Proceedings of the International Conference on Environmental Changes in Karst Areas - I.G.U.- U.I.S.- Italy 15-27 Sept. 1991 ; Quaderni del Dipartimento di Geografia n. 13, 1991 - Università di Padova, pp. 325- 331

# CORROSION TERRACES AS GEOECOLOGICAL RESPONSE TO POSTGLACIAL DEVELOPMENT OF GLACIOKARSTIC ROCK SURFACE

Jurij KUNAVER
Dept. of Geography, University of Ljubljana, Slovenia

## ABSTRACT

*G.K.W.: geography of karst regions, environmental changes,landforms destruction and modification, mountain Karst areas*
*Geogr.K.W.: Eastern Alps, Kanin Mts., Dinaric Mts.*

The article deals with corrosion terraces, a specific landform of barren glaciokarst. They are a secondary development stage of different microcorrosion landforms located on solid limestone surface. They resemble Auschgleichsflächen but they are of greater dimensions and more complex development, so they are geoecologically important.

## INTRODUCTION

Until recently the term "corrosion terraces", has not been used for the surface landforms of barren karst. They are several tens of centimetres high walls cut into bedrock which have been linked so far with Ausgleichsflächen and described as their third subclass in the case of Kanin Mts., Slovenia (Kunaver, 1983, p.267). We have assumed that they can occur on surfaces with substantial inclination, yet in compact bedrock still having evident traces of glacial activity. Thus, the basic characteristic of these surface landforms is the minimum of 10 cm high wall dividing two flat surfaces levelled by corrosion. Figure on p.268 (op.cit.) shows, that deep Kluftkarren or even minor Schachtdolinen or kotlics can be cut into Ausgleichsflächen; however, they can be claimed to be of younger origin. Walls, measuring up to 30 cm or even more, seem to be remnants of some extremely large Ausgleichsflächen which mainly do not develop nowadays any more. They are supposed to be remnants of certain forms which occurred and developed in the past.

A question about these forms arose when similar ones were also discovered in other parts of Kanin Mts., i.e. on the northern (Italian) side, and more so when similar forms were also discovered elsewhere. The same phenomena were found in the Dinaric Mountains as well, i.e. in the South Velebit, in the central part of Prokletije Mts., and in Steinernees Meer in the North Limestone Alps in Austria. So we have come to a conclusion that these cases are not isolated, but that they represent infrequent surface forms of the barren mountain or high mountain karst which is regularly more or less accompanied by these forms. It was corrosion terraces in the Prokletije Mts.,(Caf Bor area at the altitude of 1800 m) in particular that raised some basic questions about their origin and development. Due to their particular position and geological versatility of the area, and because of the proximity of vegetation and its possible intense changing in the past, the question was also raised, about the impact of vegetation and pedologic cover on the development of corrosion terraces, and thus also the question about direct and indirect impact of man.

## MORPHOLOGICAL CHARACTERISTICS OF CORROSION TERRACES AND TERMINOLOGY

At first we linked the terraces, as far as their morphology and origin are concerned, with Ausgleichsflächen, i.e. with the process of their genesis. But after similar forms have also been found in considerably different environments and at diverse altitudes, the question about their origin can be solved in another way today. Considerations about the Holocene climatic and vegetational fluctuations and the impact of man have also been included here. At the same time, the need for giving the phenomenon an adequate name is becoming evident: to differentiate between Ausgleichsflächen, which have lower walls and are of recent origin, and terraces we are to introduce a new technical term. They could be called "corrosion terraces", since several cases have been found where at least two or three flat shelves are laid one above the other and separated by a steep or vertical slope or wall.

Let us look now at some concrete examples. Formerly described corrosion terraces (op.cit.) on the Kaninski Podi (Kanin plateau) under Veliki Babanski Skedenj occur at the altitude of 2000 m. They represent a first type of corrosion terraces. The height of wall is about 30 cm. The characteristics of shelves are only slightly dissected rock surfaces and the fact that the lowest one, surrounded by the wall on three sides, resembles a large Ausgleichsfläche. Its bottom is perforated by a widened corrosion fissure caused by the progressive corrosion process. Above this, the next rock shelf follows which is very poorly dissected and ending again in a steep wall, of approximately equal height as the lower one. But this one is flat on the one part and inclined on the other.

On the northern, i.e. Italian side of Kanin Mts., there is an area of similar, very distinctive corrosion terraces; they lie on smooth, glacially eroded karst plateau at the altitude of appr. 2100 m, under Col delle Erbe, and fully resemble the above described ones, and thus they belong to the first type (Fig.1).

A second type of Ausgleichsflächen have been found in the central part of the Kaninski Podi at the altitude of 2100 m, as well as on Steinernees Meer in the north Austrian Limestone Alps. The latter location lies on limestone pavement, appr. 850 m north of Riemannhaus, in close vicinity of the location of Trittkarren. In both cases, these are a kind of more or less distinct, linear bends in otherwise evenly inclined surface of limestone pavement.

The next area to be mentioned in this context is Caf Bor (1810 m) which belongs to glaciokarst of Bjelis in the central Prokletije (Plav, Montenegro). It is a location of corrosion terraces on the roches moutonnees by the alpine pasture of Caf Bor below the saddle of the same name, representing a border line between Yugoslavia and Albania This region of typical high mountain glaciokarst has been poorly known and described so far. By now, it has only been studied by J.Cvijic and recently by S.Belij. These corrosion terraces have slightly lower position when compared with the above

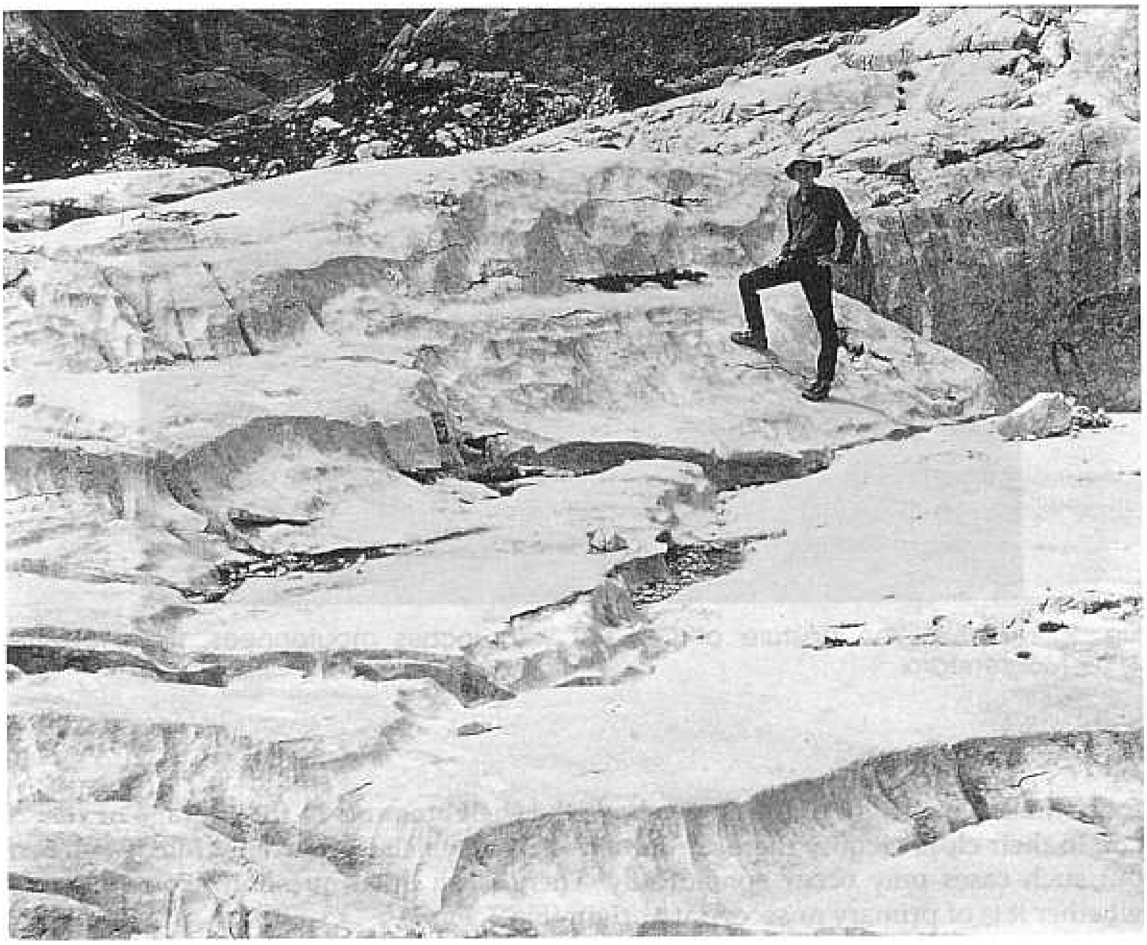


Fig. 1: Corrosion terraces below Col delle Erbe, Kanin Mts. Italy.

mentioned ones, and they also differ from them by their typical location. In this area the vast limestone region of Bijelic tectonically meets with non carbonate flysch-like region located to the north. From the latter, superficial denudation and erosion brought vast deposits of accumulation fans of glacial and periglacial origin which accumulated on the contact with limestone and on limestone itself (Fig.2).

