ESSAYS IN THE ECOLOGY AND CONSERVATION OF KARST

EDITED BY ILONA BÁRÁNY-KEVEI & JOHN GUNN

International Geographical Union
Comission Sustainable Development and Management of Karst Terrains

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Environment of the Aggtelek Lake (Aggtelek National Park, Hungary)

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Preface

This book is an important outcome from the work of the International Geographical Union Commission 96.C21, "Sustainable Development & Management Of Karst Terrains" over the period 1996-1999. The overall aim of the karst commissions of the IGU is: 'To promote geographical research on karst areas' and for the period 1996-2000 our specific aims were:

- To improve understanding of the relationships between humans and karst environments
- To develop appropriate theories and technologies for the rational and sustainable use of karst resources in the late 20th and early 21st centuries

In fulfilling these aims, a primary objective was to promote research on karst geo-ecology and specifically more detailed investigations of the karst system from the surface vegetation/soils to subsurface features. Through this research we hoped to make a distinctive contribution to the conservation of karst geoecosystems by promoting informed land management and the rational and sustainable use of resources in karst areas.

The present volume contains a series of essays from Full and Corresponding Members of the Commission most of which are based on verbal or poster presentations to an „International Symposium on Nature Conservation and Sustainable Development on Karst Terrains" held in Budapest and Miskolc, Hungary from 5-9 September 1999. The 25 chapters in this book contain papers that have been grouped into four broad themes:

- Karst geo-ecology
- Human impacts on karst terrains
- Land management on karst terrains
- Karst geomorphology and hydrology

Karst geo-ecology

The five papers that address this theme are all concerned with aspects of soils and vegetation on Hungarian karst areas. *Beck and Borger* trace the development of soils in the Aggtelek area from the Cretaceous through to the present. There are links to two other themes as the authors draw attention to human activities that have resulted in substantial modification and soil erosion and note that while the soils still provide protection for autogenic recharge, there is a need for land managers to consider the direct inputs from the allogenic catchment. This aspect of catchment management is considered in the later papers by *Gunn* and by *Móga*. The papers by *Hoyk* and by *Zseni* address aspects of the vegetation and soil nutrients in two Hungarian karst areas, while *Bárány-Kevei and Mezősi* examine the relationships between soil chemistry and the heavy metal content of vegetation, another topic that has important considerations for land management. The final paper in this section, by *Darabos*, differs from the others by focusing on soil micro-organisms, and provides a link to the final theme by discussing their role in the limestone solution process.

Human impacts on karst terrains

A wide range of human impacts are addressed in these seven papers. The first, by *Day* examines the effect that burning of secondary vegetation has on soil carbon dioxide concentrations in a karst area of Belize. The measurements indicate that soil CO_2 levels in tropical karstlands may vary considerably over short time periods, particularly as a result of human activities such as forest clearance and burning, and they suggest that studies of soil CO_2 influence on carbonate rock dissolution in tropical karst should take into account the potential for both short-and long-term variations in soil CO_2 levels. Aspects of deforestation on karst feature in each of the three papers that follow. In the first, *Tyc et al* explain how deforestation and related human activities contributed to the development of an unusual karst-aeolian ecosystem. This has presented modern land managers with a dilemma in that without further human intervention there will be regeneration of the natural climax vegetation, which is relatively common, and the rare and unusual features that characterise the aeolian ecosystem will be lost. *Szymczyk* examines related aspects of the same problem paying particular attention to the role of karst groundwater. The paper by *Okamoto et al* has similarities to that of *Beck and Borger* in that they document changes to soils resulting from human impacts on karst in Japan that date back to the mid-Holocene. In Japan the impacts reached a peak between the 17th and 19th centuries AD with intensive deforestation and consequent large scale soil erosion, with associated water pollution, and floods. Interestingly, there are analogies with the area of Poland described by *Tyc et al* in that the replacement of charcoal as a fuel by coal and oil in the late 19th century was followed by natural reforestation and large areas in the Akka Karst have become secondary forests dominated by deciduous oak or birch.

Although the replacement of charcoal, and subsequently to a large extent coal, as a source of fuel has reduced some large scale human impacts on karst areas, the transport of oil poses its own problems and *Kranjc* documents the impacts of a series of oil spills in karst areas of Slovenia. A key point here is that the oil has a long residence time, unlike water soluble pollutants, and is not easily broken down by natural processes. As a result the impacts may be very long-lasting and it seems likely that oil based contaminants will remain in the karst long after natural regeneration has healed most of the damage caused by deforestation for charcoal production. The risk of pollution from oil spills, and the problems of managing karst areas with large allogenic catchments which extend across international borders, are also considered in the later paper by *Móga*. The impacts of land use change in the Budapest area over the past 200 years are described by *Mari and Fehér* whose paper also includes particularly valuable data collected from Szemlő-Hegy cave on a continuous basis since 1987. The wider importance of studies of percolation waters in caves is demonstrated by the fact that contamination of infiltrating water could ultimately lead to pollution of the famous, and economically extremely important, thermal springs. This is picked up in a later paper by *Tardy*.

The six papers discussed above, and the vast majority of published papers, have considered 'external' threats to caves and karst and there have been very few studies of the 'internal' impacts from human visitors to caves other than accounts of the regrettably all to common damage to speleothems. Hence, the final paper in this section by *Fehér et al* which examines cave-human interaction is particularly valuable. The interdisciplinary team studied both the extent to which human presence changes the environment in a cave and the physiological changes that take place in a cavers body while underground. The authors also draw implications for the commercial use of caves for speleotherapy.

Land management on karst terrains

Nine papers cover differing a wide variety of problems relating to land management in karst areas of Australia, Hungary, Ireland and Russia. A common problem, alluded to above, is that whereas management of the land above a cave system may be subject to legal constraints designed to minimise adverse impact, the allogenic catchment is frequently excluded as it may have no intrinsic scientific / conservation interest. *Gunn* presents an interesting alternative case where the Marble Arch Caves, Northern Ireland, and their autogenic catchment are not yet accorded any legal protection but potentially serious impacts from land use changes in the allogenic catchment have been alleviated because the area contains a large expanse of blanket bog, a priority habitat under the European Union Habitats Directive. Two papers from Australia examine different aspects of management at Jenolan Caves, one of the best-known and most often visited tourist attractions in Australia. *Gillieson and Thurgate* consider 'external' aspects and explain how land classification can be used as a tool for defining management units in the Jenolan area to which differing management strategies may be applied. *Hamilton-Smith* focuses on 'internal' aspects describing new and innovative managerial arrangements and an ongoing program of both environmental and social monitoring. In contrast to Jenolan where there is a strong focus on a single site, *Trofimova* examines the many problems surrounding the conservation of the many caves in the Irkutsk amphitheatre, Russia. Although the area contains Lake Baikal, a World Heritage site, little has been achieved in management of the caves and karst. The following paper, by *Móga*, also addresses the problems of land management at a World Heritage site, in this case the caves of the Gömör-Tornai karst, in the Hungarian-Slovakian border territory. The author makes the point that the UNESCO resolution that established the site concerns only the caves and does not automatically include the overlying karst planinas or the allogenic catchment, despite the fact that without special protection of the whole karstic environment the caves themselves cannot be properly defended from harmful effects.

The Aggtelek National Park forms part of the Gömör-Tornai World Heritage site and *Botos* describes a planning method for the park that uses GIS and is based on forestry and ecological factors. The aim was to optimise the segments of functionally and environmentally protected landscapes and the result is a vegetation pattern that can be implemented by forestry managers. In contrast to the Aggtelek National Park which has been established for a number of years, the Western Mecsek Hills do not enjoy any protection and *Havasi and Parrag* make the case for a new landscape protected area. Similarly, *Szabó* makes the point that the Hungarian dolomite karst terrains have been relatively neglected and discusses the geomorphological value of surfaces in the recently established Balaton Upland National Park.

The final paper in this section moves from rural to urban areas and *Tardy* briefly outlines the basis of a large scale, long-term, research and action programme designed to protect the hydrothermal karst and springs of Budapest. The earlier paper by *Mari and Fehér* provides a useful background to the type of problem that the research described by *Tardy* is designed to address.

Karst geomorphology and hydrology

The four papers in this section address more 'traditional' topics, although the first, by *Zámbó and Telbisz*, provides a link to the earlier them of limestone geo-ecology by examining the significance of soil zone processes in the evolution of surface karren. Contrasting approaches to the problem of estimating limestone solution rates are presented in the papers by *Telbisz et al* who used a hydrochemical approach in their detailed study of a doline and underlying cave in the Aggtelek karst and by *Urushibara et al* who used limestone tablets to assess the variations in subaerial and subsoil solution in seven areas of Japan. *Telbisz et al* found significant differences between the solution of Ca and Mg carbonates, while *Urushibara et al* found differences between tablets made from Slovenian and Chinese limestones and tablets made from Japanese limestones. Finally, *Fogarasi* describes the infiltration characteristics in a long-residence time Hungarian karst.

Summary

The essays collected in this book provide a good cross-section of current research into the ecology and conservation of karst terrains. The majority of the papers are from eastern Europe but the problems discussed, and solutions proposed have wider applicability. It is hoped that they will stimulate future research in other areas as well as providing useful information for land managers. They will also form a basis for a future project of the IGU Karst Commission, production of a textbook on Limestone Resources and Landscape Management.

As editor I have attempted to clarify all of the abstracts, and some of the texts, from authors whose first language is not English. I hope that in doing so I have not changed their meaning and regret that time did not permit us to return all edited papers for checking. I would like to thank all those who contributed to the organisation of the symposium and field excursion in Hungary, and particularly to Lajos Csikász for his assistance in producing this book.

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SOILS AND RELIEF OF THE AGGTELEK KARST (NE HUNGARY): A RECORD OF THE ECOLOGICAL IMPACT OF PALAEOWEATHERING EFFECTS AND HUMAN ACTIVITY

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Summary

The soil parent material in the Aggtelek area, northeast Hungary was a thin allochthonous sheet deposited across the exposed lithologies, including the limestones of the karst area. The oldest weathering residue (latosol/oxisol) developed during the Cretaceous/Eocene. Later, the planation surface of the same period was buried by sediments from the Carpathian uplift. After the old etchplain landscape was re-exposed during the Miocene/Pliocene, the natural soil cover of today developed during several periods of the Quaternary. This soil cover is a complex of interglacial terra fusca, which is covered by a Holocene cambisol. The soils have been heavily altered and partly eroded as result of human impact. However, in general the input of noxious substances is very low in the study area, and comparison of the soil characteristics shows that most of the soils still provide sufficient protection for autogenic recharge to the karst aquifer. Nevertheless, the danger of pollution is extremely high since the adjoining non-karstic Tertiary sediments are intensively used by agriculture. The allogenic surface runoff from this area drains straight into the karst aquifer via ponors. Sufficient protection can only be ensured if all the allogenic catchment area is also excluded from agricultural exploitation. Another problem within the Aggtelek National Park is rapid recolonisation (succession) by forest. The current ecological characteristics of the landscape will change by this process, and it is also counter-productive with regard to touristic development of the region. It can be proved that in many places soils heavily altered by human impact provide the best conditions for rapid succession and as a result the protected characteristics of the landscape get lost.

1. Introduction

A sensible strategy of sustainable ecological management requires precise knowledge of the local natural resources and conditions. Such a strategy should also aim to consider human impact, and to recognise and plan appropriate contingencies for potential detrimental effects. Also in karst regions this is a basic assumption about existing and future sources of danger. The exploitation of karst water for drinking water supply in an area where surface water and water close to the surface is a scanty resource, is an example of the usefulness of a broadly orientated ecosystem research in this particularly sensitive environment. In this connection it must be noted that the soils take a very important position, beside the knowledge of the subterranean karst system, as filter and buffer against harmful and noxious influences. Since 1st January 1985 the karst landscape in the northeast of Hungary has been protected as Aggtelek National Park which is closely connected to the Slovakian Karst Region Protection District in the north. At the same time both areas are protected internationally by UNESCO (project: „Man and the Biosphere" - MAB). In 1995 UNESCO declared the subterranean karst system of the Aggtelek and Slovakian nature reserves as part of the World Heritage.

On the surface, to a huge extent the appearance of the landscape is the result of mainly arable and pastural agriculture for the most of the area. The remaining woodlands have also been intensively used. In addition, agricultural use has resulted in intense soil erosion which in places led to extensive exposure of the limestone. Recently, the mosaic of small woods, juniper heathland, transitional areas and open landscape, which is essential for the abundance of species and the survival of numerous endangered species, has gradually disappeared owing to increasing succession. The inevitable consequence is an increasing monotony of flora and fauna. The recolonisation of the impressive doline karst by forest means the same to the attractiveness with regard to tourism, which could be an important source of income in future. Since the catchment of the karst springs stretches to the southern adjoining Pliocene sediments, these areas also must be taken into consideration of ecological reflections. The non-karstified Pliocene zone is still used as arable land and drains into the karst area via ponors (see *Fig. 1*). Especially after heavy precipitation pollutants from the agriculture can reach the karst system unfiltered with the surface flow and affect the karst water quality.

2. Landscape development and natural basis

The research area (*Fig. 1*) is situated in the SW of the Aggtelek National Park between the villages of Aggtelek and Jósvafő. Geologically, geomorphologically and hydrologically it can be divided into three regions:

1) The most extensive central sector is based on Triassic „Wetterstein"-limestone

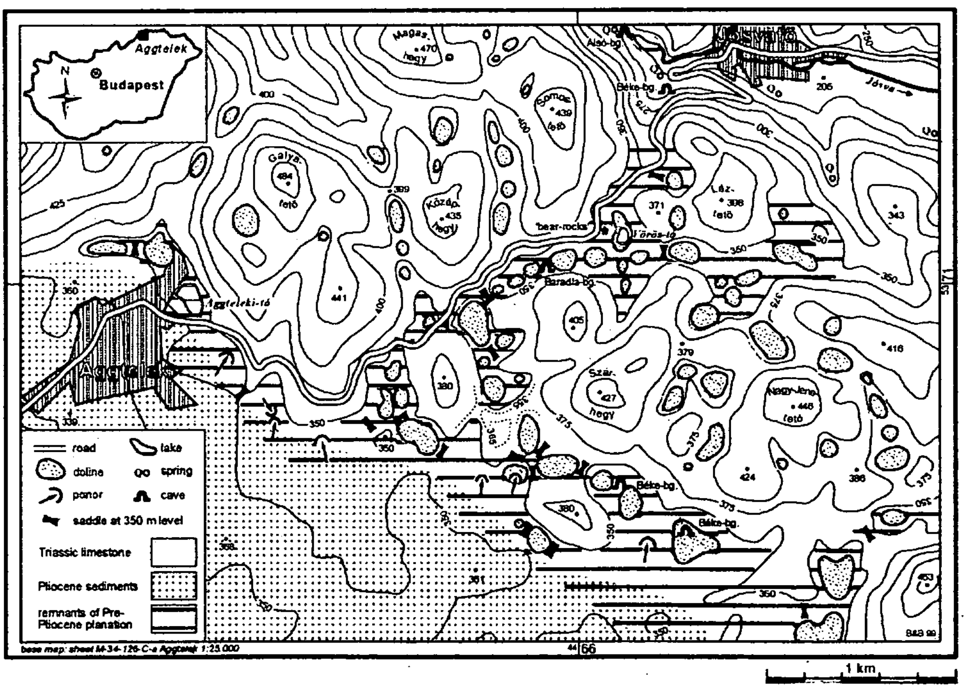

Fig. 1 Simplified geology and geomorphology of the SW Aggtelek karst

and portrays a strongly karstified landscape characterised by small hills, dry valleys, and large dolines.

2) Along a NW-SE-striking fault in the southwest of the studied area, a basin filled with Miocene and Pliocene loose sediments (a mixture of gravel, sand and clay), often with an impersistent, thin loessial cover, occurs adjacent to the karst region. This part of the landscape shows a slightly undulated relief with surface drainage. As a covered karst region it is used as farmland.

3) Next to the village of Jósfavő a deep valley incised about 120 m into the limestone during the Pleistocene, likewise along a NW-SE striking fault. During the cold phases of the Quaternary the karstifiable rock was sealed by permafrost. This valley with the small river Jósva, which is fed by several karst springs, forms the actual local water course of the area.

The oldest relief elements are remnants of a Cretaceous planation surface. According to *Grill 1989* the development of the planation surface was the result of semihumid tropical conditions during the mid-Cretaceous. But more likely the formation of such a planation surface took place under extremely wet and hot climatic conditions (cf *Bremer 1986; Bárdossy & Aleva 1990; Borger 1999*) during the Cretaceous, particularly Late Cretaceous, greenhouse climate (e.g. *Thomas 1989, 1994; Hugget 1997)*. Above all, the extreme greenhouse conditions can be attributed to CO_2-contents in the atmosphere which were much higher than those of today (see *Berner 1994)*. From c. 120 to 66 million years before present the wet and hot zone of deep weathering extended up to c. 60° north (*Thomas 1994*). For example *Lidmar-Bergström (1993, 1995*) and *Lidmar-Bergström* et al. (1997) report the existence of widespread planation surfaces in the south of Scandinavia deriving from these times.

After the Cretaceous climatic optimum the planation surface of the Aggtelek was divided up by the main faults striking NE-SW. These oldest faults were already created at the end of the Jurassic and beginning of the Cretaceous but equalized at the surface by the etchplain. During the lower Tertiary the Aggtelek region was buried by sediments of the rising Carpathian crystalline centre. A second direction of main faults - striking E-W - was created during the Oligocene and Middle Miocene. From Miocene to Pleistocene a new strong upheaval phase of the entire Carpathian orogen took place with the result of a far-reaching uncovering of the older relief elements. The Aggtelek was left as a subdued mountain landscape with horst and graben structures.

In the study area relicts of the three essential stages of relief development are preserved. Nearby the Vörös-tó („Red Lake" - see *Fig. 1*) residues of Cretaceous deep weathering - with basal knobs and latosol/oxisol remnants - occur. The basal knobs are surrounded by the latosol/oxisol, which was interpreted by *Jakucs* (1977) as a Cretaceous terra rossa. But the most distinctive evidence of the Cretaceous relief development is found in the well preserved and dominant remains of the old etchplain. The old etchplain was broken into several pieces by subsequent tectonic movements and its parts were moved into different altitudes (with variations up to more than 400 m). Most of the Cretaceous weathering products were eroded as well as the sediments of the lower Tertiary. The earliest possibility of deep karst was in the Late Miocene, but it more probably occured for the first time in the Pliocene after the nonkarstifiable sediments and weathering residues were widely removed and an adequate distance to the local water course was given by the persistent uplift. The tectonic situation of limestone plateaus of the same age and origin but with different extent of uplift was the reason for the considerable variation in the beginning of karstification of each plateau, depending on the particular vertical distance to the local water course. According to *Bárány-Kevei* (1998) canyon-like valleys could be incised at the Pliocene/Pleistocene where clay beds cropped out near the surface. In the investigated area this geological condition is not found. The map (*Fig. 1*) shows valley-like remnants of the Pre-Pliocene drainage system at a constant level about 350 m. It reaches from the Miocene surface below the cover of Pliocene sediments far into the karst region - probably depending on the water course of that time. The palaeo-drainage system shows a control by the main tectonic lines and their transversals. The wide and flat valley-like relief leads to the surface of the Miocene filling below the the Pliocene sediments of the basin (see fig. in *Mezősi 1984*: 185). Their shape and contours, as well as the existence of the latosol/oxisol at the „Vörös-tó" (Red Lake) allows the speculation that the first occurrence of these „valleys" took place as Miocene planation bands (in the sense of *Bremer 1981*). The tectonic dependency is not incompatible to this.

The impressive doline karst of the region is the result of quite young processes which started in Quaternary times. In the Aggtelek *Jakucs (1977)*, and *Bárány-Kevei & Mezősi* (1995) subdivide the dolines according to their geomorphological position into three types: „plateau"- „basin-" and „valley-dolines". The latter are predominant within the research area where they are arranged along the tectonic structures, having respectable diameters of 50-300 m and depths of 15-40 m. In addition figure 1 clearly shows that a uvala-like expansion of such dolines is mostly combined with tectonic intersections of one of the two major fault strikes (SW-NE, E-W) with their transverse joints. A peculiarity within the study area represents the uvala with the Red Lake („Vörös-tó"), where both the two major fault strikes and their transverse joints meet. Perhaps the very high degree of jointing was the reason that here the Cretaceous basal surface of weathering (*„Verwitterungsbasisflaeche"*) locally survived on a small block in a tectonically protected position. Exactly at the same locality also the well-known Baradla cave changes its course from its W-E main direction to a S-N course with a sharp bend.

3. Origin of the initial soil materials

Up to now there are no recorded detailed soil investigations from the Aggtelek area. Two exceptions are the works by *Bárány-Kevei & Mezősi* (1995) and *Bárány-Kevei* (1998), which give prominence to the question of soil influence on doline development. In this connection the widespread reddish-brown soils are interpreted as Pleistocene relict soils (Mediterranean terra rossa) of warmer interglacial periods (*Bárány-Kevei 1999*), or, as in the case of the Red Lake, as Cretaceous terra rossa (*Jakucs 1977*). In addition, the brown forest soils and rendzinas are mentioned as typical Holocene soils.

In a karst area pedological investigations are often problematical because frequently the soil terminology and the soil is not compatible with the soils which are developed in reality. The terms terra rossa and rendzina presuppose soils which are by definition (AG Boden 1994) the product of limestone weathering and their solution residue respectively. Our own analyses verify the high purity of the outcropping limestone with a solution residue less than 0.5 % as also indicated by *Zámbó* (1995). According to this, the formation of a rendzina with just 10 cm thickness requires solution of c. 20 m of limestone over the Holocene without loss by rainwash and/or deflation. The application of this calculation to the profiles of the Aggtelek, which partly reach down to depths of more than 2 m below the surface, shows that Quaternary soil development cannot solely be attributed to limestone dissolution. However, in general such geochemical calculation have not been considered or even noted by the pedological literature. In the Aggtelek the majority of the soil substrata leads back to the input and weathering of allochthonous materials as it is also described in other karst regions (e.g. *Burger 1984* - Rhenish Slate Mountains; *Borger 1990* - Swabian Jura). The limestone is not the main source of the soils. Regardless of the position, age, or later redeposition, the soil substrata are predominantly allochthonous.

To clarify the origin of the soil substrata 30 samples from 20 soil profiles from different geomorphological and geological positions were selected (see *Fig. 2*). The soil samples were analysed by thin sections, X-ray diffraction (XRD), scanning electron microscope (SEM) and heavy mineral analyses. Preliminary data, obtained from micro-geomorphological techniques, verify the suspected allochthonous origin of most of the soil substrata independent of the sampled location, the soil age, or a later redeposition. The most explicit proof is the high occurrence of quartz and quartzite grains, which cannot originate from the absolutely quartz-free limestone. Additionally, with the scanning electron microscope negative prints of dissolved feldspars are visible on the quartz grains, indication that they come from a crystalline source. Furthermore, SEM analyses of the surfaces of the quartz grains reveals percussion marks from fluvial transportation. The percussion marks are partly overprinted by chemically produced features showing the

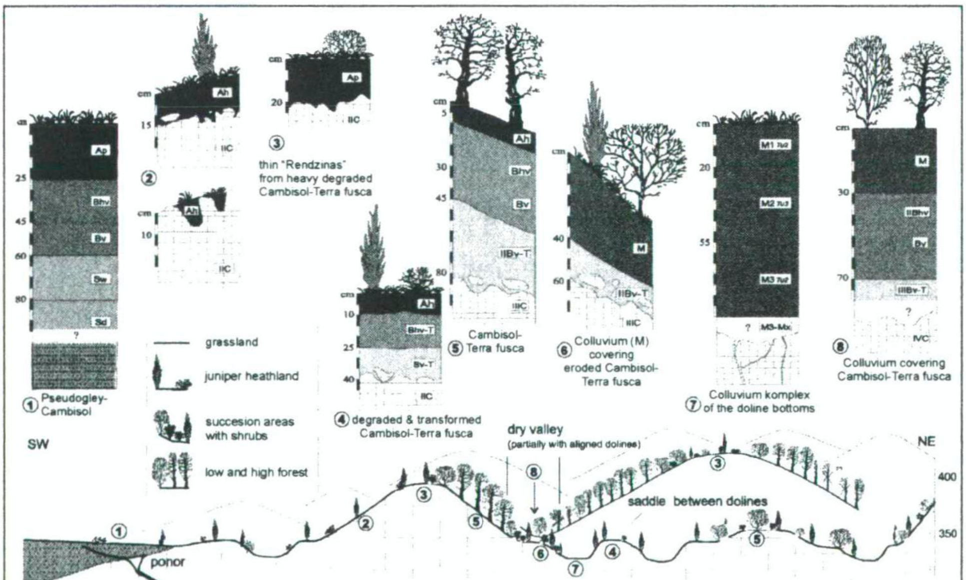

Fig. 2 Schematic profile of the most common relief elements, soil types and vegetation units

influence of post-sedimentary weathering. Considering these results, the source material of the soils can only originate from the crystalline Carpathians.

Heavy minerals	*extremely stable* Z	T	R	*very stable* An	Ky	Sil	*stable* Ep	St	*unstable* Hbl	Gr	rest	opaque	*counted transparent minerals*
Soil-cluster I	43	35	10	-	6	1	3	-	-	-	2	1117	*500 (5)*
Soil-cluster II	10	9	5	+	1	1	52	4	2	9	7	56	*2800 (28)*
Soil-cluster III	19	31	7	+	+	1	27	3	2	3	7	154	*500 (5)*

( ) =samples

Z = zircon, T = tourmaline, R = rutile, An = anatase, Ky = kyanite, Sil = sillimanite, Ep = epidote-group, St = staurolite,
Hbl = hornblende, Gr = garnet

rest = alteration products/minerals an other unidentifiable components

Soil-cluster I = Cretaceous-Eocene soil (Vörös-tó Uvala)

Soil-cluster II = dominant soils of the Aggtelek karst

Soil-cluster III = soils of the covered karst on Pliocene sediments

Fig. 3 Average spectra of heavy minerals

4. Development and age of the soils

Although the analyses show that the matrix of all investigated soils has the same crystalline origin, with the help of different characteristics of the soil substrata it is possible to differentiate between three major soil clusters. Cluster I consists of the Cretaceous latosol, which differs very clearly from all other soils. Cluster II contains the recently dominating soils of the karst region, while the soils of the Pliocene sediments in the SW of the working area are summarized in cluster III.

The expanse of the Cretaceous latosol (Cluster I) at the western edge of the Red Lake uvala in fact is very small, but it occupies a key position in furthering understanding of the course of the soil development in the Aggtelek. The origin of the Cretaceous latosol/oxisol (cluster I) as the result of wet and hot environmental conditions is already visible in the field. Explicit signs of this are a high content of clay (> 80 %), its red colour, and a large number of lateritic iron concretions (up to several cm in diameter). The thin sections show a red hematite-rich matrix with quartz grains (predominantly silt-sized, occasionally also as sand grains) and pisoliths.

Here, the quartz grains, as one of the most stable primary minerals, are heavily weathered (as visible in thin section and by SEM). They are fractured in a manner which is consistent with that observed in materials subjected to intensive chemical weathering (cf *Schnütgen & Spaeth 1983*). Furthermore, the quartz grains are heavily corroded by chemical palaeo-weathering processes. Quartz grains inside the iron concretions especially indicate very extreme weathering. Some of these quartz grains reach an alteration of stage 5 after the weathering scale by *Borger* (1993) showing the breakdown of quartz grains. The quartz grains of this stage are completely corroded and split up into numerous fragments - a process which is only possible naturally under the extreme conditions of a wet and hot environment.

Minerals (clay-fraction)	Quartz	Kaolinite	Mica family	Haematite	Goethite	number of samples
Soil-cluster I	1	3	-	+	+	4
Soil-cluster II						22
Terra fusca horizon (IIBv-T)	1-2	1-2	1	-	-	
Cambisol horizons (Bv,M)	3	1-2, 3*	1-2	-	-	
Soil-cluster III	3	3	2-3	-	-	4

* not eroded soils beneath forest cover

4 = dominant included, 3 = very clear included, 2 = clear included, 1= included, + = minor included

Soil-cluster I = Cretaceous-Eocene soil (Vörös-tó Uvala)
Soil-cluster II = dominant soils of the Aggtelek karst
Soil-cluster III = soils of the covered karst on Pliocene sediments

Fig. 4 Clay minerals (X-ray diffraction – XRD)

However, there is little evidence of disarticulation of the fragments as they tend to remain in spatial and optical continuity with one another and do not show any dislocation. This clearly demonstrates that the weathering must have occurred in situ and after the deposition of the quartz grains as allochthonous material above the limestone. Clearly this in situ character of the weathering product is also visible in the iron-rich clayey matrix material which has an identical composition inside the corrosion features and in the surroundings of the quartz grains. Neither redeposition after the Cretaceous weathering nor any disturbance by later pedogenetic processes has occurred.

The intense weathering is also proven by heavy mineral analysis. About 90 % of the spectrum consists of extremely stable minerals as zircon, tourmaline, and rutile (see *Fig. 3*). Other minerals, such as feldspar and mica arrived from the crystalline source, but under the Cretaceous environment they were completely dissolved and transformed to kaolinite - the typical secondary clay mineral of wet and hot climatic conditions. Because Kaolinite is the only clay mineral in the investigated latosol remnants (*Fig. 4*) this is another proof of wet and hot climatic conditions.

In Europe a sufficiently long lasting period with such an environment was last present during the Cretaceous and, to a lesser extent, during the Eocene (cf. *Borger 1999*). This confirms the Cretaceous classification of the red soil of the Aggtelek by *Jakucs* (1977), although admittedly it is not the weathering residue of the outcropping limestone, as it is closely connected with the specification as terra rossa (*Jakucs 1977*). The presence of quartz grains characterize this soil as a remnant of the oldest preserved and in situ weathered allochthonous material deposited over the limestones of the research area.

Because of recent economic exploitation it is not easy to locate completely preserved profiles of the recent soils (cluster II) of the karst region. Over a widespread area the soils are degraded. The best preserved profiles are located at relief positions on shaded slopes, which were unfavourable for agriculture. But even the shaded slopes, which are adverse for arable farming, were intensively used to produce charcoal and burnt lime. However, here soil erosion was not as effective as on sun-exposed slopes and flat hill tops which at first were used as arable land and with increasing degradation later used intensively for pasture. After the soils were almost eroded, the arable land was used as pasture. Today the former farmland - especially on the sun-exposed slopes - is mainly juniper heathlands which are now subject to rapid succession and recolonisation of forest (*profiles 2 and 3, Fig. 2*). On the other hand considerable soil thicknesses are still to be found on the more or less continuously wooded shady positions. According to the extent of the human impact, several variations of soil profiles occur.

Little disturbed profiles show two layers of different material (*profiles 5 and 8, Fig. 2*). The upper layer is characterized by features of a cambisol. The soil type of the lower layer looks like a terra fusca. The cambisol layer is more silty than the terra fusca layer. Moving down the profile, a rise in the clay content from 50 to 70 %, and a distinctive change of the soil colour from brown to reddish brown (10YR to 5YR) take place. The lower layer ('terra fusca'-like soil) also contains a lot of quartz grains showing the allochthonous origin. An obvious difference to the latosol is that the quartz of the terra fusca-like soil does not show any in situ-weathering. The heavy mineral spectra are dominated by more than 50 % of epidote, and even less stable minerals such as garnet (see *Fig. 3*). The initial material of this soil was locally transported by wind and originates from the Pliocene sediments, as proven by electron microscopy. The terra fusca is the result of inter-glacial pedogenesis (cf. *Bárány-Kevei* (1999). The cambisol has, in contrast to the terra fusca-like soil, no pisoliths, but open pores. While the heavy mineral assemblages of both substrata show no differentiation, the higher amount of kaolinite, quartz, and mica in the upper layer (cf *Fig. 4*) also points to a development which differs from that of a terra fusca. The cambisol represents Holocene pedogenesis and the sediment itself dates back to the latest periglacial period.

Covering a good third of the investigated area the most degraded soils (*Fig. 2*) occupy a particularly large portion of the total surface. From their appearance these soils look very similar to rendzinas since the limestones are mostly covered by a thin and very humic A horizon. However, they are not rendzinas but rather represent remnants of the terra fusca layer which resulted from the same allochthonous material as the other soils. That means that the rendzina-like soils also do not result from limestone weathering. Because of this the term rendzina is not problem-free with regard to soil genetics and for this reason is provided with inverted commas below. Once the slopes, which are nowadays characterized by these 'rendzinas', were wooded hills covered with much thicker soils as evidenced by root karren created below an adequate soil cover. Today the remnants of the heavily degraded soils indicate that a complete mix of matrix and organic substance took place leading to a homogeneous and loose texture of dark colour which is reminiscent of rendzinas.

The corresponding colluvial soils dominate the situations at downslope positions, dry valleys, and dolines where they accumulate as particularly thick sediments (*Fig. 2, profile 7*). Their composition is a variable mixture of both layers of the cambisol-terra fusca, as clearly indicated by the micromorphological analyses and the granulometric compositions too (*Fig. 5*).

Frequently, partial degraded profiles occur at the saddles between dolines developed on the Pre-Pliocene planation surface (see *Fig. 1*). At these locations terra fusca remnants are preserved in varying thickness. Today their upper profile sections are mostly loosely structured and brown-coloured by humous substances (*Fig. 2, profile 4*). Only at this level, which stretches at an altitude of ń 350 m from the Pliocene sediments to the karst area, the truncated cambisol-terra fuscas contain some fine gravel-sized quartzite pebbles.

