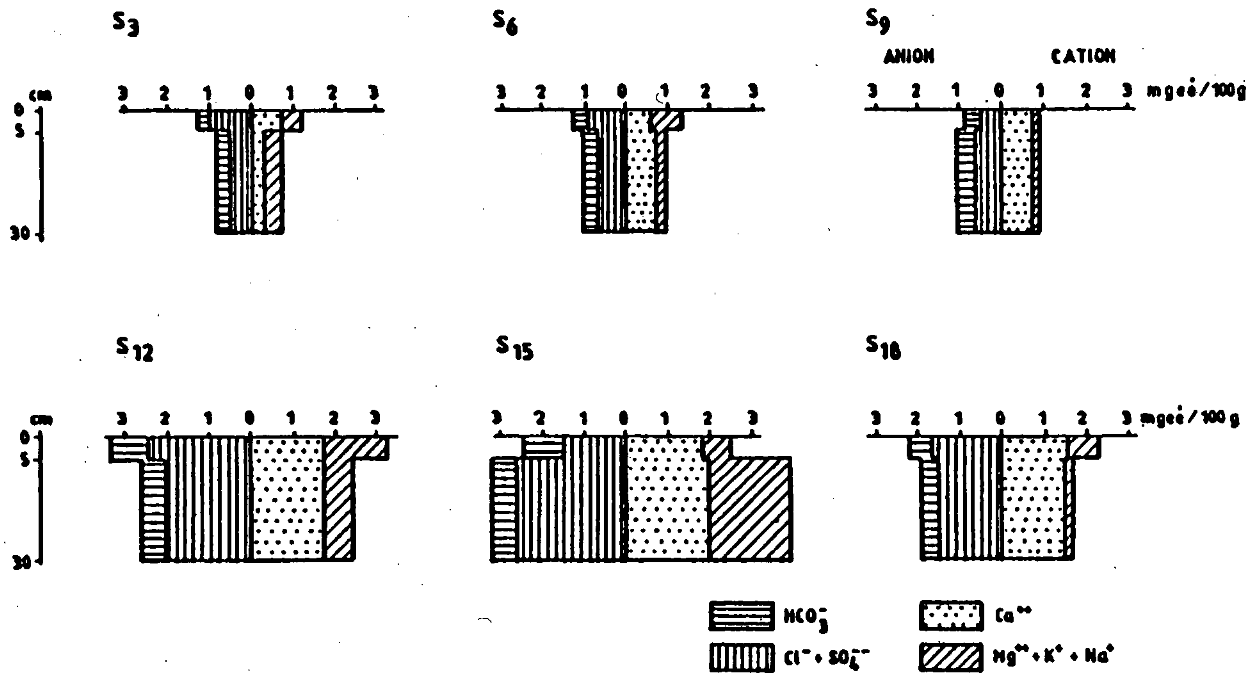


Figure 4 *The quantity of anions and cations which are soluble in water on the southern slope at level 3,6,9,12,15 and 18 metres*

The bacteria activity of the different dolina types

The pure numerical evaluation of the bacteria population - neglecting the environmental conditions - would provide misleading results. it is also a problem that the systematical registration of the number of bacteria according to their daily and seasonal changes in technically impossible. Therefore, the tests are only based on data obtained in 1-1 point of time. However, these data are useable for geomorphological investigations, because the purpose is to show the differences according to the expositions. Although the data collected in the same time cannot be absolutely accepted, they can be used in comparing them according to slopes, because the same percentage of error is probable in their comparation.

The bacteria activity of soils of the different dolina types was studied through the karstic soil samples from 5 cm and 30 cm depths; these samples showed different CO_2 production characteristics due to their different slope exposition. The samples gathered by 0.5 m levels from 7.5 m thick soil accumulations on the bottom of dolinas and karstic valleys were also examined. .

The samples of thin soil cover came from Aggtelek Hills. The dolina marked "A" is a grass covered (Nardo-Agostion-tenuis) "basin" type dolina, the dolina "B" belongs to the "valley" group and partly covered with pine forest and partly with grass (Nardus stricta). The distance between sampling points was 3 m.

The two dolinas of Aggtelek Hills are basically different concerning their vegetation cover; therefore, the distribution of bacteria population is also largely different. The distributional differences depending on the microclimate - which was analyzed above - are clearly observable in the dolinas that are not covered with wood. In this case, the soil is only deep in the dolina bottom, while the soil is thin (40-70 cm) at the sides due to the high slope gradient.