Glacial readjustment of roches moutonnees is also proved by certain Karrentische which have a maximum of 10 cm pedestal. The prolonged roches moutonnees, running parallel to the valley, have well preserved forms of glacial erosion, to which the positioning of layers have contributed in the first place. But intense alteration of the surface caused by Holocene corrosion activity of soil and vegetation is also evident. There are also some deep Schachtdoline-like depressions on the ridge, most probably of older origin than Holocene. Thus, traces of Würm glacial erosion can be observed on the ridge in close vicinity with Karrentische, indentations of soil or vegetation origin, Schachtdoline-like depressions and karst terraces. Close proximity of these phenomena, which might genetically even exclude one another, raises some questions about the development of this barren karst surface in Holocene. Here, karst terraces mostly occur in the form of narrow rounded shelves, located for the most part on the top of the ridge. They can follow one another or they can occur as independent

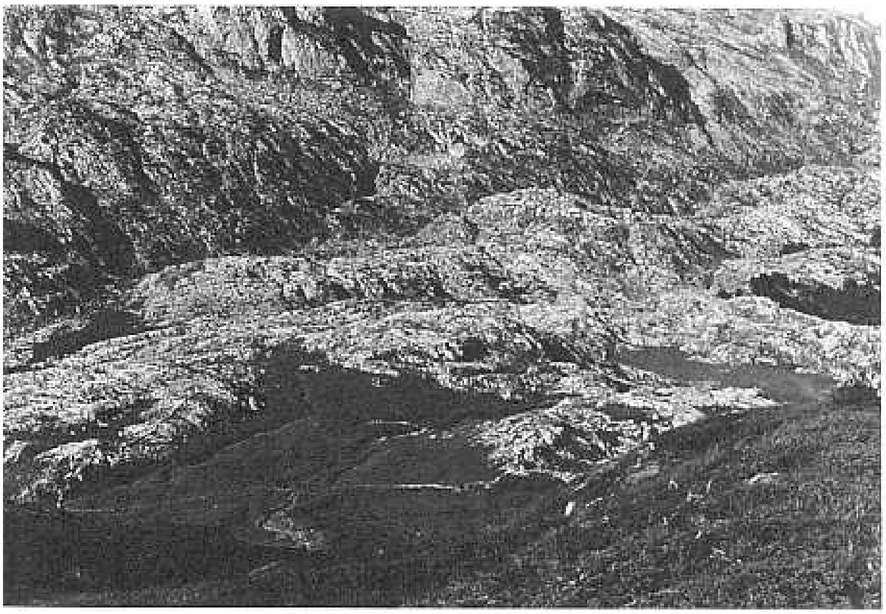


Fig. 2: The alpine pasture of Caf Bor with roches moutonnees, the Prokletije, Montenegro.

formations. The height of the slope above the shelf amounts to the average of 15 - 20 cm. In their close vicinity there are certain shelves which are partially filled with turf, but such cases only occur sporadically. There is an open question about this turf, whether it is of primary or secondary origin (Fig.3, Fig 4).

Corrosion terraces of Caf Bor reveal closer genetic and formal connection with the subterranean karst forms. There might have been some more vegetation and soil in the past on this naked ridge, but most probably they disappeared due to the impact of man. Namely, this is a pasture area of the nearby alpine pasture of Caf Bor and because of the vicinity of Karrentische it is difficult to claim that vegetation and soil had substantially changed the surface of the former glacially rounded ridge. Any other explanation is less probable.

Let us mention in the end, as an illustration and comparison, the extraordinary large Ausgleichsfläche and kamenitzas of recent origin in the region of Bojin Kuk (1100 m) at Veliko Rujno in the South Velebit. Bojin Kuk is known by its steep towers, mainly formed by exfoliation in Jelar-Promina limestones of Eocene age. The walls of the shelves are up to 15 cm high, but the walls of old abandoned shelves are even up to 40 cm high, or even more.

## PROBLEMS OF DEVELOPMENT AND CONCLUSIONS

Because of morphological similarities and characteristics of locations, we assume that the above described examples are also genetically alike. The differences occur, above all, in dimensions and directions of corrosion terraces, which can be the result of local conditions and/or the result of unequal durations of development. We can undoubtedly state the following facts:

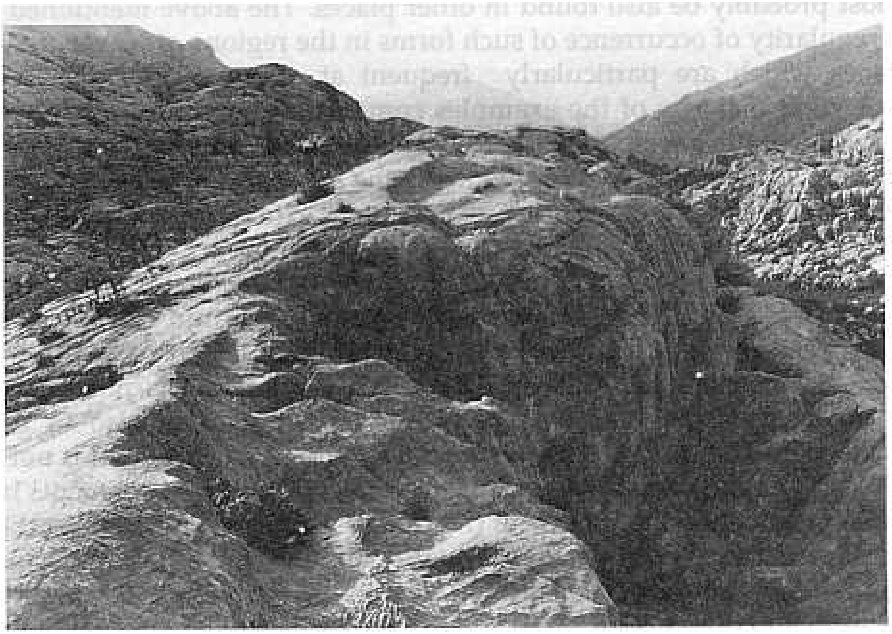


Fig. 3: Corrosion terraces on the top of roches moutonnees at Caf Bor.

Fig. 4: Successive corrosion terraces at Caf Bor, possibly originating from subcutaneous corrosion.

1. Locations of these forms at the above described sites are not isolated or casual but can most probably be also found in other places. The above mentioned examples prove the regularity of occurrence of such forms in the regions of barren non-dissected rock surfaces which are particularly frequent at zones of glaciokarst of certain altitudes. A great majority of the examples come from the altitudes between 2000 m and 2100 m, one comes from 1800 m, and another one from 1100 m. Except for the lowest location, all corrosion terraces belong to the areas of typical glaciokarst.

2. Morphologically these forms are, to a great extent, independent formations, which can be proved by the following:

- It is the cross section of a terrace which is important for the morphological identification. Transition from a more or less flat surface into a wall is sharp. It is usually composed of two parts: the upper, vertical one, which passes into its lower, evenly formed concave end. This transition into flat surface is not in the form of corrosion notch as is the case of kamenitzas and very often also in the case of Ausgleichsflächen. The surface of the vertical wall and its concave end is not all evenly smooth but can be composed of individual more or less hollowed segments in the form of Rillenkarren. Somehow the profile of the wall resembles the wall of Trittkarren. The next element is the levelling, which is usually slightly wavy, non-dissected and not very wide shelf that can pass at its bottom side into the next terrace. Water is drained in the form of film and does not accumulate. The above described characteristics point to a difference between these forms and the typical Ausgleichsflächen which are still being formed.