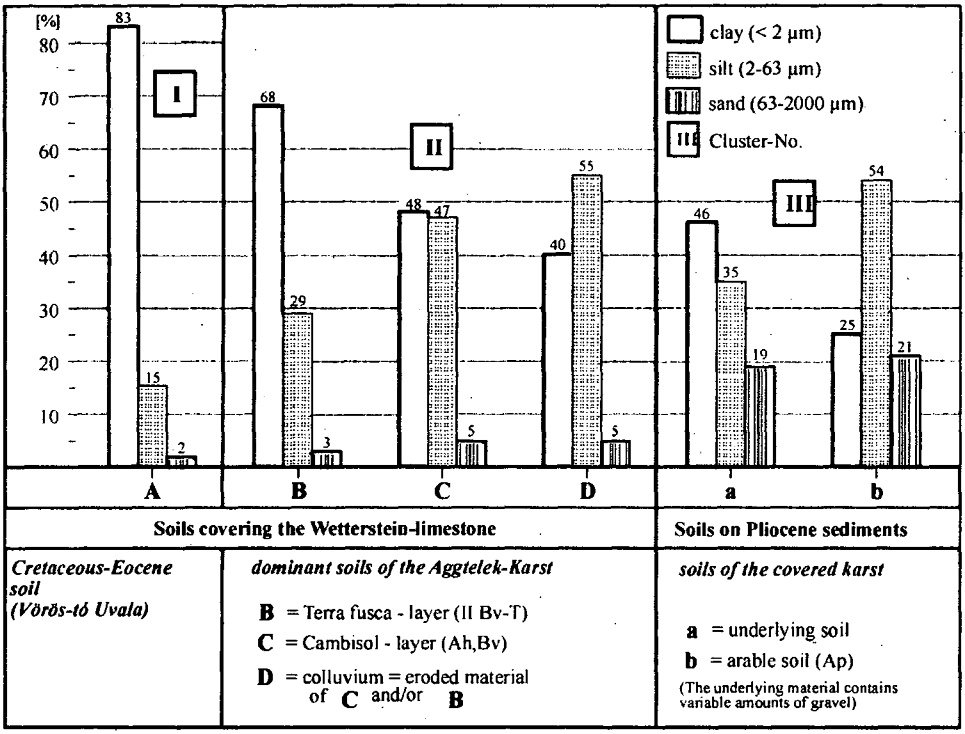

Fig. 5 Grain size distribution in the different soil types

This detritus is derived from the Pliocene sediments, where it is found in far higher density. The fact that these pebbles also occur in upper relief positions in the karst region can only mean that the dolines of the Pre-Pliocene level must be younger than the Pliocene deposition of these pebbles. Therefore a Pre-Quaternary age of the dolines at this level is very improbable.

The soil which is developed on the Pliocene sediments (*cluster III; see Fig. 2, profile 1*) differs very clearly from the soils of the karst area. As well as a high content of gravel, the amount of sand is also much higher. While the sand proportion on the Pliocene sediments is about 20 %, in the karst area it reaches at most up to 5 % (*Fig. 5*). In addition the soils of the Pliocene area show a tendency to pseudogley-dynamics. On the one hand the soils of the Pliocene area, with its predominantly subdued relief intensity, are not directly connected to the karst drainage, on the other hand here the soils tend to self-compaction with increasing depth owing to their considerable thickness. As a result of agricultural activities the upper profile sections always represent a humic plough horizon. Between the pseudogleyed lower profile sections and the plough horizon a brown soil horizon is generally present uninfluenced by the stagnation layer.

Currently the agriculture is concentrated on the Pliocene sediments around Aggtelek village, but previously farming spread across the entire area including the limestone hills as the present plough horizons everywhere prove. Today the natural soils of the karst area in particular are only partly reconstructable, but the Pliocene sediments also were subject to erosion because of arable farming. Their only exploitational advantage over the limestone area depends on the substratum characteristics because the unconsolidated Pliocene clays, sands, and gravels were always able to provide cultivatable land up to now.

The heavy mineral assemblage of the Pliocene sediments (*Fig. 3*) does not differ qualitatively from those found in the soils of the karst area. Both the Pliocene sediments and the allochthonous soil substrata of cluster II had the same origin. However, quantitatively the Pliocene mineral assembly clearly shows higher proportions of stable minerals indicating the greater age of the Pliocene sediments. Fundamentally, and corresponding to the heavy mineral suites (except the Cretaceous latosol), the XRD spectra of the clay fraction show similar reflections in all investigated soils, only the reflection intensities vary (*Fig. 4*). In all, the XRD spectrum of cluster III shows higher amounts of kaolinite, quartz, and mica than the terra fusca, but a comparison of the Pliocene substratum and the cambisol layers of the cambisol-terra fuscas shows hardly any difference. The Pliocene sediment therefore can be identified as a secondary source (after the Carpathian crystalline rocks) for the soil substratum of the karst area. For the redeposition of the mainly silt-sized grains to the tops of the hills only an aeolian tranport mechanism during periglacial phases of the Pleistocene comes into consideration. Relevant evidence is given by SEM analyses, because as well as quartz surface features indicative of transport by fluvial processes the SEM also clearly shows those indicative of aeolian processes. Aeolian-created percussion marks, such as upturned plates, are younger than the fluvial crescentic impact scars, because the fluvial features were overlain by the aeolian features. The fluvial impacts were generated during the transportation and sedimentation of the grains to the Pliocene sediment. The difference in granulometric composition between the Pliocene sediment and the aeolian redeposited material of the cambisol horizons is easily explained by selective transport.

To sum up it can be said that the soils of cluster I (latosol) represent remnants of Cretaceous to Eocene development. After a huge time gap, the terra fusca-like soil derived from interglacial times of the Pleistocene. The cambisols, both of cluster II (from locally redeposited fine-grained components of the Pliocene sediment by aeolian transportation during the latest periglacial period) and cluster III (in situ development of the Pliocene sediment), are Holocene. Soils resulting from human impacts are the rendzina-like soils, colluvisols and truncated variants of older soils.

5. Ecological potential of the soils

The intensive cultivation of the Aggtelek in historical times created extensive erosion of soil material and alteration of the landscape. It is of interest to know how much security the soils are able to provide against a noxious input into the karst system (cf. *Pfeffer 1995*).

5.1. Filter and buffer capacity towards noxious substances

To judge the capacity of the soils with regard to the protection of the karst water against a harmful input, first of all those soil characteristics are of relevance which are able to adsorb noxious substances. As many studies with regard to the sorption capacity of the soil matrix show (e.g. *Bastian & Schreiber 1994, Beck 1998*), and as is well known, the main adsorbers are clay and humus. Next to the quantity of these adsorbers the pH-value influences the effectiveness of the buffering capacity and filtering effect of a soil with a tendency towards an exponential capacity loss in case of increasing acidification. Furthermore it is necessary to consider the thickness of the soils and their infiltration ratios (for infiltration measurements in the Aggtelek see *Zámbó 1995*).

Without exception all the soils of the karst area ensure quick and effective infiltration in spite of their high content of clay. Even after heavy and persistent rainfall surface runoff occurs nowhere, apart from artificially compressed places. The corresponding soil profiles do not show any indication of adhesive water nor stagnation layers. The thin sections show a network of open and porous pores. The distinct addition of non-swellable kaolinite supports this result from the terrain analysis as well. Together with the soil thickness this constitutes an important criterion, because the entire profile is at the disposal of noxious substances, whereas the ecological valuation of the filter capacity of the pseudogley-cambisol within the area of the Pliocene sediments exclusively should take the horizons above the stagnation layer into consideration. However, in the area of the Pliocene sediments surface runoff occurs after strong precipitation events. Then a noxious input can reach the karst aquifer directly via ponors. Such areas have to be classified as highly insecure concerning the quality of the karst water. A similar problem occurs in areas where only thin rendzina-like soils cover the karst. They are not thick enough to guarantee effective filtering, although the substratum has a high sorption capacity (*Fig. 6*). Here, the damaging consequences concerning soil erosion produced by human influences become clearly visible. Generally the colluvisols are more than thick enough, have a high humus content, and favourable pH-values thus ensuring a much better filter capacity. Owing to redeposition humus enrichment and increasing pH-value accompanied the admixture of fresh materials from the subsoil. The occurrence of thick colluvium accumulations in subsurface contours and dolines - in preferred places for water inlet - is an example of the fact that the disadvantageous consequences of the soil erosion can have positive effects in other places. But it is clear that such a balance is completely hypothetical. Particularly in karst hydrological systems each surface unit is closely connected to the entire system owing to the direct access to the karst aquifer. The weakness of any unit cannot be compensated by even the most favourable properties at other places.

As the profile examples (cf. *Fig. 6*) show, vegetation also influences the sorption capacity. Under a forest the pH-values decrease up to 0.5-1.0 pH-units in comparison to a juniper heathland on the same soils. This has a negative effect on the microbiological decomposition of organic pollutants, and generally reduces the sorption capability.

It is also essential to take into consideration whether the profiles are truncated or not. If a truncation has taken place the lower horizons have been exposed and a change in their characteristics arises. In this way the human impact causes a change of the soil characteristics - the pH-value is higher than in undisturbed but leached soils. Human influences have resulted in a varied soil mosaic with very different soil compositions, thicknesss, and substratum characteristics which contrast with formerly more uniform soil conditions. Fig. 6 shows an approximate valuation (after *UM 1995 and Beck 1998*) of some profiles in terms of pH-values, humus content, clay proportion, and thicknesses (cf. *Fig. 2*). Hydromorphous characteristics are taken into consideration. Since the thickness can also fluctuate quite a lot within each soil type (in terms of the whole profile or single horizons), additional details are given with regard to the minimum thicknesses which must be available, in case of the present soil parameters, to ensure a relatively high karst water protection.

Soil type Horizon(s) **(Vegetation)**	**Relative sorption power of the substratum** (pH - humus % - clay %)	**Sorption-efficiency of the investigated soil-profiles**	**calculated minimum thickness of single horizons for efficient filtering**
Soils of the karst region			
"Rendzina" (Ah) (Juniper heath-, grassland)	+ + + + (6,5 -11 - 50)	Profile 2 = very low Profile 3 = low	35 cm
Colluvium (M) **(Grassland)**	+ + + (5,5 - 6,5 - 40)	Profile 7 = very high	50 cm
Colluvium covering Cambisol-Terra fusca **(Forest)**			
(M)	+ + (4,5 - 5 - 35)		80 cm
IIBv	+ (4,1 - 2 - 47)		100 cm
IIIBv-T	+ (4,4 - 1 - 65)	Profile 8 = very high	90 cm
Colluvium covering eroded Cambisol-Terra fusca **(succesion area, shrubs)**			
M	+ + + (5,5 - 5,5 - 44)		55 cm
IIBv-T	+ + + + (6,5 - 2 - 64)	Profile 6 = very high	40 cm
Degraded Terra-fusca **(Juniper heathland)**			
Ah / Bhv-T	+ + + (5,4 - 7 - 55)		45 cm
Bv-T	+ + + + (5,7 - 3 - 72)	Profile 4 = high	40 cm
Cambisol-Terra fusca **(Forest)**			
Ah / B(h)v	+ + (4,8 - 6 - 45)		60 cm
IIBv-T	+ + (4,6 - 1 - 76)	Profile 5 = very high	70 cm
Soils on Pliocene sedim. *Pseudogley-Cambisol* **(farmland, grassland)**			
Ap	+ (5,3 - 4,5 - 22)	Profile 1 = intermediate	95 cm
Bv	+ + (5,7 - 3 - 30)	(no filtering at	75 cm
Sw	+ (4,9 - 2 - 44)	runoff events)	100 cm

Fig. 6 Evaluation of different soils and soil horizons with respect to their pollution buffer potential

Fig. 6 clearly shows that both the remnants of the original soils and most of the anthropogenically altered soils are still able to serve their protective function to a sufficient extent as long as an adequate profile thickness is present. But, this statement does not apply to the widespread and heavily degraded soils described as „rendzinas". Covering about one third of the investigated area they are a very serious problem to the protection of karst waters. These locations are even more critical given that about half are wooded again. Under forests the mean pH-value is lower, which increases the pollutant mobility. In addition, pollutant-bearing water can reach the karst aquifer quickly along well evolved root tubes without much filtration effect. Generally, also aeolian pollutant input is increased in relation to forest-free positions due to the filtering effect of the treetops. In the study area this effect is strengthened as well, since particularly these locations are the most exposed to the predominant winds.

5.2. Stress status of the soils

Statements about the protective function of soils against noxious inputs inevitably presuppose an idea about the scale of the utilization. If the general input is low, the capacity of the soils increases equivalently. In reverse, a high general input of noxious substances requires a more effective filter effect and buffering capacity. A precise but quick method to estimate the general stress caused by noxious substances, is to analyse the amount and distribution of several heavy metals in soil profiles. If their input is high, the top soils should be enriched with heavy metals in comparison to the deeper parts of the profile. But here the comparison of the upper and lower soil horizons does not show significant differentiations. Quite the reverse is true. Fairly often the heavy metal content of the lower profile sections are higher than those of the top soils (*Fig. 7*). The reason is a natural consequence of a higher amount of clay. However, on average no substantial differences of the heavy metal content are identifiable as shown in Fig. 7. At the same time the low values show that no serious endangering of the karst water results from this, even if pollutant displacement into the depths was likely. The pollutant input is too small for this to occur. Only the lead enrichment of the top-soil horizons, which are almost completely immobile in the present pH-regime, show that rural Aggtelek is not completely spared from pollutants via aeolian input. But also this lead concentration is relatively low and in no case a critical lead load is existing. Only in two cases are the upper limits of the natural background values of all heavy metals (as shown in *Fig. 7* and calculated from the corresponding clay proportions) only slightly exceeded. These two soils are located under wood and reflect the already mentioned increasing effect of forest land. In all other cases the heavy metal content remains below the natural possibilities.

In the Aggtelek area a maximum value of heavy metals occurs within iron concretions. The oxisol of Vörös-tó („Red Lake") particularly contains much pisoliths with distinctive heavy metal enrichments (Pb 430, Zn 927, Cu 140, Ni 346, Cr 317, Co 622 mg/kg). However, within these pisoliths the heavy metals are immobile and therefore of no ecological consequence.

In summary, this evaluation shows that in the Aggtelek the remnants of undisturbed soils, and even those soils showing considerable anthropogenic influence, preserve an adequate sorption capacity (taking into account the fact that the general input of noxious substances is quite low) and provide sufficient protection for the karst waters against noxious substances (in the case of today's agriculture and forestry).

Much more critical is the input of noxious substances from agriculture in the Pliocene sediment area. In general, soils are not able to eliminate the micro-organisms from fertilization with liquid manure and have only low adsorption potential in respect of water-endangering substances as nitrate, ammonia, or others. Organic pollutants from pesticides could be adsorped by the soil matrix, but with the surface runoff they reach the karst system without any difficulty. That is why today the source of danger is located less in the karst area itself, but more in its adjoining catchment area of the Pliocene sediments. For ecological management this requires comprehensive protection which includes the whole area up to the water divides of the Pliocene area.

Heavy metal [mg/kg]	Pb	Cu	Cr	Co	Ni	Zn
Karst region*						
Top-soil horizons	**51** (17-87)	**22** (15-37)	**37** (17-48)	**16** (11-19)	**25** (16-37)	**89** (48-124)
Rest of the profiles	**34** (16-50)	**27** (19-42)	**36** (27-47)	**18** (12-23)	**31** (20-49)	**98** (54-140)
Background value	*55*	*50-60*	*75-90*	-	*70-100*	*110-150*
Pliocene region**						
Top-soil horizons	**35**	**12**	**26**	**12**	**14**	**35**
Rest of the profiles	**10**	**22**	**28**	**7**	**14**	**40**
Background value	*50*	*35*	*60*		*55*	*95*

* Average from 8 profiles in bold type, minimum and maximum content in parenthesis
** Average from 2 profiles

Background value = value representing the maximum of normal natural soil-content divided into clay-amount-groups (UM 1993).

Heavy metal break down with aqua regia (AbfKlärV, BMU 1992)

Fig. 7 Average heavy metal concentrations of soils compared with natural background values

5.3. Soil and succession

Observations made at the study area for several years indicate a change in the several types of grassland, juniper heathlands and bushes rapidly leading to woodland. The juniper heathlands especially are the habitats of rare and protected plants. Last but not least their preservation is also very important for the touristic development of the region. But the observations show a relative quick change of the vegetation. Already the juniper heathlands are often overgrown by shrubs, sometimes even by young forests. Their survival is seriously endangered by succession. The succession starts with the addition of sloes (*Prunus spinosa*), wild roses (*Rosa arvensis, Rosa canina*) and wild pears (e.g. *Pyrus pyraster*). During a later succession phase mainly shrubs appear, predominantly whitehorn (*Crataegus monogyna*), privet (*Ligustrum vulgare*), wayfaring tree (*Viburnum lantana*), cornelian cherry (*Cornus mas*) as well as field maple (*Acer campestre*), wild service tree (*Sorbus torminalis*), and mountain ash (*Sorbus aucuparia*). During this phase the species of the later stock of trees which dominate the sun-exposed slopes have already appeared, particularly various oaks (*Quercus pubescens, Quercus cerris*). Owing to the increasing lack of light juniper and roses gradually become stunted in this succession phase. The less anthropogenically influenced shaded slopes are the location of high timber forests with mainly oaks and hornbeams (*Quercus petraea, Carpinus betulus*).

The species assembly associated with succession shows a tolerance towards drier soil conditions. Moreover, all species prefer calcareous soils and have little demands on soil conditions. The successional course and the species involved are laid down more or less by these skeleton conditions and the climatic setting. The speed of forest recolonisation also depends on the growth-supporting capabilities of the different soils. The best conditions occur on colluvisols where the succession has reached the highest dynamic as shown by the chemical and physical soil values (*Fig. 8*). Similar to the filtering effect and the buffering potential the plant promoting soil conditions also show the better status of the colluvisols in relation to the original soils. The comparison between an unchanged cambisol-terra fusca and the corresponding colluvisol (*Fig. 9*) clearly shows the improvement of soil

	Pliocene sediments	Wetterstein limestone - karst landscape			
soil type	Pseudogley-Cambisol	"Rendzinas"	Colluvisols	eroded Cambisol-Terra fusca	Cambisol-Terra fusca
profile-sample	①	②③	⑥⑦⑧	④	⑤
textural classific. top- (undert. soil)	silty loam (silty clay)	silty clay	silty clay to loamy silt	silty clay (clay)	silty clay, clayey loam, (clay)
soil acidity pH	moderate 5 - 6	slight 6 - 6,5	moderate 5 - 6	moderate 5 - 6	high 4 - 5
org. substance	moderately humic	very humic	very humic	moderately humic	moderately humic
N - reserve	moderate	high	high	moderate	low
humus-quality	moderate	moderate	high	moderate	low
cation exchange capacity	moderate	moderate	moderate	moderate	moderate
base saturation	moderate	very high	high	moderate	low
nutrients	moderate	high	high	moderate	moderate
soil humidity	very favourable	very unfavourable	favourable	unfavourable	very favourable
soil aeration	favourable	very favourable	favourable	moderate	favourable
total evaluation	moderate	reduced to moderate	favourable	moderate	reduced

Fig. 8 Evaluation of different soils with regard to growth-promoting properties

characteristics as pH-value, the better quality of humus represented by the C/N ratio, and the higher nutrient contents correlated with an increasing of the base saturation. The only, but decisive, reducing influence on the water balance is given by the reduced soil thickness of the 'rendzinas' and their heavily truncated soil profiles.

This limitation is very effective on rendzina-like soils occuring on sun-exposed positions, where the successional dynamic is reduced by soil dryness. The supply of nutrients is not the limitting factor even if the soil thickness is short, because the space available for the plant roots is not only limited to the few centimetres of the thin top-soil horizons. As the profilings show, the smallest pockets and widened joints within the limestone are also utilized. Without this possible additional supply the growth of a secondary forest in such positions would be not that easy.

6. Conclusion

Anthropogenic exploitation has heavily changed the ecological system of the Aggtelek in many respects. The recently protected landscape is the result of human activities and not a natural landscape. A most diverse cultivated landscape resulted from a formerly forest-dominated area. Meanwhile the agricultural use has today been drastically curtailed, but in spite of all anthropogenically caused changes the basis for a succession back to a secondary forest adapted to the local climate has not been irretrievably lost. The

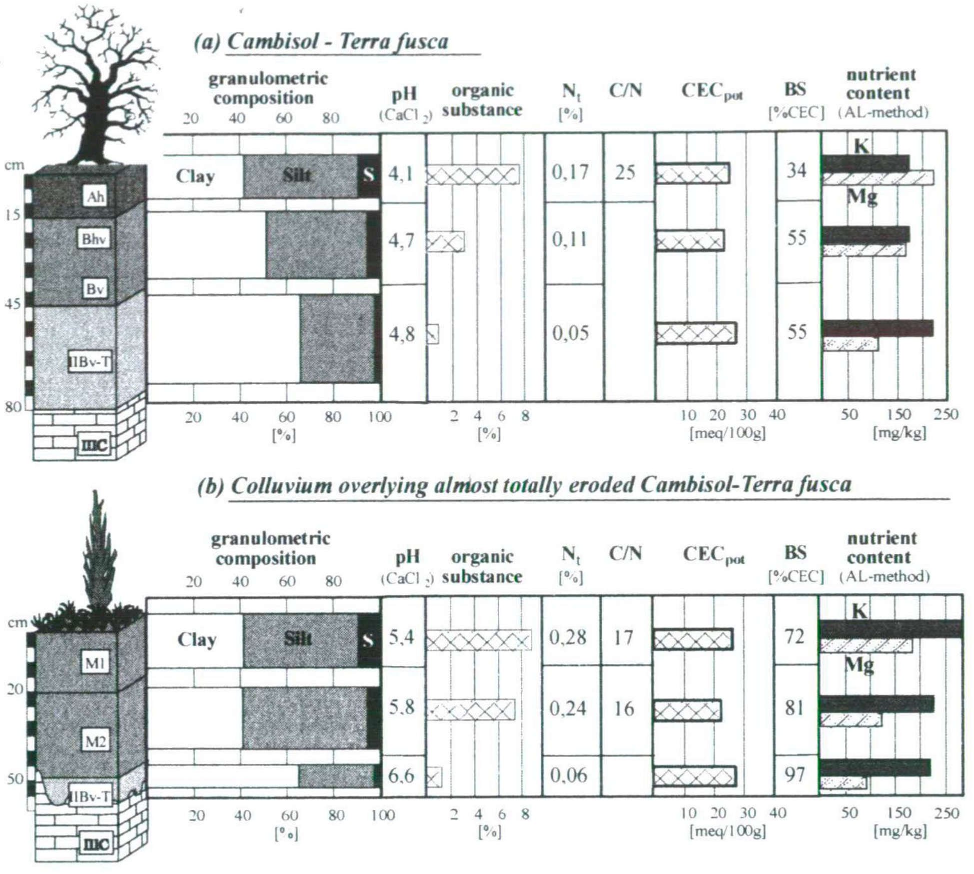

Fig. 9 Comparative soil qualities
(a) profile beneath forest cover and unaffected by man
(b) profile resulting from human activities

investigation shows that in many places the exact opposite applies to the Aggtelek, in the course of which a progressive succession continously leads to a secondary forest. However, this is in contrast to the desired preservation, especially with regard to biotopes worthy of protection as for example the juniper heathland which contains a lot of rare species. In some places the renewal by anthropogenically caused erosion and redeposition processes has even led to an improvement of the habitat factors as long as soil is available in adequate thickness. Therefore, without the necessary human reintervention and without comprehensive ecological management, the recolonization of secondary forest along with the loss of the diverse and valuable landscape can be predicted in the foreseeable future.

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SOIL AND VEGETATION ON KARST TERRAINS IN THE PROJECTED PROTECTED LANDSCAPES OF WESTERN MECSEK, HUNGARY

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Summary
Previous studies of the karst in the Western Mecsek area have shown that it is largely in a natural condition, has a high conservation value and is in need of protection. Consideration is being given to declaring the karstic territory and its wider environment a protected area in the Danube-Dráva Natural Park. This paper describes a study of the areas soil and flora designed to demonstrate the almost untouched, natural, state of an area. The soil studies focused on determining the pH, showing the tendency of a shift towards lower pH values, and examining the calcium content. The results show that indirect anthropogenic effects can be detected by a pH shift towards lower values, but the same tendency of acidification is less characteristic in dolines which are the most sensitive points of karstic fields. Examining the vegetation, and paying special attention to the ranking into nature conservation categories, a significantly high ratio of association forming and accompanying species and the presence of protected species in relatively high numbers can be seen that proves the nature conserving feature of the territory. On the basis of the investigations carried out, maintenance of the present state of the territory can be seen to be a desirable objective and in order to realize it protection of the area is absolutely justified.

Introduction

The Mecsek Mountains are the southernmost mountain-range of Hungary. There are three adjoining karstic areas in its western part: near the villages of Abaliget and Orfű, and in the Melegmány Valley. These three areas are part of the Western Mecsek Mountains Protected Landscapes proposed by the Danube-Dráva National Park. The southern part of this area is covered by sandstone, so this is not part of our project. The intensive karstic processes began in the Pleistocene and has been continuous till today (*Lovász 1977.*), which can be proved by the high number of dolines which are still forming. There had been geoecological examinations of the area near Orfű, which were now extended to the Abaliget and Melegmány areas. The goal of the examination, which concentrate on the soils and the flora, is to prove that these areas are worth protecting. There had been similar research in the Aggtelek karstic region and in the Bükk Mountains, too (*Bárány-Kevei 1983.*).

The pedological examinations were carried out in laboratories. The vegetation, however, was inspected on site.

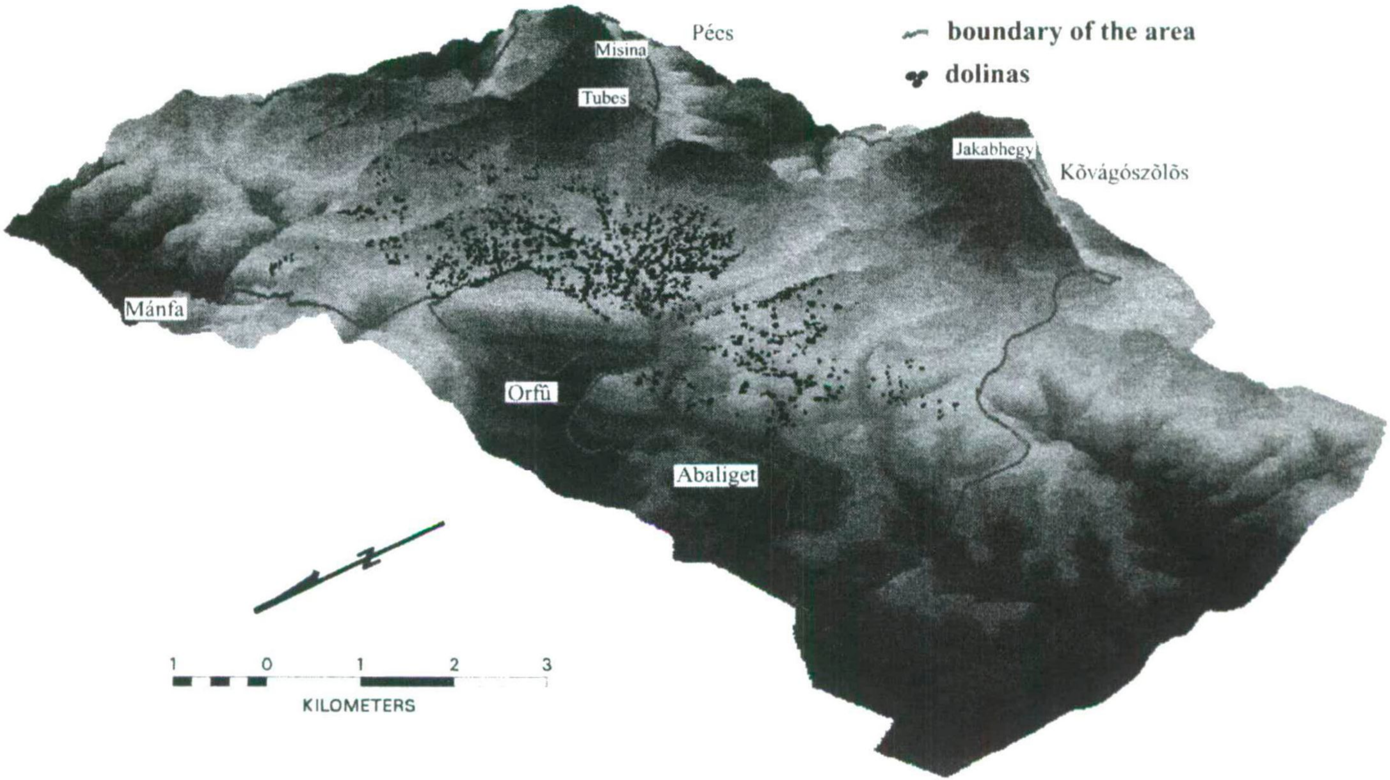

Fig. 1 The projected protected landscape

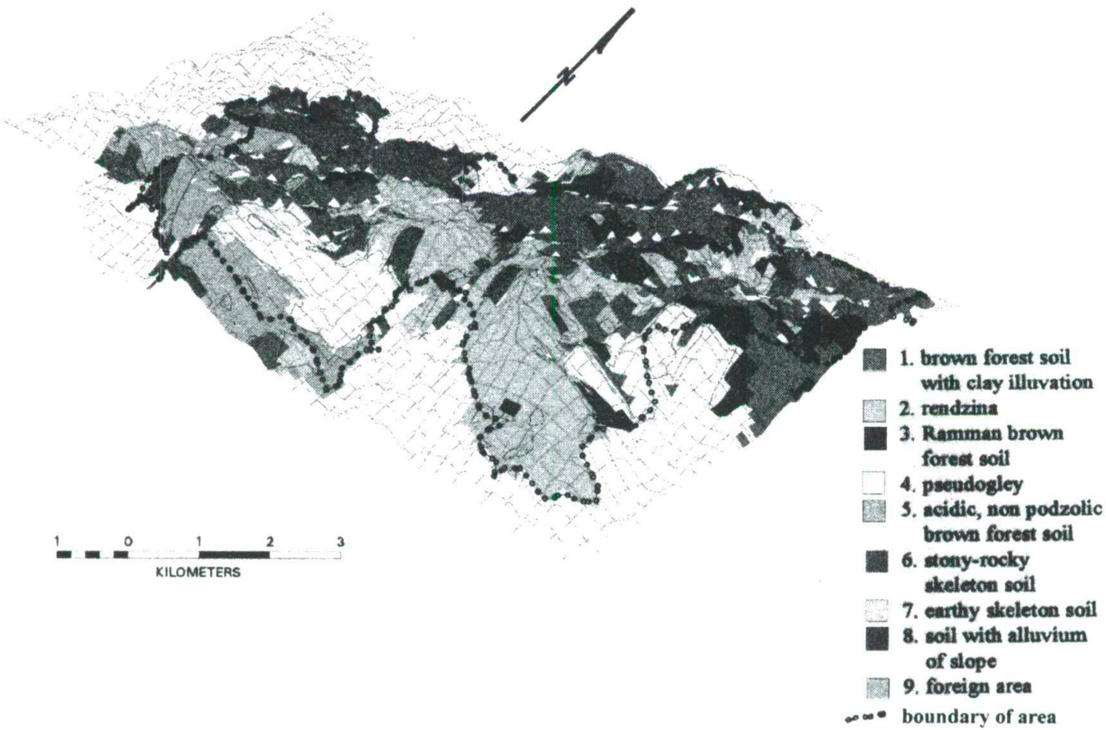

Fig. 2 Soils of the projected protected landscape

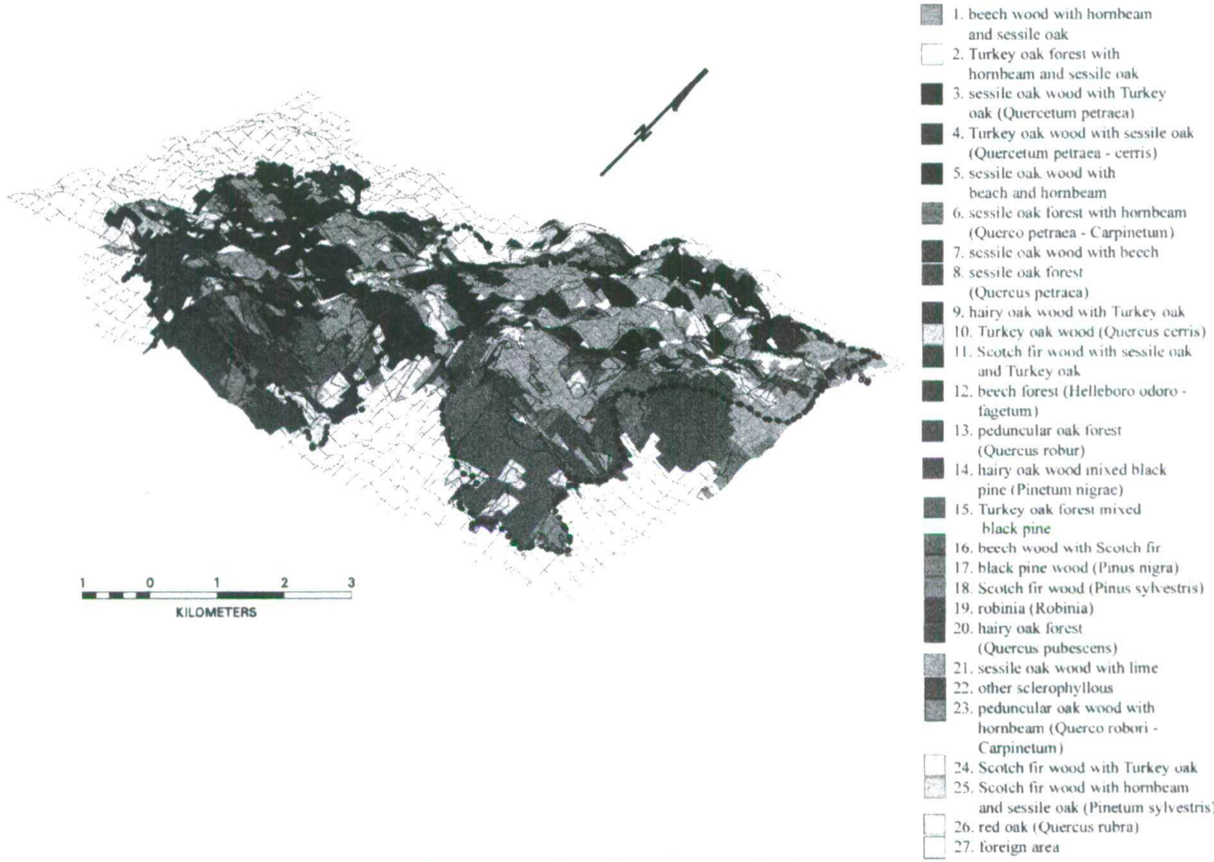

Fig 3 Vegetation of the projected protected landscape

Table 1 The carbonate-content of karstic soils in Western Mecsek (%) (1: 10 cm depth; 2: 50 cm depth)

number of sample	carbonate-content
1/1	0
1/2	0
2/1	0,106725
2/2	0,04269
3/1	0
3/2	0
4/1	0
4/2	0
5/1	0,17076
5/2	0,064035
6/1	0
6/2	0,04269
7/1	0
7/2	0
8/1	**4,6959**
8/2	**15,7953**
9/1	0,08538
9/2	0,12807
10/1	**49,5204**
10/2	**34,152**
11/1	0
11/2	0,064035
12/1	0
12/2	0
13/1	0,106725
13/2	0,04269
14/1	0,12807
14/2	0,04269
15/1	0
15/2	0
16/1	0
16/2	0,021345
17/1	0,08538
17/2	0,04269
18/1	0,08538
18/2	0,04269
19/1	0,08538
19/2	0,04269
20/1	0,064035
20/2	0,08538
21/1	0,08538
21/2	0,08538
22/1	0,021345
22/2	0
23/1	0,021345
23/2	0,04269
24/1	0,04269
24/2	0

Maps

The maps showing the area (*Fig. 1-3*) were made by digital techniques. The soil and the vegetation maps (*Fig. 2, 3*) were drawn on the basis of sylvicultural data. These maps show not only the karstic areas but the full area of the projected conservation area. By comparing these maps, one can notice several relationships between the soil and the vegetation. These relationships can be examined especially in the southern part of the area. On the southern slope of the Tubes Mountain, for example, the dominant soil-type is rendzina, which is accompanied by hairy oak and black pine - sessile oak. On the southern slope of Jakab-hegy, the dominant soil type is acidic, non podzolic brown forest-soil and the dominant vegetation type is sessile oak. There are mostly black pine plantations on stony-rocky skeleton soil. The soil of the Abaliget karst is mainly brown forest soil with clay illuviation. This type is accompanied by rendzina near Orfű, and by Rammann brown forest soil in the Melegmány Valley. It is usually the exposure that defines the type of vegetation there. On the northern slopes beech stands with sessile oak and hornbeam are dominant, on the southern ones, however, oak forests with hornbeam are typical.

