DIFFERENCES OF DYNAMISM OF KARST-FORMATION PROCESSES IN MICRO-AREAS

by

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The climate is known to be of decisive importance in the regulation of the intensity of karst-formation. In the course of our earlier studies wide-ranging arguments were presented, justifying the placing of the climatic variances of karst-formation at the centre of morphogenetic analysis.

It can safely be said that the karstic corrosion of limestone rocks is essentially a formal reflection on the soluble base-rock of the phenomena of the biological and chemial development of the soil covering the rock. At the same time, however, it is an important condition that, as regards their extents and natures, these biological and chemical developmental phenomena are decisively of a climatogenetic regulation.

The simple reason for the manifold quantitative and fundamental qualitative differences in the karstic denudation of limestone areas with the same lithological, tectonic and orographic characteristics, but belonging in different climatic zones, is that these areas differ with regard to temperature and precipitation; because of this, specific vegetation types live on their surfaces and various soil biological, and hence chemical, processes occur.

The results of Hungarian and international research in recent years convincingly attest to this argument. It is time, therefore, to make the next step. If it has proved true that differences in the volume of precipitation and in the temperature (mainly by biochemical transposition) give rise to differences in the dynamism of karst-formation in the comparison of geographically widely-separated regions, *then it must also be true if a comparison is made between regions with different climatic features, which are not widely separated geographically.* That is, the distance can play no part at all in the process.

In other words, this means that *the karstic process in a given micro-area is always determined by the microclimatological characteristics of the area in question,* while these are functions of not only the macroclimate of the region.

The planetary zonality of the macroclimate is manifested in the karstic process in so far as it determines the features and proportions of the individual microclimatic areas within the climatic region. If the different local conditions of orography, exposure, wind-shelter, etc., within a given macroclimatic region produce a micro-area with extreme microclimatic properties, the qualifying factors of which differ appreciably from those general for the climatic zone, then the local intensity of the karstic processes will also differ considerably from that of the overall karstic process characteristic of the macro-area (region). The intrazonal appearance of *(the)* most of the karst-morphological, extra-zonality features is connected with this. *In a zone, therefore, the nature of the process of denudation of the surface must be interpreted as a statistical mean proportional of the concrete, not necessarily similar denudation processes of the numerous micro-areas forming the zone.*

It is obvious that this finding does not refer only to karstic denudation, but in accordance with the aims of this paper the question will here be analysed further only in this respect. It is subsequently most important to establish the smallest physical-geographic regional units for which the differences in microclimate producing the differences in intensity of karst-formation may still be expressed in form.

It is interesting that the synoptic study of this field from the aspect of the geomorphologist has not previously been initiated either in Hungary or abroad. For this reason, apart from our own investigations it is necessary to rely on the results primarily of certain pioneering climatologists, pedologists and biologists, obtained in analyses with quite different aims. Perhaps the most important of these are the researches of WAGNER, which, in addition to the exact conceptual clarification of microclimates of various magnitudes, provide a tremendous amount of valuable observation material on karst regions, relating to long periods of time, for the assessment of the possible morphogenetic connections (WAGNER 1954, 1955/1—2, 1956, 1960, 1964, FUTÓ 1962, BÁRÁNY 1967, etc.). However, the soil respiration studies of soil scientists (in this respect primarily FEHÉR [1954]) are also extraordinarily significant, as are those phytocoenological researches which analyse the plant-association types of a karst region of homogeneous rock material in a microclimatic interpretation (BACSÓ—ZÓLYOMI 1934, JAKUCS 1954, 1955, 1956, 1961, 1962).

Due mainly to the above authors, we know that there are very considerable microclimate-genetic soil-intensity differences for example on the karstic surfaces of mountains of medium height, and not only in the rhizosphere processes of the characteristic forest associations, shrub-forests and steppe-meadows accompanying slopes of a northern or southern exposure (thus, for example, even within a single dolina), but in even much smaller area-mosaics than this (for instance, in the root-crowns of two plant species living immediately adjacent to one another). This refers particularly to the mutual relation of the soil respiration and the production of carbon dioxide in the soil, which depend very sensitively quantitatively on the activity of the soil microorganisms. However, it is just these which are the most essential aggressivity-determining factors as regards the ability of the water percolating from the soil towards the karst to develop the karst.

Thus, if it can be proved that, for example, there are differences of a microclimatic sense, but of a considerable magnitude, in the quantities of heat, in the courses of the heating-up and cooling-down curves, in the amount of precipitation, in the soil moisture, etc. of dolina slopes of northern and southern, and of eastern and western exposures, then as postulate these entail differences in the natural vegetation living on them, in the bacterial flora in the related pedosphere, and also in the soil aeration, etc.; the partial dynamic division of the karstic process within the dolina then follows clearly from this. That is, the corrosion denudation will of necessity be of a different value on the dolina slopes of different exposures. From this condition, the conclusion may readily be drawn that *the form and aspect of the karstic dolinas are a formal reflection of the organization of their adequate microclimatic areas.*

In the following we shall examine some of the premises of the above argument, which was formulated only as a working hypothesis.

WAGNER reports series of measurement data on the microclimate of one of the dolinas of Középbérc on the Bükk plateau, which are more detailed than the earlier sources (BACSÓ—ZÓLYOMI 1934, LÁNG 1953, GEIGER 1961, FUTÓ 1962). These data give an accurate indication as to the measure of the characteristic temperature differences and the tendencies of these in the interior of the dolinas (WAGNER 1960, 1963, 1964, AMBRUS 1965, GÖMÖRI 1967). It is shown that in Hungary the slopes of the dolinas which heat up the most intensively and for the longest periods of time are those of south-eastern or southern exposure, while the sides of north-eastern or northern exposure remain the coolest. *If the eastern and western exposures of a dolina are compared, however, the sides facing the east are always the warmer.*

The differences in temperature of the opposite slopes become particularly evident in the early morning hours, when in summer the temperature differences in the air layers close to the soil of the eastern and south-eastern exposures moy be 10 °C or even more. In the afternoon, however, when the western slopes receive direct irradiation, the inversely compared temperature differences remain lower.

The variations of the amount of heat and the heating-up during the day show up more perceptibly for the southern and northern exposures, but in addition to this for the eastern and western exposures, in the comparison of the *soil temperatures*. Figure 1 gives the observations of four soil-climate stations placed in four different exposures of a dolina, referring to a soil-depth of 2 cm.

Naturally, the differences in inclination of the slopes are reflected primarily by the magnitudes of the amplitude, but the characteristic courses of the heating-up curves, particularly of the eastern and western exposures, the shift of the positions of the maxima, and the steepness of the heating-branch of the diagram, also partially involve the features of other factors causing the more extensive continentality of the eastern slopes.

The complex assertion of several factors must be seen in this relation. Of these, only a few will be mentioned:

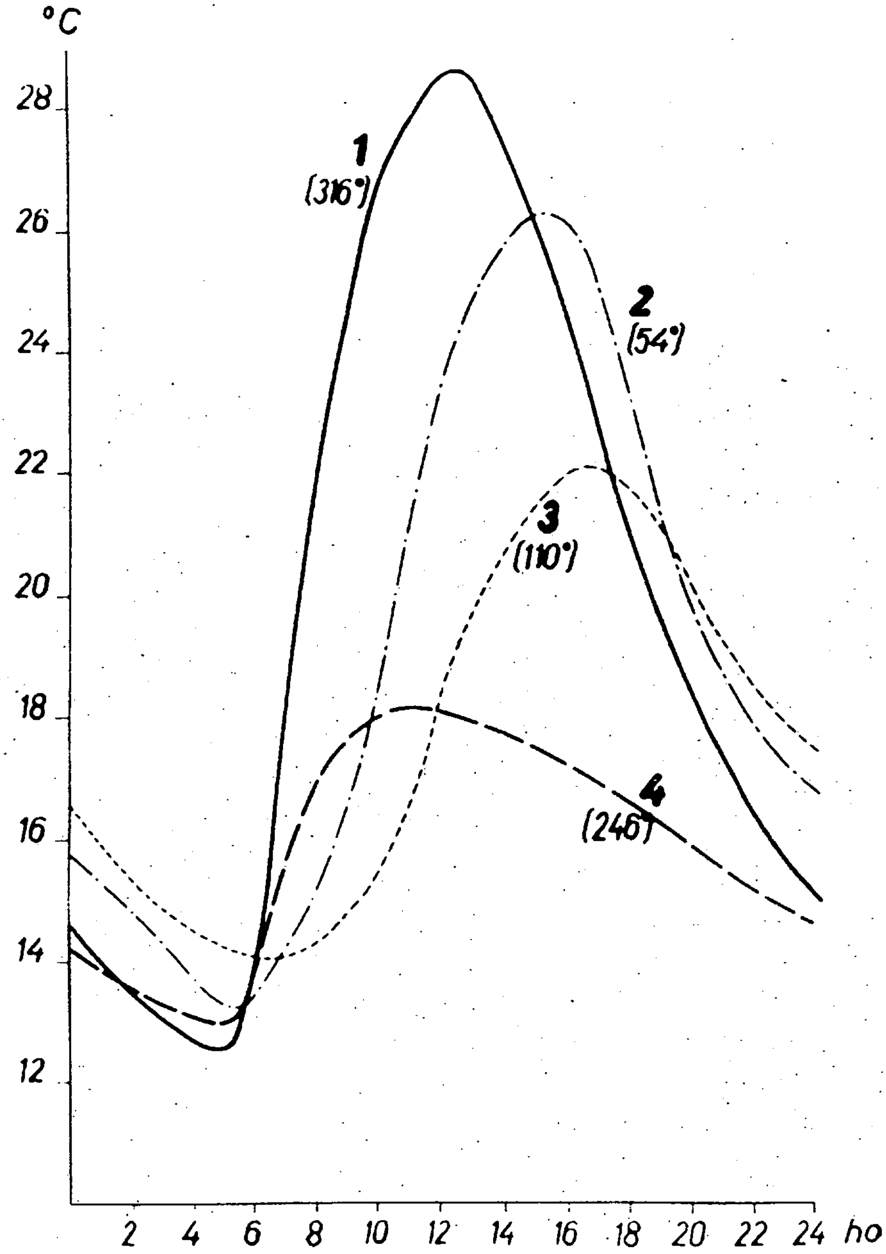


Figure 1. Soil-temperature curves, measured for a depth of 2 cm, from soil-temperature stations with different exposures in a dolina at Középbérc in the Bükk mountains. The 24-hour temperature diagrams were prepared from the average values of the observations of WAGNER for four consecutive cloudless days (6, 7, 8, 9th August, 1965).