3. As for terminology, the above described terraces can be called either corrosion terraces or Megaausgleichsfläche. Since the main accent of this form is its wall, where the morphology and the dimensions of the upper and the lower levelled parts are less important, although still being its components, this form might be terminologically defined as corrosion terrace.

4. As for the genesis, it might be said that Ausgleichsfläche as well as corrosion terrace, are both the result of a similar or even the same process, i.e. horizontal levelling of barren limestone surface which also comprises formation and regression of walls. Although the formative features are similar to those of Trittkarren and kamenitzas, it is necessary to distinguish between them because of the difference in dimensions.

5. Corrosion terraces are the result of development in the last period of Holocene. In interpreting terraces geomorphologically, it is necessary to take into account the climatic, vegetational and pedologic development of individual region. The fundamental question is whether the corrosion terraces have developed independently or are they a successive formation, originating in some other form? Judging from our observations we incline to support the second possibility. In fact, it is a matter of development of a corrosion terrace which had formerly been smaller.

We assume that the initial corrosion wall, out of which a larger one developed later, had been a form of an Ausgleichsfläche or some other horizontal microform of the barren karst, a depression, excavated either by the subcutaneous corrosion or by the glacial erosion. Therefore, not only is the original form important, but also the fact that in solid bedrock and in proper climatic conditions, rock surface can be formed and developed, for a longer period, under special circumstances which result in special forms. This is the process of levelling of a rock surface. Corrosion terraces could be therefore defined as zonally reformed older climozonal karst forms.

6. A tendency of augmenting the height of walls is evident as a result of their retreat. A conclusion about their age can be also made from this fact. According to this

thesis, lower terraces are of absolutely younger date, and vice versa - the higher ones are of older date, i.e. their genesis was longer. Another indicator of their age is also the fact that some terraces have remained untouched by vertical karst dissecting, while in others this process has already begun and can completely ruin them. Eventually, karst terraces are not forms to be searched for in a Kluftkarren surface.

If a supposition is made that corrosion terraces originate from depressions in rock surfaces generated by continuous or discontinuous vegetation and soil cover (which is very likely at these altitudes in the past), then it can also be concluded that at some time in the past vegetation limit was at higher altitude and that the arrangement of altitude belts in high mountain regions was different from the present one. This fact is more or less proved by means of Hohlkarren, the frequency of which is higher at the altitude between 1900 m and 2000 m in our regions. There can be no doubt today about shifting of altitudes of climatic and vegetational zones in the past, caused by climatic oscillation and the impact of man.

## REFERENCES:


BÖGLI, A. (1960) - Kalklösung und Karrenbildung. Z.f. Geomorphologie, Suppl.b.2.

FORD, D., P. WILLIAMS (1989) - Karst Geomorphology and Hydrology. Unwin, London.

KUNAVER, J. (1973) - O razvoju slovenske terminologije za mikroreliefne kraske oblike (On the Development of the Slovenian Terminology of Microkarstic Landforms). Slovenska kraska terminologija. Kraska terminologija jugoslovanskih narodov, book 1. Zveza geografskih institucij Jugoslavije. Ljubljana 1973. pp. 68-76.

KUNAVER, J.(1983) - Geomorfoloski razvoj Kaninskega pogorjas posebnim ozirom na glaciokraske pojave (Geomorphology of the Kanin Mts. with Special Regard to Glaciokarst). Geografski zbornik - Acta geographica, XXII/4, 1982. Ljubljana.pp. 267-268.

PERNA, G., U. SAURO (1978) - Atlante delle microforme di dissoluzione carsica superficiale del Trentino e del Veneto.Trento: Museo Tridentino.

SLOVENSKA KRASKA TERMINOLOGIJA (1983) (Slovenian Karst Terminology) - Kraska terminologija jugoslovanskih narodov, book 1. Zveza geografskih institucij Jugoslavije, Ljubljana. p. 12

TRUDGILL, S.(1985) - Limestone Geomorphology. Geomorphology texts B. Longman, London. pp. 66-70.

Proceedings of the International Conference on Environmental Changes in Karst Areas - I.G.U.- U.I.S.- Italy 15-27 Sept. 1991 ; Quaderni del Dipartimento di Geografia n. 13, 1991 - Università di Padova, pp. 333-339

# THE SOIL EFFECT IN KARST DEVELOPMENT

Lazslo ZAMBO
Department of Physical Geography, Eotvos Lorand University
Budapest, Hungary.

## ABSTRACT

*G.K.W.: soils, air in caves and soils, denudation rate, leakage, morphogenetic processes*
*Geogr.K.W.: Global Karst, Hungary*

In most cases karstification, including the formation of surface and underground karst features through the interaction of carbonate rocks and water, takes place across the medium of soils on the rock surface or in cracks or under redeposited soil mantle. Consequently, soil properties affect karstification and occasionally control its entire dynamics, while in other cases they only modify the physical and chemical conditions of infiltration.

The limestone solution (or corrosion) capacity of infiltrating water, characteristic of the soil itself, is formed by several processes. The limestone solution capacity (corrosion capacity) can also describe the soil, when it is expressed in relation to the amount of infiltrated water: this figure is normally much higher than that of the solution capacity of rainwater. In order to be able to compare the rainwater to the water migrating in the soil, rainwater samples were also regularly collected during the observations; they were uniformly analyzed and their aggressive $CO_2$ content was calculated; their limestone solution capacity was then defined.

## INTRODUCTION

Today it is accepted that the soil which mantles the karstifying rock, even if as a thin veneer, plays a direct role on the surface or subsurface and also an indirect role in deep karst formation.

In the soil the influences of several components of the geographical environment (atmosphere, hydrosphere, biosphere and lithosphere) are manifested in a complex manner. These influences are not merely juxtaposed, but appear in interaction to form an independent factor, where it covers the surface of karstifying rock. It is not present in all karstic processes; e.g. it is absent in the solution processes of open karsts in an absolute sense. However, it is present in most karst types, for covered, partially covered karsts or even for parts of open karsts where cracks and depressions are mantled by patches of soil - even if only a small portion of the surface is affected. They have an even more important role in marking sites where corrosion is most intensive, leading to a morphological differentiation of the surface.

The net influence of soil on karst corrosion can only be measured as solution aggressivity per unit rock surface. I attempted to express soil impact in the grades of limestone solution capacity of percolating water, acquired in the soil.

The hypothesis - namely, soil-cover has an impact on karstic morphogenesis - was controlled with the comparison of the corrosion effect of various soils and soil accumulations under different physical geographical conditions, with the annual repetition of measurements and with the comparison of corrosion values of various rock surfaces that were not covered with soil and were in similar positions, exclusively under the effect of atmospherics.

With the definition of sub-soil corrosion capacity, developed as a combined result of several soil phenomena, an important term was gained that can be numerically expressed and can be compared in various types of karstlands.

The joint effect of all pedological factors affecting the karst corrosion capacity of infiltrating water is called soil effect. From concentrated effects of several pedological processes, corrosion capacity under the soil can be grasped through certain parameters.

The validity of results in this topic is delimited by the well-known laws of climatic karst morphology, as formulated by K. Priesnitz (1974): " There is variation, combination and compensation between the factors of karstification. The delimitation of climatic karst provinces is only possible through the efficiency analysis and consideration of the individual factors."

## THE PARAMETERS OF SOIL EFFECT.

### Soil temperature as a parameters of soil effect.

Corrosion in and under the soil depends - through a chain of reactions - on the temperature conditions of the immediate environment. Temperature is among the most important physical partial factors of solution. Temperature directly affects the limestone solution capacity of water, the absorption of $CO_2$ in water and the rate of solution reactions. Since the formulation of Henry's law their processes are well known from many laboratory and field measurements, soil climate analysis and calculations. The solubility of gases (including $CO_2$) increases with increasing pressure and decreases with rising temperature, as the presence of dissolved electrolytes and some organic matter hinders solution. After J. Tillmans (1932), many investigations tabulated karst corrosion plotted against temperature and its overevaluation led to erroneous conclusions.