Soils

The pedological examinations consisted of the analysis of pH-value, carbonate-, and heavy metal-content. The *pH-value* of the soil is acidic, the average value is 5-6. The graph (*Fig. 4*) shows that the average pH in the Melegmány area is a little bit higher, and there are more values around neutrality. This can be explained by the higher carbonate-content of the soil. The acidic pH is natural, because these soil types (the main type of soil is brown forest soil with clay illuviation) usually have such a pH-value (*Stefanovits 1975.*). There is, however, a considerable difference between the pH in water and in potassium chloride solution. When this difference is higher than 0.5, the soil is acidifying. There were only two samples that didn't show a difference higher than 0.5 near the surface and in a depth of 50 cm. The differences in the other samples were around 1.2. It can clearly be seen that there is a tendency towards acidification, especially in the Orfű area. The acidification may be caused by human activity, it originates mainly from the industrial areas of the city of Pécs. The acidification is caused by indirect effects which can be traced by comparing the acidity of the samples collected from slightly under the surface and another one from a depth of 50 cm. The pH of samples taken from deeper sections is usually higher because acidification is more intensive closer to the surface. Ten out of the 24 soil and vegetation samples were collected from dolines and the rest from plateaus between dolines and from valleys. If we compare the pH of soil samples from dolines and the ones from plateaus, it can be seen that the pH of the samples from dolines is higher. This led to the conclusion that dolines are more protected against acidification, which makes them especially important.

The *carbonate-content* of the soils is low (*Table 1*), which is not surprising on karstic bedrock. Some samples even had no measurable carbonate-content In the samples, however, in which the difference between the pH in water and in potassium chloride is below 0.5, we have detected high carbonate-content. It proves the considerable buffer-effect of carbonate-content, so in these cases carbonate-content decreases the intensity of acidification. One of the two samples were collected from a watercourse and the other next to the travertine cascades of the Melegmány Valley (samples 8 and 10). The *heavy metal tests* were carried out with aqua regia and atomic absorption spectrophotometer. Ni, Co, Fe, Mn, Cr, Cu, Pb, Cd were tested. The low quantity of these elements (*Table 2*) implies that the pollution from human sources is low, which proves the existence of natural conditions in the area.

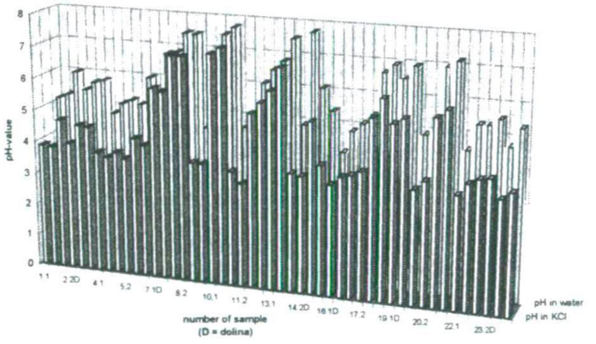

Fig. 4 The pH of soils in Orfű

Table 2 The heavy metal-content of karstic soils in Western Mecsek (ppm)(1: 10 cm depth; 2: 50 cm depth)

Nr.of sample	Pb	Ni	Co	Cu	Fe	Mn	Cd	Cr
1/1	26	34	17	12	28850	761,5	0,3	19,5
1/2	21,5	39,5	12	14,5	32450	667,5	0,05	20,5
2/1	25	35	16	13	29000	778,5	0,3	21
2/2	24	36	13	13	28050	718	0,1	20
3/1	26	44,5	12	17	36400	599	0,6	27
3/2	25	58	16	23	42500	841,5	0,5	29,5
4/1	22,5	33	14	10,5	27500	572,5	0,55	18
4/2	19,5	40,5	15	17,5	34650	532,5	0,45	20

Nr.of sample	Pb	Ni	Co	Cu	Fe	Mn	Cd	Cr
5/1	22,5	35,5	9,5	13	28900	448	0,2	20,5
5/2	17,5	42	13,5	18	32600	558	0,2	20,5
6/1	24,5	41,5	13	13,5	29000	1054	0,5	20,5
6/2	21,5	40,5	15,5	14	29500	260,5	0,5	19
7/1	22,5	43	11,5	17	30400	1100	0,35	23,5
7/2	20	45,5	13	19	32650	875,5	0,65	21,5
8/1	42	49	16,5	21	27550	1525	1,45	25,5
8/2	36,5	46	13	21,5	24400	1397,5	1,5	23,5
9/1	30,5	36,5	14	17,5	32350	1152	0,2	22
9/2	24	43,5	21	23,5	37200	1042,5	0,7	21
10/1	38,5	47	11,5	12,5	18450	604,5	3,35	18,5
10/2	38,5	48	18,5	10,5	16200	224	3	17
11/1	16,5	29	9	12	23550	323,5	0,3	18,5
11/2	20	40,5	12,5	14,5	28700	772,5	0,35	18,5
12/1	35	52,5	14	17,5	24400	948,5	0,95	32
12/2	30	54,5	18,5	17	37450	770,5	1,15	30
13/1	23	36	12	14	28650	704	0,35	23
13/2	20	41	15	13,5	27450	1071	0,65	20
14/1	23,5	35,5	12,5	13	30200	696	0,15	20
14/2	20	44,5	15,5	19	35850	575	0,35	22
15/1	26,5	38,5	12	12	27150	1395	0,55	20
15/2	23,5	36,5	11	12,5	28700	1108,5	0,15	19
16/1	17,5	29	10	10	24800	579	0,1	17,5
16/2	18	34	11,5	12,5	26350	722	0,55	16
17/1	28	33	17	10	28000	810,5	1,05	19
17/2	26,5	36	20,5	12,5	29800	883,5	0,85	18
18/1	32	54	17	20	39650	1242,5	1,05	29
18/2	28,5	63	19,5	22	40650	889,5	1,2	27,5
19/1	23	52,5	15	19,5	37850	713,5	0,7	26
19/2	23,5	49,5	16	19	36600	577	0,7	22,5
20/1	21,5	32,5	13,5	9,5	25850	649,5	0,1	18,5
20/2	21,5	46,5	19	15	32900	803	0,8	20,5
21/1	23	38	11	16	28100	1122,5	0,3	24
21/2	19	31,5	10	10,5	22650	698,5	0	17
22/1	25,5	38,5	19	13,5	31000	704,5	0,35	20
22/2	20,5	59,5	14,5	25	39850	628	0,85	26
23/1	25,5	34,5	14,5	10,5	26700	950,5	0,25	18
23/2	19,5	41	18	15,5	31100	812,5	0,85	18,5
24/1	22,5	34	11,5	9,5	26700	474	0,15	19
24/2	23	52,5	18	19	35500	620	0,5	22
average	**24,6**	**41,8**	**14,4**	**15,3**	**30307**	**790,8**	**0,64**	**21,4**
limit val. of poll. (in Hung.)	**70**	**50**	**50**	**100**	**(no data)**	**1100**	**1**	**100**

Vegetation

The vegetation was examined with the help of ecological indexes considering temperature (T-values), water-balance (W-values), soil reaction (R-values) and nature conservation categories (TVK-values). Considering the *temperature* (*Fig. 5.*), most of the plants (80-100%) indicate deciduous forest climate which is combined with submediterranean deciduous forest climate - which refers to the typical vegetation in the

Mecsek Mountains - and atlantic evergreen forest climate. Plus, in the above-mentioned watercourse, which is in a ravine forest, there are some plants that indicate coniferous wood and deciduous mixed forest. Looking at the graph showing *water-balance* (*Fig. 6.*), one can see that most of the plants indicate moderately fresh, fresh, and moderately damp conditions. These values are caused by the fact that these areas are covered by forests. The samples which have a higher number of plants that refer to wet and damp conditions were collected by springs, streams and the travertine cascades of the Melegmány Valley. Species that represent moderately dry conditions can be found in the areas where several relatively open oak companies are. On the basis of *soil reaction* (*Fig. 7.*), species that indicate moderately calciphilous and neutral circumstances are in majority. Plants referring to calciphilous and basic conditions can be found mostly in samples, which showed a high value of carbonate-content.

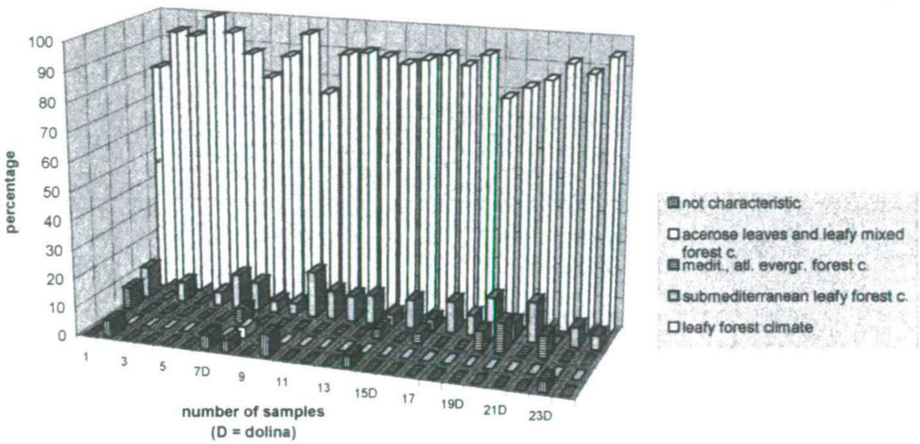

Fig. 5 Categories of T-values (temperature)

The graph showing the *nature conservation values* (*Fig. 8.*) reveals that most of the presented species refer to natural circumstances (accompanying, associated, protected). The proportion of plants signing degradation (weeds) rarely exceeds 10 %. These latter samples were either collected near tourist-paths under heavy usage or close to the Orfű-Pécs highway. The test point near the highway (sample 8) shows well enough how human activity can degrade precious natural areas. It is on the bank of the fore mentioned watercourse with a ravine forest containing several protected species. The high proportion of weeds here refers to the interfering effect of the nearby highway. The samples from the dolines reveal that they host greater variety of species. There are more plants that endure shadow because of the steep sides of these karstic forms. The graph showing the preservation categories reveals that there is a tendency that the proportion of protected species is higher in the dolines than in other areas. It shows how important they are from the point of view of nature preservation. Dolines are one of the most sensitive places of the karstic surfaces as, beside swallets, they are the points where pollution can enter the karstic system. Therefore it is good that the dolines of all three examined areas are free of human interference, which supports the idea of declaring these areas to be protected.

Conclusions

The *goal* of our pedological and vegetation examinations carried out in the Western Mecsek karstic area is *to support the efforts to pronounce these areas protected.* The analysis of the carbonate- and heavy metal-content, and the pH have shown that *there is harmful antropogenic influence* in the area, but it is only an *indirect effect* which manifests itself in acidic subsidence. *Ecological indexes* also show that this part of the Mecsek Mountains is still in a *natural condition,* which justifies the claim to make this area a nature preserve. On the basis of the comparisons of samples from dolines and other forms, it must be noted that *dolines are the most valuable places of the three karstic areas* examined. The pH of the soils of the dolines *is* close to the values of the prevailing soil type (brown forest soil with clay illuviation), whereas the pH of samples from other places is lower. The analysis of the vegetation also showed that *dolines are in a natural condition* in a greater degree, because they host a higher number of protected species. *Karstic area is a vulnerable natural system* that reacts with great sensitivity to antropogenic influences, so it requires an increased protection. Particular stress must be laid on dolines, where we found original vegetation and undisturbed soils. Because of their importance, they are being surveyed and enumerated at present. The first step to preserve the condition of this area is to declare it protected. In the framework of general protection *dolines should be strictly protected.* The declaration of protection would not only mean the creation of a new nature preserve but could also have a favourable effect in the extended surroundings because the comprehensive karstic system is quite far-reaching.

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SOILS ON KARST AREAS OF THE BŰKK MOUNTAIN, HUNGARY

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Summary
The soil has an important role in the karst ecological system because it can buffer harmful effects and in the last ten years there have been several studies of soils in Hungarian karsts. However, there have been few measurements of soil nutrients in karst areas. During this investigation the pH (H_2O) and pH (KCL) and the carbonate content of soils were measured. Soil moisture, which is important for plants take-up of nutrients, was also part of the investigation. On the basis of the results it is concluded that: the nutrient indices of the beech forest and beech with pine forest soils are most advantageous in respect of the plant available calcium, magnesium, potassium and total nitrogen. The plant available calcium is correlated with the plant available potassium and magnesium; the higher the calcium content the higher the potassium and magnesium content. The difference of the potassium content of soil between the different type of plants is lower than that in the case of the other nutrients. The soils are weakly supplied with magnesium. More than half of the examined soils are well-supplied with phosphorus.

Introduction

I studied the characteristics of the soil nutrient system in karst areas. In the last ten years the investigation of soils on Hungarian karst came into limelight. The soil has an important role in the ecological system because it can buffer the harmful environmental effects that take effect quickly (*Bárány-Kevei, I. 1980, Bárány-Kevei 1992, Bárány-Kevei, I. - Mezősi G. 1978, Zámbó, 1986*). The determination of soil nutrient content is not common on karst areas, so we have few results on this subject. There is only one soil profile in the Bükk plateau where among others the nutrients were determined. But there are great differences in the nutrient supply of the soil on small areas especially if we investigate it in different ecological conditions.

Methods

Two soil samples (from depths of 5-10, 10-20, 20-30, 30-40 cm) were collected from every km^2 in an 8 km^2 study area on the Bükk plateau (Bükk National Park, Hungary). The sites represented different ecological conditions: beech wood, pine forests, beech with pine forests, woodland nursery and open field. The quantity of total soil-nitrogen and of plant available phosphorus, potassium, calcium, magnesium were measured. Although, it is not actually a nutrient type, we have also measured the collective quantity of exchangeable and soluble sodium. This enabled us to calculate the S-value (exchangeable basis) of the soil. The plant available Mg and Ca were measured by Atomic Absorption Spectrophotometer, the K and Na by flame photometer (extracted by 1 mol/dm^3 CH_3COONH_4). We used the modification of the technique devised by Kjeldahl to determine the total N and the Olsen's method to measure the plant available P. Investigation of soil cannot be carried out without the knowledge of pH and carbonate content of soil. Therefore the pH (H_2O) and pH (KCl) plus the carbonate content of soils were determined. The soil moisture – which is important for the plants nutrient take-up – was also measured.

Description of the sample sites

Sample site 1: Beech with pine forest, without any undergrowth. The 2-5 cm thick leaf-litter is mainly pine needles. The soil is greyish-brown. The stone content is about 50 % on the surface. There are a lot of roots in the upper 20 cm of the soil.

Sample site 2: Beech-wood. There is moss on the soil surface. The stone content is about 50 % on the surface. The soil is greyish-brown and interweaves with roots strongly.

Sample site 3: An about 100 years old beech forest. The area is exposed to northwards. The layer of leaf-litter is thick. The soil is dark brown. It has a high organic material content. The stone content is about 50 %.

Sample site 4: Open field on the ridge of a doline row. The soil is greyish-brown. The stones appear in the depth of 15-20 cm.

Sample site 5: Pine forest (Pinus sylvestris and Picea). The Pinus sylvestris trees are on the brink of ruin. Despite it is a pine forest, it has rich undergrowth. Nettle can be seen in the forest, which is not common in pine forest. There is 4-5 cm thick moss on the soil surface. The soil has a thick organic layer. The limestone appears in the depth of 5-10 cm. The stone content is about 60 %, while in the lower layer 80 %.

Sample site 6: Open field at a doline edge. The stones appear in the depth of 20-30 cm, the stone content is 40-50 %. The stones are rounded; processes of the solution are well visible. The soil is brown; former it was a forest soil.

Sample site 7: Pine forest (Picea), the undergrowth is rare. The upper 20-25 cm layer of the soil is dark grey, the lower is clayish, lighter.

Sample site 8: Pine forest on the bottom of a doline. The undergrowth is rare. The soil is moss covered and light brown.

Sample site 9: Beech-wood with rare undergrowth. The soil is very strongly interweaves with roots. The organic, humic layer is 4-5 cm thick. The stones appear in the depth of 10-15 cm. The stone content is 40 %. The soil is greyish brown.

Sample site 10: Beech-wood, which is not so closed and according to this the undergrowth is thicker. It is on a slope, dipping at angles of 10 degrees. The soil is a dark brown rendzina and it is getting darker downwards in the soil profile. The humic layer is very thin. The stone content is about 50 % from the surface.

Sample site 11: Open field on the bottom of a doline which, is a sinkhole as well. The upper 20-cm of the soil is strongly interweaves with roots. The clay appears in the depth of 30 cm.

Sample site 12: Beech with pine forest. The undergrowth is thick because the forest is relatively opened. There is a 5-10 cm layer of leaf-litter on the surface. The soil is greyish-brown. The stones appear in the depth of 25-30 cm.

Sample site 13: A woodland nursery (mainly pine but there are some beeches as well) on the edge of a doline. The soil is a dark grey rendzina. The stone content is 80 % on the surface.

Sample site 14: Open field on the slope of a twin doline. The soil is yellow-brown with high clay content. It is getting light-coloured downwards in the soil profile.

Sample site 15: An old beech forest with thick undergrowth and with a lot of fern. There is moss on the surface of the stones. The soil is a dark brown rendzina. The stone content is 50 % from the surface. Because of the stones and roots were so dense, we were able to dig only to the depth of 30 cm, so we have only 3 soil samples from this sample site.

Sample site 16: Open field on the „Nagymező". The upper 10-cm of the soil is black. The lower part is yellow with high clay content.

Discussion

Following the measurements we were able to compare the nutrient system of the soils which occurred in different ecological conditions. There are differences between the nutrient status of the soils from beech and pine forest and from open fields:

The nutrient indices of the soils of the beech wood and beech with pine forest are the most advantageous in respect of the plant available calcium, magnesium, potassium and total nitrogen.

The soils of the open fields have the lowest nutrient status but the highest plant available phosphorus.

Determination of pH and carbonate content of soils is important not only because of the nutrients. In the case of karst areas it is important to know the connections because the characteristic of the bedrock point towards the fact that the soil has high carbonate content and according to this has neutral pH. After the measurement we have made we found that the soils of Bükk plateau have a low carbonate content, which has a big influence of the presence of the nutrients. In connection with this the pH of the soils is also lower than it was expected. In the case of $\Delta pH = pH\ (H_2O)-pH\ (KCl)$ the often high (around 1) values show that in these soils the acidification is important.

The pH is connected with the calcium content of the soil. The soils with lower pH have lower plant available calcium content. The soils which are mixed with fragments of limestone (Sample sites 1, 2, 3, 4, 5, 6, 9, 10, 12, 13 and 15) have a higher plant available calcium content than those which have not been (Sample sites 7, 8, 11, 14 and 16). In the soils, in which the ΔpH is high, the plant available calcium content is always low. In the soils which are mixed with fragments of limestone, the pH and plant available calcium content increase downwards in the soil profile. The plant available calcium content decreases downwards in the soils which have not been mixed with limestone. (*Fig. 1*)

The plant available calcium is connected with the plant available potassium and magnesium; the higher the calcium content the higher the potassium and magnesium content and vice versa. (*Fig. 1, 2, 3*)

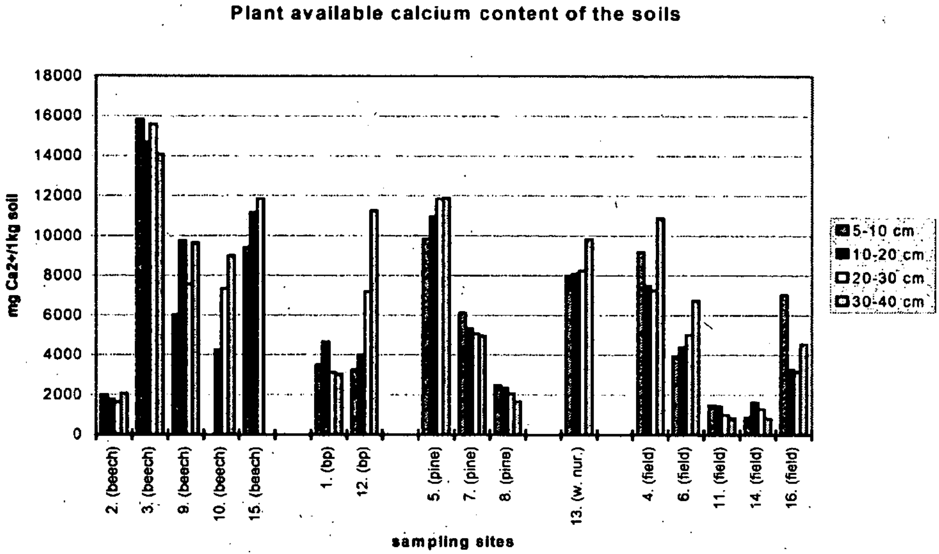

Fig. 1 Plant available calcium content of the soils

The difference between the potassium content of soil and the different type of plants is lower than that in the case of the other nutrients. (*Fig. 2, Table 1*)

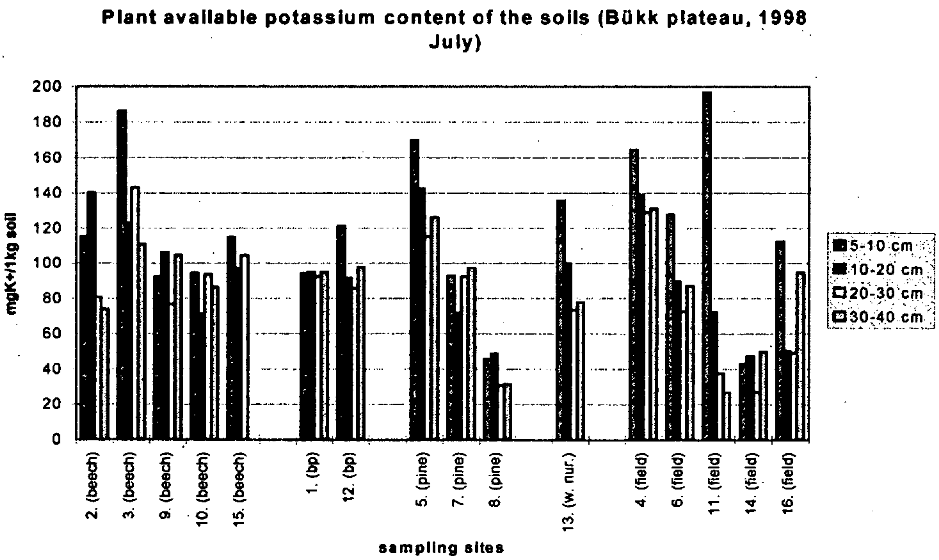

Fig. 2 Plant available potassium content of the soils

Table 1 Distribution of the potassium content

K content of soils	number of soil samples (%)					
	sum total	beech	beech with pine	pine	woodland nursery	field
very little	5 (7,9%)	0	0	2 (16,7%)	0	3 (15,0%)
little	7 (11,1%)	0	0	2 (16,7%)	0	5 (25,0%)
moderate medium	8 (12,7%)	3 (15,8%)	0	1 (8,3%)	1 (25,0%)	3 (15,0%)
medium	22 (34,9%	8 (42,1%)	7 (87,5%)	3 (25,0%)	2 (50,0%)	2 (10,0%)
much	10 (15,9%)	5 (26,3%)	1 (12,5%)	2 (16,7%)	0	2 (10,0%)
very much	11 (17,5%)	3 (15,8%)	0	2 (16,7%)	1 (25,0%)	5 (25,0%)
sum total	63	19	8	12	4	20

The soils are weakly supplied with magnesium. This is interesting because most of the examined soils in Hungary are supplied well. I have some soil samples in which the plant available magnesium content is lower than the lowest limit of the measurement. (*Fig. 3, Table 2*)

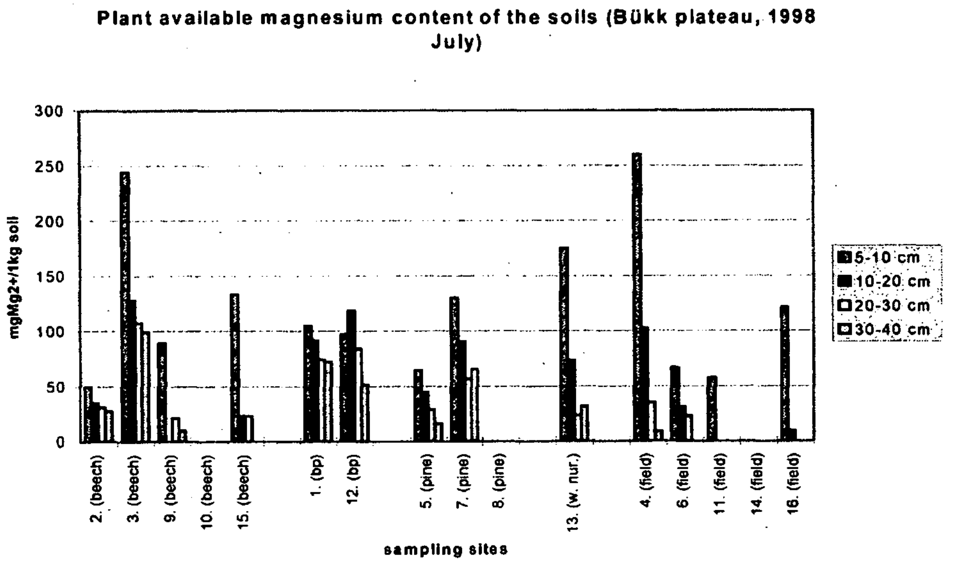

Fig. 3 Plant available magnesium content of the soils

Table 2 Distribution of the magnesium content

Supplying of soil with Mg	number of soil samples (%)					
	sum total	beech	beech with pine	pine	woodland nursery	field
weakly	47 (74,6%)	14 (73,7%)	4 (50,0%)	10 (83,3%)	2 (50,0%)	17 (85,0%)
moderately	7 (11,1%)	1 (5,3%)	3 (37,5%)	2 (16,7%)	1 (25,0%)	0
well supplied	9 (14,3%)	4 (21,1%)	1 (12,5%)	0	1 (25,0%)	3 (15,0%)
sum total	63	19	8	12	4	20

More than half of the examined soils are well supplied with phosphorus. The soils of the open fields have the highest plant available phosphorus content. (*Fig. 4, Table 3*)

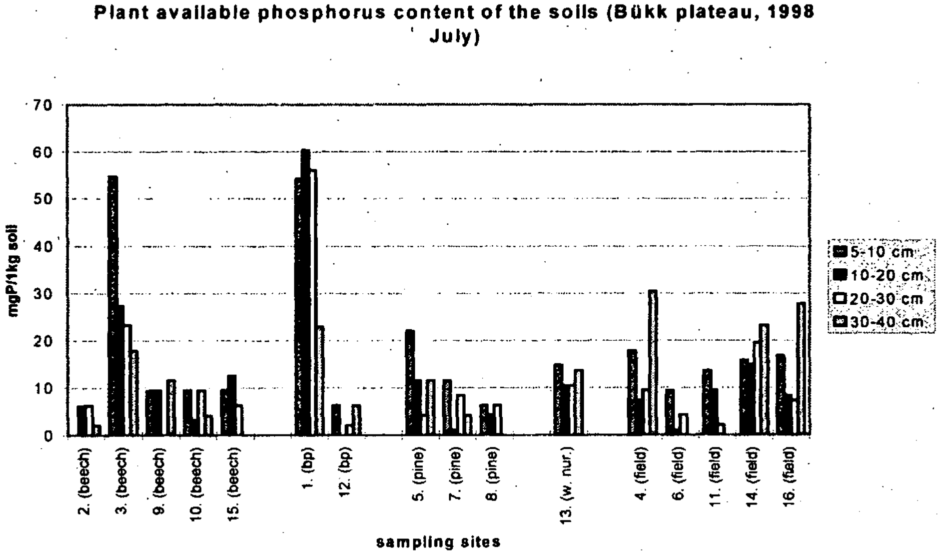

Fig. 4 Plant available phosphorus content of the soils

Table 3 Distribution of the phosphorus content

Supplying of soil with P	number of soil samples (%)					
	sum total	beech	beech with pine	pine	woodland nursery	field
weakly	15 (23,8%)	4 (21,1%)	2 (25,0%)	4 (33,3%)	0	4 (20,0%)
moderately	14 (22,2%)	4 (21,1%)	2 (25,0%)	4 (33,3%)	0	4 (20,0%)
well supplied	34 (54,0%)	11 (57,9%)	4 (50,0%)	4 (33,3%)	4 (100%)	12 (60,0%)
sum total	63	19	8	12	4	20

The soils are weakly and moderately supplied by nitrogen.

Two interesting connections between the nutrients and the ecological conditions are:

1. The open fields can be divided into two groups based on their pH, total carbonate content and plant available calcium content. The soils of sites 4 and 6 have higher pH and plant available calcium content than the soils of sites 11, 14 and 16. In the fore-mentioned two soils the pH increases downwards in the soil profile while in the latter three it does not. These three soils have very high ΔpH values (1-1,7) which show that in these soils the acidification is important. There is no carbonate content in the soils at sites 11, 14 and 16. In the other two soils the carbonate appears in the depth of 15-20 cm. Based on the environmental conditions the five sites can be grouped into two classes. In the case of sites 4 and 6, the limestone fragments appear in the depth of 15-20

cm in the soil profile whereas at sites 11, 14 and 16 there were no fragments as the parent material was not reached.

2. The connection of the plant available calcium, potassium and phosphorus content of the soils can be best seen in the three pine forest soils (sampling sites 5, 7 and 8). Sampling site 5 has the highest nutrient values and site 8 has the lowest.

Summary

The characteristics of the soil nutrient system in an 8 km^2 sized study area on the Bükk plateau were examined. The pH, total carbonate content, total soil-nitrogen content, plant available calcium, potassium, magnesium, phosphorus contents of 63 soils were measured. The nutrient system of soils in different ecological conditions were compared and differences between the nutrient status of the beech wood, pine forest and the open field soils were found. Knowledge of soil pH and the N, P, K, Ca and Mg content of soils can be can be important for environmental protection, sustainable forestry and management of meadows.

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THE RELATIONSHIPS BETWEEN SOIL CHEMISTRY AND THE HEAVY METAL CONTENT OF VEGETATION ON KARSTS

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Summary
The soil-vegetation system is of great importance to processes in the karst geo-ecological system. Soils can buffer those environmental impacts that change the karst system. Within certain limits, soils can bind the non-karstic materials (e.g. heavy metals) which enter the soil by deposition or by land utilisation. Acidification of soil can result in entry of heavy metals to vegetation via water. The present paper describes investigations in the dolines of the Bükk and Aggtelek regions, Hungary. The heavy metal contents of soil and vegetation on slopes vary with distance from the transportation routes. The heavy metal intake of plants is more significant on slopes nearer the transportation routes and in pinewoods on acid soils.

Introduction

The soil-vegetation system of karst regions is important from the viewpoint of the processes in the sensitive karst geo-ecological system. Soils can buffer those environmental impacts which change the processes of the karst system. Within certain limits, soils can buffer the different damaging materials (e.g. heavy metals) which get into the soil by different depositions or by land use. Through the acidification of soil, heavy metals in water may be taken up by vegetation and can have toxic impacts for the plants. The present study investigates the heavy metal content of plants in relation to the soil chemistry in two dolines in areas of the Bükk and Aggtelek regions that are ecologically different.

Methods

Soil and plants samples were collected in the E-W and N-S sections of dolines. The plant samples were collected from 1x1 m quadrates (without selection), and were air-dried. Soil samples were analysed in the laboratory for pH value (digital pH meter), and the heavy metal content both of soils and plants were measured on a Perkin-Elmer ASS.

Discussion

In an earlier investigation we showed that the heavy metal content is higher in the karst soils than could be derived from the parent rock alone (*Bárány-Kevei, 1998*), the excess being from dry and wet deposition. These acid precipitation's cause soil-acidification. In general heavy metals do not accumulate in acidic soils but are transported into plants by uptake of soil moisture. This means that the mobility of heavy metal depends on the soil pH. *Brümmer et al.* (1991) established that the metal mobility related to pH value is Cd pH < 6.0-6.5; Mn < 5.5; Zn < 5.5; Ni < 5.5; Ni < 5.5; Co < 5.5; Al < 4.5; Cu <4.5; Pb < 4.0; Fe^{3+} < 3.5.