1. In summer there is generally less cloud in the morning hours than in the afternoon.

2. Already in the early morning the eastern exposure receives by direct radiation the amount of heat which is of such decisive importance for the heating-up of the soil. During this same period the soil of the western exposure heats up very slowly by means of conductive heat transfer from the air, with its low specific heat. In the afternoon hours, however, when the western exposure receive direct irradiation, cooling-down of the eastern slopes by emission of heat can proceed only slowly, since the air in contact with the soil is strongly heated during the day. The eastern exposure is thus hot continuously throughout the complete period of irradiation, whereas the western exposure is hot only in the afternoon.

3. The frequency of summer showers is higher in the afternoon than in the morning. Because of this, in the intensive heating-up of the western exposures the thermal content of the direct irradiation is more frequently used for evaporation than on the slopes of eastern exposure.

4. The angle of incidence of the precipitation is controlled by the wind-direction prevailing at the time of the rainfall. This is usually a W—NW wind, and thus the eastern and south-eastern slopes receive statistically more precipitation than western and north-western dolina slopes of the same inclination.

The characteristic daily courses of the soil temperatures of the various exposures not only affect the soil at a depth of 2 cm, of course, but also determine the heat economy of practically the total active soil profile. The pedosphere processes of the dolina sides of eastern and southern exposure will thus always be more extreme than those of the sides of western and northern exposure. This can be perceived particularly well in the daily temperature fluctuation of the soil at a depth of 30 cm, where a variation of temperature can hardly be observed for the soils of the western exposures.

The above, very considerable differences in temperature, precipitation and heating-up within a dolina act in multiple connection on the CO_2 production of the soil of the dolina, on the intensity of the soil respiration, and heating-up within a dolina act in multiple connection on the CO_2 of microflora and fauna of the vegetation and the soil, and via all these on the karstic process itself in the long run, and on its local differences of dynamism.

For example, the moisture contents of the soils of dolina sides of various exposures are among others unmistakably connected with the extent of irradiation and the degree of heating-up. This is documented, for instance, by the results of our detailed dolina-recordings in a vegetation-free dolina (about 1300 m NNE from the bell-tower of the Protestant church in Jósvafő) of the Északborsodi karst; the vegetation-free state of the dolina at the time of the study (May, 1962) was the result of ploughing. The results of the determination of the moisture content by the drying-out of samples collected from the soil level at a depth of 10 cm are shown in Figure 2 in an interpolated form.

It has so far been confirmed that even within a single dolina there are very marked differences of soil temperature and soil moisture, and

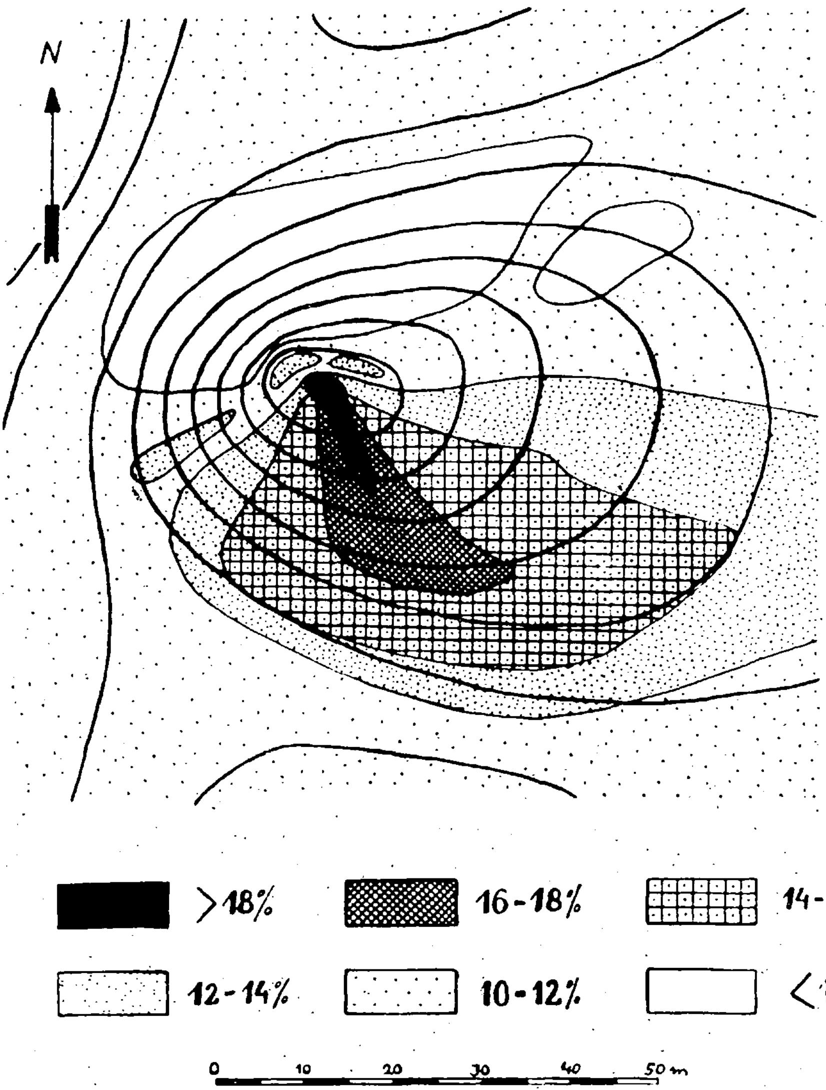


Figure 2. Example of the distribution of the moisture content of the soil at a depth of 10 cm in a vegetation-free (ploughed) dolina with uniform soil-quality. The values of the soil moisture are expressed as weight percentages. The contour lines depict the 1 m isohipsae. The chart was interpolated (according to a 10 m square mesh-grid) on the basis of 81 observations (original).

that these factors are related with the points of the compass. The further development of the chain of thought in the direction of the proof of the microclimatic regulation of the differences in dynamism of karstic corrosion is already quite apparent.

One of the fundamental precepts of biology, on a text-book level, is that the life-furctions of microorganisms living in the soil react sensitively to changes of the soil temperature. In 1926 RUSSEL published a diagram clearly depicting the sensitive fluctuation of the number of bacteria in the soil with the daily course of the temperature (Figure 3).

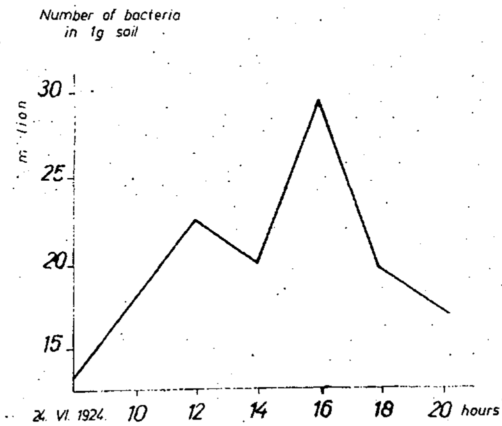


Figure 3. 12-hour variation of the number of bacteria living in the soil as a function of the daily course of the temperature of the soil level studied (observations of RUSSEL [1924]).

Based on extensive series of experiments and observations, however, FEHÉR (1954) also points out that in itself the optimum temperature is still not a sufficient criterion of the stimulation of the population of a soil microorganism; this can be ensured only by the synchronous occurrence of the temperature and soil moisture optima. According to his investigations, which were recently supported by those of BECK (1968), the crucial optimum for the virulence and multiplication of the bacterial flora in the soil is ensured by a temperature of 25 °C, with a simultaneous soil moisture content of about 25 wt.%, naturally under adequate soil-aeration conditions. The decrease or increase of any of these factors immediately results in a strong decrease of the number of bacteria. The extents of the correlations can be estimated numerically from Figure 4.

Under the climatic conditions in Hungary, the variations of the temperature and moisture content of the soil generally develop antagonistically. In summer, when the temperature attains the optimum values, the water content of the soil is usually low. Even when it is temporarily higher at the time of a more considerable precipitation, the higher temperature again impedes the optimum development of the bioactivity by providing the heat required for evaporation.

Because of the considerable exposures of the dolina sides, this antagonism which is characteristic of the Hungarian climate appears still more markedly in the dolinas. For this reason, in the soil of the dolina slopes of eastern and southern exposure, which heat up rapidly and srongly, there will be shorter periods when the temperature and moisture conditions are almost optimum for the bioactivity (the strong insolation following night or early morning rains in summer). At such time the sudden increase in the number of bacteria and the accompanying enhancement of the CO_2 production in the soil lead to the peak values extremely quickly. In general, however, as regards the conditions of existence of the microorganisms the effects of the higher quantities of heat are adversely affected by the often prolonged, strong drying-out of the soil in summer, and because of this on slopes with such extreme amplitudes of temperature and soil moisture the bioactivity and hence the intensity of karstic corrosion also exhibit very wide fluctuations.

In contrast with this, we have seen that there are no such similar extremes of either temperature change or moisture content in the soils of dolina sides with northern or western exposures. The generally lower, but more even temperature course and the more significant soil moisture do at times exhibit different degrees, but they definitely ensure a more settled soil microorganism level. In implicit form, therefore, this has already been used to point out the perhaps most decisive cause of the less fluctuating, but weaker tendency to corrode, which is characteristic of the soil waters of the exposures in question.

In connection with this, it should be noted that in the morphogenetic effect arising from the differences in exposure of the dolina sides WAGNER lays great stress on the insolation factors disintegrating the rocks, this process being more pronounced on the rocky slopes with eastern exposure which heat up rapidly, and on the physical disintegration factors involved in the possibilities of more intensive lithoclase formation due to the movements of expansion. However, there have so far been no concrete investigations on the limestone dolina sides to confirm this very realistic-seeming conception, and thus his view must for the present still be regarded as a working hypothesis regarding the extent of the morphological assertion of the factor.