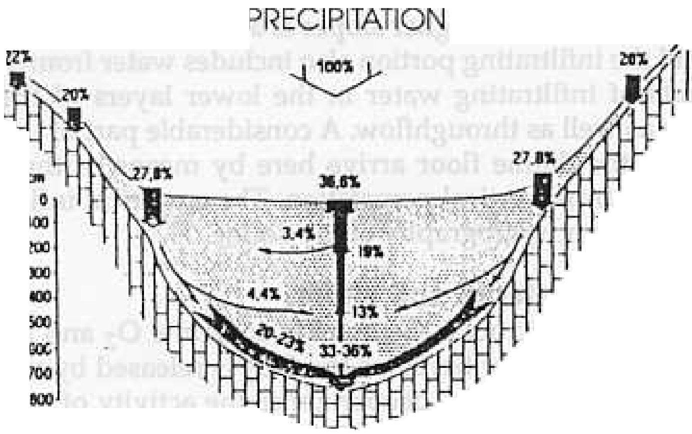
The indirect impact of temperature on solution capacity is manifested in two phenomena: in controlling the rate of weathering and the intensity of biological activity in the soil. Recent geochemical and microbiological papers (Loughman, TC 1969; Feher, d 1954 etc.) have revealed intricate relationships.

My observations show that only the temperature in the immediate environment of solution has to be considered. The concentration of aggressive materials in percolating waters depends on temperature and varies on depth and only the temperature at the contact is influential in solution. The role of the broader environs is defined by L. Jakucs (1971), who emphasized the temperature of the solution microspace.

Indirectly, temperatures figures of the macros and microclimate are more important, as the amount of aggressive at the point of solution depends on their production in and transport from the broader environs.

1-3 degree differences are observed in simultaneously measured temperatures, resulting from topographic and pedological endowments. These deviations are only

Fig. 1 - Infiltration model of Doline




important in corrosion under soil if important limits of soil biological activity are very close to them and thus they influence $CO_2$ production. For instance, freezing of the profile lasting for weeks is reflected in the extremely low average winter solution capacities.

## Water budget of soil as a parameter of soil effect.

The amount of water reaching the site of solution depends on the water budget and depth of soils mantling the karsts. In addition to quantitative aspects, water budget properties play an important part in the circumstance that how long and over how large a surface seepage water is in contact with the materials of the environment; both the rate and the surface of reaction depend on the above properties.

The knowledge of the amount of infiltrated water is indispensable for the determination of the rate of corrosion and for the calculation of local solutional form development. Adjusted to academic and practical demand, numerous measurements and calculation methods have been elaborated.

On slopes, the fundamental elements of any surface karst form, infiltration is controlled by soil cover. In addition to the properties of terra rossa soils, infiltration on slopes is also influenced - as indicated by our investigations - by inclination and to a lesser extend by slope morphology. However, all these effects are manifested in the properties of soil cover and influence the calcareous basement indirectly. The observation sites were identified to measure the processes of the widest spread karst slope forms. Data were gathered for a karst plateau, convex, steep slope segment and doline margin (fig 1 ). The typical average values of infiltration on the slope sections studied are interpreted to include the infiltrating portion of precipitation reaching the surface in that point together with the amount of water percolating in the direction of slope which reaches the bed-rock in the point in question.

As a consequence, moving downslope the infiltrating portion of precipitation increases as large amounts of water are involved in throught flow. Expressed in percentages, infiltration corresponds to the empirical figures for each slope segment and thus can be used for calculation, but it does not derive exclusively from precipitation at the given site.

The typical infiltration values of doline slopes and soil fills are shown - relying on 497 measurements - in fig. 1. The typical infiltration calculated from annual precipitation over the doline slopes also includes the part infiltrated from throught flow into the limestone body. In the larger amounts of precipitation along the margins of doline fill, throught flow from higher slopes is also manifested. Over the almost flat surface of doline fill the infiltrating portion also includes water from overland flow. The decreasing amounts of infiltrating water in the lower layers of the fill show water storage in the pores as well as throughflow. A considerable part of the high amounts of water infiltrating on the doline floor arrive here by means of throughflow, while a smaller portion comes from vertical percolation. The empirical infiltration model also show the generalized inner hydrography of the doline.

## $CO_2$ product as a parameter of soil effect.

The oxidization and microbial life quickly consume $O_2$ and the $CO_2$ content of soil pores increases. In the upper horizons the $CO_2$ is released by root respiration and produced by aerobic bacteria; in the deeper zones the activity of aerobic microflora is accompanied by the $CO_2$ produced continuously by anaerobic microorganisms and fermentation processes.

The actual $CO_2$ concentration of the soil depends - in addition to $CO_2$ production - on the diffusion of $CO_2$ into the atmosphere. Also by diffusion $CO_2$migrates between soil horizons and accumulation layers. A balance is seldom struck as recharge in the active horizon of $CO_2$ production keeps pace with $CO_2$ diffusion when suitable conditions exist. The velocity of molecular diffusivity can be calculated from the Einstein-Stokes equation :

$D = kT/$

where k = 1.37 * 10 (exp -6) erg, K = Boltzman constant = molecular radius

Velocity is proportionate to T temperature.

The maintenance of the balance between $CO_2$ dissolved in water (as $H_2CO_3$ and the $CO_2$content of the air necessitates continuos $CO_2$ diffusion between the soil solution and the air, since infiltrating water finds ever changing conditions when moving downward. In the wandering of $CO_2$ the changes are factors influencing aggressivity. This supports the fundamental concept of the paper, viz. the soil and its inner condition, soil dynamic processes shape the limestone basement through controlling the $CO_2$content of the soil solution (its solution capacity ).

The total $CO_2$ of a soil solution exists in three distinct forms. Dependent on the degree of contact and the condition of solution, $CaCO_3$ affected by carbonic acidic water dissolved and in the form of fixed $CO_2$ (as $Ca/HCO_3/_2$) forms part of the $CO_2$ content of water. The remnant $CO_2$ in water as free $CO_2$, partly serves to keep fixed $CO_2$ in solution as balance $CO_2$ coexisting in water is not tackled here. Analyses were made on the basis of 1205 data from the soil profiles of the observation sites of the dissolved $CO_2$ forms. The averages of the large number of measurement reflect great diversity for the soil profiles and accumulations. From the average distribution of the $CO_2$ forms in the whole soil mantle - 2,54 mmol per litre total $CO_2$, 0.7 mmol per litre fixed $CO_2$ and 1.32 mmol per litre aggressive $CO_2$ - the proportions in the individual soil horizons are markedly different and reflect soil properties concerning solution.

A part of $CO_2$ production, which plays a major role in the changes of solution capacity, is certainly the result of oxidation - reduction of organic matter, because the amount of $CO_2$ content in the deeper zones, where there are no roots and which are badly ventilated, is significant; further, its quantitative changes and periodicity cannot be attributed to the diffusion of $CO_2$ gas, but rather to the activity of micro-organisms in the soil.

The most intensive activity of aerobic bacteria was observed at the 0.5 - 0.8 m level of the accumulation; it suddenly decreased at 0.8 m and remained low down to 3 - 5 m of depth. From there down, the activity of bacteria grow again - with a few exceptions - down to 7 m, where it reached a secondary maximum close to the limestone.

The activity of anaerobic bacteria showed similar characteristics, although it was very intensive at the top level and was almost uniform down to the limestone, where the activity suddenly grow and reached a maximum in the profile. The latter is clearly expressed with the ratio of the number aerobic bacteria to anaerobic ones; this value fell to 1.6 at the environment of the limestone.

## LIMESTONE SOLUTION CAPACITY IN THE SOIL

The limestone solution (or corrosion) capacity of infiltrating water, characteristic of the soil itself, is formed by several soil processes. The limestone solution capacity (corrosion capacity) can also describe the soil, when it is expressed in relation to the amount of infiltrated water: this figure is normally much higher than that of the whole solution capacity of rainwater. In order to be able to compare the rainwater and the water migrating in the soil, rainwater samples were also regularly collected during the observations; they were uniformly analyzed and their aggressive $CO_2$ content was calculated; their limestone solution capacity was then defined. The analyses produced the following figures for the research field (partial data are neglected):

- average aggressive $CO_2$ content of rainwater : 0.278 mmol/l;
- average aggressive $CO_2$ content of infiltrated water before limestone solution : 2.192 mmol/l;
- ratio of these two characteristic data 1: 7.5 .