Heavy metal content and pH values of soils

Although the heavy metal content of soils is partly a function of soil pH, the content of organic material and the permeability of the soil are also very important factors (*Kádár, 1991*). Our study investigates the heavy metal content and pH values of soils in two dolines in the Bükk and Aggtelek Mountains.

Table 1 Chemistry of soils in Aggtelek dolines (1998)

Sample	$pH(H_2O)$	PH(KCl)	$pH(H_2O)$-pH(KCl)
N (5-10)	6,10	5,24	0,86
N (10-20)	6,36	5,42	0,94
N (20-30)	6,58	5,81	0,77
N (30-40)	7,01	6,32	0,69
E (5-10)	**5,53**	4,52	1,01
E (10-20)	**5,64**	4,65	0,99
E (20-30)	6,17	5,16	1,01
E (30-40)	6,03	4,81	1,22
S (5-10)	7,05	6,53	0,52
S (10-20)	7,24	6,45	0,79
S (20-30)	7,20	6,03	1,17
S (30-40)	7,20	6,00	1,20
B (5-10)	**5,54**	4,70	0,84
B (10-20)	**5,68**	4,64	1,04
B /(20-30)	**5,86**	4,54	1,32
B (30-40)	**5,85**	4,70	1,15
B (40-50)	**5,70**	4,70	1,00
R (5-10)	**5,95**	5,14	0,81
R (0-20)	6,06	5,16	0,90
R /(20-30)	6,52	5,63	0,89
R (30-40)	6,29	5,09	1,20

Table 2.Chemistry of soils in Bükk dolines (1998):

Samples	$pH(H_2O)$	pH(KCl)	$pH(H_2O)$-pH(KCl)
N (5-10)	**5,90**	5,30	0,60
N (10-20)	**5,88**	5,26	0,62
N (20-30)	6,13	5,49	0,64
N (30-40)	6,12	5,24	0,88
E (5-10)	**5,87**	5,06	0,81
E (10-20)	**5,99**	5,23	0,76
E (20-30)	6,20	5,40	0,80
E (30-40)	6,20	5,09	1,11
S (5-10)	6,84	6,42	0,42
S (10-20)	7,37	6,88	0,49
W (5-10)	6,93	6,61	0,32
W (10-20)	7,20	6,85	0,35
B (5-10)	**5,03**	4,46	0,57
B (10-20)	**5,45**	4,77	0,68
B (20-30)	6,40	5,84	0,56
B (30-40)	6,51	5,84	0,67
B (40-50)	6,52	5,83	0,69

N = Northern slope; E = Eastern slope; S = Southern slope; W = Western slope.

Near the surface and on the bottom of dolines the soils are more acid than in the deeper soil horizons (*Table 1; Table 2*). The lower pH value supports the mobility of heavy metals.

According to our investigation the heavy metal content is higher in the karst soils than in the parent material (*Kevei-Bárány. - Hoyk. - Zseni, 1999*). The average heavy metal content of limestone according to Merian (1984) is the following (ppm): Mn 700; Fe 15.000; Co 2; Ni 15; Cu 4; Zn 23; Cd 0,165; Pb 5. Therefore, the heavy metal content of the studied soils originates from dry and wet depositions from the neighbouring industrial area (from the chemical factories of Sajó valley and industrial area of Slovakia).

Heavy metal content of plants

The uptake of heavy metals depends on the species of plant. Some authors have investigated the accumulator and excluder strategies of plants with respect to heavy metals (*Baker, 1981*). Metals can be concentrated in plants both in case of low and high background levels. *Peterson* (1971, 1975) listed twelve species with variation in plant/soil ratio for Zn, for Pb, for Cd and for Cu. There are three types of plant-soil relationship:

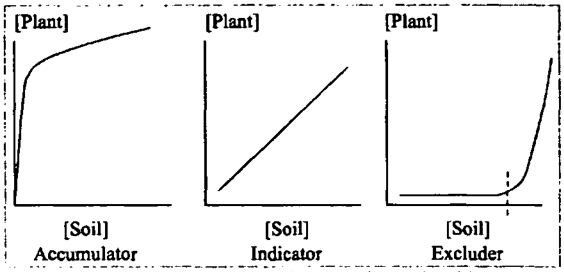

Fig. 1 The three types of plant-soil relationship

- Accumulators: the metals are concentrated in plant parts above ground both in case of low and high soil concentrations.
- Indicators: uptake and transport of metals to the shoot are regulated so that internal concentration reflects external level,
- Excluders: metal concentrations in shoot are maintained constant and low over a wide range of soil concentration, but above a critical soil value the mechanism breaks down and unrestricted transport will be the result (*Fig. 1*).

Accumulator and excluder plants are extreme types; indicators are intermediate types from the point of view of metal uptake.

As the origin of heavy metal contamination in karstwater is important, we need to know how much of the metal originates from the soil. Human activity has had a moderate impact on the investigated karst terrains. The depositions (wet and dry) have significant relation with the heavy metal content of karst soils.

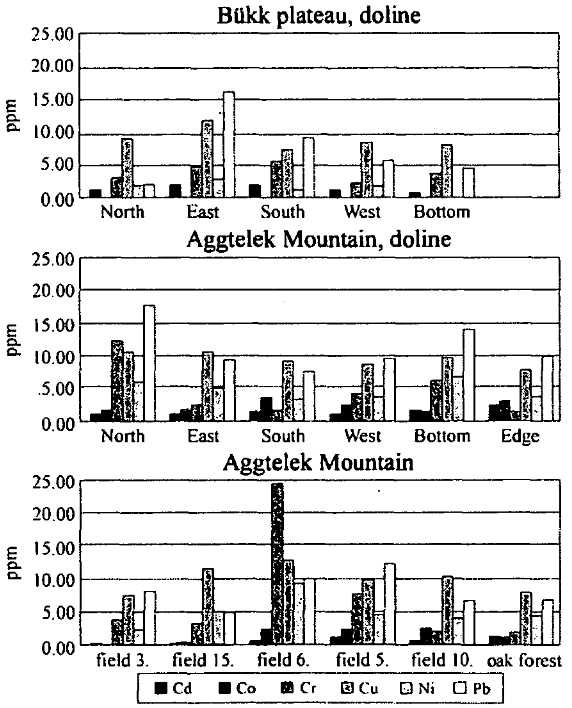

Fig. 2 The heavy metal content of the plants on different slope aspects

The following species occur in the grassy vegetation of the Aggtelek doline: *Dipsacus laciniatus, Cirsium arvense, C.vulgare, Eryngium campestre*; all are nitrophyllic grassy species indicating degradation. On the eastern slope *Sedum sexangulare, S. acre, Potentilla arenaria* are the dominant species. On the southern slope the dominant vegetation is composed of *Festuca, Agrostis and Arrhenaterum*. On the western slope *Agrostis, Festuca and Agrostis* species are characteristic in the grassy association, but *Juniper* can be found on the slopes as well. On the northern slope the vegetation is *Brachypodium pinnatum* with a forest steppe like environment.

The following species occur in the investigated doline in the Bükk: on the W, S and E slopes the dominant species are: *Potentilla*

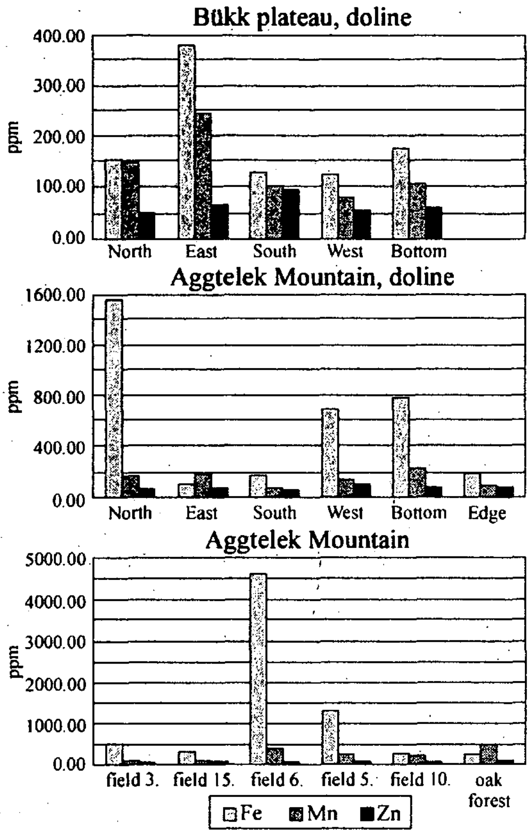

Fig. 3 The heavy metal content of the plants on different slope aspects

erecta, Succisa pratensis, Ranunculus auricomus, Rumex acetosa, Ribes alpinum.. On the S slope *Molinia coerulea, Astrantia major, Aegopodium podagraria, Lysimachia vulgaris, Anthriscus silvestris, Carduus nutans, Viola mirabilis* occur. On the N slope the dominant species are: *Salvia pratensis, Coronilla varia, Dianthus pontederae, Scabiosa ochroleuca, Polygala vulgaris, Digitalis ambiqua, Prunella grandifolia, Campanula persicifolia, Chalamintha acinos.* The W, N and E slopes are covered by *Dactylis glomerata, Origanum vulgare, Geranium sanguineum, Teucrium chamaedrys, Galium verum, Trifolium alpestre, Poligonum convolvulus.*

In the doline mostly *indicator (Festuca, Campanula, Rumex,)* and *excluder (Viola, Lotus) species* occur. In the latter case the plants show limited metal accumulation.

Fig. 2 and *3* show the heavy metal content of plants in the investigated dolines in Bükk and Aggtelek and in some different ecological types of Aggtelek Mountains. Field 3 is bare tillage, where there was previously a vineyard and the soil was eroded. Field 5 is arable land, that drains to the Zomborlyuk swallet. The metals are derived from chemically polluted arable land. Field 6 is situated at the edge of a doline. Field 10 is on the karst cone of Közép Mountain. Field 15 is situated at the Red Lake. The red clay soil has lots of metals. We have collected soil samples from original oak forest, too.

At the bottom of dolines, where the pH vales are generally low, metal-ions can not accumulate, and it is possible that the plants took up the metals from seeping water. We have carried out a detailed investigation on the connection between soil pH and heavy metal content of plants. For the research Pb, Cd and Cr were chosen (*Fig. 4, 5, 6*).

The heavy metal content of the soil showed differences on the slopes located nearer or farther from the transportation routes. On the slopes of doline nearer to the routes and in the pinewoods on acid soils the heavy metal uptake of plants is more significant. For example, on the northern slope of the doline in Aggtelek, the road is on the edge of the doline. In its bottom high lead concentration was detected. In this case the pH value is low, therefore, the plants can take up more lead. The greatest lead value can find on the field near the Zombor-swallet. This swallet drains water from the agricultural area.

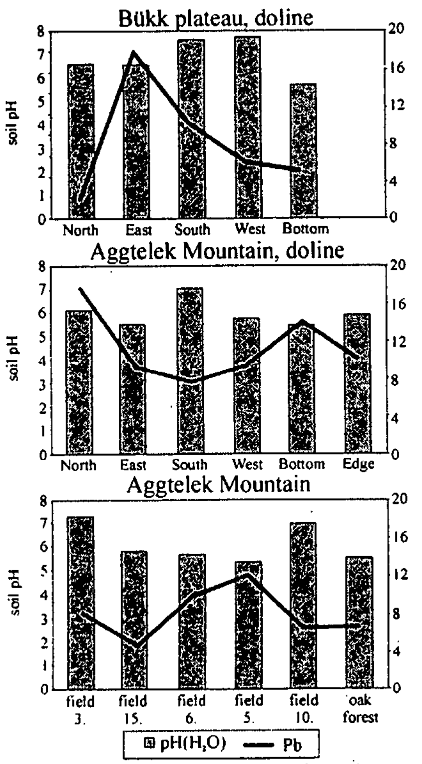

Fig. 4 The soil pH and Pb content of the plants on different slope aspects

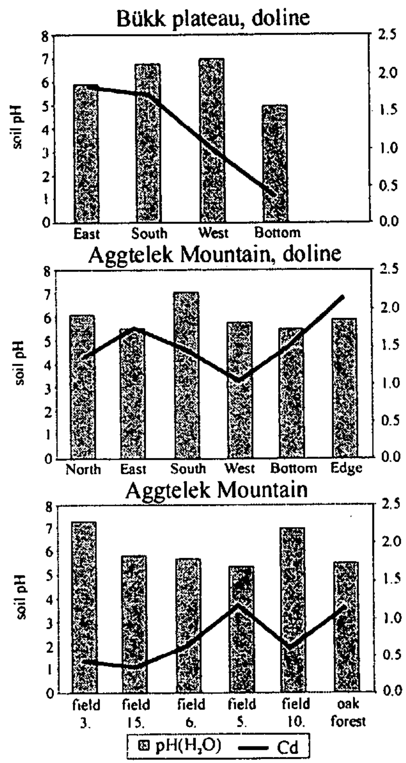

Fig. 5 The soil pH and Cd content of the plants on different slope aspects

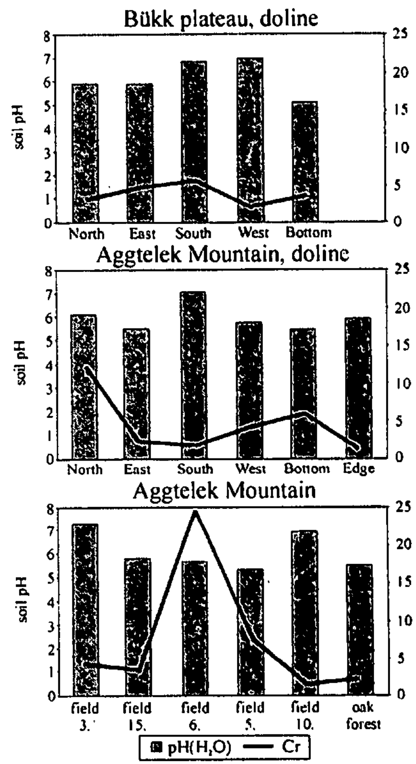

Fig. 6 The soil pH and Cr content of the plants on different slope aspects

Conclusions

Our investigation has demonstrated a relationship between soil pH and the heavy metal content of plants on karst territories:

1. The heavy metal content of vegetation is higher in the Aggtelek Karst than in the Bükk Mountains.
2. The heavy metal content changes with pH, if the soil pH is low, the heavy metal content of vegetation is higher than at higher pH values.
3. The content of heavy metal in plants is close to the maximum of heavy metal content of soils.
4. In Aggtelek, near the swallow-hole, the heavy metal values are high in close relationship with the land use.
5. In the doline of Aggtelek the highest metal values were measured on the northern slope, in the neighbourhood of the road.

In the future we would like to study the ratio of heavy metal content of soil and plants, because the higher ratios will show which are the accumulator plants in the investigated area.

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THE ROLE OF SOIL - MICROORGANISMS IN KARST CORROSION

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Summary

Soils in karstic areas are easily damaged by human activity and hard to sustain. Therefore, it is very important to investigate the processes in these soils from the point of view of conservation of karst. The life-activity of biological-microbiological communities, as principal sources of CO_2 and various acids in the soils, play an important role in karst corrosion, though the main aggressive sources of soils have not been described and measured exactly. This paper describes new laboratory analyses of the production of material aggressive to $CaCO_3$ by selected soil microbes. The process of pH change by microorganisms and the amount of $CaCO_3$ dissolved by selected microorganism strains were measured under „optimal" conditions. Data were obtained on the difference between CO_2 and other chemicals, and the production of aggressive agents by various microorganism groups. At the same time, the most important microbial strains, their behaviour, and the processes controlled by them under different environmental conditions were also examined. Furthermore, the quantity of microorganisms was determined in soil samples gathered on the Aggtelek Karst in Hungary.

Introduction

„Microorganisms are dangerous - they make one ill" - this is probably the image most people have of microorganisms. Really, what does it mean microorganisms from the aspect of karst research? These problems are relatively difficult to investigate because they possess an interdisciplinary relation, but might help to explain that in what degree the soil-microorganisms play an important role in the processes of the karst corrosion. Today, researchers of the role of types of soil cover on a limestone surface attach a great importance to their direct influence on the karst relief evolution. The complex soil effect is due to the joint influence of many factors (soil permeability, evapotranspiration, microclimate, soil aeration, soil life, and others), which together control the amount and aggressivity of karst water (*Kevei-Bárány and Zámbó, 1985-86; Zámbó, 1991, 1993)*. One component is the

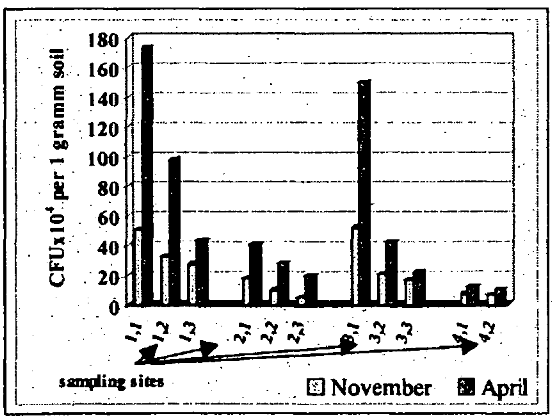


Fig. 1 Colony Forming Units of aerobic and facultatively anaerobic bacterial communities of the soil samples taken from

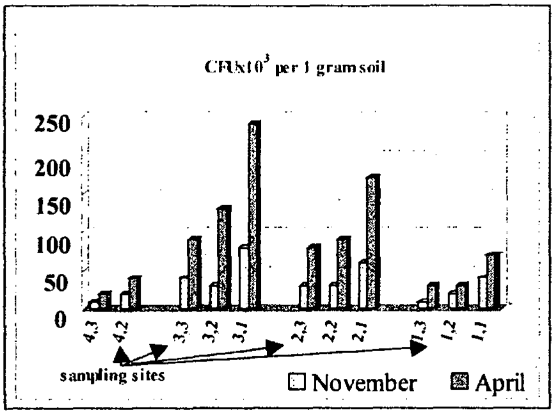


Fig. 2 Colony Forming Units of microfungi communities of the soil samples taken from Béke-dolina

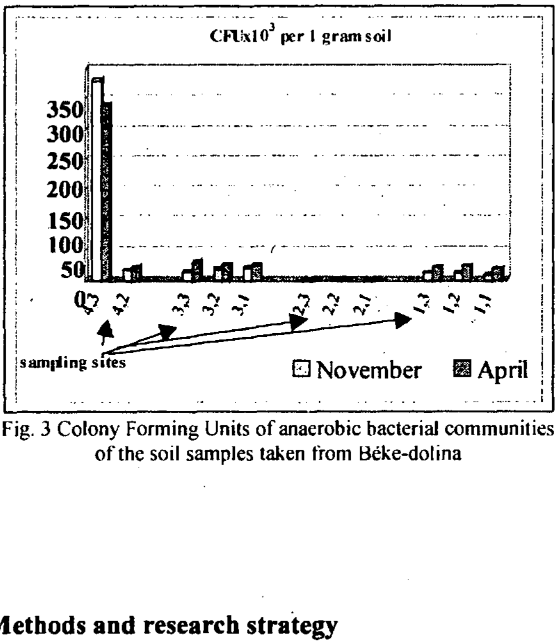


Fig. 3 Colony Forming Units of anaerobic bacterial communities of the soil samples taken from Béke-dolina

amount of CO_2, which is originated from the soil biological activity. The major part of produced CO_2 amount is attributed to the activity namely aerobic or anaerobic respiration or fermentation of soil-microorganisms - such as bacteria and microfungi. Moreover any acids, whether inorganic or any of a variety of organic acids produced by subsurface microbes in consumption of organic matter for energy production, would also be very corrosive, depending on the intensity of metabolism of microbes (*Ehrlich* 1998; *Jakucs at al. 1983*; *Lovley and Chapelle, 1995).* The regular renewing of aggressive matter production by microorganisms alters the chemical composition of the soil atmosphere, and later that of the infiltrating waters *(Killham 1994)*. Therefore, the microbial life-activity indirectly becomes the principal affecting factor of karst corrosion processes and determining the circumstances and rate of the limestone corrosion by microbes is very interesting and complex problem in the karst research in Hungary, too.The aim of the present paper is to give more information about microbiological communities in the soil of limestone areas and their role in the processes of limestone corrosion.

Methods and research strategy

There are several methods to able to investigate the solution of limestone (karst corrosion) by soil-microorganisms' s activity. The stages of present research strategy were the following:

- Determination of the sampling sites and methods,
- Selecting some dominant soil types covered the Hungarian karst areas and collecting the soil samples (*Szegi 1979)* from the following soil types, in

Béke-doline of Aggtelek Karst, which are also common in other karst regions in Hungary.

1. Soil type of terra rossa-like (*Zámbó 1993)* of more than 1 m thickness, common in karstic depressions
2. Rendzina (T_2) of 0.3 m thickness, common on karst slopes and uplifted surfaces
3. Soil type of terra rossa-like(T_1)of 2 to 3 m thickness, common on karst slopes and the valley floors
4. Doline fills of more than 5 m thickness

In the cases of „1", „2" and „3" the soil levels of 0-10 cm; 10-20 cm and 20-30 cm were examined and in the 4th case, the levels of 270 cm and 750 *cm (Zámbó and Darabos 1993*).

- Examination of the number and the topographical distribution of the main groups of microbes living in the „karst soil" and identification of the isolated microorganisms (microbiological methods */Bergey' 1986; Collins 1967; Covan, and Steel 1965; Szabó 1974; 1986/*)
- Carrying out some new laboratory model analysis using some selected microbes (The methods of laboratory analysis were invested by the author.)

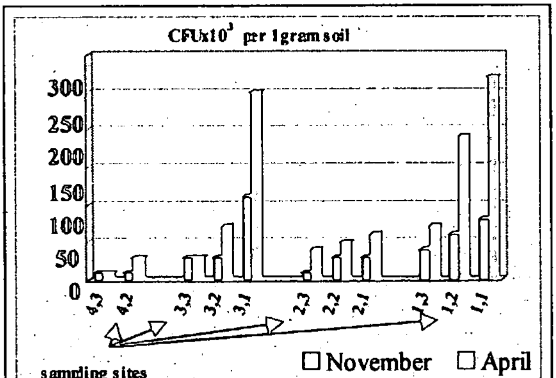
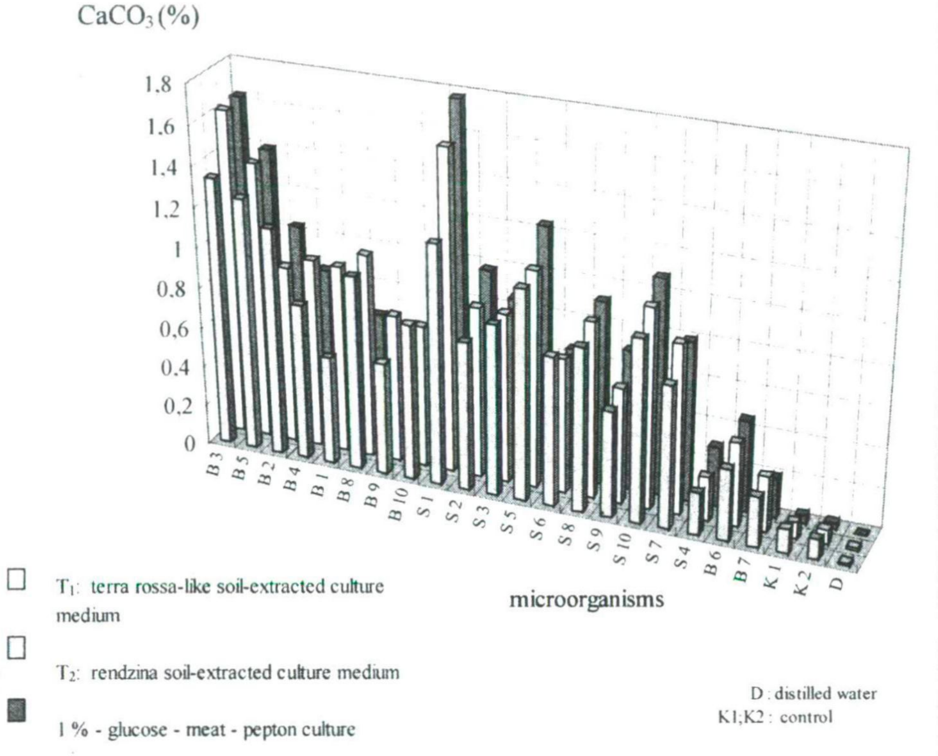


Fig. 4 Colony Forming Units of Streptomyces of the soil samples taken from Béke-dolina

In the laboratory model analysis, the CO_2 production of the individual strains of microbes was calculated in the artificial environment. Thus, significant data could be obtained for the difference of CO_2 production between each of the selected strains under the different circumstances. For the purposes of this, 50g of cleaned limestone rubble of 3.5 to 5 mm diameter was put into Erlenmeyer-retort and the whole system was sterilised in the autoclave. In the other retorts, we used 1 %-glucose-culture-medium (pH 7) and soil-extracted-culture- medium (pH 7) from two types of soils (soil like terra rossa (T_1) and rendzina (T_2)) in order to study the problems of the nutritional requirements of microbes, and to compare the degree of $CaCO_3$ corrosion. In the soil-extracted culture medium the various necessary mineral elements and nutritive matters were available for microbes. Each of culture medium of 50 ml was made, sterilised, and inoculated by clasper unit of different strains (list of them is shown on *Fig. 5*). Finally, we poured the inoculated medium on the limestone rubble in the sterile conditions. After all the above, the retorts were incubated up to a definite time in laboratory temperature (21°C). At the end of incubation period, we measured the pH-values of culture mediums taken-out and the weight of cleaned limestone rubble. As control tests, we made the same amounts of limestone dissolve in distilled water (D) and in microorganism-free-medium (K).

In the following investigation, we used special culture medium (Czapek-medium of pH 5) which is an ideal environment for microfungi and in which the growing and activity proved to be bigger than that of other microbes (*Szegi 1973*).



B1	B. megaterium var. 1.	B6	M. luteus	S1	S. cellulose	S6	S. gelaticus
B2	B. cereus var. 2.	B7	B. megaterium var. 7.	S2	S. atroolivaceus	S7	S. diastaticus var.
B3	B. megaterium var. 4.	B8	B. megaterium var. 8.	S3	S. diastaticus	S8	S. exfoliatus
B4	M. kristinae	B9	B. cereus	S4	S. spadicis	S9	S. atroolivaceus var.
B5	B. mycoides var.	B10	B. mycoides	S5	S. anulatus	S10	S. actuosus

Fig. 5 $CaCO_3$-corrosion by microorganisms in the different types of the culture medium (B: Bacterium, M: Micrococcus, S: Streptomyces)

Result and discussion

1. Analysing the CFU number and the topographical distribution of the main groups of microbes (*Fig. 1, 2, 3, 4*) in autumn and in spring periods, usually large population of microbes was found in each spring-soil samples. The quantity of *Bacterium* (and *Sterptomyces* – a kind of *Bacterium*) strains proved to be bigger than that of microfungi. Except of the doline's depth, the major part of the microbes was the aerobe bacteria at each of the sites. Usually, the number of microbes decreased following the

depth. The great number of anaerobe-microbes in the deepest zones, which are hardly ventilated, is significant.

2. The most common 10 *Bacterium* and *Streptomyces* strains, which were found at all the sample sites, were isolated, selected and finally identificated (*Fig. 5*) in order to be used in the further laboratory analysis.

3.a. Shown by Figure 5, the amount of dissolved $CaCO_3$ was different depending on the strains, because they produce different amounts of $CaCO_3$-aggressive materials (CO_2 and carbonic acids). The dissolution of $CaCO_3$ was bigger in the 1 % - glucose - meat - culture medium than in both of the soil-extracted-culture mediums. This happened because the organic carbon is the major constituent of the food supply and it means a strong stimulation for the microbial activity. Anyway, the significant loss of limestone in the soil-extracted-culture mediums leads us to suggest that these soil types represent favourable conditions for microorganisms and these soil types for karst corrosion. The solution (corrosion) in the terra rossa-like (T_1) soil-extracted culture medium was usually more significant than the solution in the rendzina (T_2) soil-extracted culture medium. In the cases of the control tests, and the solution impact of the nutrient solution on the limestone was negligible. At the same times the pH changing was measured in every case. If the amount of $CaCO_3$ was considerable, then the pH-change, change between the starting pH-value and the end of the process pH-value, was also significant. On the other hand, when the amount of $CaCO_3$ dissolved during the process was not very big, then the pH-value also differed less at the end of the process from the starting value. This can be explained with the influence of the microorganisms present at the tests and their metabolic products (CO_2 acid and other acids) on the $CaCO_3$.

The various strains adapted to the environments in different ways, thus they produced aggressive matters differently as well, therefore the effect, and the observed amount of dissolved $CaCO_3$ differed depending on the various strains of microorganisms. Results of the test it can be concluded, that the pH-value and the composition of the nutritive matter of the culture medium is influencing a great deal the activity of microorganisms.

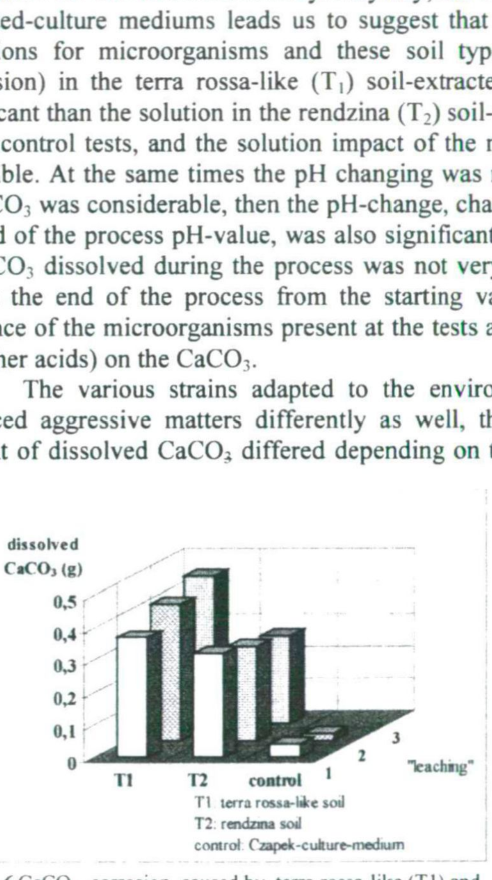


Fig. 6 $CaCO_3$ -corrosion caused by terra rossa-like (T1) and rendzina (T2) soil types in the Czapek - culture- medium (pH 5)

3.b. As the result of this test (*Fig. 6*), the microfungi have a significant corrosion effect, too. According to the result of this test, it can suggest that, the low pH-value (4 or 5) of condition existed in the „karst soil" are made the species-composition of original micro-organism community changed, and can reduce the microorganisms activity producing CO_2. The changes in the easy-to-wound and hard-to-sustain soils covering the karstic areas are caused mainly by human activity. Therefore, these results are very important from the point of view of conservation of karst.

Conclusion

It was clearly shown by the different tests that the life-activity of microbial communities, as principal sources of CO_2 and various acids in the soils, play an important role in karst corrosion. The various ecological factors (pH-value, the amount of acids, microelements and ions etc.) have a very important and determining role for the activity of microorganisms. Under the optimal conditions the activity of microorganisms is usually a decisive importance in the production of aggressive material by karst soil. In natural conditions, of course, we have to consider the complex effects of karst soil types, and that the microorganism strains are not acting alone, but the result of their joined actions are reflected in the process of the karst corrosion and in the evolution of karst areas.

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HUMAN IMPACTS ON KARST TERRAINS

SHORT-TERM DECLINE IN SOIL CARBON DIOXIDE CONCENTRATIONS UPON BURNING OF SECONDARY VEGETATION IN THE KARST OF BELIZE

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Abstract

A series of forty soil carbon dioxide measurements were taken in hillslope soils at a single 0.5 hectare site in the karst of the Cayo District, Belize immediately prior to and following the burning of the secondary vegetation during March of 1984. All measurements were made with a Draeger probe at a soil depth of approximately 20 cm. The secondary growth had been cut, but not burned, prior to the first set of measurements, which indicated a mean soil CO_2 concentration of 1.5 % (n=10). The plot was burned the following day, on which no measurements were possible. Measurements the day after the burn produced a drastically reduced mean soil CO_2 level of 0.1 % (n=10), suggesting the virtual cessation of biological respiration within the soil. Measurements on the following two days indicated a gradual recovery of soil CO_2 levels, with mean soil CO_2 contents of 0.3 % (n=10) and 0.9 % (n=10) respectively, the latter following a brief rain shower. These measurements indicate that soil CO_2 levels in tropical karstlands may vary considerably over short time periods, particularly as a result of human activities, and they suggest that studies of carbonate rock dissolution in tropical karst should take into account the potential for both short- and long-term variations in soil CO_2 levels.

Introduction

Soil carbon dioxide, which is essentially the product of subsurface biological respiration, is an important short-term storage component in global carbon cycling and also exerts a critical influence on subsoil carbonate dissolution in karst landscapes. As such, variations in soil carbon dioxide contents are important indicators of changes in biological respiration levels in the soil and useful surrogate measures of soil-atmosphere carbon flux. Moreover, they are valuable indicators of changing potential for subsoil carbonate dissolution in karstlands.

Soil carbon dioxide is produced essentially by organic decomposition and the respiration of soil biota, which are influenced by soil environmental conditions, such as temperature, moisture content and pH (*Miotke, 1974, Ford and Williams, 1989*). Burrowing animals, soil microorganisms, aerobic litter decay and plant root respiration all contribute to soil CO_2 accumulation, which is most effective in damp soils with textures and structures which hamper rapid gas diffusion to the atmosphere (*Miotke, 1974, Ford and Williams, 1989*). Soil CO_2 levels generally increase with soil depth and temperature, and may vary seasonally and diurnally.

In karstlands, soil CO_2 levels are an important indicator of potential subsoil carbonate dissolution activity because CO_2 dissolution by percolating water increases carbonate dissolutional capability, or aggressivity (*Miotke, 1974; Smith and Atkinson, 1976,* *Gunn and Trudgill, 1982; Ford and Williams, 1989*). The partial pressure of CO_2 both in the soil and in the unsaturated zone directly influences the rate of carbonate dissolution (*Smith and Atkinson, 1976; Atkinson, 1977; White, 1988*). Soil CO_2 levels in karstland soils typically range from 0.1 % to 11 % (*Miotke, 1974, Ford and Williams, 1989*).