Naturally, the discussed microclimatic exposure characteristics in a dolina are not only essential quantitative and qualitative determinants of the phytoedaphon, but also permanently favour the structure of the macroflora. For example, steppe-meadows rich in forest-steppe species (Festucetum sulcatae) occur on the (usually rocky) slopes of southern exposure in the unwooded dolinas in the Bükk mountains (Hosszúbércirét, Kismező, Nagymező) or on the Északborsodi karst (Verőtető, etc.); in contrast, mesophil mountain meadows (Festucetum ovinae) can be found on the eastern and western slopes and in general on the rim too (if the soil is not deep); on the northern slopes either the former or hazel

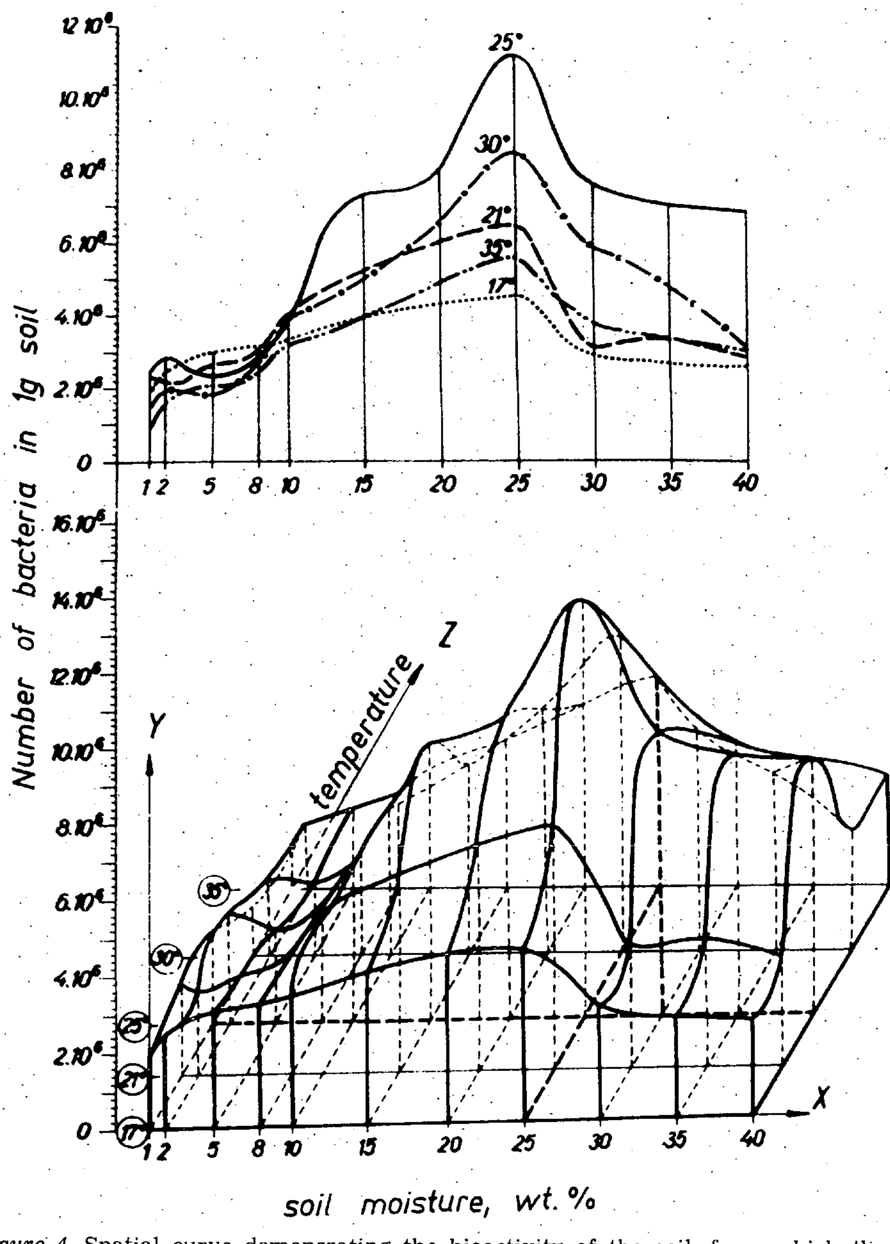


Figure 4. Spatial curve demonsrating the bioactivity of the soil, from which the reflection of the complex effects of temperature and moisture on the number of soil bacteria can be read off numerically. The X-axis gives the soil moisture in weight %, the Z-axis the soil temperature in °C, and the Y-axis the number of bacteria referred to 1 g soil. The upper diagram gives a projection of the curves in the X—Y plane (after FEHÉR).

groves occur (if rockier: Coryletum avellanae); and on the flatter parts with deeper soil, such as the shoulders and the bottom of the dolina matweed swards (Nardetum strictae) occur. If the bottom of the dolina is rocky and funnel-like, then high, dry-stalked vegetation may develop there (Aconitum, Gladiolus, etc.) (JAKUCS 1961/1—2, 1962). These plant-associations exhibit inversion zonation in the dolinas.

Such a vegetation inversion has otherwise been demonstrated by GEIGER (1961) in the Lower Austrian Gstettneralm dolina, and by HORVÁT (1953) in dolinas of the Yugoslav Karst mountains.

It is obvious that other associations are found in other vegetation zones (altitude zones), and the situation is completely different even in a wood-covered dolina. However, the differentiation according to exposure is characteristic there too. Via pedosphere transposition, all this has a great effect on the subsurface karst-formation, since the demands of the various plant species towards the soil differ, as do the effects on the development of the soil and on its state as regards its chemistry, its microorganisms, its moisture, its aeration, etc.

For abvious reasons, these relations have still not been examined in magnitude with regard to the association types of the natural flora living on the karsts, but as regards the agricultural plants and some other, mainly tree species, series of relevant concrete results have long been available. Table I (after STOKLASA—DOERELL [1926]) shows the CO_2-productions in the soil the soil of six agricultural plants and four soil bacterium species; the amounts of CO_2 formed correspond to 1 g dry weight of the roots or bacteria.

TABLE I

plant or bacterium	24-hour CO_2 production (in mg CO_2)
sugar-beet	0,3 — 5,4
barley	63,2 — 74,6
wheat	87,6 — 94,8
rye	100,7 — 131,0
oat	111,5 — 135,4
buckwheat	212,5 — 274,0
Clostridium gelatinosum	480
Bact. Hartlebi	600
Azotobacter chroococcum	1270
Bacillus mesentericus	13000

It is immediately seen from the Table that from the point of the edaphic CO_2-production the bacteria (but microorganisms in general) are of much greater importance than the plant roots. The fact that despite this there is an unmistakable connection between the formation of the root-karr channels and certain plant species in the karst vegetation (e.g. Nardus stricta) (JAKUCS 1956) is in our view probably connected with the phenomenon that bacterium populations of different species live in different numbers in the root zones of the various plants; indeed, partly in symptomatic relation with this, the local soil moisture concentration in the rhizosphere (particularly in an arid period) points to the adequateness of a plant species.

The importance of this connection between the plant roots and the number of bacteria in the soil was determined quantitatively by THOM and HUMFELD (1932) (see Table II).

TABLE II

	number of bacteria in 1 g soil	number of fungi in 1 g soil
in soil without roots	5 500 000	100 000
in the rhizosphere in general	26 000 000	800 000
in the immediate vicinity of the root-hairs	136 000 000	7 000 000

Since the carbon dioxide production of the soil depends very strongly on the edaphon amount (FEHÉR 1954, GEIGER 1961, FEKETE 1952, 1958, STEFANOVITS 1963, FEKETE—HARGITAI—ZSOLDOS 1964, BECK 1968), on the above basis it is almost necessary that there should also be considerable differences in the amounts of carbon dioxide produced by soils of different flora-cover (and hence different homus content) and of different vegetation type. That this is in fact so has been confirmed by the now classic observations of STOKLASA and ERNEST (1922). Some of these data are given in Table III, with the note that although these observations do not refer to karst, similar tendencies are exhibited on karsts.

By comparison with Tables I and II, it is immediately obvious that the ability of the roots of certain plants (together with the related phytoedaphon) to corrode limestone will be many times larger than that of some other plant living in the same area (e.g. in a dolina), the rhizosphere of which requires a bacterial symbiosis differing both quantitatively and qualitatively. Thus, the question raised at the beginning of this paper, as to which are the *smallest* natural geographical area units for which the microclimatic genetic differences inspiring the differences in intensity of karst-formation can still be formally expressed, can have only one answer: *there are no such smallest magnitudes.*

The reason for this is that in the subsoil karst-formation, where the normal surface planation processes (wind, water erosion, etc.) which otherwise ensure areality can not play a role, even within the smallest area innumerable minute faults with different denudation dynamics exist in direct proximity to one another. These may be of the order of a square metre, a square centimetre, or a square millimetre. *In these sometimes infinitesimally small micro-areas, which are differentiated in their degrees of corrosion, characteristic adequate solution microforms develop, which*

TABLE III

Carbon dioxide productions of various types of soil (after STOKLASA—ERNEST)

type of soil	depth	amount of CO_2 produced (mg) in 24 hr from 1 kg soil at 20°C
adobe	surface soil	49,7
adobe	subsoil	7,6
calciferous	surface soil	18,5
calciferous	subsoil	9,8
marsh	surface soil	41,2
forest	surface soil	36,4
forest (humus-poor)	25 cm	9—12
forest (humus-rich)	25 cm	20—26
pasture	25 cm	10—16
barren (humus-poor)	25 cm	8—14
good rye and wheat soil	25 cm	30—48
good clover soil	25 cm	53—60

in their sum total then form the traditional karst-morphology form-types, such as the karr-field, the dolina, etc.