The limestone solution capacity is defined as the aggressivity calculated for an area unit, where the amount of water involved in solution is also considered. (This amount is formed by the part of rainwater that contacts the limestone: the quantity of effective precipitation, or the infiltrated water that reaches the limestone.) The effective quantity of precipitation over the research field can only be estimated due to the lack of extensive rock surfaces that are not covered with soils at all; this figure is put to 30%. (Only a part of run - off water comes in contact with the limestone surface at molecular level and can express its aggressivity.) These data is equal to 200 1/m(exp2)/year, which - expressed in limestone solution capacity - is 5.5 g/m(exp2)/year.

The average limestone solution capacity of water in the soil before solution (from total data)is 26.65 g/m(exp2)/year. The ratio of these two basic data is 4.84 .

The value of solution in and under the soil may be normally 5 times higher than corrosion of free rock surface (fig 2).

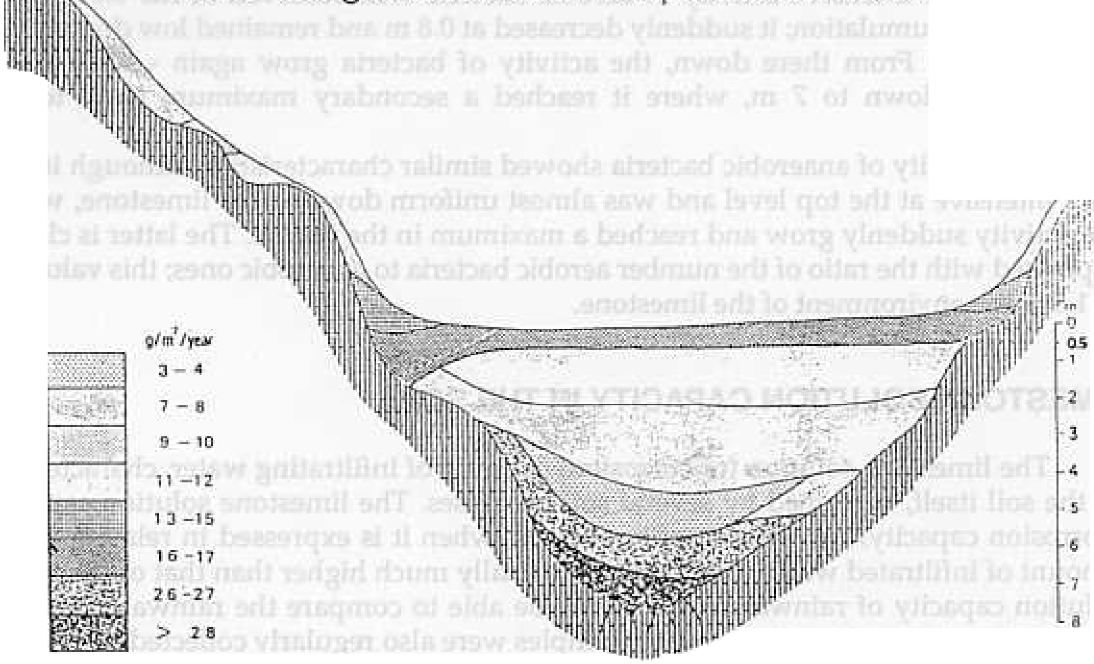
### Seasonal changes in the potential limestone solution capacity.

The seasonal changes demonstrate the following :

1. Limestone solution in thin soils shows a seasonal rhythm. Its maximum values are typical after snow melting and in summer, and a secondary maximum appears in early winter.

2. The solution capacity in the upper layers of thick soil accumulations is often different from year to year, and the seasonal rhythm is only evident in the top zone. The changes in the solution capacity of the middle zone show special characteristics and

FIG. 2 - Canghes of corrosion in slope and doline soils




there are no seasonal regularities. The solution processes in the lowest zone are valid for the whole year, and their rhythmical changes are not regular.

## CONCLUSIONS

As the amount of water present at the site of solution equally depends on soil properties and on precipitation, there are no unambiguous relationships between the seasonal amount of precipitation and the rate of solution; they may be closely, medium or poorly correlated (positive or negative ).

Consequently, without other information the amount of precipitation in itself is not suitable to characterize the intensity of karst corrosion.

The investigations described above demonstrate that soil impact is a major factor in karstic development and in karst morphogenesis; the numerical expression of soil impact may lead to a new and comprehensive explanation of phenomena over karstlands.

## REFERENCES


BARANY, I. (1980). Some data about the physical and chemical properties of the soil of karst doline. Acta Geogr. , vol XX , pp 37 - 49.

COMBES, P.J. (1978). Nouvelles donnees sur les relations entre la paleographie et la gitologie des bouxites du troisieme horizon dans la zone du parnasse. IV Internat. Congr. for Study of Bauxit and Alluminiun. Vol I . Bauxites. Athen pp. 92 - 100.

FEHER, D. (1954) Talajbiologia. Akademiai Kiado, Budapest, pp. 186 - 201

FORD, D.C., DRAKE, J.J. (1982) Spatial and temporal variations in karst solution rates: the structure of variability. Space and Time in Geomorphology, pp. 147 - 170, Allen and unwin.

FORD, D.C. (1985) Dynamics of the karst system: a review of some recent work in North America. Ann. Soc. Geol. de Belg. vol 108, pp. 283 - 291.

LOUGHNAN , F.C. (1969) Chemical weathering of silicate minerals.

Am. Elsevier Publ. Co. New York.

MIOTKE, F.D. (1974) Der $CO_2$-Gehalt der Bodenluft in seiner Bedeutung fur die aktuelle Kalkosung in verschiedenen Klimaten. Abhandlunger der Akademia der Wissenschaften in Gottingen Mathematisch-Phyxikalische Klasse, III. Folge 29, pp. 1 - 52

NICOD, J. (1976) Variations de $CO_2$ dans le soils . Proceedings of the International Symposium on standardization of field research methods of karst denudation (corrosion ). Ljubljana 1 - 5. Sept. p.

ZAMBO, L. (1986) The importance of soil effect in corrosional development of the karsts. Cand. Diss., Budapest, pp. 1 - 170.

ZAMBO, L. (1986) Description of the measuring methods of sub-soil solution. Annales Univ. Sci. Bud, Sectia Geographica, p. 40

ZAMBO, L. (1986) Impact of karstic soils on limestone solution and some practical experiences. Annales Univ. Sci. Bud. Sectia Geographica, p. 82.

ZAMBO, L. (1988) The soil cover as a factor of karstification. Annales Univ. Sci. Bud. Sectia Geographica, pp. 56 - 68.

Proceedings of the International Conference on Environmental Changes in Karst Areas - I.G.U.- U.I.S.- Italy 15-27 Sept. 1991 ; Quaderni del Dipartimento di Geografia n. 13, 1991 - Università di Padova, pp. 341-344

# SOLUTION OF ENVIRONMENTAL PROBLEMS OF SPELEOTHERAPY IN THE TRESIN KARST REGION (CZECHOSLOVAKIA)

Vladimir PANOS
Institute of Geography,
Czechoslovak Academy of Sciences
Brno, Czechoslovakia

## ABSTRACT

*G.K.W.: Cave environment, karst resources, speleotherapy*
*Geogr. K.W.: Tresin Karst Region, Northern Moravia*

The paper informs briefly on karst environmental problems braking the development of speleotherapy in the Tresin Karst Region (Northern Moravia, Czechoslovakia). The solution of the problems has been enabled by financial help of the European Communities that accepted the suggestion of the Czechoslovak Federal Committee for Environment and incorporated the pertaining investigations of the Tresin Karst Region into the international environmental research programme PHARE 1. The conclusion will be appreciated by an international expert commission and its recommendation will be accepted and realized by the Czechoslovak authorities. The written positive standpoints of the I.G.U. Study Group: Environmental Changes in Karst Areas and of the Bureau of the International Speleological Union became the most effective documents for such a perspective decision.