Based on worldwide variations in measured soil CO_2 levels, *Brook et al* (1983) constructed a controversial world model of soil carbon dioxide which suggested that actual evapotranspiration (AET) was the best predictor of soil PCO_2 and that soil PCO_2 levels in tropical areas were generally higher than those in other areas. About 50 % of variation in the partial pressure of soil CO_2 was explained by temperature, 20 % by precipitation, and the balance by seasonal water availability and organic growth factors. Although the effects of long-term changes in soil CO_2 levels, for example as a consequence of global environmental change, have been considered in such contexts (*Yonge, 1997; Yuan and Liu, 1998*), there has been little recognition of the potential impact on karst of short-term variability, for example as a result of transient human activities.

By contrast, there have been numerous studies of the short- and medium-term impact of human activities on soil chemistry and biology, particularly in the context of „slash and burn" agriculture in the tropics (e.g. *Jordan, 1987, Kotto-Same et al, 1997*). Overall, cutting and burning results in a marked increase in soil nutrient leaching losses, and in the loss of forest system carbon, particularly from the above-ground tree biomass; this accelerated carbon flux, in turn, contributes to atmospheric CO_2 accumulation and change (*Kotto-Same et al, 1997*). Despite leaching losses, soil nutrient stocks are not depleted as long as there is a supply of decomposing organic matter on the soil surface (*Jordan, 1987*). Similarly, the soil organic matter is a relatively stable carbon pool, with relatively high rates of carbon reaccumulation (*Kotto-Same et al, 1997*).

That notwithstanding, burning of tropical forests has a marked short-term impact on carbon flux to the atmosphere. The magnitude of CO_2 pulses from direct burning emissions per unit area in tropical forests has been calculated to be ten times that of boreal areas (*Auclair and Carter, 1993*), and burning may increase soil CO_2 fluxes by an order of magnitude, although they may decline to preburn levels within a few *days (Zepp et al, 1996*). Soil CO_2 effluxes may not be immediately impacted by fire, possibly being maintained at preburn levels by microbial decomposition of labile compounds released as a result of the fire (*Burke et al, 1997*). By contrast, in years after burning there may be a significant reduction in soil CO_2 flux, with recovery to preburn levels taking several years (*Burke et al, 1997*). Similar impacts have been demonstrated in tropical karstlands, including Belize (*Furley, 1987; Furley and Newey, 1979; Cooper, 1989*). Typically, clearance resulted in changes in soil organic contents, pH, nutrient cation levels and soil physical properties.

The Study Area

The study was undertaken in the Hummingbird karst of the eastern Cayo District in the Central American country of Belize (*Fig. 1*). The Hummingbird karst is part of a broader karst belt in central Belize that is known as the Boundary Fault karst (*Miller, 1996*). These karstlands, their geomorphology and landuse have been described in detail previously (*Day, 1987b, 1991, 1993; Day and Rosen, 1989; Miller, 1987, 1996*). The study

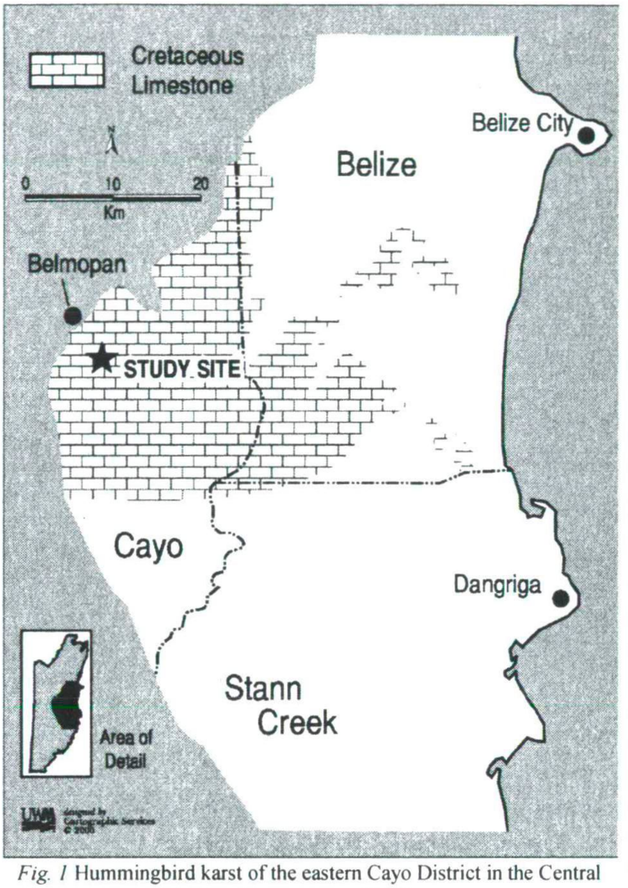

Fig. 1 Hummingbird karst of the eastern Cayo District in the Central American country of Belize

area is broadly that described by *Day* (1986, 1987a) and by *Furley and Newey* (1979), located in an area of polygonal karst approximately 7 km south of the Belizean capital city of Belmopan (*Fig. 1*). The site of the soil CO_2 measurements is a southeast-facing 0.5 hectare plot on the lower slopes of a residual hill which attains about 35 m in height. Overall slope angle is about 30 degrees. Area soils are reddish brown rendzinas or mollisols, with some vertisols, derived from the carbonates. Most are rubbly clay loams with a blocky structure and variable drainage. Upper slopes are xeric, and soil moisture generally increases downslope. Soil depth locally exceeds 50 cm in joints and solutional pockets, but is generally less; soil is absent on steeper slope segments, with thickness generally increasing downslope. Vegetation consists of mixed secondary forest (bush) containing a wide variety of deciduous and semi-evergreen trees, shrubs, vines and herbaceous plants, and rich in calcicolous species (*Furley and Newey, 1979*). The forest has suffered both pre-and post-European clearance, plus the ravages of hurricanes and wildfires (*Furley and Newey, 1979; Furley, 1987*). Mean annual temperature is about 25 degrees Centigrade, with mean annual rainfall of approximately 2300 mm. A marked dry season extends typically from January through May (*Walker, 1973; Furley and Newey, 1979*).

Forest Burning in the Belize Karst

Milpa, or „slash and burn" agriculture is common in the Belize karst and is generally associated with the short-term cultivation of corn, beans and squash, although other crops may be involved (*Bliss et al, 1987*). Small areas of secondary forest are cleared using axes and chainsaws to cut larger trees and machetes to clear vines, saplings and shrubs. Some larger, desirable trees, particularly the Cohune Palm (Orbignya cohune) may be left to provide shade or fruit. Cutting usually takes place during the dry season, typically in January or February but sometimes as late as March or April. Burning of the plant debris follows a period of drying, typically lasting from one to four months. Burning eliminates smaller branches, making the field more accessible, may kill weed seeds and affect soil bacteria, and provides a nutrient-rich ash (*Jordan, 1987*). Planting follows, usually within weeks after burning and just prior to the onset of rains at the end of the dry season. The site may be cultivated for a single season or for several years, depending largely on competition from weed species (*Kellman and Adams, 1970*) and is then abandoned to fallow.

Methodology

A series of forty soil CO_2 measurements were taken in the study site hillslope soils immediately prior to and following the burning of the secondary vegetation on March 17, 1984. The secondary growth had been cut, but not burned, prior to the first set of 10 measurements, which were made on the morning of March 16. The plot was burned the following day, on which no measurements were possible. Subsequent sets of ten measurements were taken the morning of the day after the burn (March 18) and on the mornings of the following two days (March 19 and 20). Measurements were not made systematically at exactly the same locations, rather the ten measurements each day were made at different locations within the site of the burn. All measurements were made with a Draeger probe (*Miotke, 1974*) at a soil depth of approximately twenty centimeters, thus avoiding problems of comparison between different soil depths.

Results

The first set of measurements, prior to the burn, indicated a mean soil CO_2 concentration of 1.5 % (n=10) (*Table 1*). Measurements the morning after the burn produced a drastically reduced mean soil CO_2 level of 0.1 % (n=10), within the soil, and measurements on the following two days indicated a gradual recovery of soil CO_2 levels, with mean soil CO_2 contents of 0.3 % (n=10) and 0.9 % (n=10) respectively, the latter following a brief rain shower on the evening of March 19.

Table 1 Soil Volume % CO_2, 20cm Depth, Belize, March 1984.

Date	3/16	3/17	3/18	3/19	3/20
Mean	1.62	n.a.	0.13	0.33	0.92
s	0.35	n.a.	0.07	0.12	0.20
n	10	n.a.	10	10	10

Discussion and Conclusion

In general, the ranges of soil CO_2 levels measured are not remarkable for tropical karst soils (*Miotke, 1974; Day, 1978; Brook et al, 1983*). The preburn mean level of 1.5 % is not atypical for Caribbean and Central American tropical karst soils at depths of 20 cm (*Day, 1978*), indeed it is modest, probably as a consequence of the effective diffusion of CO_2 from the soil during the dry season. The much-reduced soil CO_2 levels recorded on the day after the burn suggest a temporary soil CO_2 impoverishment perhaps reflecting an evacuation into the atmosphere of pre- existing CO_2 from the soil during the fire and/or a dramatic decline of biological respiration within the soil during and immediately following the burning. The slow recovery on subsequent days, particularly after a brief rain shower on March indicates that the soil CO_2 impoverishment was transient, lasting probably less than a week. In comparable studies elsewhere, *Zepp et al* (1996) recorded net soil CO2 fluxes rising by an order of magnitude immediately after burning of savanna sites, but returning to preburn levels within a few days. Similarly, *Kotto-Same et al* (1997) reported that soils had relatively high rates of carbon reaccumulation after burning. The recovery of soil CO_2 levels after the rain on March 19 mimics the stimulation by moisture of soil respiration and CO_2 fluxes in other settings (*e.g. Hao et al, 1988; Zepp et al, 1996*). The results give no indication of the impact of burning on soil CO_2 fluxes and concentrations beyond the immediate postburn period. Although it appears that recovery is rapid, it is possible that impacts may persist for several years (*Burke et al, 1997*). These measurements indicate that soil CO_2 levels in tropical karstlands may vary considerably over short time periods, particularly as a result of human activities such as forest clearance and burning, and they suggest that studies of soil CO_2 influence on carbonate rock dissolution in tropical karst should take into account the potential for both short-and long-term variations in soil CO_2 levels.

Acknowledgements

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HUMAN IMPACT AND SPONTANEOUS REGENERATION OF A KARST-AEOLIAN ECOSYSTEM IN AN ANTHROPOGENIC DESERT NEAR OLKUSZ (SILESIAN UPLAND, POLAND)

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Summary

The presence of thick, sandy, Quaternary cover sediments over Triassic and Jurassic carbonate rocks, with a well-defined karst-fissured aquifer, in the eastern part of the Silesian Upland (South Poland) has resulted in an unusual karst-aeolian environment. The occurrence and specific properties of karst water discharging within fluvio-glacial and aeolian sands created conditions for the development of unique floristic associations. However, intensive human activity, principally heavy industry and mining, changed the ecosystem. Archaeological and historical data indicate that ancient exploitation of lead ores began in the eastern part of Silesian Upland in the first millennium AD. Intensive exploitation and production of silver and lead in this karstic area is dated to the 13th century. In the early metallurgic works, charcoal was used as the basic fuel. Medieval deforestation of the Olkusz area was the main factor in the development of an anthropogenic sandy desert (the Bledow Desert) over the karst-fissured system. During the 16th and 17th centuries there was a second period of intensive deforestation of the area. The wood(oak and beach trees mainly) was used for charcoal production and for construction of underground and surface drainage canals. In that period, local artificial drainage was accompanied by total destruction of the ecosystem, with the exception of the unique karst spring ecosystems. With the introduction of coal as a fuel for industry in the 19th century the reforestation process began. In addition to huge dewatering of the karst-fissured aquifer and the chain of changes induced by man in the karst-aeolian environment due to contemporary lead and zinc ores exploitation, spontaneous regeneration of forest ecosystems is recorded. Utilisation of the Bledow Desert as an army polygon for several tens of years (mainly during and just after World War II) and a large fire in early 1990's interrupted 20th century spontaneous reforestation. This present a major problem for nature protection in the area, whether to protect a desert that is unique in Europe but whose aeolian landscape is an artefact of human activity and will need to be artificially maintained in the future or to permit the area to be overgrown by means of spontaneous succession, thereby protecting the karst-fissured aquifer.

Introduction

Evaluation of transformation stage and setting environmental protection strategy for karst areas are serious practical problems. This task is very complicated and more complex in areas of confined or semi-confined karst aquifers and in areas of buried karst with palaeokarstic features. In such areas it is difficult to identify zones exposed to human activity influencing transformation and destruction of all karst system. On the base of experiences from semi-confined, buried in Pleistocene sands and clays, affected by intensive human activity karst area of eastern Silesian Upland in South Poland as example, the authors remark complexity of interdependence between different components of the environment. Direct proximity and interactions between carbonate Triassic and Jurassic rocks and thick cover of Quaternary sediments result in an unusual karst-aeolian environment (*Fig. 1 and 2*). Sustained and intensive human activity in eastern Silesian Upland resulted in the development of an anthropogenic sandy desert (the Bledow Desert). This desert is the only sandy area with contemporary active aeolian processes in Central Europe. Now, the established desert ecosystems are in danger due to overgrowth and spontaneous regeneration of forest environments. It is necessary to emphasise that forest biocenoses are the climax for south Poland and without human support all the area will overgrow by trees. Hence, it has become a conflict of interests and dilemma for nature protection priority. The question is, whether to protect a desert that is unique in Europe but whose aeolian landscape is an artefact of human activity and will need to be artificially maintained in the future or to permit the area to be overgrown by spontaneous succession, thereby protecting the karst-fissured aquifer.

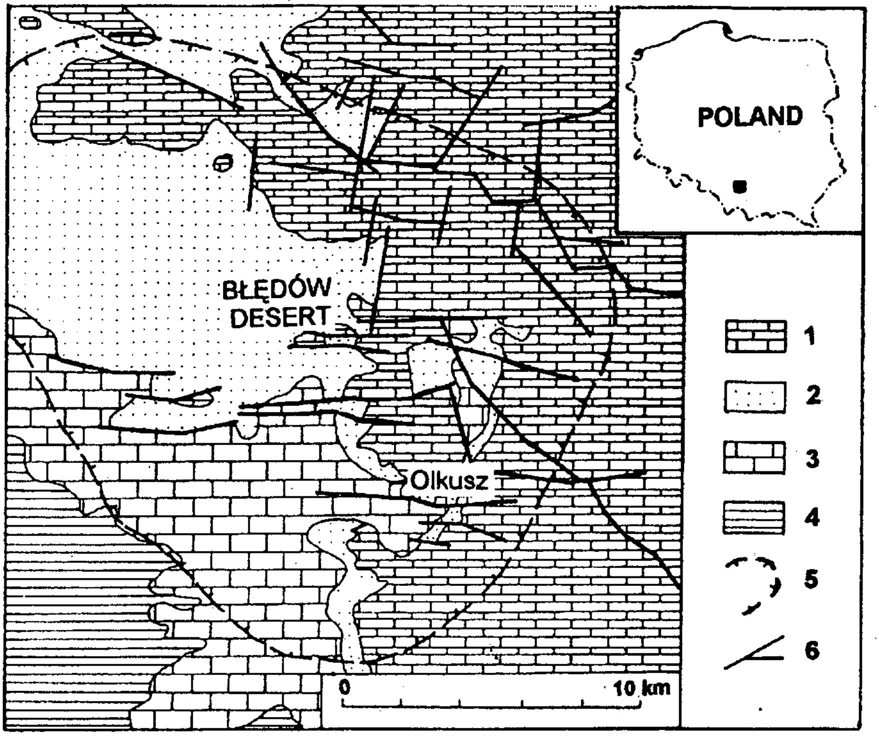

Fig. 1 Location and outline geology (without Quaternary sediments) of the Bledow Desert
1 - Upper Jurassic limestone; 2 - impermeable Upper Triassic and Lower Jurassic rocks; 3 - Middle Triassic limestone and dolomites; 4 - Palaeozoic impermeable rocks (mostly Permian); 5 - extent of the hydraulic depression cone in Triassic carbonates; 6 - main faults

Geological and hydrogeological setting and karstification of the Olkusz area

The karst of the eastern Silesian Upland is developed in carbonate rocks of Middle Triassic (Mushelkalk) and Upper Jurassic age (*Fig. 1*). The principal features of the

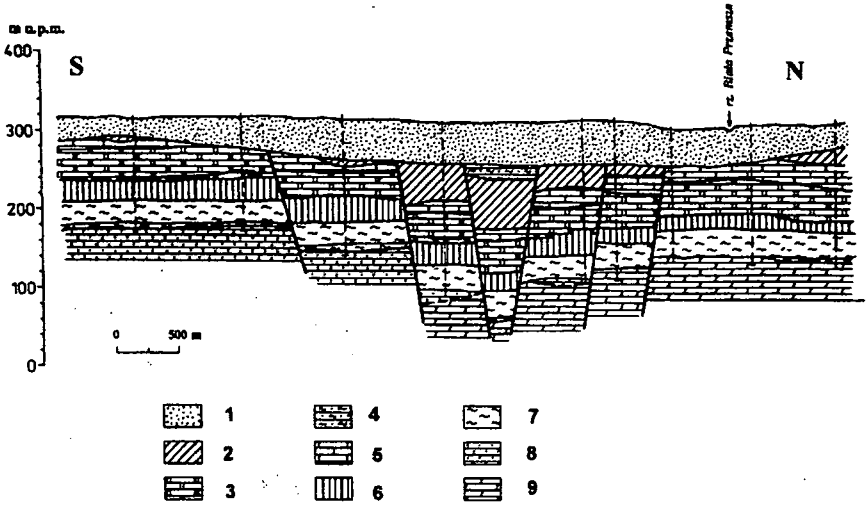

Fig. 2 Longitudinal geological cross section of the central area of the Bledow Desert
1 - sands and clays (Quaternary); 2 - shales and mudstones (Upper Triassic); 3 - ore bearing dolomites (Middle Triassic); 4 - marls and limestone (Jurassic); 5 - marly and diplopora dolomites (Middle Triassic); 6 - limestone, dolomites and marls (Middle Triassic); 7 - dolomites and marls (Lower Triassic); 8 - conglomerates, sandstone and mudstones (Permian); 9 - limestone, dolomites and sandstone (Devonian).

geology of the Olkusz area are shown on *Fig. 2*. Folded Palaeozoic rocks lie at the massif's base. The main mass of the geological profile consists of a monoclinal structure of Mesozoic rocks, principally Triassic carbonates. The whole structure is covered with thick Quaternary sandy-clay sediments. The origin and age of these sediments are not well defined. After sedimentological data they should be fluvio-glacial, proluvial-fluvial and in places proluvial-deluvial deposits (*Szczypek, Wach 1989*). The superficial sands are bedded, fine- and medium-grained. The mean thickness of sandy-clay sediments varies between 10 and 20 m. In meridional palaeovalley of Biala Przemsza river, situated in the centre of the area, the thickness reaches 45-60 m.

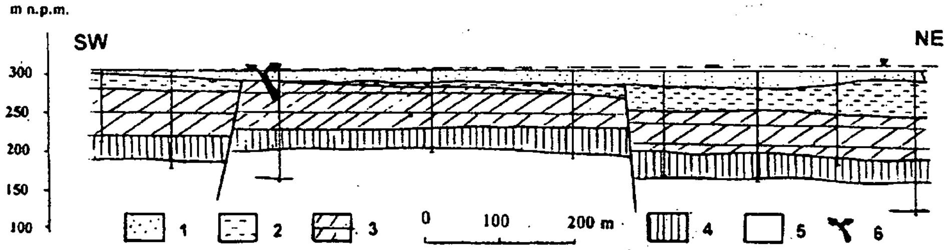

Fig. 3 Geological cross section in the vicinity of the travertine dome in Laski.
Groundwater level according to 1958 data.
1- Quaternary sediments; 2- Upper Triassic shales; 3- Middle Triassic diplopora and ore bearing dolomites; 4- Roethian dolomites and marls; 5- Permian sandstone; 6- hydrogeological window and place of ascend outflow of groundwater in artesian condition (location of travertine dome).

The base of the karst-fissured system consists of Permian-Lower Triassic sedimentary rocks. By tectonic and sedimentary boundaries, Middle Triassic limestones and dolomites are in hydraulic contact with the underlying karstified Devonian rocks (*Motyka 1988; Rozkowski, Wilk 1980*) (*Fig. 2*). Tectonic model of the Olkusz area is complex. The main mass of carbonates and impermeable layers are divided into small tectonic units by faults and parallel horsts and grabens. Polygenetic and polycyclic systems of buried karst, with traces of paleokarst, established in early phases of regional karstification, are divided and separated by impermeable fault zones. Occurrence of impermeable sediments of Upper Triassic in the top layer of Triassic carbonates determine semi-confined, partly artesian karst-fissured type of the aquifer (*Fig. 2*). In zones of impermeable layer discontinuity hydraulic connection between karstified Middle Triassic rocks and Pleistocene sandy cover occur (*Motyka 1988; Tyc 1997*) (*Fig. 3*). Under natural

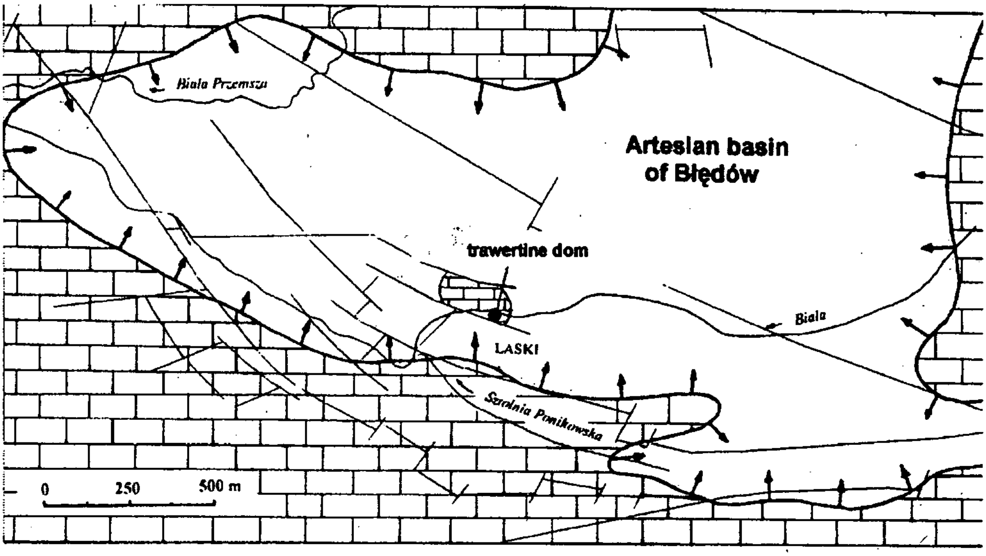

Fig. 4 Geological situation and location of the hydrogeological window and travertine dome in Laski. Area with arrows shows the extent of the local artesian basin within the Triassic carbonates rocks.

conditions karst water recharges sandy sediments and outflows by ascending springs to river valleys. As a result, travertine deposition occurred in such places surrounded by aeolian sands. The travertine dome in Laski is a good example of this phenomenon (*Fig. 4, Photo 1*) (*Gradzinski et al. 1999*). Exploitation of the lead-zinc deposits and groundwater for water supply caused the development of a 350 km^2 cone of depression. The pumping rate for the area is c. 380 m^3/min (6.3 m^3/s). The base of the induced drawdown lies below most of the open and filled karst features. Contemporary artificial drainage is connected with a pre-Quaternary system of karst water circulation (*Tyc 1997, 1999*). As a result of mining within the Triassic carbonate aquifer, new hydraulic components have appeared; artificial water galleries that take over the role of master conduits in the functioning of the karst circulation. Most of the ascending karst springs in the area of Bledow Desert have disappeared and some changed their role to function as ponors recharging the aquifer with polluted surface water. All these hydrogeological changes have impacts on the karst-aeolian ecosystem.

Photo 1 Travertine dome with cave in Laski (for the location see *Fig. 4*). (photo. *A. Tyc*)

Origin of the artificial desert near Olkusz

The climate of Poland, with mean annual precipitation of 600-700 mm, is not favourable to desert or semi-desert environments. Despite the common occurrence of sandy areas across the whole country, mainly of fluvio-glacial origin, the climatic conditions are such that they are covered with vegetation, mainly with pine forests. So, there are no natural sandy deserts in the eastern Silesian Upland and Olkusz area. The sand cover is due to human activity. Archaeological and historical data indicate that Bledow Desert is a result of deforestation during ancient exploitation of lead and silver ores. Ancient exploitation in the Olkusz area and in other parts of eastern Silesian Upland began in the first millennium AD. The first shallow mines and metallurgic works were situated on hills of the Triassic ore-bearing dolomites, in conditions of bare rock outcrops. The beginning of the intensive exploitation and metallurgy of lead and silver is dated for 13^{th} century. Medieval deforestation was the main factor influencing development of an anthropogenic sandy desert over the karst system in the Olkusz area. In the period of strong development of extractive industry the surrounding forests were the main fuel source for the developing mining and metallurgy. Therefore, the Bledow Desert area was completely deforested. Transportation or accessibility of ores was not the main technical problem of the early exploitation. A serious problem was the dewatering system. Due to water inflow, development of exploitation by underground mining was difficult and several phases of mining can be distinguish in its history. The rise and fall of mineral exploitation over time were followed by complete deforestation and reforestation of the Bledow Desert. After Medieval deforestation, the 16th and 17th centuries saw a second period of intensive wood cutting and degradation of forest in the area. Wood was used for charcoal production and for construction of underground and surface drainage canals. Oak and beach trees were mainly used for construction. In that period, local artificial drainage was accompanied by total destruction of the ecosystem, except the unique karst springs floristic associations (*Rahmonow 1999*). Intensive exploitation of wood in the late 16th century resulted in supply difficulties. In that period mines and metallurgical works imported wood from other regions. The reforestation process followed the introduction of coal as fuel for industry in the 19th century. In addition to large scale dewatering of the karst-fissured aquifer and a chain of human induced changes in the karst-aeolian environment due to contemporary lead and zinc ores exploitation, spontaneous regeneration of forest ecosystems is recorded. Comparison of forest in the early 19th century and at the present shows that in the Olkusz area and Bledow Desert forest terrains increased in surface area. However, utilisation of Bledow Desert as an army polygon for several tens of years (mainly during and just after World War II) and large fire in the early 1990s interrupted spontaneous reforestation.

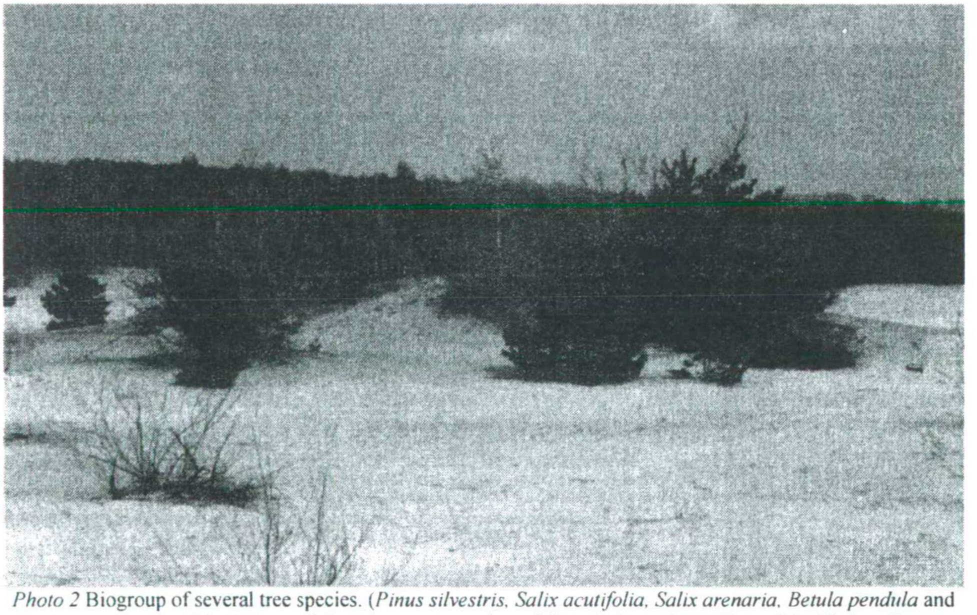

Photo 2 Biogroup of several tree species. (*Pinus silvestris, Salix acutifolia, Salix arenaria, Betula pendula* and *Juniperus communis*) Late stage of the primary succession of flora during reforestation of the Bledow Desert. (photo. *A. Tyc*)

Spontaneous reforestation of the artificial desert

Until recently, the Desert of Bledow formed part of one of the largest inland areas of blown sands in Central Europe. All the time river valleys, Biala valley in the central part of the desert predominantly, were the place of specific flora associations within the area.

Artesian conditions give in several sites possibilities to establish karst springs with cold water overflowing on the sandy deposits (*Fig. 3 and 4*). It was very characteristic that before artificial dewatering in the 1970s endemic (e.g. *Cochlearia polonica*) and relict (e.g. arctic species of *Scorpidium furgescens*) flora species, as well as mountainous species of vascular flora (*Michalik, 1979*) were found in such springs. In that period the area of blown sands covered more than 12 km^2 in the central part of the present Bledow Desert. Bare sands and deflation fields were common phenomena. It was in marked contrast to surrounding environments. In the early 1970s, the Olkusz region began to be influenced by large scale dewatering of the lead-zinc mines (see *Fig. 1*). In spite of this, the process of reforestation intensified. Sand areas are presently rare and are generally covered with bushes, sods or even woods. In contrast, the very rich floristic associations with overflowing karst water in the valley bottoms were destroyed by dewatering.

Understanding reforestation processes and their future effects on karst-aeolian ecosystems is one of the most important tasks for nature protection in eastern Silesian Upland. Different stages of plant succession have been observed and recorded on selected transects through the Bledow Desert. Phytosociological, ecological and soil investigations were conducted in order to find the regularity of plant succession and link them with the soil and hydrological processes. On the transects, the presence of 16 plant associations (3 forest assemblages) as well as 6 plant communities with undefined phytosociological range has been recorded. From an ecological point of view all plants have adapted to live in warm, dry, full lighted habitats deficient in organic mater (*Czylok et al. 1998; Rahmonow 1999*). Ability to change is one of the most characteristic features of biocenose. Irreversible directive tendency to changes of floristic associations is called succession. It is possible to state that the regeneration and reforestation of the Bledow Desert realised by means of succession. Moreover, two types of succession – primary and secondary – have been distinguished in the transects. The primary succession consists of the following stages: (1) encroachment of plants, (2) sodding, (3) bushes, (4) biogroup formation and (5) afforestation. The secondary succession proceeds after similar schema of stages but on sands rich in organic mater. Wind and animals play an important role in plant succession by spreading new species from the surrounding areas. Very important is the artificial overgrowing of the borders of the Bledow Desert by *Elymus arenarius*, *Salix arenaria* and *Salix acutifolia*, which are not native to the Silesian Upland. Plant succession is a common phenomena in sandy areas of Poland, deforested by human activity, but in the Bledow Desert there are two stages of succession that are unknown elsewhere, the participation of algae in the first stage of succession and a stage of biogroup. Special attention has to be paid to the role of several species biogroups (*Pinus sylvestris, Salix acutifolia, Salix arenaria, Betula pendula and Juniperus communis*) in the processes of overgrowing the Bledow Desert (*Photo 2*). Following afforestation, soil profiles are developing. Fossil soils detected in sand profile mark several stages of plant succession and afforestation of the area in the past.

Conclusions

The phenomena and processes presented in the paper show how management and protection of intensively transformed and impacted karst terrains presents complex and difficult problems. The coincidence of karst and aeolian ecosystems in the eastern part of the Silesian Upland results in very specific relations between these two very different environments. Many centuries of management and changes of natural structure in these ecosystems have created new relations and plant associations, often unknown in natural conditions. In the particular example of the Bledow Desert, such relations were created between covered and buried karst systems that have been strongly transformed by ore exploitation and aeolian sand environments strongly affected by repeated phases of deforestation and reforestation. Research and registration of the contemporary transformation processes, mainly plant succession, are very important in the context of contemporary mining industry closure in the eastern Silesian Upland and the slow restoration of hydrogeological conditions from the period before artificial drainage in the karst aquifer. In future, karst waters will again be able to recharge sandy areas of the Bledow Desert.

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SIGNIFICANCE OF KARST WATER OUTFLOWS TO THE SPONTANEOUS REGENERATION OF BIOCENOSIS IN THE SIEMONIA SANDPIT, POLAND

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Summary

The Silesian Upland has been intensively exploited by industry, and particularly by the mining industry. Since 1937, an ever increasing demand for supplies of sand to be used by the construction and mining industry has been met by increased sand exploitation and growth of working areas. Exploitation of the deposits is accompanied by process such as: drastic transformation of the environment, losses of biocenosis, and considerable areas of bedrock exposure. As the sand is extracted from lower and lower levels, the resulting deep sandpits are often flooded with karst water from the Triassic deposits and characteristic ecological conditions occur at the bottom of these pits. The high dissolved calcium carbonate of the groundwater inputs, waterlogging of the ground and modification of the ground temperature regime by water inflows have a great influence on the formation of unusual plant associations as well as on the whole biocenotic structure at the bottom of workings. The annual temperature range is reduced, especially in the lower layers of the ground, because of the small temperature range of the water inflows (from 7-9°C in winter and up to 11°C in summer). This affects the near-ground layer microclimate which in turn has a great influence on the development of vegetation cover. The initial plant associations are a result of environmental conditioning and by the large number of variegated horsetail. *Equisetum variegatum* which belongs to the characteristic plant species associations that appeared in the area after glacier recession. Large numbers of rare and protected species of flora and fauna are associated with such initial biocenotic systems and where there has been no reclamation the flora in the excavations also consists of many rare and protected species.

Introduction

The Silesian Upland has been one of the most intensively exploited areas of Poland, particularly by the mining industry. The immense demand for supplies of sand to be used by the construction and mining industry has caused the manifold increase of sand exploitation and constant growth of working areas (Greszta, Morawski 1972, Wrona 1977, Furdyna 1979). The deposit exploitation has been always connected with a process such as: drastic transformation of the environment, devastation and losses of biocenosis and mother rock exposure in the considerable areas. During a process of step working of sand it frequently happens that layers are ruptured, causing the creation of peculiar hydrologic preconditioning at sandpit bottoms (Greszta, Skawina 1965, Wrona 1973, Dwucet, Krajewski, Wach 1992). What is more, the change determines the direction and rate of the natural regeneration of biocenotic systems.