In the dolina bottom, where the soil mantle is thicker than 1.5 m, the number of bacteria is fairly high (4.0 and 5.2 x 10^6) at both levels, while it is generally smaller on the slopes. *(Figure* 5)

The differences in the soil-ecological conditions of the dolina without wood and that mostly covered with wood are most clearly demonstrated by the number of bacteria; further, it can be stated thereon that the soil phenomena are significantly effected by the macro-flora or the microclimate modified thereby.

The number of aerob bacteria per 1 gramm of soil at 5 cm soil horizon is the multiple of the values observed at same levels of unwooded dolinas. (*Fig.* 5) The difference between the two dolinas is already less remarkable at 30 cm horizon, but it is still large. This is explained by the fact that the trees - with grass vegetation - densely interweave the soil at 5 cm depth, modify its structure and create more favourable ecological conditions for the activity of microbes than the unwooded dolinas can have.

A similar type of difference between the two dolinas can also be observed when the number of anaerob bacteria is compared.

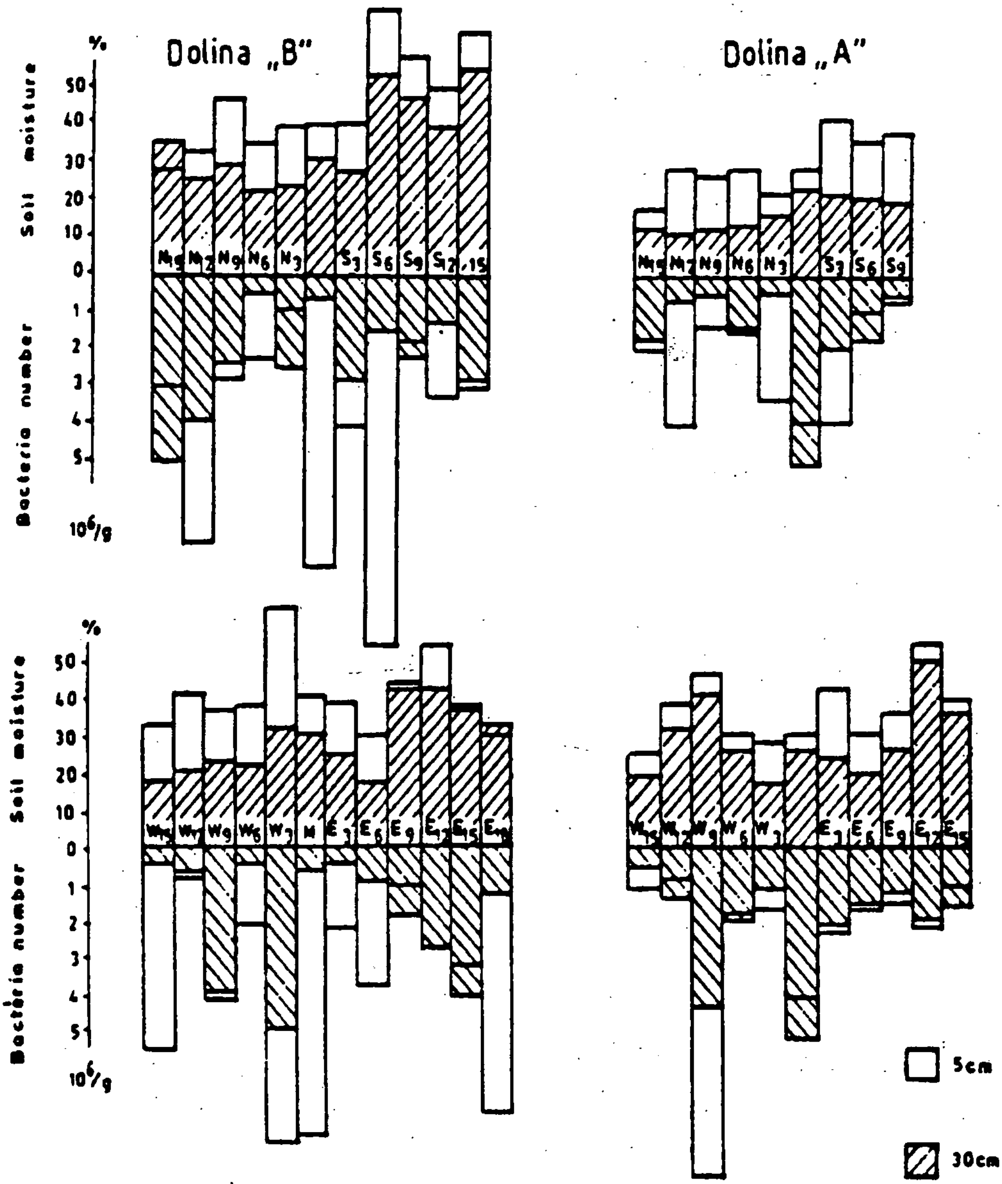


Figure 5 *Bacteria number and soil moisture in a grass covered doline ("A") and a pine covered doline ("B") at 5 and 30 cm depth*

In dolina "A ", in accordance with its higher moisture content, the northern slope (southern exposition) shows a large number of bacteria at 5 cm depth. At 30 cm, however, the number of bacteria declines, because the soil moisture content is lowest on this slope. (At 5 cm depth the daily convectional precipitations create favourable moisture conditions, although the irradation is fairly strong. However, at 30 cm the short time precipitations can not be so much effective due to intense irradation and evaporation).

On the southern slope (northern exposition), at deeper levels (3 m isohypse), the number of bacteria is even larger at higher levels, however, the development of a large number of population is hindered by the low soil temperature and the soil moisture exceeding 40 %.

The number of bacteria most reliably follows the changes of soil moisture on the western slope (eastern exposition); it increases or decreases accordingly. The moisture content and the number of bacteria grow until the middle of the slope (9 m isohypse), then they decline. The temperature maximum in the morning probably favourably effects the development of bacteria population.

The less extraordinary moisture content and temperature characteristics of the eastern slope (western exposition) result in a fairly uniform distribution of the number of bacteria. The soil is warmer there, the difference in the moisture content of the two soil levels is less explicit; therefore, the number of bacteria at 5 cm and 30 cm depths is almost the same throughout the slope and it generally linearly flows the moisture conditions.