Of course, it would be quite erroneous to draw from this any conclusion such as that the development, character and arrangement of the macroforms on a karst come about only from the statistical sum of the partial processes of the microfacies. In reality the reversible assumption also acts in the opposite direction: the criteria and proportions of the microclimates and association-units and the arrangements of occurrence of their types are determined by the zonal macroclimate of the area, by its petrological nature, and by its topographical, tectonic, hydrographic, etc. variances. *That is, although the corrosion processes themselves do proceed in the mosaics of the micro-areas, these mosaics fit into one or more larger systems, and the characteristic features of such systems are no longer qualified by the mathematical sum of the partial processes of the mosaics.*

Methods of studying the CO_2 contents of gas mixtures from micro soil areas

We have seen that the investigations most closely approaching our problem arose from researches not of geomorphologists, and even less of karst-morphologists, but primarily of agronomists, pedologists and biologists. It is natural, therefore, that the data do not refer to the undisturbed soil and vegetation processes of karst and their CO_2-production correlations, but are concerned in fact mainly with cultivated plants. The few references in the karst-genetic literature (TROMBE 1951/2 1952, 1956, SMYK—DRYZAL 1964, etc.) too are either based on only one or two measurements, or generalize observations in the pedological literature arising from other pedofacies. And although this dependence on analogy (while we can not rely on series of measurements concretely for karstic regions) is completely self-evident, and indeed can also provide reasonably good results, an effort nevertheless had to be made to provide an answer to the problem on the basis of researches into the problem itself.

However, this was not an easy task, and the series of investigations which have been begun have by no means been completed. A particular difficulty was caused above all by the fact that we ourselves had to develop suitable methods of research. The methods applicable at present to the recording of soil respiration and permitting the analysis of the soil atmosphere could not be used in our case.

It is well known that the proportion of CO_2 in the soil air is generally determined by taking a sample from the undisturbed soil by means of a suitable apparatus (most often with a metal cylinder with a sharpened rim, containing a volume of 1 litre), then transporting the sample to the laboratory (excluding the possibility of exchange of the air), expelling the soil air from it with water or a 10% solution of common salt, and collecting the air bubbles with a funnel. The soil air thus obtained is then analysed for its CO_2 content by absorption in potassium hydroxide solution in the ORSAT smoke-examination apparatus, or by the GORBUNOV barium hydroxide (hydrochloric acid titration) method (BOROVJEV—JEGOROV—KISELJEV 1951, di GLÉRIA—KLIMES—SMIK—DVORACEK 1957, BALLENEGGER-di GLÉRIA 1962).

If it is desired to establish the extent of CO_2-production of the soil in unit time, the course of the analysis is modified as follows: a slow current of air is sucked through the soil samples in the laboratory, the carbon dioxide contents being measured both on entry and on exit (via absorption, by volume or weight analysis or titration), and the difference between the two is used to calculate the CO_2 content referred to the measurement time and the amount of soil used in the experiment.

In another procedure a metal bell, closed from the side and above and prepared for this purpose, is pressed to a certain depth into the soil; the air expired under the natural conditions from this is collected in the bell, which is next connected to an appropriate apparatus (e.g. the LUNDEGARDH apparatus), and the amount of CO_2 absorbed by the $Ba(OH)_2$ is determined by the above-mentioned method of titration with hydrochloric acid (BALLENEGGER 1953, FEHÉR 1954).

We too carried out our first investigations into the CO_2 content of karst surface soils with the above method, but the time and laboratory requirements of these procedures induced us to develop a more rapid method of measurement which could be employed on the spot. In addition to attempts to use the time more profitably, this was also induced by other aspects. It was observed that the time between the taking of the soil sample and the performance of the laboratory work is of great importance as regards the CO_2 content of the soil air. Of soil samples of the same nature, collected from under the same vegetation at the same time and immediately adjacent to one another, that one was always found to contain significantly more CO_2, from which the air was expelled latest. This is otherwise understandendable, since nothing justifies the stopping of the biovegetative and other oxidative processes to the extent of the oxygen-reserve of the atmosphere in the hermetically sealed soil sample. In serial examinations, however, where the comparison is the essence, this circumstance means that the method is of practically no use.

If it was desired to measure the extent of the soil respiration, the problems increased still further. By virtue of the nature of the matter, such a determination demanded so much time (according to the methods employed, the laboratory or field observation time necessary to record a single datum was at least 5—10 hours), that a statistically evaluable series could not be obtained by this means either.

Since our research aims required the comparison of the CO_2 contents of adjacent karst surface soil areas with different microclimates, and mainly in syncronism, it became unavoidable to develop a method of measurement which was rapid and could be performed on the site. Two procedures were elaborated for this purpose, and in the absence of any earlier publications in this respect, a brief account of these will be given below.

Method I. The soil gases are extracted by means of a thin copper probe, with an external diameter of 5 mm and the wall of which is perforated at the end. This can simply be inserted into the soil to the required depth. It should be noted that the lower end of the 40 cm long probe ends in a conical point, and a steel rod of the same thickness as the internal diameter of the tube can be slid into it. This rod is left in the probe when the latter is inserted into the soil, and must be removed from it only immediately prior to the extraction of the air sample. The tight-fitting steel lining serves partly to strengthen the thin-walled tube during the insertion, and partly to prevent the entry of soil particles into the probe through the perforations, but mainly to exclude the outflow of the soil air before required and the possibility of its admixture with other air.

Following the insertion of the probe, the surface of the soil within some dm^2 of the point of insertion is made impermeable to air; this is possible, for instance, by applying a film of thick oil (e.g. spent oil). (In the case of very porous, lumpy soils it is better to use melted paraffin or stearin.) The soil air is sucked out with a spring-motor or a small-current omtor (fed by a torch battery), specially constructed for this purpose, and connected to the above-ground end of the probe; the air is then led into an empty balloon (a football bladder proved very suitable) connected to the air-exit of the pump (see Figure 5).

After the extraction of about one and a half decilitres of soil air (depending on the air-permeability of the soil this requires 10—150 sec),

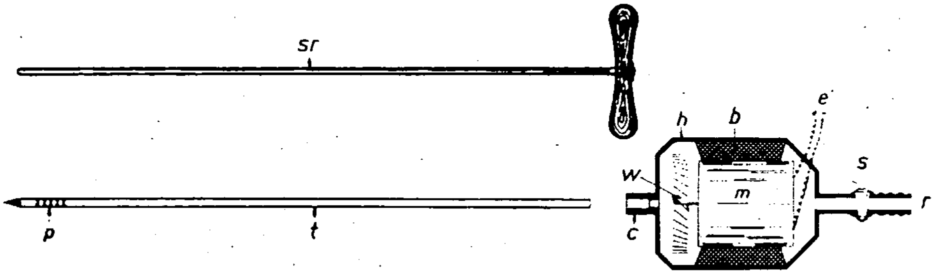


Figure 5. Principle of the soil probe constructed for the extraction of the soil gases (original).

t= thin-walled gas-extraction probe tube
p= perforation in the tube wall
c= air-tight cuff on the connection to the pump cose
w= 16-blade air-turbine wheel
m= small-current (12 V) motor (e.g. car windscreen wiper motor)
b= motor-support brackets
e= energy-supply leads with air-tight insulation
h= pump housing
s= stop-tap
r= rubber tubing
sr= steel support rod

the rubber tubing is clamped and connected to the ORSAT apparatus; the soil air is first used to flush out the apparatus, while a second filling is absorbed with a potassium hydroxide solution, which is then analysed by titration (Figure 6).

The method, which was first employed in 1965, can be carried out on the site, one person performing 4—5 determinations per hour. If it is wished to repeat the measurement at a later time (e.g. the following day), it is best to work with several probes and to leave the inserted probe in the soil during the period of repetitions.

In 1965 and 1966 this procedure was used to perform serial measurements in practically all of the karstic mountains of Hungary (Északborsodi karst, Bükk, Pilis, Gerecse, Bakony, Mecsek, and even in the Soproni basin at Fertőrákos). After the recording of some 300 measurements, it had to be recognized that although the differences in the CO_2 concentrations of the pore gases from the different soils and levels exhibit a considerable magnitude (several per cent) even, within small distances, while even at a given observation point the soil air space too is of high amplitude (depending on the time of day and other factors), there being very rapid changes of concentration at such times; nevertheless our data can still not provide a sufficient basis for the recognition of the regularities.

One of the possible reasons for this might be that the accuracy of the results is affected by the admixture of the soil air with the natural air present in the housing of the pump. This undoubtedly modifies the results, but at the same time the amount of normal air mixed in with

Figure 6. Study of soil air with method I on the Bükk plateau. The ORSAT gas-analysis apparatus can be seen in the right half of the picture, while on the left edge is the probe implanted into the soil, together with the attached suction head and the rubber tubing.

the sample is always the same (ca. 30 mm^3), and hence only the absolute values were modified, the ratios remaining relatively not affected.

However, the need to make the method more accurate was also justified from another aspect. The some 150 ml of soil gas absolutely necessary for the analysis was collected from the variable-diameter depression lens of the soil surrounding the perforated end of the probe, and the extent and form of this lens depended on the porosity factors and moisture content of the soil,. i.e. on unknown factors. Because of this, the method could not be used effectively to examine in particular the specific CO_2 productions of the rhizospheres of plant species living in direct proximity to one another.