Research area

The Siemonia sandpit was at work from 1939 to 1959 and the area was under examination from 1997 to 1999. The research work had the aim to state the influence of karst water flowing into the bottom of excavations on the formation process of biocenosis. The sandpit lies in the western part of the Silesian province, about 11-km north-west to Będzin City. The investigated surface workings are situated at the western roadside leading Będzin - Tarnowskie Góry, in the lowering of the Jaworznik valley, in the immediate vicinity of the left tributary of the Brynica River. Pleistocene and Holocene Quaternary deposits (mainly: sand and gravel originating from river-glacier accumulation, sandy clay, dune sand) are underlain by the Carboniferous and Triass in part exposure deposits in the area of the sandpit. Amongst the Triass occur: shelly limestone of the lower Traiss (building the neighbouring hills) limestone, sand, gravel and clay of the Bunter, the Rhaetian limestone and dolomite, which are outcropped here and there. The Carboniferous deposits of the Siemonia sandpit consist of coal shells and coal sandstone (Doktorowicz-Hrebnicki 1954, Zielinski 1960). There are three water-bearing stages connected with the Palaeozoic, Mesozoic and Carboniferous deposits in the investigated area. The Triassic stage is of the greatest importance, but only the Rhaetian limestone and dolomites have hydrological meaning. The Quaternary water bearing stage with an unconfined water table is derived from fluvial-glacier accumulation. The Quaternary waters are in contact with slates and sandstone and characterised by high minerals and high iron content (Zarzycka 1993).

The research area is about 1152 ha in area, of which about 70 ha was exposed to the reclamation in order to restore park and forest areas. Besides, two shallow water basins connected by a sluice occupy about 40 ha and are supplied by the Jaworznik stream as well as smaller watercourses. The natural regeneration has been observed in the rest of the area, flooded and lower lying (about 40 ha).

Biotopic Conditioning

The most important factors, which decided of habitat conditions in a floor of the surface workings in the area of the Siemonia sandpit, were water inflows penetrating the Triassic limestone and dolomites. The waters were characterised by high minerals and calcium ion content, with slight alkine reaction and belonged to types: HCO_3-SO_4-Ca-Mg and HCO_3-SO_4-Ca. The water temperature ranged from 7^0 C to 11^0C. The water physical-chemical properties of three chosen inflows are presented in *Table 1.*

Moistening, one of the biotopic conditions, was modified by discharge and consequently ground conditions. In summer, the temperature, which was taken near the water seepage, fluctuated from 7^0 C to 11^0C, (*Fig. 1*). That is why the decrease in the annual temperature range was observed, especial in higher layers of the ground within inflows (*Fig. 2, 3*).

Table 1 Physical and chemical properties of investigated water seepage in scarps within the vicinity of the Siemonia sandpit

Nr	pH	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	C	HCO3	$SO4^{2-}$	NO3	Cl
		mg/l	mg/l	mg/l	mg/l	mg/l	µS/cm	mg/l	mg/l	mg/l	mg/l
I	7,4	315	120,2	3,7	3,85	0,67	557	268,4	73,7	-	4,89
II	7,2	360	108,2	21,8	7,1	1,32	584	262,4	77,0	-	9,4
III	7,3	415	140,3	15,8	7,6	3,27	736	317,0	92,4	-	4,75

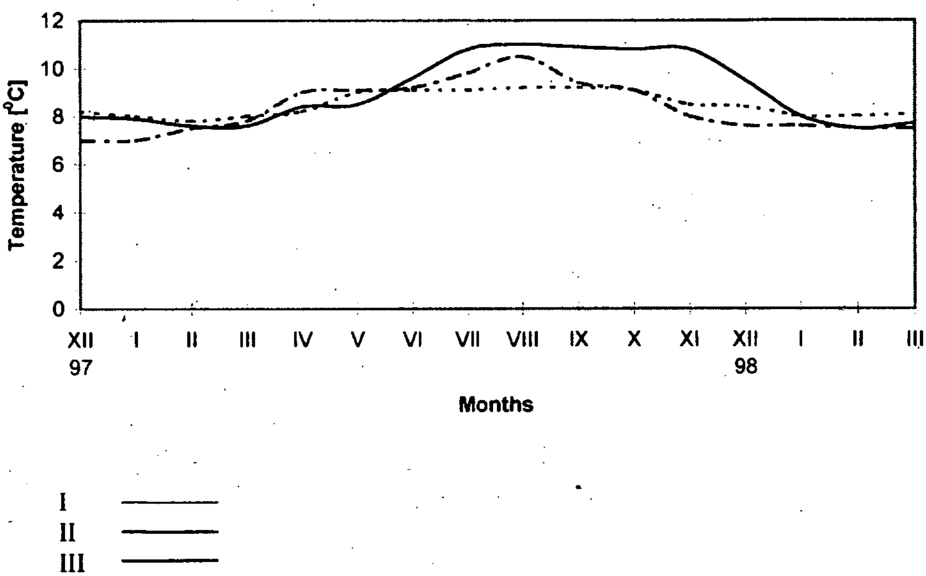

Fig. 1 Temperature conditions of investigated water seepage during the period December 1997 to March 1999 (for water seepage from *Table 1*)

In winter, even if the temperature dropped to –20 °C for seven days, the frost penetration were noticed in 3-4 cm layer of the surface ground. It implies that the frost penetration either in such low air temperatures or in the absence of snow blanket depends strictly on the level of ground water. The studies suggest, in the above mentioned water conditions, that the ground did not freeze at all or only in 1cm in depth, but only in the sites, where the water plane wasn't lower than 10 cm. The frost penetration up to 4 cm was recorded in the sites, where water was kept in 4cm - 40 cm in depth. So, the frost penetration depended on the species compositions and the rate of plant coverage in the sites, where the water table included about 10-50 cm.

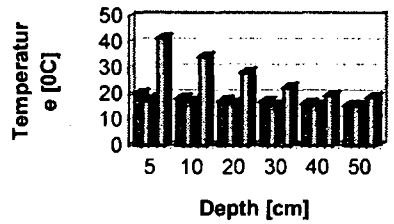

Fig. 2 Ground surface temperature in selected plots from the Siemonia Sandpits in July 1998.

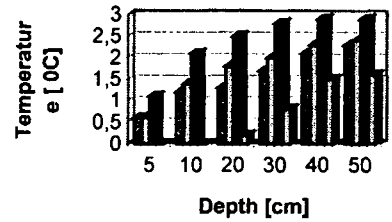

Fig. 3 Ground surface temperature in selected plots from the Siemonia Sandpits in January 1998

Siemonia Sandpit - Community with Equisetum variegatum (7m above the bottom of an excavation).
Siemonia Sandpit - Community with Equisetum variegatum growing in the bottom of an excavation.
Siemonia Sandpit - Community with Equisetum variegatum growing in the bottom of an excavation
Siemonia Sandpit - dry, psammophilus grasslands with Corynephorus - controlled plot

The process of soil cover formation at the bottom of the sandpit reflected the hydrological conditioning. Observations of soil profiles indicated intense growth of topsoil A_0 (up to 25 cm for 40 years) and were made in areas with differential moisture rate and habitats of plant communities. The results referred to the fragment with variegated horsetail occurring in swampy and periodic flooded grounds. The external aspect of the particular plant associations was connected with unfrozen inflows, which modified the microclimate of the surface ground layers.

An interesting phenomenon was the formation of large naleds, connected with the small ground water outflows (class1, according to Aleksejew classification 1987), that affected plants, especially in severe winters. This phenomenon was also observed in other excavations (in Pogoria I, Maczki Bór and near Ogrodzienic). The influence of karst water discharge in the floor of the Siemonia sandpit is shown in *Fig. 4*.

Vegetation

The above mentioned hydrological conditionings in common with the interaction of the local climate were modified by the influence of concave landforms such as surface excavations (*Kozłowska-Szczęsna 1990*). And the holistic impact determined the generation process of characteristic phytocenosis occurring in wet floor areas and bog-springs. In the process of natural succession appeared pioneering communities. They consisted of anemochores (bryophytes, horsetails, orchidaceous) and communities with considerable percentage of variegated horsetail *Equisetum variegatum*. The glacial epoch survivor occurs in a periglacial zone in Alaska and the Arctic region (*Crocker, Major 1955, Święs 1988*) whereas Polish botanists regard it as mountain species (*Walas 1939, Szafer 1986, Zając 1996*). From the conservation point of view, it is worth recording that pioneering stages of the succession created biotops for many rare and vanishing species such as: *Malaxis monophyllos, Liparis loesela, Drosera rotundifolia, Pinguicula bicolor, Tofieldia calyculata*. Plant communities occurring in the floor of the excavations were also observed in other sandpits (Pogoria I, Kuźnica Warężyńska, Maczki - Bór and Jaworzno - Szczakowa) in the eastern part of the province (*Celiński, Czylok 1995, Czylok 1997*). The encroachment of shrubby communities with *Salix rosmarinifolia* (resemble the association *Betulo-Salicetum repentis* and the association from the class *Scheuchzerio-Caricetea fuscae*) was noticed in the later stages of the succession. The stage depended on microhabitat factors (groundwater level, topographic features, vegetation). In the transition stage of overgrowing, the great participation had the communities from the alliance of *Magnocaricion* and appeared in flooded ground lowerings.

In the oldest parts of the outcrop workings, there were particular forest associations with predominant *Equisetum variegatum* in the ground flora and with predominant *Salix rosmarinifolia* in the undergrowth, however, in other places the ground cover contained a lot of species from the class *Scheuchzerio-Caricetaea fuscae*. *Molinia coerylea* encroached on small areas together with the mesotrophic and the ologotrophic vegetation from the alliance of *Molinion* what was caused likely by storing thin layers of cap-rocks. In other areas, where the considerable differences of the groundwater level (up to 60 cm) caused the temporary process of rotting and realising biogenic and thus nutrient enrichment, also occurred the plants.

Also interesting was the process of overgrowing in unfrozen streams and the all-year vegetation. These species belonged to the alliance of *Sparganio-Glycerion fluitantis* and contained fully- stocked plant surfaces with *Berula erecta, Veronica anagalis* and *Veronica becabunga*. The results of the studies suggest that the space distribution depended on: distance of outflows, stream flow, river bed features, vegetation.

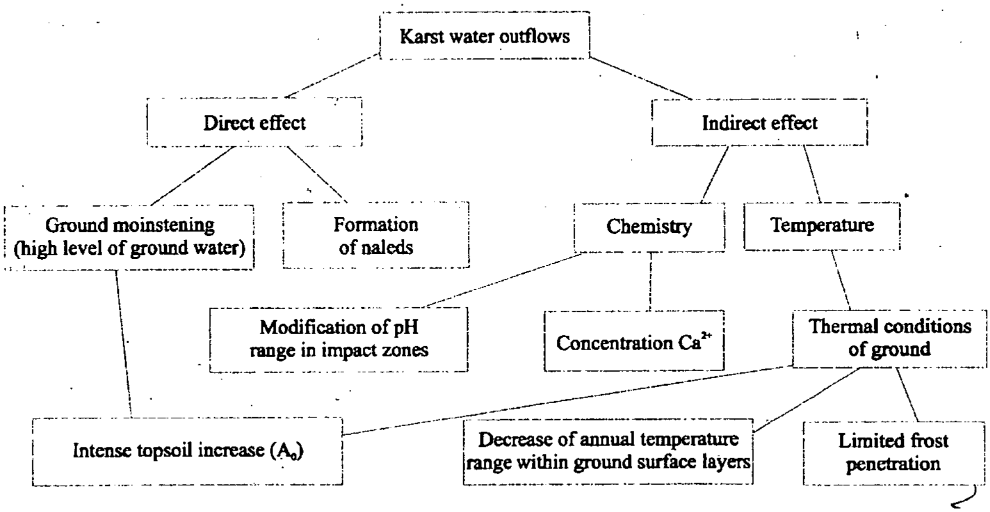

Fig. 4 Influence of karst water outflows on habitant conditions in the excavation floor of the Siemonia sandpit

In the Silesian province, the area of sand workings is estimated to be about 1200 ha and may increase in the future. This is why further studies on the natural regeneration of biocenosis are necessary. The research work indicates that a unique biocenosis develops as a result of natural succession in areas flooded by carbonate karst water and the basal complex is built of impermeable layers under the Quaternary deposits. This kind of substratum structure causes the high level of ground water and enables the creation of habitats for plant communities.

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PAST HUMAN ACTIVITIES AROUND THE AKKA KARST, NORTHEASTERN JAPAN

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Summary

Past human activities around the Akka Karst, Northeastern Japan, were investigated archaeologically and pedologically. The first appreciable human occupation in the study area was during the Middle Paleolithic. Some tools such as scrapers were excavated from the entrance of the Hyotan-ana Cave. The vegetation change from forest to grassland induced by human activities, such as forest burning, occurred around the Akka Karst during the early-middle Holocene. There are many archeological sites of the Jomon Period (12-2.4 ka BP) on the fluvial terraces and in caves around the Akka Karst. Thick melanic Andisols (black volcanic ash soils), which were associated with grassland vegetation, mainly occurred along the rivers in the study area. Moreover, a buried humus horizon was found on the karstic plateau, which contained To-Nb tephra (8.6 ka BP) and was covered with To-Cu tephra (5.5 ka BP). This horizon was very dark (10YR2/1) in colour and had humus dominated by A type humic acid. Therefore, grassland vegetation occurred not only on the fluvial terraces but also on part of the karstic plateau in the early-middle Holocene. Intensive deforestation of the karst commenced around the 17th century. An iron smelting industry thrived around the Akka Karst between the 17th to 19th centuries, which required a lot of charcoal. Therefore, the forests on the karst were used as charcoal-fuel woods and repeatedly cleared. The land transformation of iron sand mining and the destruction of forests caused soil erosion on the steep slopes, water pollution, and floods during heavy rains.

Introduction

The present landscapes of many karst areas are the result of human activities, as the term "karst" itself implies rocky and barren landscape made by human impact over a long time (*Gams, 1993*). In the Mediterranean karsts, human impact for thousands of years have been reviewed in detail (e.g., *Gams, 1993, Gams et al., 1993, Sauro, 1993*). In Japan, the Akiyoshi-dai Plateau has been well known in terms of past human activities on karst (e.g., *Kuramoto, 1996*). Most parts of the Akiyoshi-dai Plateau are now occupied by grassland vegetation (*Shiomi & Nakamura, 1981*), and were used as hayfields at least in the middle 18th century (*Kuramoto, 1996*). Kita (1996) reconstructed past human land use on the Akiyoshi-dai Plateau since the 16th century on the basis of historical documents. However, the period of vegetation change from forest to grassland is still unclear, although it appears to have been induced by human activities.

Melanic Andisols (black volcanic ash soils) are usually found around the volcanoes in Japan. They are also observed around the Akka Karst, Northeastern Japan (*Fig. 1*). The present vegetation of the Akka Karst is mainly secondary forests and plantations. However, grassland vegetation probably occurred in the Akka Karst as well as on the Akiyoshi-dai Plateau, because melanic Andisols are formed under grassland vegetation (e.g., *Shoji et al., 1993; Sase & Hosono, 1996; Soil Survey Stuff, 1997;*

Sugiyama, 1999). Moreover, several Quaternary tephras can be used as time-markers to estimate the formation age of melanic Andisols. Therefore, it is possible to clarify the period of vegetation change from forest to grassland in the Akka Karst.

The aim of this paper is to clarify the past human activities around the Akka Karst. First we review archaeological studies around the Akka Karst. Then we discuss past human land use on the karst on the basis of relationships between pedological analysis and archeological studies.

Outline of the Akka Karst

Fig. 1 shows the location of the Akka Karst. The Akka Limestone is distributed in the northeastern part of the Kitakami Mountains, northeastern Japan. Several rivers flow eastward from a non-limestone area in the Kitakami Mountains and dissect the Akka Limestone into blocks of karstic plateau up to 400-700 m above sea level (*Fig. 1*). More than 100 caves have been recognised in the Akka Limestone. Dolines are well developed, especially in the northern part of the study area. The Akka Limestone, which is 50 km wide

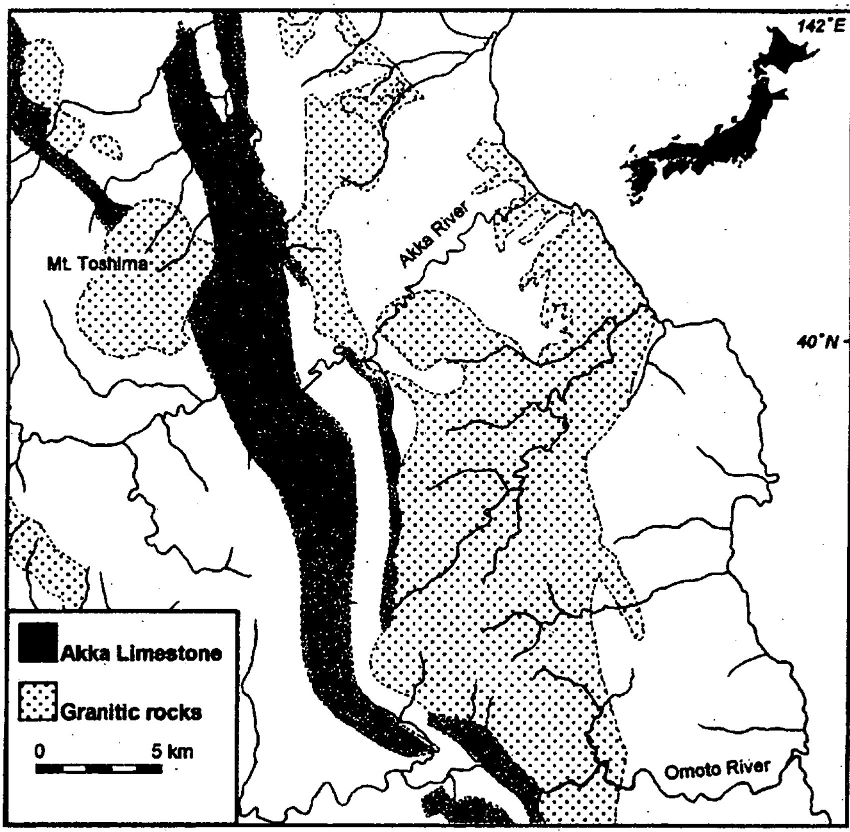


Fig. 1 Location map of the Akka Karst. Closed circle shows the location of the Hyotan-ana Cave

in the N-S direction and 1-4 km wide along the E-W direction, is a member of the Akka Formation (50-700 m in thickness) which consists of bedded limestones, alternating strata of limestone and chert, and chert in an upward sequence *(Sugimoto, 1974; Murai et al., 1985; Okami & Ehiro, 1988)*. The Akka Formation is considered to have formed on seamounts in the late Triassic. The limestone bedrock is overlain by several late Quaternary tephras (*Okamoto, 1998*), which are not only the main soil parent materials but also good time-markers.

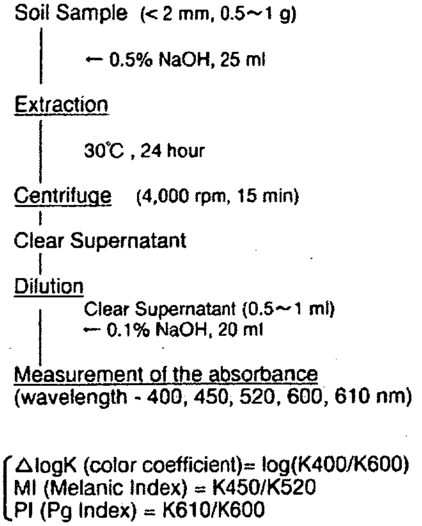


Fig. 2 Method of humic acid analysis proposed by *Honna & Yamamoto* (1992)

The Akka Karst is characterized by warm humid summers and cold wet winters. The mean annual precipitation and temperature are 1,131 mm and 9.9 °C. Precipitation is distributed throughout the year although there is a greater amount from July to September. Snow often falls during December to March. The present vegetation of the Kitakami Mountains including the Akka Karst is influenced by past human land use (*Osumi, 1998*). Beech (*Fagus crenata*) and deciduous oak (*Quercus mongolica* var. *grosseserrata*) forests presumably occupied most parts of the Kitakami Mountains (*Sugawara, 1987*), before human activities changed the landscape. Now, most of the Akka Karst is occupied by secondary forests dominated by deciduous oak (*Q. mongolica* var. *grosseserrata*) or birch (*Betula ermanii*), and by plantations of Japanese larch (*Larix karmpgeri*), Japanese cedar (*Cryptomeria japonica*) and Japanese red pine (*Pinus densiflora*). Pastures are distributed on the karstic plateau in the northern part of the study area.

type	values
A type	MI≦1.7, ΔlogK≦0.650
B type	1.7<MI≦2.0
P type	MI>2.0, PI≧1
Rp type	MI>2.0

ΔlogK= log(K400/K600)
MI = K450/K520
Pg = K610/K600

Table 1 Classification of humic acid type (*Honna & Yamamoto, 1992*).

Method of Soil Analysis

In Japan, melanic Andisols which have a thick black horizon at or near the soil surface are generally found near the volcanoes. Their colour are 2/2 or darker (Munsell colour value and chroma). The intense black colour is attributed to the accumulation of organic matter from which A type humic acid is *extracted (Shoji et al., 1993; Soil Survey Stuff, 1997)*. A type humic acid indicates a high degree of humification, and originates from a large amount of root residues supplied by grassland vegetation (*Sase & Hosono, 1996; Soil Survey Stuff, 1997*) or from charcoal and cinder (*Kumada, 1983*). Furthermore, melanic Andisols contain 6 % or more organic carbon *(Shoji et al., 1993; Soil Survey Stuff, 1997)*. According to humic acid analysis and phytolith (plant opal) studies (e.g., *Sase & Hosono, 1996; Sugiyama, 1999*), the vegetation changes from forest to grassland were probably the results of human-induced deforestation including the burning of forests. In other words, the occurrence of melanic Andisols implies grassland vegetation.

(1) humic acid analysis

Humic acid was extracted from about 0.5 gram of air-dried soil (< 2 mm) by suspending it in 0.5 % NaOH for 24 hours (30 °C). The method proposed *by Honna & Yamamoto* (1992) was adopted for classification of humic acid types as shown in *Figure 2.* The extract was centrifuged at 4,000 rpm for 15 minutes. About 0.5-1 ml of clear supernatant was diluted with 20 ml of 0.1 % NaOH. The absorbencies at wavelength 400, 450, 520, 600 and 610 nm were measured with spectrophotometer. *Kumada* (1965) recognised four types of humic acid, A type, B type, Rp Type and P type. To classify humic acids, ΔlogK (the colour coefficient), MI (the Melanic Index) and PI (the Pg Index) were calculated as follows:

$$\Delta \log K = \log(K400/K600)$$
$$MI = K450/K520$$
$$Pg = K610/K600$$

where K400, K450, K520, K600 and K610 are the absorbencies at 400, 450, 520, 600 and 610 nm, respectively (*Honna & Yamamoto, 1992*). Classification of humic acid types on the basis of ΔlogK, MI and Pg are shown in Table 1 (*Honna et al., 1988; Honna & Yamamoto, 1992*). A type humic acid is employed as one of the criteria for the melanic Andisols, which indicates an MI of 1.70 or less and a ΔlogK of 0.650 or less.

(2) carbon and nitrate contents

The carbon and nitrate contents in air-dried soils were measured with a CHNS/O analyzer (PE2400 Series II, Perkin Elmer). Then, the C/N ratio was calculated.

Vegetation change on the karst estimated by soil analysis

Fig. 3 shows columnar sections of melanic Andisols around the Akka Karst. Melanic Andisols occur along the rivers and on the mountain slopes. They contain Towada-Chuseri (To-Cu) and Towada-Nanbu (To-Nb) tephras. These tephras were supplied from

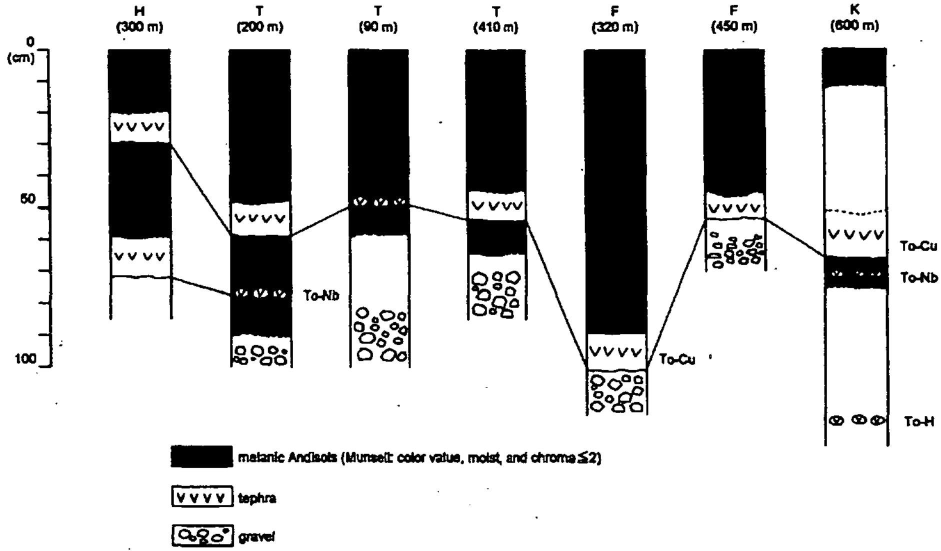


Fig. 3 Columnar sections of melanic Andisols around the Akka Karst.
H: hills, T: fluvial terrace, F: foot slope of karstic escarpment, K: karstic plateau, ( ): above sea level

the Towada Caldera about 5.5 ka BP and 8.6 ka BP, respectively (*Oike, 1972; Machida & Arai, 1992*). Moreover, a soil pit was excavated on the karstic plateau about 600 m above sea level (*Fig. 4*). The present vegetation at this site was a secondary forest dominated by deciduous oak (*Quercus mongolica* var. *grosseserrata*). Samples were taken from all horizons except the tephras in this soil profile (*Fig. 5*). The results of the soil analysis are shown in *Table 2*. The A1, A2 and 2A1 horizons had intense black colour. Carbon and nitrate contents ranged from 0.6 % to 14.9 % and 0.06 % to 1.00 %, respectively. The highest carbon and nitrate contents were found in surface horizon (A1). Distinct peaks of 7.1 % and 0.42 % occurred in the buried humus horizon (2A1), which dated from about 5-9 ka BP based on the tephras ages. The humic acids of the A1, B, 2A1 and 2A2 horizons were classified into A type, because MI was less than 1.7 and ΔlogK was less than 0.650. The MI of the A2 and B-horizons was greater than 1.7 and less than 2.0, so the humic acids in these horizons were classified into B type humic acid. The humic acid of the 2BC horizon was C type because its MI > 2 and PI = 1. These results suggest that the A1 and 2A1 horizons should be classified into melanic Andisols. Although the B and 2A2 horizon indicated non-melanic and low carbon content, their humic acids were of the A type. This would have been influenced by A type humic acid which originated from charcoal (*Kumada, 1983*), because both horizons contained many small charcoal fragments. The surface horizon (A1) had characteristics of melanic Andisols, which was probably affected by repeated forest clearing between the 17^{th} and 19^{th} centuries. According to *Shoji et al.*(1993) and *Sase & Hosono* (1996), grassland vegetation promotes melanic Andisols whereas forest vegetation promotes non-melanic Andisols. Forests probably occurred about 9 ka BP around the sites. Then vegetation changes from forest to grassland, which was maintained before falling of To-Cu tephra (5.5 ka BP). The forests started to regenerate around 5 ka BP and were repeatedly cleared during the 17^{th} and 19^{th} centuries, because *Q.*

mongolica var. *grosseserrata* became dominants in the fuel and charcoal woods in the Kitakami Mountains (*Osumi, 1998*).

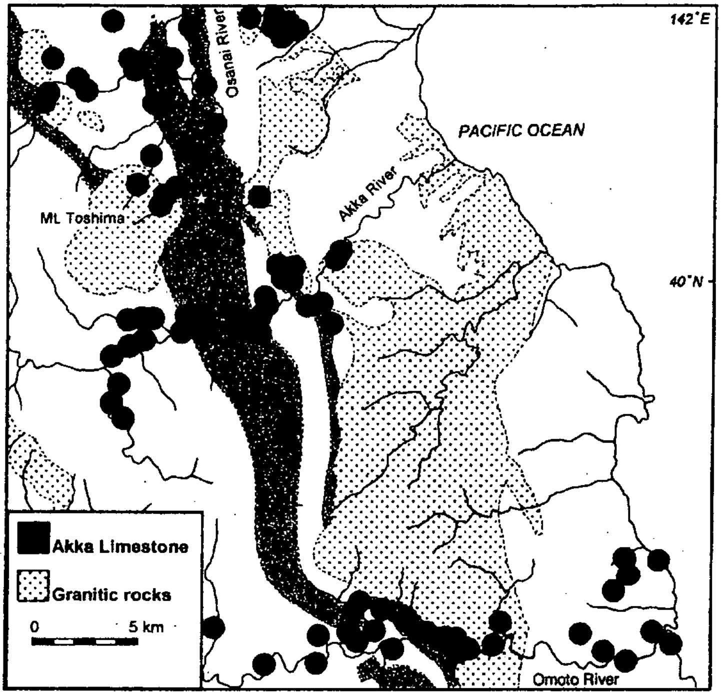


Fig. 4 Location map of archeological sites in the early-middle Holocene (Jomon Period). Complied after *Okami* (1992), The Board of Education in Iwaizumi Town (1991), The Board of Education in Yamagata ~llage (1992), and The Board of Education in Kuji City (1997). Closed circles show the location of archeological sites. Star shows the location of soil pit on the karstic plateau (Its soil profile is shown in *Fig. 5*)

Paleolithic Cave Occupation

Caves in the Akka Karst were shown to be occupied during the Paleolithic period by the archeological research of the Hyotan-ana Cave Site Research Group (1998, 1999). Several chipped stone tools as scrapers and mammalian fauna have been excavated from the entrance of the Hyotan-ana Cave. These remains were found in the sediments above a thick travertine and were covered with fallen limestone blocks. This travertine would have been deposited during a temperate phase, such as the Last Interglacial. In the north and middle parts of the Kitakami Mountains including the Akka Karst, the Last Glacial Stage was under a periglacial climate (*Higaki, 1987, 1988; Saijo et al., 1993*). There are some fossil periglacial deposits on the plateau in the Akka Karst, which were presumably formed around 50 ka BP and during 30 to 10 ka BP (*Okamoto, 1998*). Therefore, the fallen blocks would have been mainly formed by frost shattering under the periglacial climate during the Last Glacial. According to Okami (1992), the sediments above the fallen limestone blocks

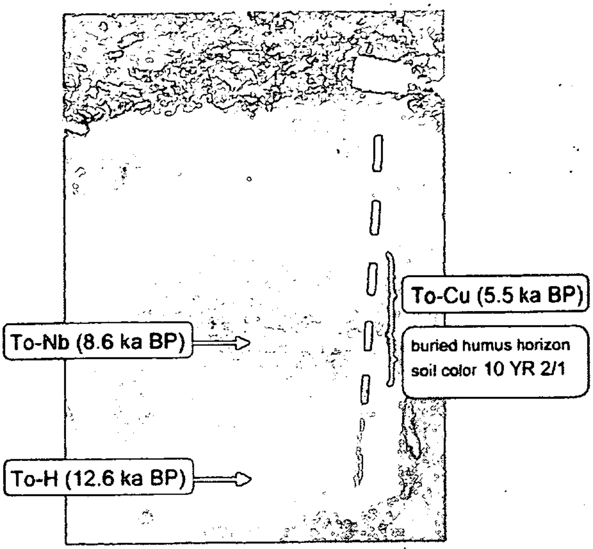


Fig. 5 Buried hums horizon in the soil profile on the karstic plateau. To-Cu, To-Nb and To-H tephras were supplied from Towada Caldera.

contain human remains since the Jomon Period (12-2.4 ka BP). Consequently, the ages of the stone tools in the Hyotan-ana Cave were estimated to data from about 12 ka BP to about 100 ka BP. As mentioned above, the first appreciable signs of human activity in the caves in the Akka Karst probably dated to the Middle Paleolithic.

Land use in the early-middle Holocene (Jomon Period)

Most of the melanic Andisols around the Akka Karst contain To-Cu (5.5 ka BP) and To-Nb (8.6 ka BP) tephras (*Fig. 3*). Thus, the formation of melanic Andisols around the Akka Karst began in the early-middle Holocene (Jomon Period), before the falling of To-Nb and To-Cu tephras. There are many archeological sites of the Jomon Period around the Akka Karst on the fluvial terraces and in the caves along rivers (*Fig. 4*). These facts suggest that there is a significant relationship between the formation of melanic Andisols and human activities in the early-middle Holocene. Moreover, a buried humus horizon that contained To-Nb tephra was found on the karstic plateau, which was covered with To-Cu tephra (*Fig. 5*). Pumice of Towada-Hachinohe tephra (To-H), which was supplied from the Towada Caldera about 12.6 ka BP (*Machida & Okumura, 1996*), was observed under this horizon. The present vegetation of this site is a secondary forest dominated by deciduous oak.