## INTRODUCTION

The health and even the existence of the human society have been menaced, since a long time, by the increasing devastation of general environmental conditions. When, on the contrary, the healing effects of the specific cave environment upon the man's organism were discovered and proved, the cave environment became one of the most important natural resources of the karst areas. This is a resource that is practically unspendable, highly rational and of great social and economical value. Its exploitation in the medical praxis does not interfere with the natural balance of the entire karst system. Due to these facts the effective care of the protection of the cave environment natural structure should have a priority to the other man's activities in the karst areas.

## SOME PROBLEMS OF THE TRESIN SPELEOTHERAPY

Due to the long-termed impact of devastated environmental conditions more than 25% of the children population in Czechoslovakia suffer from the Asthma bronchiale and more than 35% are affected by the allergic disorders of various type. Similar alerting situation has been stated in other European countries too. Consequently, a serious political and scientific attention has recently been given to the effective provisions in order to repair rapidly and permanently this alerting social problem. Thus the speleotherapy in Czechoslovakia became one of the most perspective healing methods.

The scientifically conceived speleotherapy in Czechoslovakia uses for the treatment of children patients not only effects of a system of healing natural components of the karst cave environment (inclusive ions and radon in the cave air) but also other auxiliary means (e.g. rehabilitation, psychotherapy). This is why this modern approach to the speleotherapy requires at the same time systematic karst-environmental studies, investigation of mutual interrelations among numerous components of the cave environment and their changes as well as the most effective protection of their actual healing capacity on one side and, on the other, simultaneous observations and records of their reflexes in the human body on the field of theoretical and applied medicine, especially of allergology and immunology.

In Czechoslovakia the speleotherapy has successfully been applied in three official health centres, two of them being situated in Moravia, one in Slovakia.

The most progressive unit appears to be the Experimental Speleotherapic Centre of Tresin (North Moravia) near Olomouc. It is operated by the Commission for Speleotherapy of the Czech Speleological Society (The Ministry of Environment of the Czech Republic), medically controlled by the Clinic of Allergology and Clinical Immunology of the Faculty Hospital in Olomouc and by the Institute of Sport Medicine in Brno (The Ministry of Health of the Czech Republic) and eco-karstologically backed up by the Institute of Geography in Brno (The Cechoslovak Academy of Sciences). The speleotherapy has been realized in the Tresin Cave the environment of which is significant with surprisingly high healing effects. The reasons of this fact nowadays are not yet perfectly known.

The scientific results of the research team of the Experimental Speleotherapic Centre of Tresin reached an international reputable level both on the field of ecokarstology and medicine, though the team has been working without any modern equipment. The recent discovery of radical positive influence of the Tresin Cave environment upon the immunological system of the human body is of a world priority and opens an entirely new way for the application of speleotherapy as well.

Unfortunately, the ecologically rational exploitation of natural resources of the Tresin Karst Region, that means the development of the speleotherapic centre, the secure hydroeconomic exploitation of the drinking water sources, the development of important social, recreational, tourist and forestal programmes as well as interests of the effective protection of nature, is limited and even menaced by the extraction of limestone in a near quarry and by the activity of a limestone powder mill. These commercial activities modify irreversiably the original karst surface, menace the unix environmental conditions of the speleotherapic cave as well as the existence of the exploited karst resurgence supplying the towns of Litovel and Olomouc by the excellent drinking water (250 l/s).The resurgence springs up from the paleokarst massive that is thinly covered by Quaternary alluvial and Pliocene lacustrine deposits and overflown by several arms of the Moravia River. As this buried limestone massive is heavily faulted and karstified the shakes arised from explosions in the quarry may cause, together with other negative factors, catastrophic invasions of the polluted fluvial water into the.underlying karst aquifer.

In order to help in solving the antagonistic discrepancies of various interests in benefit of the ecologically rational utilization of the unix natural karst resources of the development of speleotherapy and of the effective protection of important karst water sources the Institute of Geography of the Czechoslovak Academy of Sciences in Brno elaborated in 1990 a research project that was submitted to the Czechoslovak Federal Committee for Environment. The project was supported by the positive stand-point of the I.G.U. Study Group: Environmental Changes in Karst Areas written and signed by its President Professor Ugo Sauro during the International Conference on Anthropogenic Impact on Environmental Changes in Karst held in Blansko-Ceskovice (Czechoslovakia). According to the suggestion of the Czechoslovak Federal Committee for Environment the project was accepted by the European Communities and incorporated under the name "Protection of Natural Resources in Karst Areas" into the sponsored international research programme PHARE 1.

Actually also the Medical Service Corporation International (U.S.A.) expressed interest on the project and will support it financially in frame of the wider international medical research programme "Asthma". The recommendation of the I.G.U. Study Group appeared to be an important document for such a positive development.

## CONCLUSION

The realization of the project will enable development of eco-karstological and medical speleotherapic studies as well as the utilization of experiences for the creation of speleotherapic centres in other convenient Czechoslovak karst regions, some of which will be offered for the international use.

The main benefit of the project will be an improved and well equiped base for development of speleotherapy as of an important method of medical treatment of children affected by the adverse impact of devastated environment in Czechoslovakia and other European countries. This benefit is of course conditioned by previous complex solution of all ecological problems of the Tresin Karst Region. It is believed that - thanks to the help of the I.G.U. Study Group: Environmental Changes in Karst Areas - the research results will contribute to development of physical geography, karstology, environmental studies as well as of medicine at theoretical and applied level.

The project is justified on the ground that it represents one of important steps for the limitation of an alerting social phenomenon and for the consequential protection of the karst ecosystem which is intent on the general of the health of children.

It has to be clear that the interdisciplinarily conceived speleotherapy (eco-karstology + medicine) and the preventive complex protection of the karst environment enable a highly human and ecologically rational exploitation one of the most valuable and unspendable natural karst resources.

Proceedings of the International Conference on Environmental Changes in Karst Areas - I.G.U.- U.I.S.- Italy 15-27 Sept. 1991 ; Quaderni del Dipartimento di Geografia n. 13, 1991 - Università di Padova, pp. 345-352

# RADON ACCUMULATION IN THE CAVES OF THE MORAVIAN KARST

Otakar STELCL
Institute of Geography, Czechoslovak Academy of Sciences, Brno, Czechoslovakia

## ABSTRACT

*G.K.W.: natural and environmental changes, radon radiation*
*Geogr.K.W.: Moravian Karst, Czechoslovakia*

Submitted paper presents the basic data on the occurence of radon and its daughter products in the commercial caves in the Moravian Karst. Established concentrations and their impact on the health of visitors and guides are reviewed.

## INTRODUCTION

The presence of radon and its daughter products in the caves is a serious problem. It concerns karst research workers mainly a wide circle of speleologists whose study interest requires a longer stay in contaminated caves, as well as cave holders and administrators of caves open to the public frequently visited by tourists. It consists in the necessity of respecting hygienic rules strictly defining the conditions of activities in the environment with ionization radiation. The paper supplies information about the solution of the said problem in the accessible caves of the Moravian Karst.

## FUNDAMENTAL CHARACTERISTICS OF THE MORAVIAN KARST

The Moravian Karst is one of the best known karst localities of Central Europe. This follows on the one hand from the abundance and variety of the karst forms, and on the other hand from the very high level of investigations and the long and famous history of scientific research. In the Moravian Karst, the bases of European speleology and speleoarcheology started developing as early as in the past century. At the beginning of our century, foundations and regulations of commercial utilization of the caves in the wider sense of the so called "cave industry" were laid.

The region described occurs on the contact of the old mountain range of Central European Variscides and the recently folded mountain range of the Carpathian system. It is built of a 3 up to 6 km wide and about 20 km long stripe of very pure limestone are very intensely tectonically deformed which made possible a wide development of karst forms. In the West, they overlie granitoid rocks of the Massif of Brno of pre-Devonian age, eastwards they marge under non-carbonate of Lower Culm.

The general geomorphological character of the whole territory is given by the contrast between the distinctly planated flat surface occurring in heights of 35 up to 520 m a.s.l. and sharply incised karst canyons locally called "zleby" (throughs). The oldest karst forms are the remnants of the Lower Cretaceous fossil karst consisting of even 140 m deep irregularly closed depressions of cock-pit type, filled with kaolinic-lateritic weathering products of even Upper Cretaceous age (V. Panos, 1963; P. Bosak, 1980). The beginning of the development of the karst canyons successively created by allochthonous karst streams is put in the Paleogene (V. Panos, 1963; O. Stelcl, 1964). In Younger Tertiary (in the Badenian) the development of the karst forms was interrupted by a sea transgression the clayey sediments of which buried the older karst forms inclusive of karst canyons. The following geomorphological development resulted on the one hand in the exhumation of older karst forms, the renewal of underground karst circulation and in the origin of new forms. In this post-Badenian period the Moravian Karst obtained its present form.