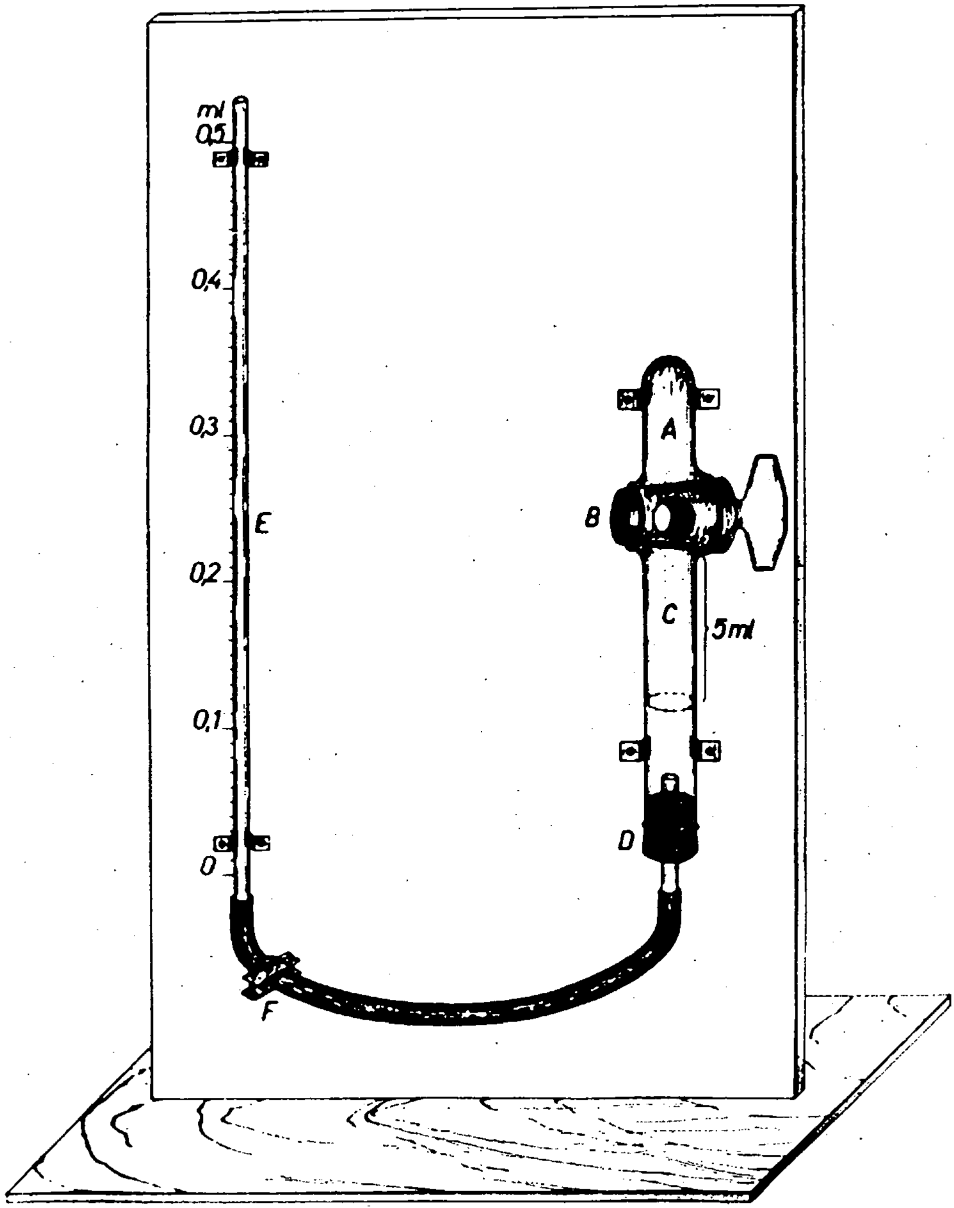
In order to surmount the above problems, therefore, a microanalytical method had to be developed, with which an accurate analysis could be carried out on a substantially smaller amount of gas. In this case controlled obtaining of a small quantity of gas from a planned locality can be much better ensured. The solution was found in 1967 in method II, described below.

Method II. The volume of the soil air sample required for the analysis was now only some 5 ml. This amount of gas is sucked out of the soil at the selected point with a PRAVAZ syringe. (It is advisable to ensure perfect fitting of the piston of the syringe with a coating of paraffin oil!) After insertion of the injection needle, the length of which is selected in accordance with the depth of the soil it is desired to examine, it is necessary here too to make the soil surface impermeable to air for a distance of about 20 cm around the point of insertion. It should be noted that during the insertion of the needle into the soil the mandrin must be left in it, and withdrawn from it only immediately prior to the connection to the syringe.

In our experience, if the soil is not extremely impermeable clay, or very miry, the extraction of the 5 ml of soil air generally presents no difficulty, and the diameter of the above-mentioned gas-depression lens is no more than a few centimetres. Thus, the extraction is localized to a well-defined pedosphere, corresponding exactly to the prescribed requirements (e.g. to the root zone of a single clump of grass).

The extracted air sample is analysed with the apparatus shown in Figure 7, according to the following:

The thick-bore ground-glass tap *(B)* divides the test-tube into two parts *(A* and *C)*. With the rubber stopper *D* removed, potassium hydroxide solution is poured into the test-tube, with the tap in the open position, so that *A* and the hole through the tap are filled with the solution and all air bubbles are excluded. (Concentration of KOH: 1 part KOH, 2 parts H_2O.) The tap is next closed, the KOH solution remaining in part *C* is poured out, and this part of the apparatus is then made free of alkali by repeated washing with water. Part *C* of the test-tube thus prepared is now filled completely with 10% NaCl solution dyed red or dark-blue, and the test-tube is inverted (mouth downwards) and placed in a flat glass bath containing the same solution. In this position, gas is


ml
0,5
0,4
0,3
E
0,2
0,1
0
F
A
B
C
5ml
D

bubbled into it from below out of the PRAVAZ syringe, until the coloured solution has been expelled from the test-tube down to the 5 ml mark on the wall of *C*. With its mouth still under the surface of the solution, the test-tube is stoppered with the rubber stopper *D*.

The glass tube in the stopper, the connecting rubber tubing and the calibrated capillary tube *E* too must also be filled with the coloured NaCl solution.

After the connection of the two parts of the apparatus, it is wiped dry on the outside, and fixed to a suitable stand in the position shown in Figure 7. The clamp *F* is opened, and the rubber stopper *D* is pushed a little further into the test-tube, so that the resulting weak excess pressure in *C* causes the capillary tube *E* to be completely filled by liquid. Any solution spurting out from the upper end of the tube *E* is carefully dried off with blotting paper, and when the upper end of the thread of liquid in the capillary tube has attained an equilibrium position (this sometimes requires 1—2 minutes because of the temperature-pressure equalization) the height of the meniscus is noted. Tap *B* is now. opened to permit communication between parts *C* and *A*. The potassium hydroxide solution trickles from *A* into space *C*, while the gas partially migrates from *C* into *A*. During this movement the CO_2 content in the gas mixture is absorbed. That is, the total volume of the gas and liquid-state phases in parts $A+C$ will now be less than the combined volumes of parts *A* and *C* before the opening of the tap by a volume corresponding exactly to the concentration of CO_2 in the gas mixture. The level of the liquid in the capillary tube *E* therefore falls in accordance with the loss of the CO_2 partial pressure.

If the capillary tube used is such that 0.5 ml liquid occupies a length of 50 cm inside it, then a fall of the meniscus by 5 cm corresponds to 1% CO_2. In this case, therefore, since a movement of 0.5 mm can be observed in the meniscus, the apparatus will be suitable for reading off directly any intermediate amount, up to a maximum CO_2 content of 10%, with a sensitivity of 0.01%. Naturally, depending on the bore and length of the capillary tube, scales which are more sensitive or less sensitive can be made.

When the measurements are carried out, however, particular atten-

Figure 7. Principle of the calibrated capillary-tube microanalytical gas-analysis apparatus (original).

A= potassium hydroxide reservoir

B= thich-bore ground-glass tap

C= reaction vessel consisting of an upper part with a 5 ml calibration and an uncalibrated lower part into which a stopper can be inserted

D= single-holed rubber stopper, fitted with a glass tube, the lower end of which is connected to rubber tubing

E= calibrated capillary tube for reading of observations, open at the upper end.

F= clamp

tion must be paid to one aspect: the apparatus reacts sensitively to even the slightest change of temperature. For this reason it is possible to work with the apparatus only in the shade, while that part of the vessel containing the reagents should be handled only with wooden holders, and should be protected from the heat of the hand and the breath.

With the necessary practice, the use of this procedure gives results quickly and accurately. It was employed in 1967 and 1968 to perform 940 measurements, the minority in Hungary, and the majority in Yugoslav karst regions. Since our researches on this theme will be completed only after several more years, a detailed account of the results gained so far will not be presented here. However, since they provide important information with regard to the understanding of the magnitudes of the karst-corrosion processes in the micro-areas, we shall now turn to some partial questions which can already be regarded as completed.

Examples of the characteristics of the CO_2-economy in the soil atmospheres of karstic micro-areas with different bio- and climatic-specifics

Even our first soil air examinations disclosed that, as regards the CO_2 concentrations of the soil gases, considerable differences are found not only between simultaneous measurements *at different positions*, but also between those for a given sampling point *at different times*. These are not only concentration level waves of large amplitude during the different periods of the year, as already described in the pedological literature (e.g. FEHÉR 1954), but gas composition changes of a much shorter period, which are nonetheless very appreciable. In the majority of cases, the same experimental result can not be observed twice, even at a given point.*

The above findings induced us, therefore, not to be satisfied with a large number of sporadic data, but to strive to compare homochronous series of data, if possible from a complete area of certain karstic forms (e.g. individual dolinas), and in addition to obtain material reflecting the tendencies of the happenings within longer or shorter time series at a specified observation point. For this reason, and particularly in 1968, measurements were generally made at one point at 2 or 1-hour intervals, during a period of one or several days.

These researches led to extremely instructive experience of prime importance, among others in one of the dolinas of a low, terra rossa limestone plateau lying to the south of the town of Karlovač in Croatia in Yugoslavia. Two needle probes were implanted into both the northern and the southern exposures of the dolina sides, one each at a depth of 5

* It should be noted here that in our experience it is necessary, when the 5 ml microanalytical method is employed, to ensure a rest period for the regeneration of the gas of at least one hour between two consecutive measurements.

cm and one each at 20 cm. The entire dolina was covered with fairly homogeneous vegetation: Pteridium aquilinum about 60—80 cm in height. On the two exposures where the stations were located the surfaces selected had the same slope (ca. 20°), and the sampling needles were implanted immediately beneath a Pteridium root. It was not possible to observe macroscopic differences in the soil composition on the two exposures, but the soil on the northern exposure was substantially wetter (even at the 5 cm level). (In the absence of the possibility of quantitative measurements, only estimations could be made in this latter respect.)