Table 2 Characteristics of soils on the karstic plateau.

horizon	Soil color (Munsell)	Soil color	C (%)	N (%)	C/N	Melanic Index (MI)	ΔlogK	Pg Index (PI)	humic acid type
A1	7.5YR2/1	black	14.9	1.00	14.98	1.69	0.640	0.947	A
A2	7.5YR2/2	brownish black	7.4	0.56	13.31	1.73	0.610	0.966	B
B	7.5YR2/3	very dark brown	4.3	0.32	13.60	1.69	0.606	0.960	A
2A1	10YR2/1	black	7.1	0.42	16.81	1.55	0.555	0.945	A
2A2	10YR2/3	brownish black	2.0	0.18	10.94	1.62	0.574	0.951	A
2B	10YR3/4	dark brown	0.8	0.08	9.38	1.79	0.617	0.981	B
2BC	10YR3/4	dark brown	0.6	0.06	9.00	2.67	1.045	1.000	P

As mentioned above, a buried humus horizon (2A1) was classified into melanic Andisols because of its soil colour, humic acid type and carbon content (*Table 2*). Melanic Andisols are formed under grassland vegetation while non-melanic Andisols are formed under forest vegetation (*Shoji et al., 1993; Sase & Hosono, 1996*). On the basis of tephra

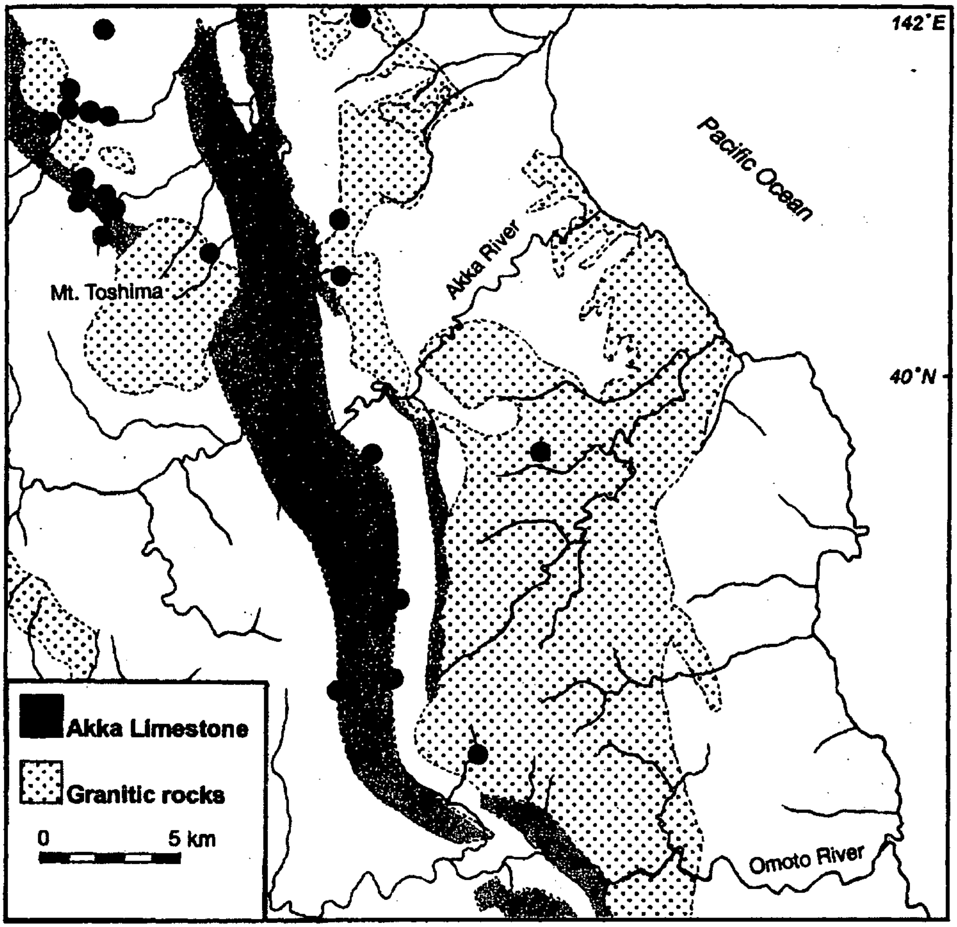


Fig. 6 Location map of the remains of iron smelting industry during the 17th-19th centuries. Closed circles show the location of archeological sites. Complied after *Takusari* (1995), *Hashiba et al.* (1996), The Board of Education in Yamagata Village (1992), and The Board of Education in Kuji City (1997).

ages, a buried humus horizon was formed during about 9-5 ka BP, and grassland vegetation was probably maintained over a period of several thousand years. This grassland appears to have been maintained by human activities such as repeatedly burning. Therefore, intense human activities probably began in the early Holocene around the Akka Karst. At that time, grassland occurred not only on the fluvial terraces but also on the part of the karstic plateau. The starting period of formation of melanic Andisols around the Akka Karst is in accord with that of a hilly area near Towada Caldera, northeastern Japan (*Sase & Hosono, 1996*), before the falling of the To-Nb tephra. The occurrence of melanic Andisols also indicates the occurrence of human activities leading to deforestation and maintenance of grassland in both areas.

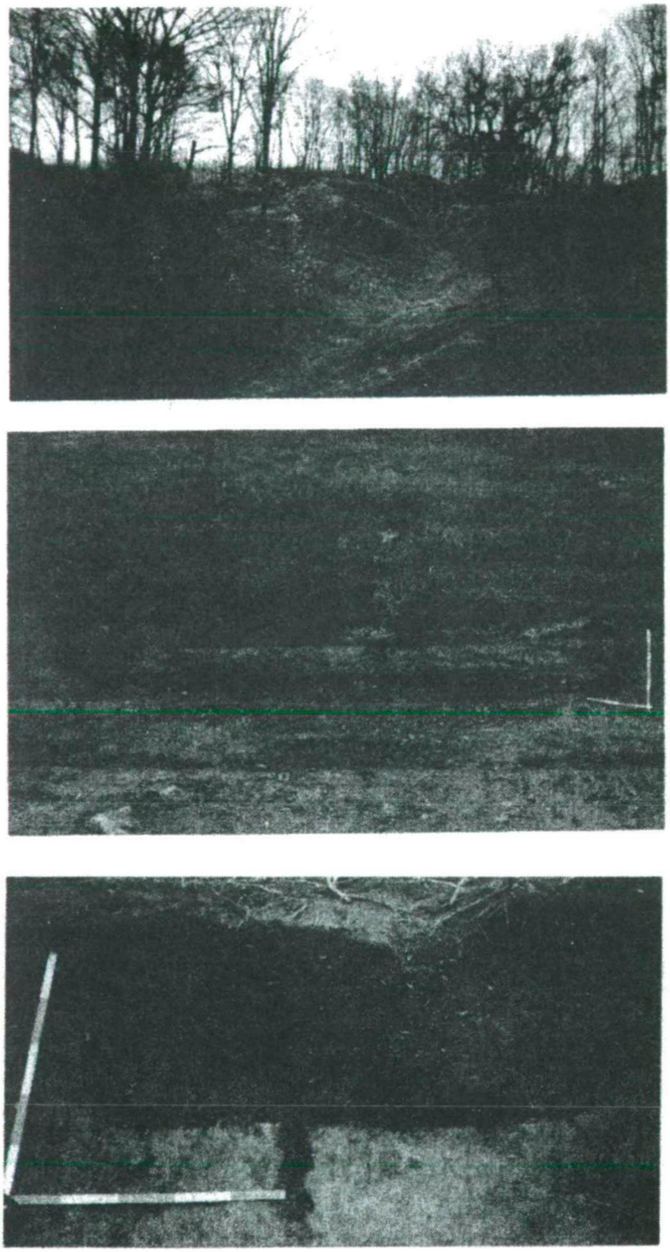
There are a few historical documents during the Medieval Age in northern Japan including the area around the Akka Karst, because the people of this area had no written language. Therefore, human activities around the Akka Karst during the Medieval Age are unclear, although several excavations have been carried out. It was not until the 17th century that that detailed accounts were made of human activities around the Akka Karst, because the number of historical documents increased starting in the 17th century and many archeological studies concerning the 17^{th}-19^{th} centuries have been carried out.

The iron Smelting Industry between the 17^{th} and 19^{th} centuries

The iron smelting industry using iron sand in the weathered granitic rock thrived around the Akka Karst between the 17^{th} and 19^{th} centuries *(Mori, 1983; Takusari, 1995; Hashiba et al., 1996)*. Over 20 ancient iron smelting industry sites have been found around the Akka Karst (*Fig. 6*). The remains of many traditional iron sand mines called "*kanahoppa*" have been found in the weathered granitic rock areas (*Fig. 7a*). The remains of iron smelting furnaces (*Fig. 7b*) and charcoal furnaces (*Fig. 7c*) are located around the Akka Karst. The radiocarbon age of charcoal fragments from a charcoal furnace (*Fig. 7c*), was 60±50 yrs BP (Beta-100615) and was calibrated to AD 1825-1835 and/or 1880-1915. The former period was consistent with the period of operation of the neighbouring ironworks (*Mori, 1983*). In order to obtain 1 ton of pig iron, iron production requires about 5 tons each of iron sand and charcoal. Therefore, a huge quantity of earth was excavated to collect iron sands in the weathered granitic rock area, and a large area was used as fuel-charcoal wood forests, which were repeatedly cut at intervals of 25-30 years. As mentioned above, the surface soil on the karstic plateau (*Fig. 5*) was classified as melanic Andisols due to its soil colour, carbon content and humic acid type (*Table 2*), although the present vegetation is a secondary forest dominated by *Q. mongolica* var. *grosseserrata*. This was probably the result of repeated clearings during the 17th and 19th centuries, because *Q. mongolica* var. *grosseserrata* has become the dominant species in the fuel-charcoal woods forests (*Osumi, 1998*). Limestone was used in the iron furnaces for flux (i.e., to prevent formation of iron oxides). Because the forest surrounding the ironworks was entirely cut for fuel and charcoal production over periods of 10-15 years, the ironworks had to transfer to other places (*Hashiba et al., 1996*). As the iron smelting industry expanded, the demand for fuel and charcoal wood increased. Thus, large destruction of forests began in the 17th century and continued to the late 19th century.

The land transformation caused by the mining of iron sand and the destruction of forests caused many problems. The waste earth from the mines was mainly thrown into the rivers. The destruction of the forests probably accelerated soil erosion on the steep slopes, especially on karst. The waste earth from the mines and the erosion on the steep slopes caused a rise of riverbed downstream of the mines. The loss of vegetation resulted in floods during heavy rains. Moreover, the disposal of solid and liquid wastes from the ironworks caused serious water pollution problems (*Mori, 1983*).

The traditional iron sand mining and iron smelting industry gradually declined starting in the middle 19^{th} century. Coal and oil replaced charcoal as fuel in the late 19^{th} century. These major changes contributed to natural reforestation. Large areas in the Akka Karst became secondary forests dominated by deciduous oak or birch (*Betula ermanii*).



(a)

(b)

(c)

Fig. 7 The remains of iron smelting industry around the Akka Karst between the 17th and 19th Centuries showing the remains of traditional iron sand mines (*kanahoppa*) in the weathered granite rock areas (a), iron smelting fumaces (b), and charcoal fumaces (c).

Conclusion

The Akka karst has been greatly affected by human activities since the early Holocene. There was a significant relationship between the distribution of archeological sites and vegetation changes based on soil analyses. In the early-middle Holocene, human-induced deforestation and maintenance of grasslands caused the formation of melanic Andisols. During the 17th-19th centuries an iron smelting industry thrived around the Akka Karst, the forests on the karst were used as fuel and charcoal wood and repeatedly cleared. These human activities caused many problems, such as soil erosion on the steep slopes, water pollution and floods during heavy rains. Following the decline of the iron smelting industry, most of the karst became secondary forests.

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OIL SPILLS IN KARST: FOUR CASE STUDIES FROM SLOVENIA

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Summary

This paper presents four case studies of oil spills that happened in the last decade on the karst surface in Slovenia. The analyses of these accidents include observations made underground and at several karst springs in the region, allowing researchers to identify the impact of spills on karst underground and especially on karst water. Comparison of discharge and oil concentration in water shows that it may take a very long time, tens of years, before all the oil is washed out of the underground. When looking for oil traces, some dry caves nearby the oil spill were visited and very high concentrations of oil were discovered in some pools of percolation water. These cannot be the result of the observed accident spills.

Introduction

In the last decade some accidental spills of mineral oils into karst underground happened in Slovenia. The present article deals with four of them. Maybe these are not the four greatest, as it is difficult to decide what is the »greatest« pollution, but they met with a wide response in public as the pollution of karst water was well visible and at the same time these are the cases, that were relatively well studied and there are data interesting also from the karst hydrology point of view. It is also important that at studies of the consequences of these accidents the members of the Karst Research Institute took part. Another reason to present the chosen cases was the fact that they happened in various types of the Slovene karst. All the treated events took place on the Dinaric karst; the accident that took place near Kozina lies almost at the border, in the region called Kras. The second location was Obrov, where typical karst of Istria lies. Other two accidents happened on the karst of Dolenjsko region where an important part lies in dolomites and on contact karst, on the contact between Palaeozoic and Tertiary silicates with Mesozoic carbonate rocks.

The spill of fuel oil in the KEKO factory (Žužemberk)

The small town Žužemberk lies in the central part of the Krka valley, which is the biggest among rare superficial rivers crossing the karst of Dolenjsko. The valley consists of two parts. The base is a wide bottom in carbonate rocks (mostly Mesozoic dolomite) bordered by higher, up to 100-m high karst plateaux, consisting of Mesozoic limestones. Into this surface of the wide »older valley«, levelled in rough but very karstified in detail, is incised a »recent« canyon of the Krka river, some 10 m deep. The karst hydrology had adapted to this morphology. Karst springs that rise far off the Krka cut their own narrow valley to reach the river; but most of the karst springs are located close to the river, on the

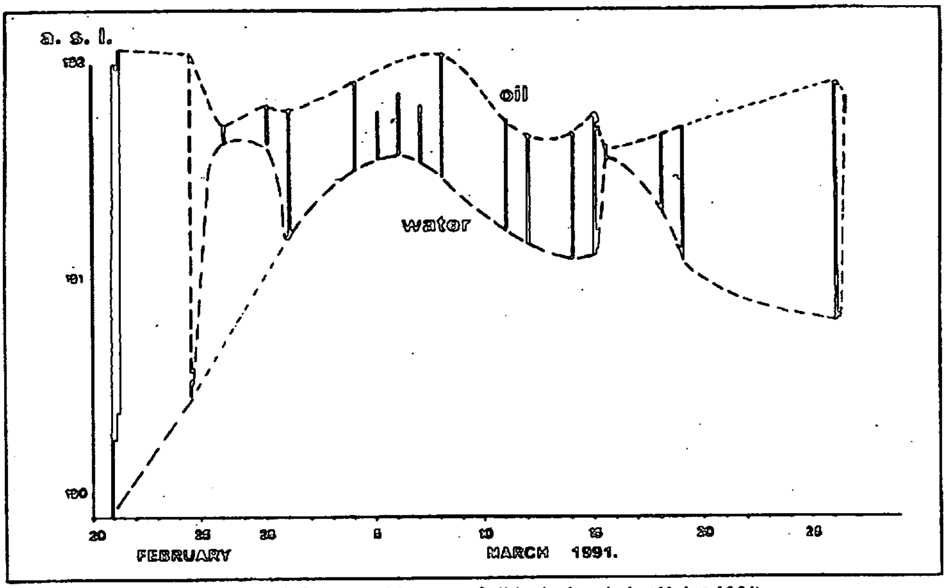

Fig. 1 KEKO factory – thickness of oil in the borehole (*Habič 1991*).

same level; in some places low waters completely flow into the springs near the river, while high waters take their springs at the border of higher lying valley and superficially flow into the Krka. A natural curiosity of the Krka is also travertine dams that appear upstream near the Žužemberk town (*Kranjc 1997*). The Keko factory is located on the mentioned upper terrace, some 100-m distant from the river. Below the edge of the steep level above the canyon there are two small karst springs; one was captured for the local water supply. After some 10-m of flow the streams join the Krka river.

In 1991 from the leaking cistern near the factory about 30 m^3 of fuel oil drained directly into the karstified rock. Shortly afterwards the fuel oil appeared in both springs but in a small quantity. With floating dams it was thus possible to prevent wider pollution of the Krka river and even the fishes survived. Regarding the quantity of oil, 30 m^3, it was presumed that a complete cleaning of the underground will last five years at least (*Habič 1991*). In the recharge area of the spring was drilled a borehole, 40 m deep, to find out what happened with this oil underground and if there was any possibility to pump it out. It was stated that oil accumulated underground in a relatively isolated oil spot. At the beginning (in 1991) the oil layer in the borehole was few metres thick (*Fig. 1*) and one part of it, unfortunately a smaller one, was possible to pump out. After four years (in 1995) the oil layer was still 62 cm thick (*Kogovšek 1995; 1996*). To August 1999, in 8 years by quite primitive techniques, 4 t of oil was pumped out from the boreholes. Nowadays the thickness of oil in the borehole reached about a quarter of a metre.

This case clearly shows that relatively great amount of oil may cause a relatively small pollution, but oil remains underground for a long time and its runoff is very slow. In this case the spring pollution had not a »catastrophic« dimension but we may say that pollution is »permanent«.

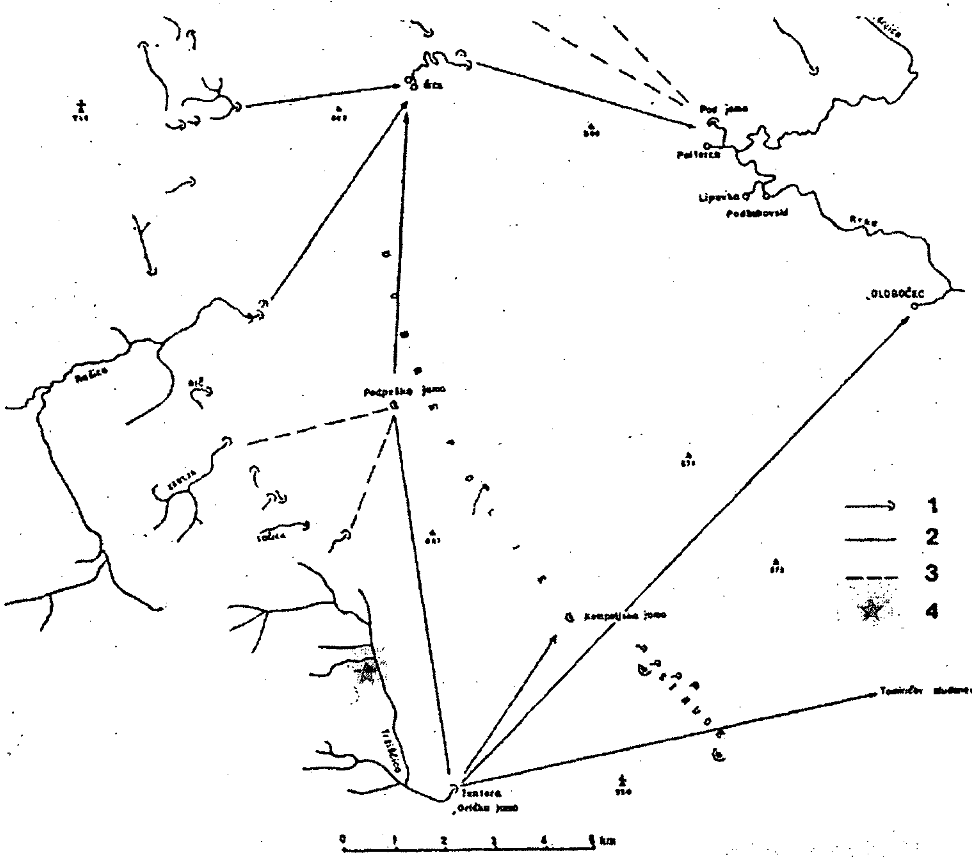

Fig. 2 Underground water connections in the Krka river springs catchment area (*Novak 1985*)
(1 – ponor, 2 – traced water connections, 3 – supposed water connections, 4 – location of the oil spill.)

The case of Globočec spring

In the north-eastern Dolenjska, near Ortnek village are located hills consisting of Triassic and Palaeozoic impermeable rocks surrounded by carbonate rocks. In these hills several streams rise and they sink at the contact with karst. The largest stream is the Tržiščica, flowing superficially to the northern part of the Ribnica Polje and disappearing into the Tentera cave. Water tracing confirmed that waters from the Tentera swallow-hole reappear in the karst spring named Globočec, 13,5 km distant (*Fig. 2*). The spring is located in a relatively deeply incised steep head valley, 1 km from the Krka. As this is an abundant spring (medium discharge 1-1,5 m^3/s) lying in the middle of the low waterless plateau called Suha Krajina (Dry Carniola) it was captured for a regional water supply in 1936 already.

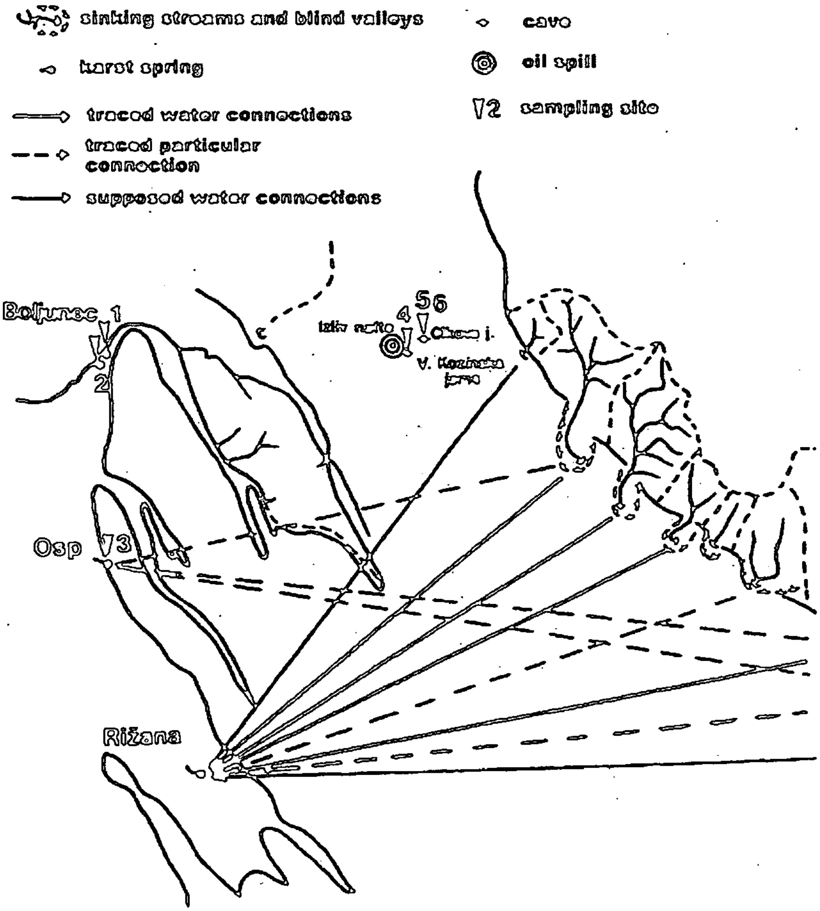

Fig. 3 Underground water connections in the Rižana karst spring catchment area (*Knez et al. 1994*).

In the village of Ortnek there is an enterprise having the storehouse for mineral oils. Owing to the break of a centrifugal pump, probably 1000 l of oil leaked out of the pump in October 1998. The workers recovered 800 l, but additional „undefined" quantity of oil ran out in the neighbour room (flooded by heavy rain) and together with water to drainage channel and to the stream Tržiščica. From the stream firemen took off 300 l of oil and water mixture. On the distance of 5 km they installed 5 barriers with absorptive material, but the oil pollution got on downstream (*Fajfar & Dolenc 1998*). The pollution reached the spring Globočec in approximately 70 hours, which gives relatively high surface and underground velocity – 7,3 cm/h. And, of course, the water supply from the spring for all the region had to be stopped, once for ten days, and second time for two weeks. The inhabitants had to be supplied with water by firemen.

Oil spill by Kozina

In October 1993 a road tanker tipped over from the main road Ljubljana – Koper near Kozina. Kozina lies off the south-eastern border of the region Kras near the edge of the plateau (about 500 m a.s.l.) above the lower coastland. 18 t of oil and fuel oil run out, and

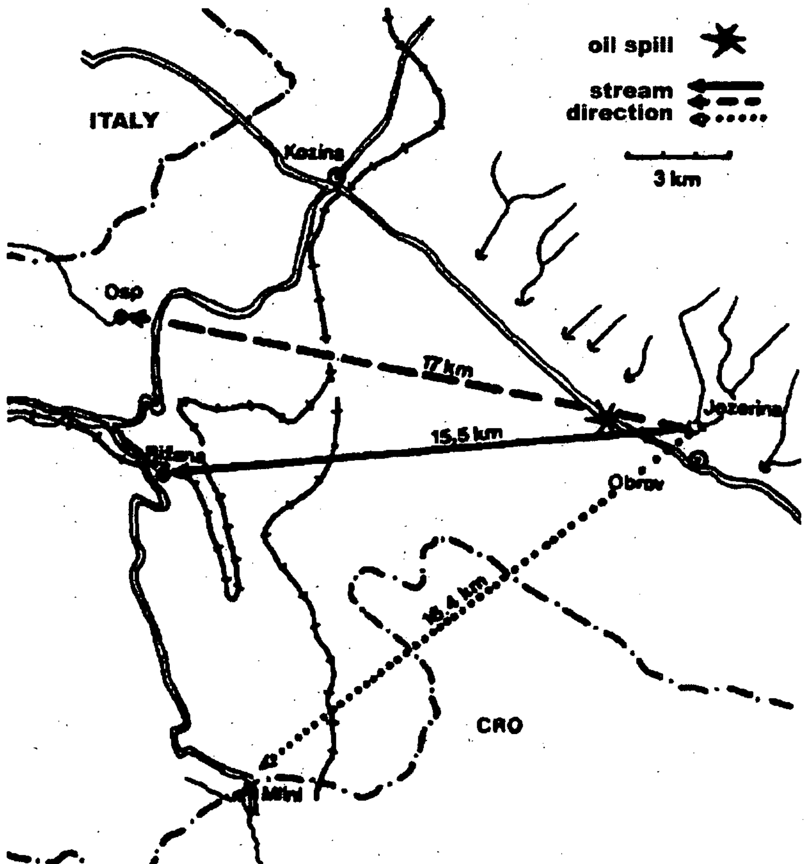

Fig. 4 The location of oil spill near Obrov and the sampling springs (*Kogovšek 1995*).

down the slope of a doline near the road. Even before the oil reached the bottom of doline it sinks into karst underground. The surface of the dolines slope is covered by grass and bush on the thin soil cover. The sinking capacity (of oil) of the slope was reckoned to be about 15 l/s. Six karst springs were observed due to detect the reappearance of the oil, between them three important ones near Bagnoli (Boljunec) on the Italian side of the border, the Osapska Reka and springs of the Rižana river, distant from 7 – 10,5 km (*Fig. 3*). All the three are direct tributaries of the Trieste Bay. The Rižana is the main water supply for the whole Slovene Adriatic coast region. The spill happened in Palaeocene limestones. Between the spill point and the mentioned springs there are bands of impermeable Eocene flysch, but the water passed under them through the limestones, as was known already according to previous water tracing. After two weeks the traces of oil appeared in the springs near Bagnoli (Boljunec) and in the spring of the Osapska Reka (from 0,005 to 0,016 mg/l) while in the Rižana spring the concentration was under 0,005 mg/l (*Knez et al. 1994*). The percolation water was sampled not only in these springs but also in the pools of two caves. The discovery of high oil concentration (the highest being 0,469 mg/l) in this water was most upsetting, although according to the position of the caves and the geological structure it was impossible that the oil, spilled in the above mentioned accident, could penetrate into these caves. Nearby these caves there are another road and double railroad – possible source of oil pollution without any special „ecological accident".

Oil spill by Obrov

In 1994 a similar accident happened in the Slovene part of the Istria peninsula, on the road connecting Trieste with Croatian port of Rijeka, near the village Obrov. 16 m^3 of gas oil flowed off into the karst underground. Rescue workers carried off the soil

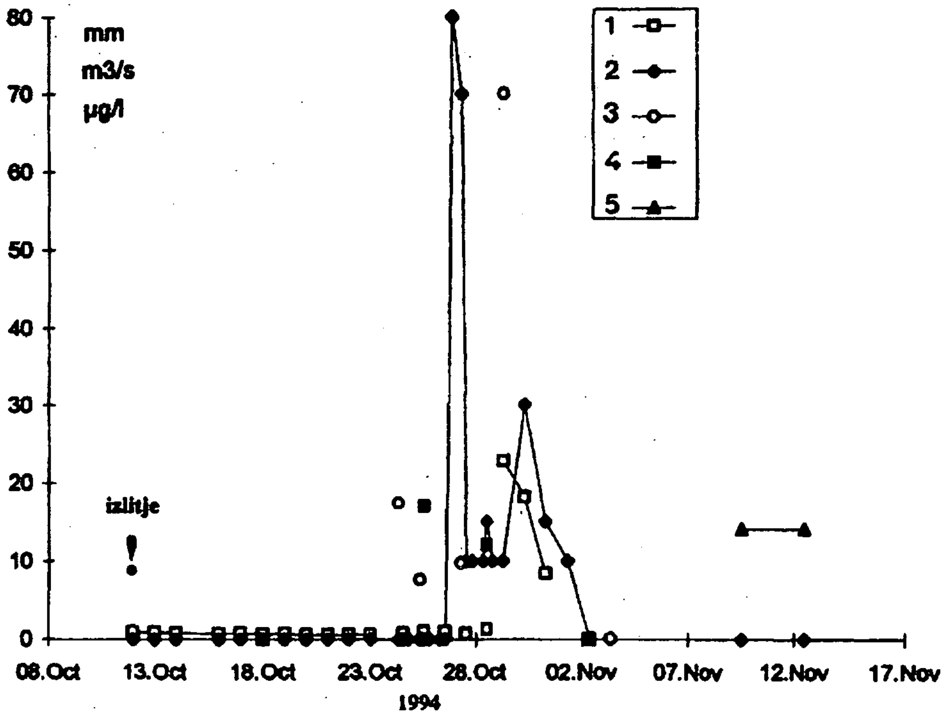

Fig. 5 Pollution concentrations in some karst springs after „Kozina oil spill" (*Kogovšek 1995*).
(1 – mean daily discharge of the Rižana river, 2 – oil concentration in Rižana (µg/l), 3 – rainfall in mm (Podgrad

impregnated by oil, but practically all the oil run away. The region belongs to the 2nd protection belt of the captured Rižana river spring, 15,5 km away. The accident point was practically on the contact of Eocene (impermeable) Flysch and intensively karstified limestone. From the sinking point of the nearby stream, flowing down the Flysch Brkini hills, water is flowing underground mainly towards the Rižana springs, and secondary towards Osapska jama cave and spring Ara near Mlini, which was proved by water tracing (*Krivic et al. 1987*) (*Fig. 4*). Oil appeared in the Rižana spring after two weeks. First 12 days after the accident it was dry weather and then heavy rain (70 mm) occurred. The maximum oil concentration was 0,08 mg/l. Based upon the discharge it was reckoned that in 10 days 88 kg of oil run through the springs of Rižana, that means about 0,5 % of all the spill. The oil appeared also in the cave Osapska jama (spring of the Osapska Reka), maximum concentration was 0,014 mg/l, and in the spring Ara near Mlini (maximum concentration 0,017 mg/l) (*Fig. 5*) (*Kogovšek 1995*).

Conclusions

From these examples one can conclude the same, as is already well known among the specialists:

- oil spill on karst can pollute karst springs lying far away also in apparently different morphological, geological or tectonical units;
- oil can remain very long in the karst underground and thus it can pollute water „permanently";
- as a „by-product" of the oil spill detection it was found that karst underground is much more polluted by oil than it was thought, and this is not necessarily the consequence of an identified accident.

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THE IMPACTS OF LAND USE CHANGE ON THE BUDAPEST HYDROTHERMAL-KARST: A STUDY OF SZEMLŐ-HEGY CAVE

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Summary
Human activities have completely changed the natural conditions of Budapest. The natural vegetation has been destroyed, and the original relief modified by extensive construction work and mining. The investigated area is situated on the south-eastern part of Hármashatár-hegy mountain range and forms part of the Buda Mountains karst. In its natural state, the vegetation and soil cover provided a filter for water infiltrating through fissures. Following destruction of natural vegetation and soil cover by human activity the narrower fissures have become plugged by infiltrating pollutants and more recharge enters via wider fissures without any filtration. Changes to the land surface over the last two and a half centuries were deduced from analysis of topographic maps of different years (18^{th}–20^{th} century) and from evaluating aerial photographs and images. The caves in the investigated area were formed mainly by dissolution of limestone by thermal water ascending along faults and there has been only minor modification by descending cold waters. Various parameters have been continuously measured in the Szemlő-hegy Cave since 1987. The results have shown contamination of infiltrating water that could ultimately be dangerous for the city's famous thermal springs.

Introduction

The natural conditions of Budapest have completely changed by now, as a result of human intervention. Natural vegetation have been destroyed, and the original relief was modified by extensive construction work and mining. The investigated area, one of the Buda Mountains karst's surface, is situated on the south-eastern part of Hármashatár-hegy mountain range and it contains the most important remnants of the thermal water activity in the past 2 million years. It is bordered by the Ördögárok on the SW, by the Danube valley on E and NE and by the range of Látó hill–Apáthy cliff on NW. The uplifted area has steep slopes, but its highest point is only at 376 m (Látó hill). The base level is at 104 m asl. at the Danube, where thermal springs discharge. The pollutants of the infiltrating water are filtrated by natural vegetation, soil cover and rock fissures with large surface. The natural vegetation and soil cover are destroyed by human activity and the fine rock fissures get plugged because of infiltrating pollutants. In consequence of the plugging of these fine rock fissures' the water gets through the wider rock fissures without filtering.

Land use change

A lot of valuable information was obtained from analysis of topographic maps of different years (18^{th}–20^{th} century) and from evaluating aerial photographs and satellite images. Comparing different maps we have depicted the changes of the land cover, we could deduct the alterations of the last two centuries. The maps of the 1st military survey of this area (1785) are the first topographic maps that have any information about land cover or land use. Thought these ones also don't show the original, natural state, they are the closest ones in time among all the time cross-sections. Its surface cover categories show only the basic land uses, mainly agricultural usage, but they provide a good base for further, more complicated stages of land use. Although these maps don't have projection, so compering them with those ones with projection is difficult and can result in inaccuracy, they still can provide a good source for illustrating a tendency. We defined the main land cover or land use categories based on the topographic maps and aerial photographs. There are nine categories:

CONTINUOUS URBAN FABRIC – Structures and transport network cover most of the land. Buildings, roads and artificially surfaced areas cover more than 90 % of the total surface.

DISCONTINUOUS URBAN FABRIC – Most of the land is covered by structures. Buildings, roads and artificially surfaced areas are associated with vegetated areas. This unit consists of block of flats, individual houses, gardens, streets and parks. This type of land cover can be distinguished from continuous urban fabric by the presence of non-impermeabilised surfaces: gardens, parks, and planted areas. Buildings, roads and artificially surfaced areas cover 50–90 % of the total surface area of the unit.