In dependence of the main development phases numerous caves developed. They occur in three main levels (O. Stelcl, 1963).The lowermost level occurs about 20 m below the present groundwater table. No direct evidence of pre-Badenian age of some of the levels has been furnished so far. At the present time, almost 1200 caves were registered (J. Pribyl, J. Vodicka, Z. Kuzdasova, S. Hofirkova, 1984). The largest called the Amatérska jeskyne Cave attains the length of 34,900 m and other discoveries can be expected (J. Pribyl, 1990). Actually 4 caves are open to the public.

These are the world-known Punkevni jeskyne Caves with the Macocha Abyss and attractive boating on the underground Punkva River, further the Katerinska jeskyne Cave, the Balcarka Cave and the Sloupsko-sosuvské Caves.

## NUMBERS OF VISITORS TO THE CAVES

First records of visits to the caves as significant natural and tourist attractiveness are from the beginning of this century. For instance, the Katerinska jeskyne Cave, was visited before its opening to the public in 1905 by 520 tourists (O. Stelcl, 1985). Since that time the number of visitors increased substantially and reached the so far highest value of 565,931 persons in 1989, about 150,000 from this number coming from abroad. Greatest interest is taken in the Punkevni jeskyne Caves, visited by almost 330,000 persons in 1989, followed by the Katerinska jeskyne Cave with 108,000 visitors, further the Balcarka Cave with 184,000 visitors and Sloupsko-sosuvské jeskyne Caves with 47,000 visitors per year. Since opening to the public, the caves were visited by about 30 millions of people which is certainly a sufficient motivation for the study of radon in the accessible caves and its possible impact on the health of the tourists and guides.

### Radon properties

Radon 222 has the character of inert radioactive gas. It is a member of the uranium-radium disintegration chain, where uranium 238 nuclide figures as the first member. The immediate mother element of radon is the radium 226 isotope from which by alfa disintegration radon develops. By further disintegration, its daughters originate. Radon gets in the atmosphere by emanation from rocks, sedimentary fillings, from water, natural gas, etc. In the Moravian Karst, the cave sediments, above all Culm gravels, are the source of radon. During the measurements, the radon concentration was not determined, but the volume activity of the radon daughter products expressed by the potential energy of the radon daughters (MeV) in the volume unit (1), which

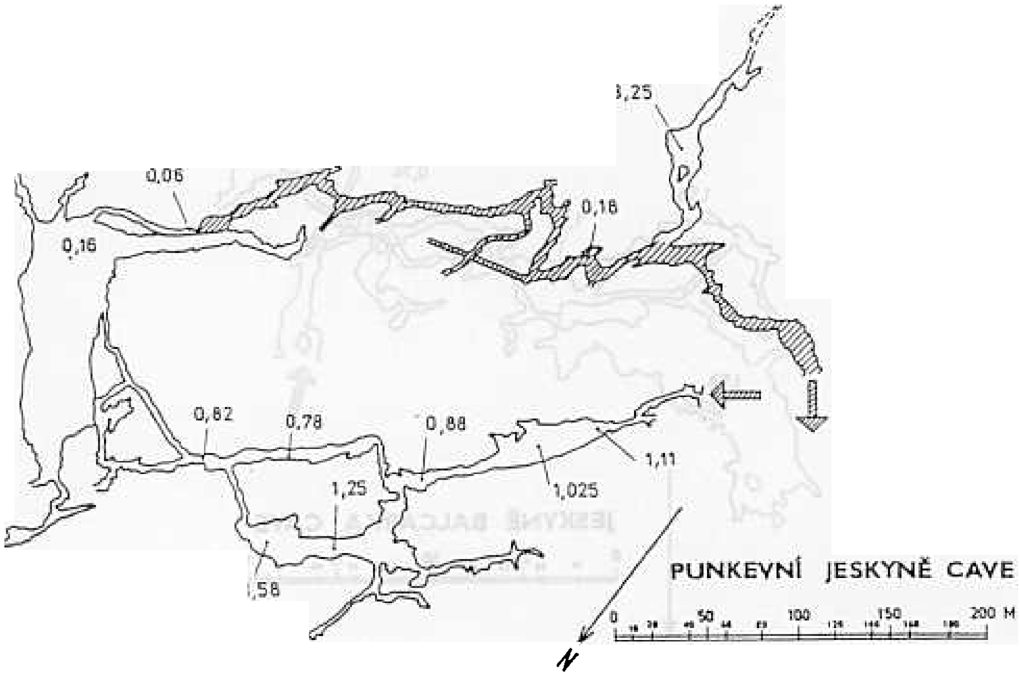



Fig. 1 - mean annual voluminal Rd. activities in the Punkevni jeskyne Caves


Fig. 2 - mean annual voluminal Rd. activities in the Katerinska jeskyne Cave


Fig.3 - mean annual voluminal Rd. activities in the Balcarka Cave

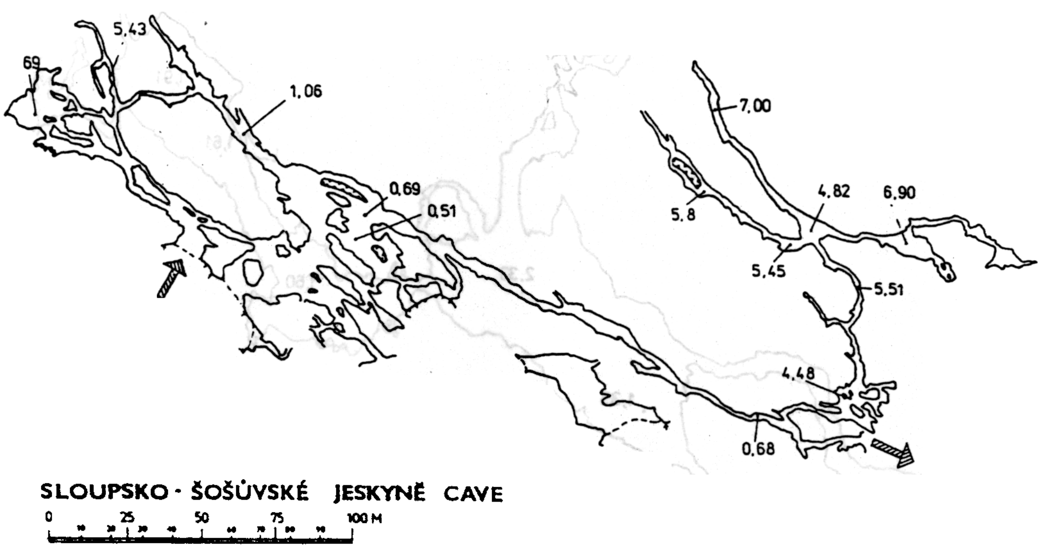



Fig.4 - mean annual voluminal Rd. activities in the Sloupsko-sosuvské jeskyne Cave

does not involve the disintegration proper of alfa radon the $10^4$ MeV/l = 0.28 Bq/l. It fluctuates in dependence on the quantity of the mother element, the possibility of emanation in the atmosphere, the circulation of air masses, the pressure, season and other factors. In the layer of the atmosphere it is low (1 - 5 $Bq/m^3$) owing to the fast dispersion into the higher atmospheric layers. In the caves, where the possibility of dispersion into outer atmosphere is reduced accumulation of radon and its daughters takes place by 2 - 3 ranks (E. Fiala, J. Valasek 1985) in dependence on natural circulation of the cave atmosphere - the draughts.

## CONCENTRATION OF RADON DAUGHTERS IN THE CAVES

First measurements of radioactivity in Czechoslovak caves were carried out in the years 1977 to 1979 (Z. Spurny, J. Sulcova, J. Koci, 1982). Within the frame of the measurements, the radioactivity in the caves of the Moravian Karst was studied, too. Special and systematic measurements of the volume activities of radon daughter products in the tourist caves of the Moravian Karst were started as late as in 1982 and have taken place incessantly up to the present. The selection of the localities (all together 33) was carried out so as to get a most complete image as possible of the values of the volume activities of radon daughters in the individual caves along the tourist routes.