Figure 8 shows the variation in the CO_2 content of the soil gases on the first day of examination (14 July 1968), which was hot, unclouded and still throughout.

The daily concentration curves of the Figure referring to the indi-

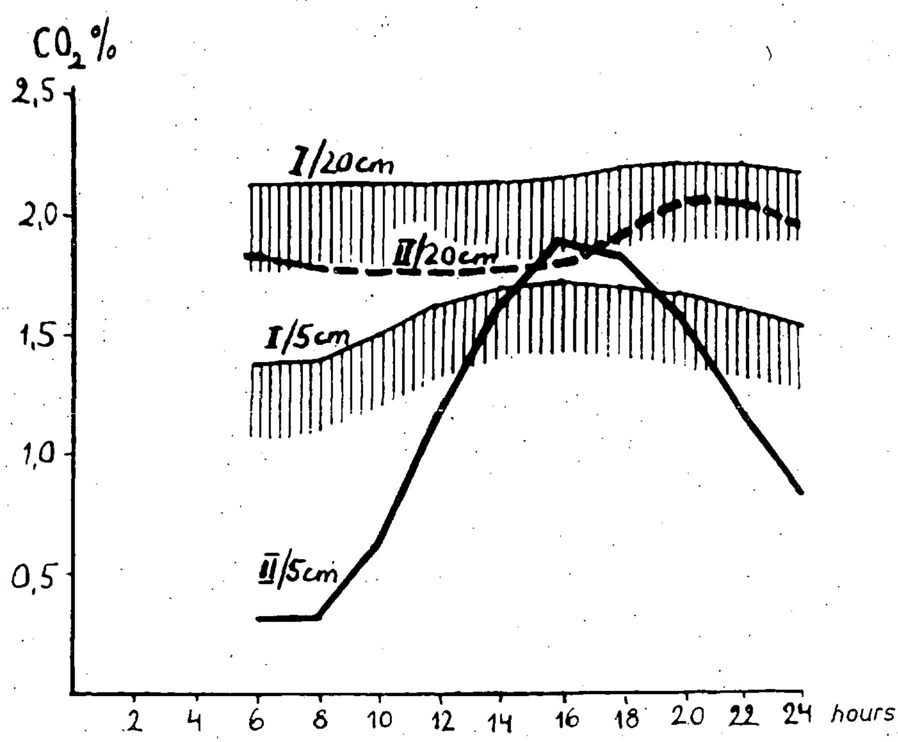


Figure 8. 18-hour variation of the CO_2 content of the soil air collected from the 5 and 20 cm levels under a well-developed Pteridium aquilinum plant on an unclouded, still summer day (14 July 1968). The measurements were recorded at 2-hour intervals on 20° slopes of northern (I) and southern (II) exposure in a dolina in Croatia (beside the main road leading towards Plitvice, about 12 km south of Karlovač). Type of soil: at 20 cm dominantly red-clay rendzina, and at the 5 cm level friable surface soil of mull type (original).

vidual points and levels give rise to the following findings, which, since no conflicting results have yet been obtained elsewhere, may perhaps be formulated already in a more generalized way.

1. The CO_2 content of the soil air in every layer of the studied exposures (in the karstic surfaces covered with vegetation) down to a depth of 20 cm exhibits *a daily course,* which adjusts itself sensitively and approximately linearly to the temperature curve of the soil.

2. The CO_2 concentrations of the soil gases at depths of both 5 and 20 cm fluctuate with much greater amplitudes in the southern than in the northern exposures.

3. As regards the daily average, the CO_2 proportions of both layers of the surface soil of the southern exposures are less than those of the nothern exposures. (It will be seen later that this point is valid only if the soil in the southern exposure is dry, while in the northern exposure it is wetter.)

4. The CO_2 concentration in the 20 cm soil gas is generally higher than at 5 cm. (It will be shown later in connection with this, that it holds only if the upper pedosphere is substantially drier than that lying below it.)

If the main conclusions drawn form point 1 and from points 3 and 4 are compared, it is clear that they undoubtedly contain some contradiction. It the proportion of CO_2 in the soil air is inteed directly related with the thermal level, then it would justly be expected that the CO_2 concentration of the soil gas would be more significant on the slopes of northern exposure receiving a higher insolation calory total, and also at the 5 cm soil level which is heated up more readily. In the given case, however, two circumstances must also be taken into consideration, which mar the biostimulative effect of the thermal level and its true reflection in the carbon dioxide proportion. These are the considerable dryness of the soil on the slopes of southern exposure, and the enhanced aeration of the soil in relation with its dryness.

That the role of the soil moisture on the biological activity of the edaphon (and by extension on the CO_2 production) is not negligible, has already been studied in Figure 4. However, the tremendous importance to be attributed to the degree of aeration of the pore-space of the soil could be decided only from the following daily diagrams taken in the Croatian dolina. The earlier period of still conditions came to an end on the day in question, and the mild gusts of wind exerted a very noticeable effect on the development of the curves (see Figure 9). The essence of these effects can be summarized in the following points.

1. Even a fairly slow wind strongly decreased the CO_2 content of the soil air.

2. This decrease of the CO_2 concentration of the gas is connected not with the slowing-down of the production of CO_2 in the soil, but with the enhancement of the exchange dynamism of the given gas reserve of the pore air space. This can be concluded, for instance, from the large peak at 15 hours for curve II/5, the development of which

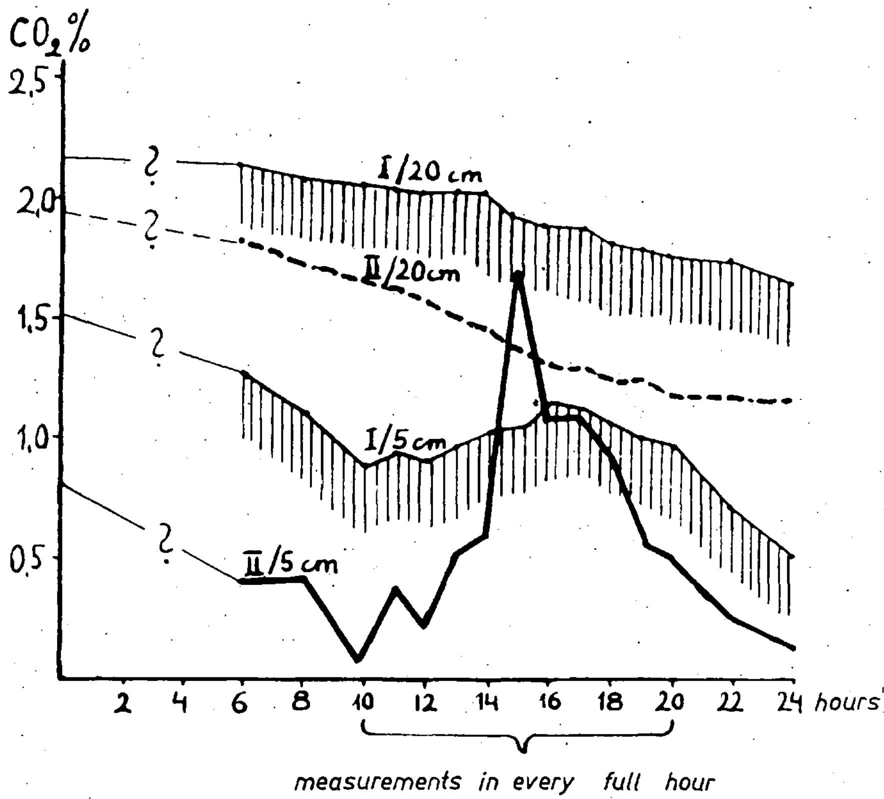


Figure 9. Variations of the CO_2 content of the soil air at the points described in Figure 8, between 6 a.m. and midnight on a summer day (15 July 1968) which was about 60% cloudless, and was moderately windy from the morning hours on (original).

without a transition in the period of calm can be understood only if it is assumed that although the biological activity of the edaphon is successively increased from low values during the earlier hours, the conditions for the remaining of the gas-phase metabolism products in loco nascendi have only now become realized. It must also be assumed that the aerobic processes in the soil are affected favourably by the passage of air through it due to the wind, and thus only the postulates of the accumulation of gas can not be satisfied as a result of the gusts of wind.

3. The wetter the soil, the slower the gas-exchange due to the wind and the less effective the process. This can be seen particularly well on comparison of curves II/5 and I/5. These differences in value, however, again lead to the result only that in both layers studied the CO_2 content of the soil air of the northern exposures still exhibits a higher concentration average than that for the southern exposures.

4. The relatively significant, but brief rise of the CO_2 concentration in the uppermost soil layer has practically no effect on the development of the concentration at lower levels, which decreases slowly during a wide time interval.

The extension of this series of investigations into the third day was justified by appreciable rainfall in the small hours of the 16th. The CO_2 content of the soil air during and following the raining exhibited extremely interesting courses at depths of both 5 and 20 cm. The series of data obtained can be compared from the curves in Figure 10, from which the following consequences are fairly obvious.