In dolina "B ", covered with pines, the changes in the number of bacteria on various slopes can not be easily described, because - unlike in the case of dolinas - the moisture content of the soil is changed by the increased transpiration and the smaller temperature undulations due to the trees. The *higher value of moisture content and the smaller temperature undulations create favourable ecological conditions;* therefore, the number *of bacteria is normally larger at every level and soil depth in wooded dolinas than in open dolinas*. This dolina has deep soil cover at several points on the slopes.

On the northern slope (southern exposition), the number of bacteria is evenly growing from the dolina bottom upwards, at large following the moisture content.

On the southern slope (northern exposition), the lower temperature values are accompanied with higher moisture content; they do not favour the development of bacteria population. Exceeding the 9 m isohypse (where the soil is loose, and pebbly already from the surface, and where the number of bacteria at 5 cm depth is 10.4 x 10E6, the number of bacteria is relatively small on the southern slope.

The moisture content is lowest on the western slope (southern exposition), because open grass association grows there and the irradiation is effective. However, the temperature conditions are favourable, because the difference between the daily extreme values is not very large. This is favourable for the microbes, which explain the relatively large number of bacteria.

On the eastern slope (western exposition), the number of bacteria is increasing from the dolina bottom upwards, which is due to the similar increase in the density of wood.

At 3 m level the ecological conditions are still generally characteristic of the dolina bottom concerning the moisture and temperature; therefore, the number of bacteria is almost the same as on the dolina bottom.

The number of anaerob bacteria is smaller in the open dolina "A " than in the wooded dolina "B': It must also be noted that the number of anaerob bacteria is less reliable than that of aerobs; only they two together are useable for slope tendency studies.

The intensity of bacteria activity is basically determined by the temperature and moisture of the soil. The number of soil bacteria is naturally also effected by other factors such as the humus content of the soil, or the pH characteristics. While the humus content of the soil is growing in autumn in general, the number of bacteria is at its peak in summer. The pH characteristics of the soil, however, linearly follows the changes in the number of bacteria; the pH is highest in summer, when the decomposition of humus is most complete, and it is lowest in winter. The unfavourable physical and chemical state of the soil also decreases the number of bacteria.

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