In the Punkevni jeskyne Caves the route passes through four climatically and genetically different parts. These are the dry section of the Punkevni jeskyne Caves, the Macocha Abyss, the Macosske vodni domy, Macocha Water Domes with boating on the underground Punkva River and the Masarykuv dom. In the Macocha Abyss the measured values resemble the outside ones. A similar situation was established even in the Macocha Water Domes where the values of total potential energy are only slightly higher owing to sufficient ventilation. There 0.06 - $0.18\times10^4$ MeV/l were measured. In the dry section of the Punkevni jeskyne Caves which can be characterized as dynamic only slightly increased values can be found within the range of 0.10 - $2.86\times10^4$ MeV/l the values above $2.00\times10^4$ MeV/l occurring but sporadically. Completely different is the situation in the Masarykuv dom where the air exchange is insufficient so that the accumulation of radon and its daughter products takes place and thus even the increase of the values of volume activities to the level of even $10.00\times10^4$ MeV/l.

The Katerinska jeskyne Cave is developed in two levels, the lower one is open to the public. The visit route passes through three mighty interconnected domes. Here a typical dynamic cave with a good air exchange in winter and summer (A. Jancarik, 1985) is concerned. This is why even the measured values are relatively low. Their annual average attains $1.78\times10^4$ MeV/l. Only one locality wrenches itself out of this average where the value of $5.10\times10^4$ MeV/l was measured for a short period.

The Balcarka Cave is situated at the eastern margin of the tectonically strongly disturbed Devonian limestones of the Moravian Karst. The cave consists of a labyrinth of narrow, sinuous corridors connecting two extensive domes. It is developed in two levels. The upper level occurs shallowly under the earth surface (about 10 m). Many of the fissures, dislocations and chimneys communicate with the surface so that the air exchange is good all over the year. To this correspond even the measured values of the volume activities of radon daughter products attaining in annual average only 1.28x10 $^4$ MeV/l.

The values measured on the individual localities differ only slightly from this average. Only for a short period, the value of 5.00x10 $^4$ MeV/l was measured on one locality.

The Sloupsko-sosuvské jeskyne Caves occur in the sinkhole area of the Sloupsky potok Brook. They represent the most expensive cave system developed in two levels connected by underground abysses attaining a depth of even 85 m. The upper level is open to the public on a length of about 3 km. It forms two genetically, morphologically and climatically different parts - the Sloupské jeskyne and the Sosuvské jeskyne Caves. The Sloupské jeskyne appear as a complicated, predominantly dynamic system with very low values of the volume activity of radon daughter products. Their annual average attains only 0.99x10 $^4$ MeV/l.

The Sosuvské jeskyne Caves have on the contrary the character of completely static caves. To this corresponds even the high mean annual value of the volume activities (5.92x10 $^4$ MeV/l) the values of the volume activities reaching on some measured spots even 12.67x10 $^4$ MeV/l.

## IMPACT OF RADON AND ITS DAUGHTER PRODUCTS ON HUMAN ORGANISM

An important property of radon is the fact that by the disintegration of the gaseous element solid matter develops (Pb, Bi, Po, At, nuclides) which deposits on the surface of objects with which radon gets into contact or are bound to aerosol and particles involved in the air which Man inhales. By long-lasting breathing in of high volume activities of radon daughter products the risk of health detriment increase. In breathing, the daughter products of radon are retained in the lungs on a relatively small area of the surface of the respiratory organs. The basal cells of the epithelium of the respiration ways are within the reach of alfa radiation occurring in the transformation of the daughter products. The alfa particles have a small reach in epithelium of the lungs but their relative biological effectiveness expressed by the high value of the quality factor is considerable (M. Fiala, J. Valasek 1985). By incessant and intensive irradiation the natural restoration of basal cells can change after a certain (latent) period into malign growth with a consequent development of a bronchial carcinoma.

If we compare the values of the volume activities of radon daughter products measured in the individual caves with the time spent by the visitors and guides underground with the CS rule determining the highest possible annual receipt (see table) we can observe:

1. in the case of tourists - cave visitors - is the annual exposure so low that it can be valued as unimportant with respect to their short stay underground.

2. In the case of the cave guides the annual exposure ranges deep below the level (6 - 45x) of the highest admissible annual receipt so that the risk of a health detriment owing to inhalation of radon daughter products is very low.

| Highest annual radon receipt with the cave guides in the Moravian Karst | | | | | |
|---|---|---|---|---|---|
| 1986 | | | | | |
| Caves | A | B | C | D | E |
| Punkevni | 0.77 | 0.63 | 7.98 | 998 | 12 548 |
| Katerinska | 1.60 | 0.36 | 8.00 | 269 | 6 039 |
| Balcarka | 1.32 | 0.22 | 8.00 | 202 | 7 320 |
| Sloupsko-sosuvské | 3.27 | 0.59 | 8.0 | 219 | 2 954 |
| 1987 | | | | | |
| Punkevni | 1.68 | 1.38 | 8.0 | 991 | 5 751 |
| Katerinska | 1.65 | 0.35 | 8.0 | 254 | 5 856 |
| Balcarka | 3.80 | 0.90 | 8.0 | 285 | 2 543 |
| Sloupsko-sosuvské | 2.53 | 0.79 | 8.0 | 367 | 3 819 |
| 1988 | | | | | |
| Punkevni | 0.73 | 0.49 | 7.99 | 804 | 13 235 |
| Katerinska | 0.92 | 0.22 | 8.0 | 286 | 10 502 |
| Balcarka | 1.60 | 0.32 | 8.0 | 243 | 6 038 |
| Sloupsko-sosuvské | 1.87 | 0.40 | 8.0 | 256 | 5 167 |

**Explanations:**

A - mean volume activity $x10^4$ MeV/l

B - highest annual receipt (exposure) with the guides $x10^4$ MeV/l

C - highest possible annual receipt of guides according to CS rule

D - highest number of hours spent by the guides in the caves

E - highest possible number of hours spent by the guides in the caves according to CS rule.

## REFERENCES

BOSAK P. (1980) - Spodnokridovy fosilni kras Rudicke plosiny v Moravském krasu. (Lower cretaceous Fossil Karst of the Rudice Plateau, Moravian Karst.) Ceskoslovensky kras 31: 57-69, Praha.

FIALA E., VALASEK J. (1985) - Objemové aktivity dcerinnych produktu radonu v jeskynich Moravského krasu. (Voluminal activities of Rd daughter products in Caves of the Moravian Karst.) Ceskoslovensky kras 36: 23-28, Praha.

JANCARIK A. (1985) - Mereni tlakovych rozdilu vzduchu ve vybranych lokalitach Moravského krasu. (Measurement of the air-pressure differences in selected localities of the Moravian Karst.) Archiv organizace Moravsky kras: 6 stran, Blansko.

PANOS V. (1962) - Fosilni destrukni krasove tvary vychodni casti Ceske vysociny. (Fossil destructional Karst forms of the eastern part of the Bohemian Highland.) Geograficky casopis, XIV: 181-204, Bratislava.

PRIBYL J., VODICKA J., KUZDASOVA Z., HOFIRKOVA S. (1984) - Prehled udaju o jeskynich Moravského krasu. (Outline of data on caves of the Moravian Karst.) Textova cast I. 98 stran, Geograficky ustav CSAV v Brne.

PIBYL J. (1990) - New Discoveries in the Amaterska jeskyne Cave, the Largest Cave System of Central Europe. Studia Carsologica 3: 89-95, Brno.

SPURNY Z., SULCOVA J., KOCI J. (1982) - Radioaktivita v jeskynich ceskoslovenskeho krasu (Radioactivity of Czechoslovak Caves). Ceskoslovensky kras 32: 7-11, Praha.

STELCL O. (1964) - Geomorfologické pomery jihozapadni casti Drahanske vrchovini. (Gromophologic situation of the southwest part of the Drahanska vrchovina Highland.) Sbornik Cs. spol. zemzpisné, 69:1 21-46, Praha.

STELCL O. (1985) - Historie zpristupnovani jeskyni v Moravskem krasu. (History of opening for public in the Moravian Karst.) Regionalni sbornik okresu Blansko 85: 38-52, Blansko.