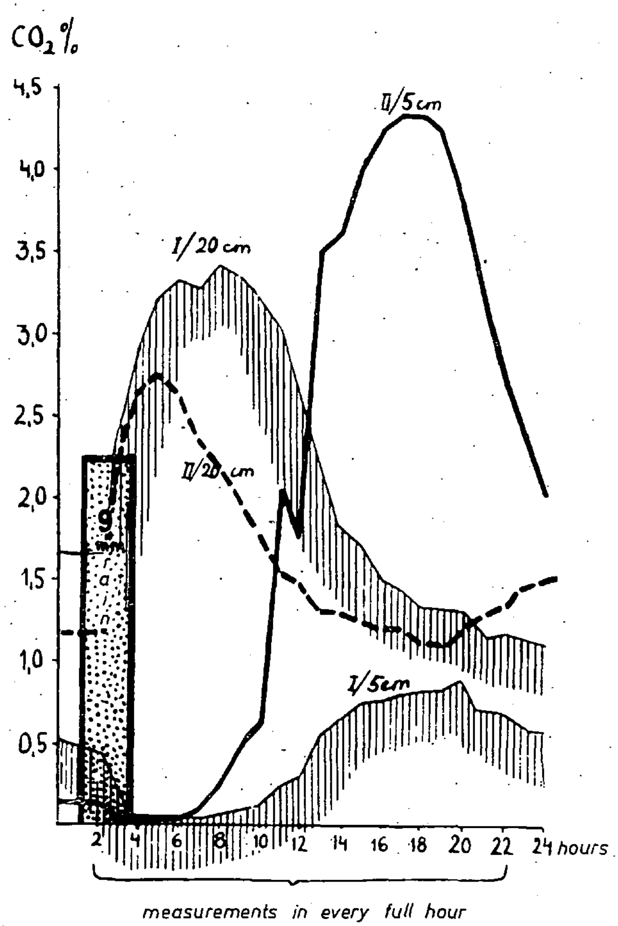


Figure 10. Variations of the CO_2 content of the soil air at the points described in Figure 8, on a cloudless, still summer day (16 July 1968) following a night storm producing about 9 mm rain. The rain, which fell from 1.10 a.m. until 3.35 a.m., was intense in the initial phase, and later gave way to a number of gentler waves with lese precipitation (original).

1. In the uppermost zone of the soil, which is wetted directly by the rain percolating downwards (in our case this included the 5 cm soil level in both the southern and the northern exposures), the rain absorbs the carbon dioxide content of the soil air essentially during the time it is trickling down, and the carbon dioxide is practically completely consumed.

2. In the deeper soil levels, which are not directly affected by the infiltration, immediately following the rainfall the proportion of CO_2 in the pore gases begins to increase rapidly, and compared to the earlier values unusually high concentration levels are attained. Here, therefore, a surprising *inversion* comes about in the CO_2 economy of the soil levels at 5 and 20 cm, which then remains essentially unchanged during the later stages of the day (if there is heating-up by strong insolation during the day).

As regards the cause of the striking phenomenon in the night, we can only think that the swelling of the upper soil layer due to the strong infiltration and hence its temporarily becoming impermeable to air prevent the earlier natural aeration of the deeper soil levels, and thus the gaseous products of decomposition and other oxidation metabolic processes taking place there accumulate.

That this factor may indeed be the principal agent behind the phenomenon emerges from the differences in the 20 cm curves for the southern and northern exposures. The sealing-in of the air due to the wetting comes to an end sooner (at around 5 a.m.) in the soil of the southern exposure (curve II/20), which was the drier before the rain, than in the soil of the northern exposure (curve I/20), which was originally wetter and thus remained soaked with water for a longer period, the concentration of CO_2 in the gas here beginning to decrease essentially only after 8 a.m.

3. As a result of the direct insolation and air-conductance heating-up during the day, the CO_2 production of the 5 cm level in the southern exposure (curve II/5) attains a value significantly exceeding all earlier ones; in this case this is connected with the coincidence of the optimum quantities of heat and moisture developing in the soil during the course of the day. It now appears, however, that the maximum of the peak is obtained with a delay of several hours compared with the usual time for the occurrence of the peak on curve II/5 for the earlier days. This is almost certainly related to the heat-extraction due to the stronger evaporation in the morning.

It should be noted that the counter-tendency of the curve between 10 and 11 a.m. can not be explained, but it is not impossible that it is the effect of a slight air-movement which we did not detect.

4. The fall of the CO_2 concentrations of the 20 cm soil levels during the day, particularly in those periods when this coincides with the increase in the CO_2 concentration of the layers lying nearer to the surface, is difficult to explain. The possibility can not be excluded, however, that

a part is played here by the absorptioon of the soil moisture which has infiltrated meanwhile to a deeper level.

5. The increase in the values of the II/20 curve after 7 p.m. show the effects of the high CO_2 concentration of the gas at a depth of 5 cm.

6. The very considerable differences in order of the afternoon increases of curves II/5 and I/5 indicate that under uniformly favourable soil moisture conditions the CO_2 production of the soil on the southern slopes, which are heated more intensely, will be several times that on the northern exposures. (This latter finding should be compared with point 3 relating to the discussion of Figure 8.)

7. Under favourable soil moisture conditions, primarily in the southern exposures, the CO_2 concentrations of the uppermost soil levels can attain higher values than in the deeper depospheres at these same points.

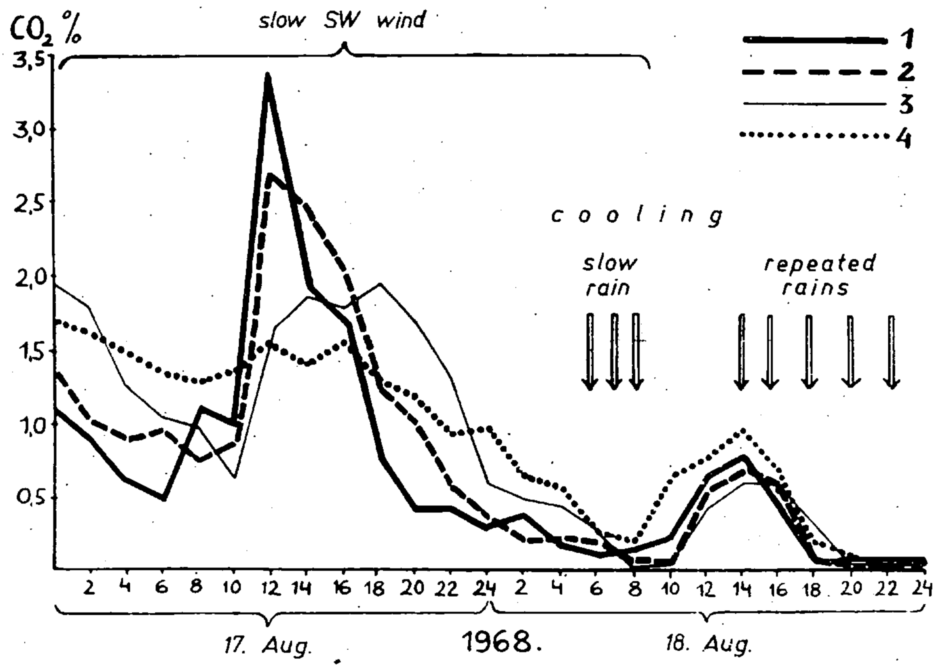


Figure 11. Example of the significance of the exposure on the intensity of karst-formation. Variations of the CO_2 content of the soil gases of the rhizospheres of Festucae growing on the sides of approximately equal steepness, but different exposures, in a dolina at Létrástető (unwooded) in the Bükk mountains, on a hot, sunny day, and the following rainy, cooler day. The curves comparing the results of analysis of the gas samples taken from the root clumps were prepared with measurements at 2-hourly intervals on 17—18 August 1968 (original).

1. Eastern exposure, Festuca sulcata
2. Southern exposure, Festuca sulcata
3. Western exposure, Festuca sulcata
4. Northern exposure, Festuca ovina

(This finding should be compared with point 4 relating to the discussion of Figure 8.)

From the several-day data series recorded on karstic plateaus in *Hungary,* we shall pick out our observations on 17—18 August 1968 in one of the unwooded dolinas at Létrástető in the Bükk mountains. These permit the comparison of the CO_2-economy characteristics of the soil gases of the slopes of northern and southern, and also eastern and western exposures, on a moderately windy, but sunny, hot day, and on the following rainy, cooler day (Figure 11).

In order that the tendencies of the soil gas resulting from the various exposures should be affected as little as possible by disturbing factors, in every exposition stations were established on sections of slope with the same angle of inclination, and rhizospheres of steppe-grasses (Festuca sulcatae) of the same variety and of the same stage of development were studied. Since well-developed Festuca sulcata was not found on the northern exposure, here it was established in the rhizosphere of a Festuca ovina, with somewhat fewer roots. At all points the samples of soil gas were collected from the 5 cm level. It must be noted that in the selection of the dolina an effort was made to site the stations in all exposures at points where the thicknesses and the natures of the soil were practically the same.

The following conclusions can be made from the 2-day series of observations.

1. On 17 August the SW wind (with an average wind strength of 4 according to the measurements of WAGNER at Kurtabérc) had the least disturbing effect on the course of the daily CO_2 level of the soil of the slope of eastern exposure, which was essentially sheltered from the wind. At noon here a CO_2 content of 3.35% was measured (daily peak), which is a very high value in a windy period, and in addition to the morning irradiation optimum is related with the favourable state of moistness of the soil. The peak in the CO_2 concentration curve for the southern slope, and even more so for the western exposure, was appreciably lower, even though the irradiation effects were favourable throughout the entire day. The effect of the dynamic aeration of the soil in decreasing the daily maximum was most strongly exerted on the western slope.

2. It can be seen that there is a difference of about 6 hours between the maxima of the curves for the soils of eastern and western exposures on the first day of the study. A shift of such an extent can be a result only of the differences in heating-up by dirrect irradiation. (On the following day, which was overcast throughout, the maxima on the curves for the various slopes practically coincide.)

3. In the northern exposure, which barely participates in the direct irradiation, the effect of the daily heating-up by air conductance in activating the CO_2 production is almost completely overshadowed by the blowing-out by the wind, and so this curve reflects the tendency of

the CO_2 concentration to decrease, characteristic for a windy day, with an almost uniform fall.

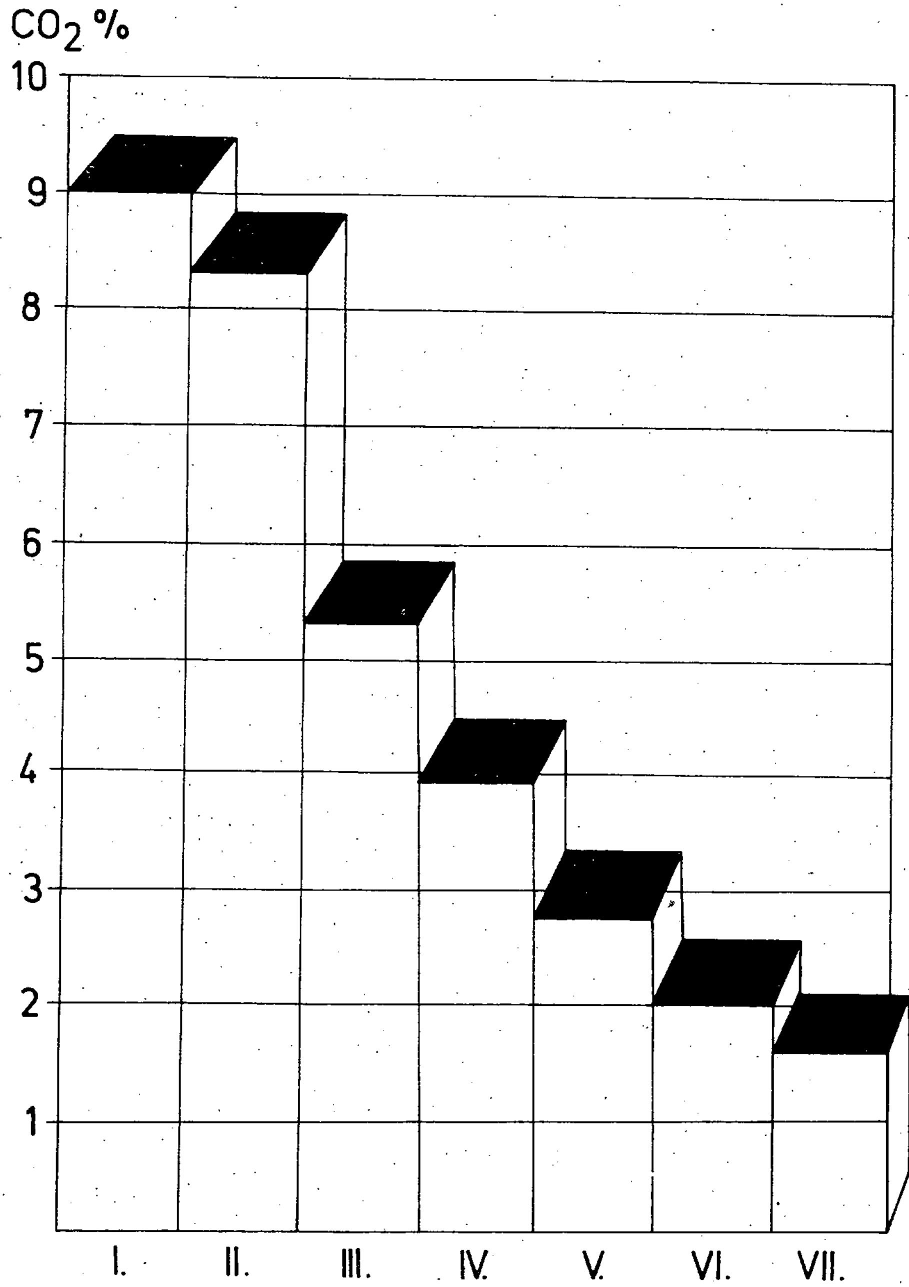
(The fact that the investigation reveals a relatively high CO_2 concentration in every exposure in the early hours of the 17^{th}, is connected with the favourable irradiation and soil moisture values and the calm on the 16^{th}, which on this day presumably led to the development of a very high peak value in every exposure. Unfortunately, in the absence of concrete measurements this assumption can not be confirmed.)

Although it is still not sufficiently clarified analytically as regards the ratio of every effective component, it can already be stated unconditionally that *the CO_2 concentration differences, which express the complex resultant of an extreme number of effects, depend on the exposure.* Those features of the quantities and course of the daily production of the gas, the existence of which has already been demonstrated by our measurements to date on dolina soils of eastern and western exposures, may often be of the same magnitude even as the differences of a similar type for the southern and northern exposures.

On a still day which was unclouded throughout, ANDÓ (1959) generally found the western exposures to be hotter on the banks of the river Tisza, and explains this via the heat extraction due to evaporation on the slopes receiving the early morning sunshine. The search for an analogy is undoubtedly justified, but in our view this is only *one* of the objective factors. We have so far not made a finding of such general validity for the CO_2 concentrations of the slopes of dolinas, for we consider that we are still not in possession of a sufficient number of data series permitting a statistical evaluation for days of different irradiation, wind and precipitation conditions. Our results to date do not otherwise

Figure 12. Diagram comparing spring maximum CO_2 concentrations obtained from the rhizospheres of the plant species of various karstic steppe associations, and from the 5—10 cm layers of the soil of different forest types. The measurements were made on cloud-free, still days in April—May 1967 and 1968 in the Bükk mountains and on the Északborsodi karst (original).
Origin of the soil air samples:

- I = from under a wetly coherent cover of dead leaves, second-year, several cm thick, in an oak wood
- II = from under a wetly coherent cover of dead leaves, second-year, several cm thick, in a beech wood
- III = from under a carpet of decomposing needles in a pine wood, from a depth of ca. 8 cm
- IV = from the rhizosphere of Nardus stricta, from the acidic and deep-soiled bottom of a dolina on the Bükk plateau
- V = from the rhizosphere of Festuca sulcata, from the steppe meadow of a rock-strewn dolina slope of south-eastern exposure at Aggtelek
- VI = from the rhizosphere of Festuca ovina, from the steppe meadow of a rock-strewn dolina of northern exposure at Aggtelek
- VII = from a soil depth of 5 cm under Carex humilis, from the steppe meadow of a dolina side of south-eastern exposure at Aggtelek


CO_2 %
10
9
8
7
6
5
4
3
2
1
I.
II.
III.
IV.
V.
VI.
VII.

support a categoric standpoint, since there were cases among the measurements not detailed here when the higher daily CO_2 production was exhibited by the western exposures, but also cases when it was exhibited by the eastern exposures. (This question should be compared with the results of the detailed examinations into the course of the temperature and the soil moisture of the dolina exposures.)

Since the CO_2 production of the soil and the overall CO_2 level are decisive factors of the aggressivity of the precipitation waters infiltraing in the soil, and hence, via this, are the main determinants of the degree of local dynamism of the karst-formation, it can be taken as practically certain that, for example, *the asymmetry of the dolinas* is connected causally primarily not with the petrological, layer-structural (strike and slope orientation) reasons assumed by the CHOLNOKY's, but with the micro-area factors outlined here. Only in this way can it happen that as regards entire mountains the direction of the deformation axis agrees for dolinas formed in limestone layers of different spatial position, as shown by our measurements in this direction in the Bükk mountains, on the Északborsodi karst, in the Mecsek mountains, and on a number of Croatian karst-planinas.

Otherwise, the various plant individuals and association-types certainly have species-specific properties in the stimulation of CO_2 production in the soil, and in the determination of the extent of soil aeration, as regards karstic plant-associations too. This becomes particularly striking when a comparison is made between the forest soil gases and those of the steppe-meadows, in so far as the concentration of CO_2 in the soil of forests is almost always substantially higher than that of the soil of meadows with no forest flora. There are several reasons for this difference. We consider the following to be the most important of these.

1. The moisture level of forest soil exhibits lower extremes, and is essentially more favourable than that of steppe meadows.
2. Because of the foliage, the forest soil is protected from the wind.
3. The forest soil is generally covered by a horizontally layered, unbroken mass of dead leaves, etc., the effect of which in inhibiting aeration may be appreciable.
4. The extensive and deep-acting rhizosphere of the trees significantly increases the depth of the bioactive soil zone, which is most important from the aspect of subcutaneous CO_2 production, and via this also increases the edaphon number relating to unit surface.

Figure 12 shows some characteristic data from our observations, on the basis of which the above points were formulated. It can be seen that as regards the karst process the most favourable soil gas conditions on Hungarian karsts are to be found under oak and beech associations, and the gas production of the soil of karst bush-forests, and particularly of steppe meadows, is less than that in the above forests. The CO_2 content of the soil of pine forests even is higher than that for steppe vegetation.

Interestingly, the maximum CO_2 concentrations in the rhizospheres of grassy plants were found for Nardus stricta, which prefers moisture and coolness. We can explain this only as a varietal characteristic, since the soil moisture features were also optimum for the root levels of Festucae and Carexes studied in exposures substantially more favourable as regards the heating-up during the period of the researches.

It will be mentioned here that the valuable results reported by BALÁZS (1964) in connection with consistent correlations between the compositions of karst springs of the temperate zone and the vegetation conditions of the related catchment areas, also confirm the higher CO_2 concentrations of soils of forest vegetations, and hence underline the significance of the effect of the nature of the vegetation on the dynamics of karst-formation (Figure 13).

In the decision of the question, naturally, one should not overlook the fauna of the soil either, since the animals living in the soil certainly contribute to the change of composition of the soil gases with their metabolism. However, studies have not yet been made to determine the magnitude of this effect and its assertion in karst corrosion.

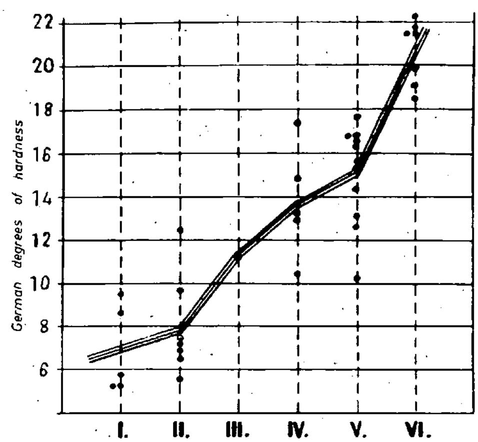


Figure 13. Relation of the water hardness of temperate zone karst springs with the vegetation cover and vegetation types of the revelant karstic catchment areas. The Roman numbers indicate the following groups:

Group	Distribution of catchment areas			Average hardness of studied water samples
	forest %	meadow, pasture, bush-forest %	rocky, bare %	
I	—	0—10	80—100	7,0 Gh°
II	—	30—60	40—70	7,8 Gh°
III	max. 10	60—90	10—40	11,2 Gh°
IV	0—25	75—100	max. 10	13,7 Gh°
V	20—75	25—75	max. 10	13,0 Gh°
VI	75—100	0—25	max. 10	20,7 Gh°

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