SPORTS FIELD

QUARRY – Areas with open-pit extraction of construction materials (claypits, quarries).

ARABLE LAND – Cereals, legumes, fodder crops and fallow land.

FRUIT TREES, VINEYARDS – Areas planted with grape and parcels planted with fruit trees or shrubs: single or mixed fruit species, fruit trees associated with permanently grassed surfaces or/and vegetable gardens.

GRASSLAND – Pastures and natural grasslands.

BUSHY VEGETATION WITH SCATTERED TREES – Bushy and herbaceous vegetation with scattered trees. It can represent either woodland degradation or forest regeneration or even colonisation.

FOREST – Vegetation formation composed principally of trees, including shrub and bush under-storeys, where broad-leaved and coniferous species dominate.

On the bases of these maps (1st military survey, 1785; 3rd military survey, 1880; topographic maps from 1922, from 1964 and from 1985) we have drawn the land covering maps of each period (*Fig. 1–5*). Analysing these maps we can see well the quick regression of natural lands and the increase of built in parts (*Table 1, Fig. 6*). In the 18th century the 42,7 % of the territory were covered by forests or bushes, this rate decreased to 8,1 percent. Opposed to this, the rate of built-in territories was 1,6 percent in 1785 and became 85,3 percent in 1985.

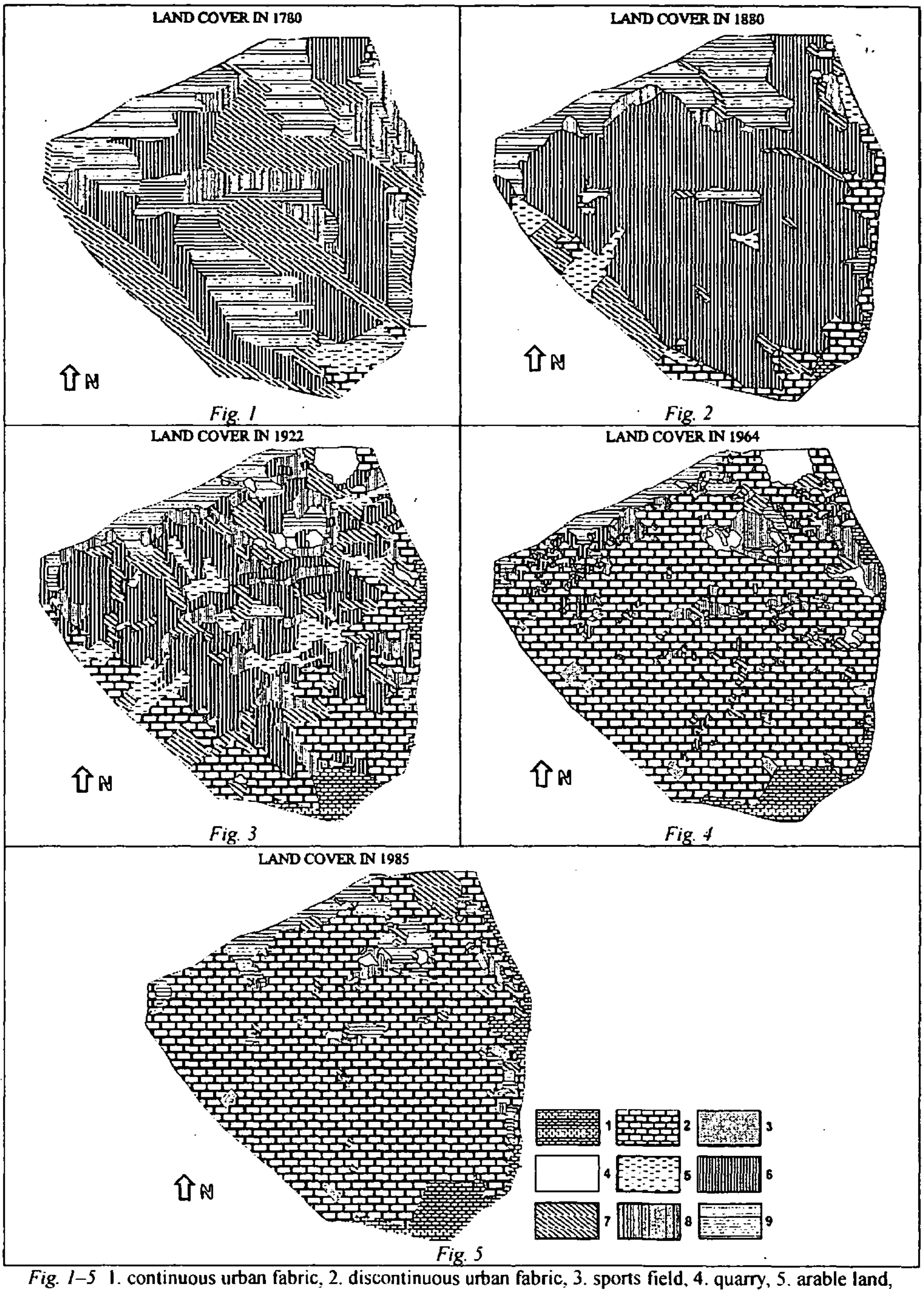

Fig. 1–5 1. continuous urban fabric, 2. discontinuous urban fabric, 3. sports field, 4. quarry, 5. arable land, 6. fruit trees, vineyards, 7. grassland, 8. bushy vegetation with scattered trees, 9. forest

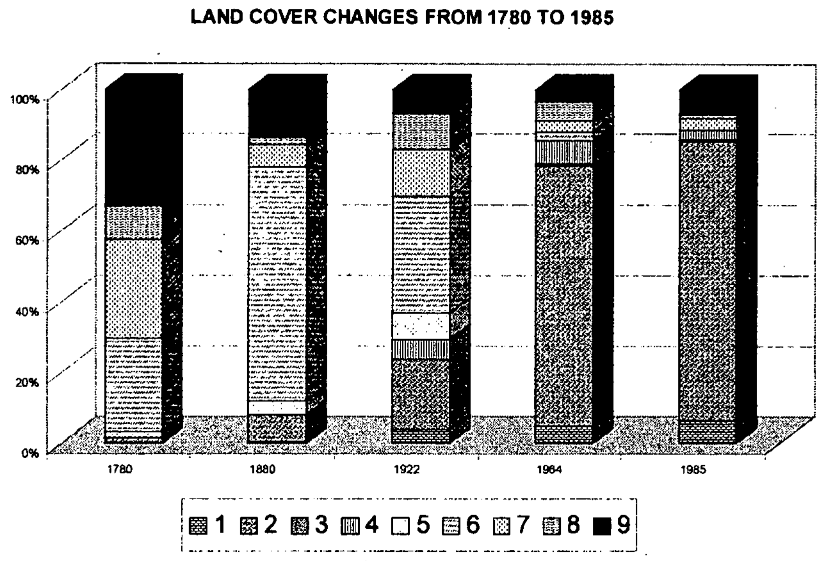

Fig. 6 Land cover changes from 1780 to 1985.
1 – continuous urban fabric, 2 – discontinuous urban fabric, 3 – sports field, 4 – quarry, 5 – arable land, 6 – fruit trees, vineyards, 7 – grassland, 8 – bushy vegetation with scattered trees, 9 – forest

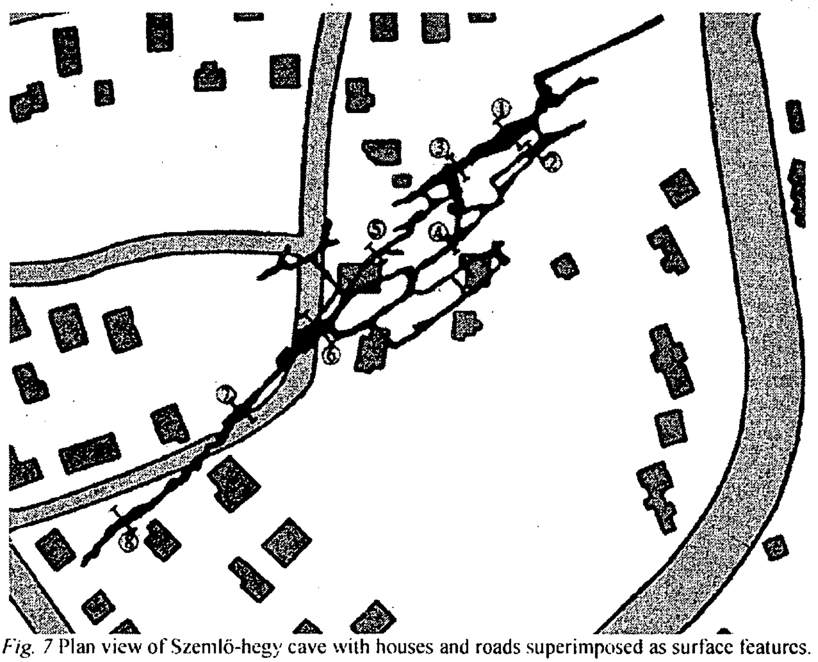

Fig. 7 Plan view of Szemlő-hegy cave with houses and roads superimposed as surface features.
1–8 measurement points
(after *Takácsné Bolner K.–Tardy J.–Némedi L. 1989.*)

Szemlő-hegy cave

The Buda karst caves are under a densely built-in territory, where not only precipitation brings in dangerous substances, but also communal sewage water endangers the karst. Szemlő-hegy cave is dissolved in an Upper Eocene limestone (Szépvölgy Limestone) and marl (Buda Marl) along three longer and three shorter NE–SW fractures and some minor tectonic lines perpendicular to them (*Fig. 7*). Thermal waters ascending along faults dissolved the cave and descending cold waters only played a modifying role. Foot level of the passages is at 160 m asl, while its discovery entrance is at 206 m asl. The total length of the system is 2200 m. Karstic infiltration is subordinate on the area, because impermeable marls cover it; moreover accelerated urbanisation further decreased it.

Table 1 Land cover between 1780-1985

	1780 %	1880 %	1922 %	1964 %	1985 %
continuous urban fabric	0	0.4	3.7	4.8	6.3
discontinuous urban fabric	1.6	7.6	20.1	73.5	79
sport field	0	0	0	0.7	0.5
quarry	0	0.1	5.5	6.7	2.6
arable land	1.5	3.8	7.5	0	0
orchard, vineyards	26.4	66.1	32.9	2.2	0
grassland	27.8	6.4	13.3	3.2	3.5
bushy vegetation with scattered trees	9.8	1.9	10.4	5.4	1,1
forest	32.9	13.7	6.6	3.5	7

Table 2 Typical extreme values of dripping waters in caves

		Hungarian average	Szemlő-hegy cave
PH		7,5–7,8	7,1–8,1
Electric conductivity	μS/cm	620–790	586–1360
Total hardness	mgeé/l	5,0–9,0	4,7–13,8
Ca^{++}	mg/l	90–160	66–228
Mg^{++}	mg/l	0,5–19	7–34
HCO_3^-	mg/l	200–480	96–260
Cl^-	mg/l	3,0–30	9–200
NO_3^-	mg/l	0,5–90	1–380

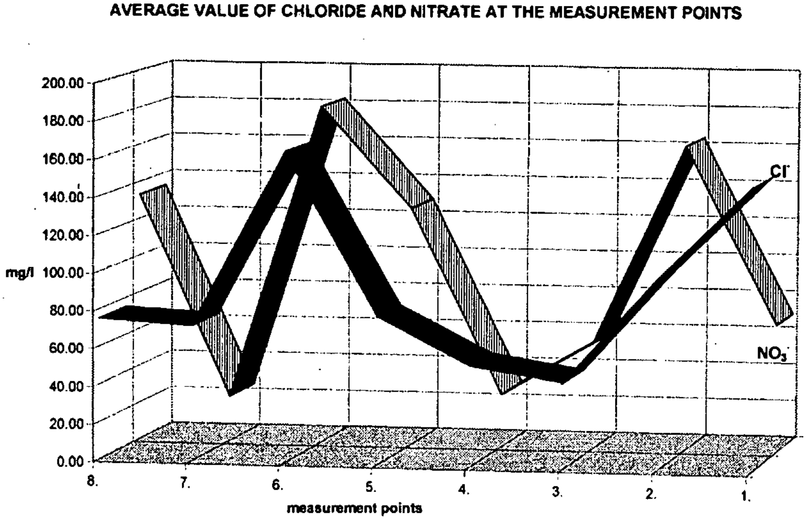

Fig. 8 Average chloride and nitrate ion concentration at the sample points

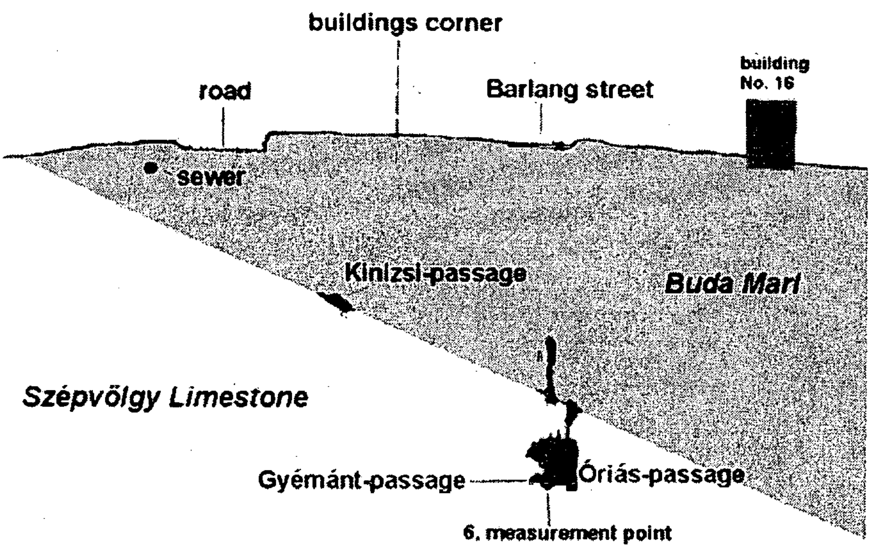

Fig. 9 Cross-section of Szemlő-hegy cave taken from measurement point 6. (after *Horváth J. 1995*)

Infiltration water quality

The chemical composition and quality of the infiltrating waters became known from analyses carried out in the caves from dripping waters. We collected water samples regularly since 1987, and analysed by the method of drinking water standard. The examined parameters: total hardness, calcium-content, magnesium-content, alkalinity, constant hardness, chloride, nitrate, nitrite, ammonia, phosphate, sulphate, potassium, sodium, pH and electric conductivity. We collected water samples from eight measurement points, from the passages of the cave (*Fig. 7*). The values of dripping waters compared to average values of Hungarian karst areas with those of Szemlő-hegy cave, we can experience that the total hardness and the concentration of Ca and Mg moves in wider range (it depends partly on the quality of the rock cover). The content of chloride and nitrate and the extreme values of electric conductivity indicate unambiguously the contamination that originated from the surface. The content of hidrocarbonate is less here, its place is partly taken up by the anions coming from contamination (*Table 2*).

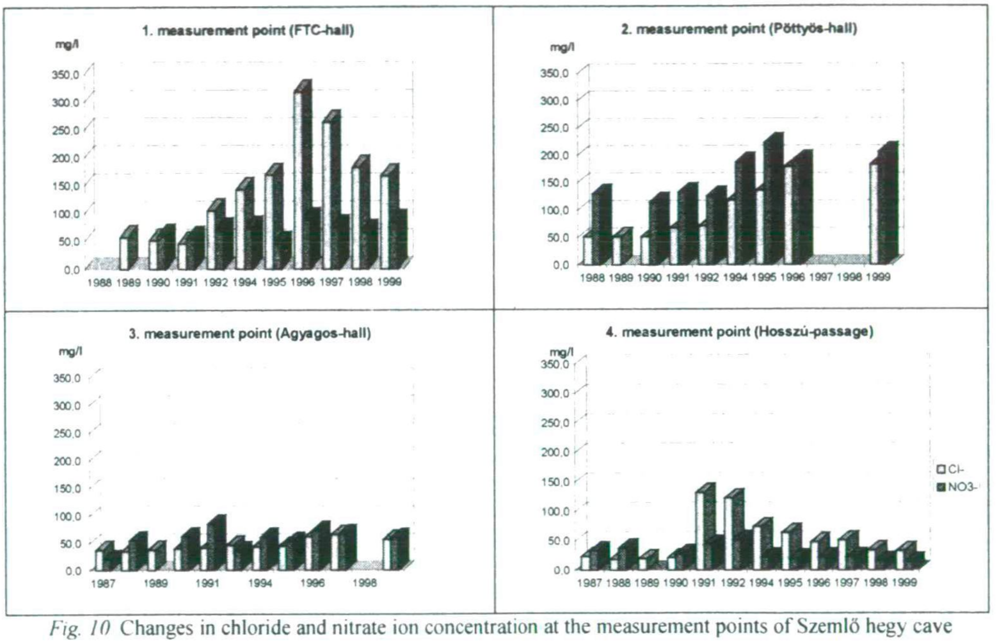

Fig. 10 Changes in chloride and nitrate ion concentration at the measurement points of Szemlő hegy cave

The water samples from different parts of the cave are very different. We illustrate the spatial distribution of contamination by the average concentration values of each measurement points with special regards to chloride and nitrate ions – mainly coming from sewage and from road salting in wintertime (*Fig. 8*). The cross section by the 6th measurement point shows the stratification of the limestone and marl, and the connection between the cave and the surface (*Fig. 9*). The strata dip is 20°. The infiltrating water gets down to the cave faster on the boundary of two strata than through the micro-cracs, so the filtration of the joint systems doesn't succeed. The outstanding nitrate ion concentration indicates the contamination (1st measurement point in 1996, 4th measurement point in 1991, 5th measurement point in 1988 etc.). (*Fig. 10–11*). The consistently ascending chloride ion concentration of 7th measurement point indicates the reduction of filtering force of rock fissures because the fine rock fissures get plugged by infiltrating pollutants. The contamination of the phosphate coming of different chemicals (detergent, artificial fertiliser etc.) appears on three points (N° 1., 5., 6.) while the nitrite appears only two points (N° 5., 6.) showing the parts of the cave which get the biggest contamination.

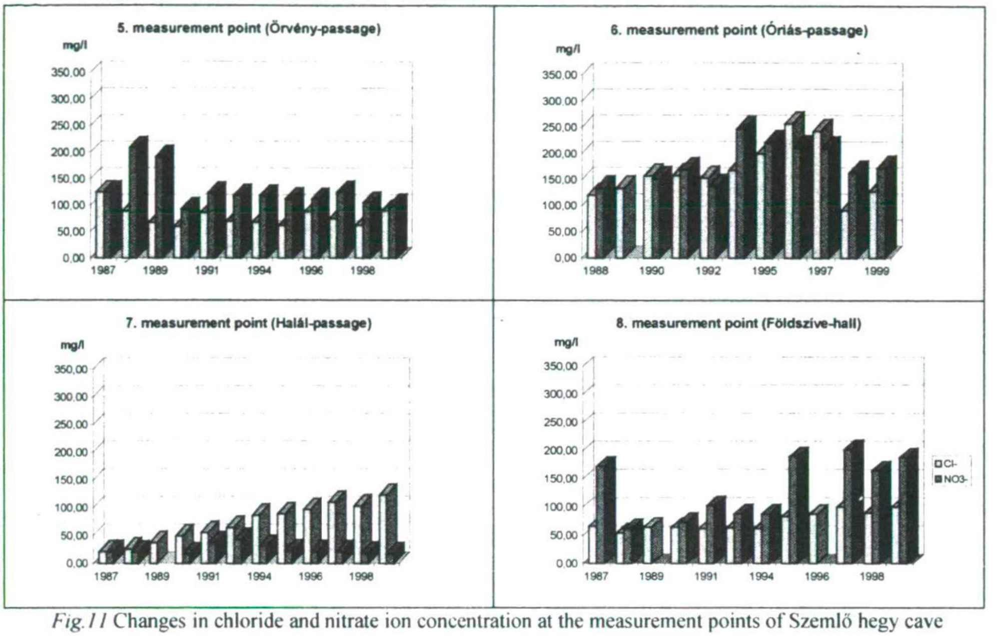

Fig.11 Changes in chloride and nitrate ion concentration at the measurement points of Szemlő hegy cave

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Maps: 1[st] military survey 1785. scale 1:28800

3[rd] military survey 1880. scale 1:25000

Topographic map 1922. scale 1:25000

Topographic map 1964. scale 1:10000

Topographic map 1985. scale 1:15000

CAVE-HUMAN INTERACTIONS IN TWO HUNGARIAN CAVES

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Summary
Between 1996 and 1998, the Physiology, Climatology and Microbiology Working Group of the Hungarian Speleological Society organised three expeditions to two Hungarian caves with major differences in their climate. Our goal was to investigate cave-human interaction, on the one hand tracing the physiological changes taking place in the human body, on the other hand examining to what extent the human presence changes the environment in the cave. The human physiological experiments included measurement of body-temperature, heart-rate, blood-pressure and changes in the liquid and ion balance, extended by blood-gas-analysis from the second expedition and by impedance-cardiography in the third expedition. The record of changes in the caves' climate has helped us to evaluate the biological data, but the data can be evaluated separately as well. They show the natural state of the caves and the changes the expedition caused. During the climate measurements, besides recording temperature, humidity and air-pressure, we made a trace-gas-analysis of the air-space and also measured changes in radon-transport. The measurements were completed by bacteriological sampling and examination of participants' endoflora.

Introduction

Between 1996 and 1998 three well equipped expeditions investigated two Hungarian caves. Researchers of various fields of expertise conducted complex series of tests to study interactions between caves and humans. They examined the effects of human presence on the cave environment, and the changes in the human body caused by staying in the cave for a long time, with roughly the same methods in two genetically different caves. During the tests for the basic research we provided extreme conditions for the participants. We collected data to improve accident prevention in caves and the effectiveness of medical activities (therapy) in caves, while also paying attention to nature conservation, and how the cave reacts to the presence of humans, which way and to what extent do environmental variables change, as well as to their reversibility. Ten participants visited the Cserszegtomaji-kútbarlang twice and the Baradla-cave one time, where they spent a week. Before moving in, we recorded the caves original climatological and bacterial characteristics. During our stay we monitored the changes in those parameters. After leaving the area we recorded the schedule of the cave's self-restoration process. We collected samples from the subjects living in the cave and compared the physiological changes with the surface control group, whose members have supplied the other half of the group. The cave group had physical exercise, in the form of speleological research.

Studied caves

The Baradla-cave can be found in North-Eastern Hungary in the Gömör-Torna Karst. The enclosing rock is upper-triassic Wetterstein Limestone, with some parts reaching into lower-triassic Gutenstein Limestone. It was formed during the Pleistocene age, its huge corridors have been created by water oozing through the rocks. The cave consists of a 7 km long main corridor and several sub corridors, that make up a total length of 23 km. Average width of the corridors are 10.5 m; average height is 7 or 8 m. Chambers are up to 60 m long and 50 m high. Sub corridors tend to be smaller in size. The main corridor begins at the main entrance, and ends at the entrance at Jósvafő. After considering the direction of the draught (from Aggtelek towards Jósvafő), we placed the camp at the boating-lake's farther end, to minimise the effect of the incoming air.

The Cserszegtomaji-kútbarlang is in South-Western Hungary at the south-western edge of the Keszthely Hills. It lies 53 meters deep between layers of Pannon limestone and Triassic main-dolomite. The original dolomite surface has been subjected to karstic erosion. The thick deposits - mainly sandstone - has filled the depressions in the dolomite, entering even the smallest cracks. In the covered, pressurised deep-karst the conditions were right for the formation of recesses. It was preceded by the silification of the sandstone; coagulation to rock was a condition of the conservation of the forming holes. That's why the arches of the holes formed by the thermal water that had dissolved the dolomite are made of sandstone, preserving the negative imprint of the dissolved dolomites fossil surface. The cave was discovered in 1930 while digging a well, that well is still the only entrance, the total length of the cave is 2400 m in a total area of 150 x 150 m forming a labyrinth. The average length of the corridors is 1-1.5 m, on the northern part of the cave the majority of the corridors are short with multiple bifurcation's. Larger chambers can only be found in the southern parts, their height can be up to 2-3.5 m, and their width about 5-18 m.

Cave climate

Climate measurements were designed, to show the changes between the cave's normal conditions and the conditions modified by the human presence. The surface's meteorological parameters were recorded by an environmental protection survey van. In Cserszegtomaj, our main measuring point, due to the labyrinthical layout of the cave was at the entrance at the only known ventilating point, 53 meters deep in the well. To strengthen the airflow we narrowed the 1.5 by 1 m entrance to 15 by 15 cm; this way we had a forced airflow, with a measurable speed. In 1996 we used handheld devices once every half-hours, for our measurements of temperature, humidity, airspeed, air pressure. In 1997 we added heat-flow and soil-moisture measurements to our repertoire along with CO_2 measurements at the campsite. This was the year, when we measured ozone, nitrogen-oxides, sulphuroxides, methane and hydrocarbons in the samples pumped into the survey van through a plastic pipe. We also recorded the changes of radon and it's daughter elements' level.

In the Baradla cave we extended our goals with the study of possible medical applications. To avoid any interference with tourism, we placed our measuring points far away from the routes of regular tours, approximately 900 meters from the entrance. Due to a concert held in the cave we had the opportunity to study the effects of the presence of hundreds of people, and the regeneration of the normal conditions, with our instruments placed, temporarily in the orchestral chamber. The instruments used in this experiment were similar to the ones used in Cserszegtomaj, but we made our measurements, (mainly temperature) at multiple heights, in the huge chamber. Similarly the surface's conditions were recorded by the same survey van.

During the first expedition to Cserszegtomaj we recorded the effects of the carbon dioxide and radon rich air coming from the depths of the cave, due to the extremely low air pressure. Except for the first two days we were unable to access the inner parts of the cave because of the high (more than 3 %) CO_2 levels. We recorded a really unique state of the cave, according to the automated radon transport measurements the probability of such a long depression is lower than 1%. The tests, repeated in 1997 under rising and high air pressure, proved the Cserszegtomaj cave's climate's dependency on air pressure, and by the detection of a steady rise of the temperature at the campsite it gave a warning of the small cave's low tolerance of human presence.

The climate studies in the Baradla cave, even with the detection of a minor rise of temperature, have shown the regenerating capacity of the enormous volume of air in the cave. The 150 persons attending the concert, even with the aid of the heat given off by reflectors couldn't change the climate significantly, or the normal values were restored quickly. This effect is very promising if we want to use the cave for therapy, also it's significance in natural preservation is important since the cave is the most visited touristic cave of Hungary.

Cave radon

The radon concentrations in the cave have been monitored from the 1970's. It was soon discovered, that from time to time extremely high concentrations build up, sometimes showing tens of kBq of activity per cubic meter. The Cserszegtomaj cave stands in the focus of attention of researchers from 1993. Prior to, and during the expedition multi channel monitoring instruments have been installed that recorded the concentration of 222Rn, the air pressure and temperature every hour. The air enclosed in the cave has a really high radon content, usually when the outside air-pressure is low. So during the 1996 camp the activity-concentration of the air in the inner parts of the cave has exceeded 45 kBq/m3. To provide background data for the physiological studies we have supplied the participants with personal dosimeters and measured the dose-equivalent received by the subjects (16 mSv). The dosimeters worn by people moving around the cave and installed in the camp have shown a difference less then 10%, that indicates, that under constantly low air pressure the radon is distributed evenly through the entire cave. This observation contradicts with our prior experiences, that suggested half the activity near the entrance, than in the inner parts of the cave.

In 1997 prior to the descent of speleologists (until 05. 21.) the level of radon was increasing slowly and steadily, showing great differences between different parts of the cave, due to local variations in the number of fractures of stone, or in the flux. Then a strong and rapid rise in the air pressure caused the radon levels to drop to near 0 at the entrance, and to 1/4, 1/3 of the original level in the inner parts of the cave.

The Baradla cave has many contacts with the outside air, and it has a huge amount of air inside, so it doesn't have as high concentrations of radon as the Cserszegtomaj-cave. Instead of the 45-50 kBq/m3 in 1996 or the "low" 15-16 kBq/m3 in 1997, here we have registered values between 600 and 1300 Bq/m3 with the average of 840 Bq/m3. A correlation between the concentrations of CO_2 and Rn can be observed in this case too.

Cave microbiology

Microbiological tests are special parts of the researches of caves. Their significance is in uncovering the cave's own flora and in tracing its changes, it's also interesting to follow the fate of the microorganisms imported by the airflow or by the crew. During the expeditions we have studied the mesophyl bacterial content, of the air in both caves, distinguishing between different species of bacteria. We have analysed the nose and throat mucus of the participants and in 1996 we even collected faeces, but since they hadn't shown significant changes, we had not done so after 1996. The air's bacterial tests have been conducted using sedimentation, gelatine-membrane and culture-medium methods, and they proved the air's high self-cleaning ability in both caves. The samples suggest, that although bacteria that get into the cave cannot settle down. During the first camp we have found a steadily decreasing number of bacteria, and the second time the number of bacteria remained constant despite the germ rich air flowing into the cave. Even in the extreme conditions of the Cserszegtomaj cave, the species-makeup found was not much different from the usual cave dwelling species. Pathological bacteria have never been found. By studying the endoflora of the participants we have concluded, that the risk of droplet infection is low. We have isolated pathogens or quasi pathogens ((Moraxella catarrhalis, Staphylococcus aureus, Haemophilus influenzae) in many members of the crew, but they have not changed hosts (moved to other persons). In the case of Staphylococcus aureus we discovered that all the infected persons had their own unique strain. In the Baradla cave the person who has been infected by S. aureus, H. influenzae, or M. catarrhalis prior to the expedition became bacterially negative by the end of the expedition.

In the case of the Baradla cave the water oozing through the covering layer of rocks, and the water of the spring in the cave has a great importance, so we have subjected them to bacterial tests too. In the dripping water we have always found a small number of bacteria as well as a small number of species, usually Baccillus and Alcaligenes. We have not found fungi or faecal-indicator bacteria. We have tested the water of the creek at the lake, unfortunately we have found high levels of Enterobacter, Escherichia coli, Flavobacterium, Baccillus and Staphylococcus species.

Health of cave explorers

We have studied the effects of the extreme climate of the cave on the 10 members of the camp. The inhabitants of the surface camp have also subjected themselves to medical tests, playing the role of a control group. The tests we conducted were: Before and after the camp: complete laboratory examination (full blood count, GOT, GPT, LDH, yGT, KN, creatinine, SeFe, ScBi, full urine analysis and TVK). Daily during the camp: blood pressure, body temperature, heart rate, fluid balance, from venous blood: glucose, Na+-, Ca+-, Mg++-, ions, LDH, CPK enzymes, from dipstick urine tests: haemoglobin, red blood corpuscles, white blood cells, sugar, acetone, UBG, bilirubin, and specific gravity, with on site blood gas analyser, using arterial capillary blood: pCO2, pO2, O2sat, pH, BE, EBE, BB, SB and BIC. In 1998 the tests also included: Na+-, K+-, Ca++-Cl--ions, lactate and glucose. In 1996-97 we've done all the tests above, and additionally a PEF test, and in 1998 before and after the camp we've done tolerance tests and impedance-cardiometry tests.

The compilation of this huge database could take years, but even at this moment we can report a few interesting findings. In the CO_2 rich environment of the Cserszegtomaj cave, we've measured the CO_2 load (that is the average volume of inhaled CO_2, using an average air intake of 20 litres/minute), that shows the dynamics of the changes, a compares well to the control group, showing differences of orders of magnitude. In the Baradla cave these numbers are less important because the CO_2 levels are much lovers, here the low temperature provided challenge for the participants. We have to admit, that in 1998 members of the surface control group had to spend 4-6 hours daily in the cave, due to technical difficulties, so this way they showed all the physiological changes of the cave group, just later.

In all of the three expeditions we found a change in the fluid balance. The cold - and in Cserszegtomaj the high CO_2 concentration - caused contractions of peripheral blood vessels, this way the central volume became higher, so the amount of urine was more than the fluid intake. Also because of the cold bilirubin and uribilinogen has appeared in the urine. This can partly be due to the hastened ageing of red blood corpuscle, but we suspect that changes have occurred in the processes in the liver, because of the temperatures just over 10 degrees Celsius, the CO_2, or maybe the high Rn concentration. The protein appearing in the urine samples suggest lover kidney threshold. We were surprised to find that high CO_2 concentration didn't cause acidic changes in the blood, instead the pH of the samples moved towards alkalic. The decrease in the serum K+ ion, despite the decrease of serum Na+ due to the increased diuresis, and the already mentioned red blood cell damage, was similarly surprising. The impedance cardiograph results also support our theory of the centralised circulation. The Z0 (chest base impedance) values show a steady decrease in the members of the cave group, and after a brief delay the effect has appeared in the control group as well, but to a smaller degree.

Summing up our experiences we can declare that the cave environment weakens the peripheral circulation, causes a central volume surplus, and the change can approach the lower limits of physiological variables without producing subjective symptoms. This phenomenon, along with the change in the acid-base balance and the K+ ion level, can be a cause of sickness and accidents in the cave. The fact, that the members of the surface control group, who have spent a few hours every a day in the cave, showed the same physiological changes, is expected to rise a few eyebrows among the doctors involved in cave therapy too.

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LAND MANAGEMENT ON KARST TERRAINS

KARST CATCHMENT PROTECTION: THE CUILCAGH MOUNTAIN PARK INITIATIVE, COUNTY FERMANAGH, NORTHERN IRELAND

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Summary

Cuilcagh Mountain, some 20 km south-west of Enniskillen, forms a distinctive ridge profile against the Fermanagh skyline, and is a prominent backdrop to much of the county's lakeland scenery. The summit (667m) is the highest point in the uplands of southwest County Fermanagh and northwest County Cavan, and the summit ridge forms the border between Northern Ireland and the Irish Republic. The mountain is topped by gritstone, exposed in places as dramatic cliffs sweeping down to the lower sandstone and shale slopes which are covered with a thick layer of peat and form one of the best examples of a blanket bog ecosystem in Northern Ireland. Below the sandstones and shales are limestones and the Marlbank area supports a fine upland karst which includes the only show cave in Northern Ireland at Marble Arch Caves. In 1990, a general concern over damage to the area's environmental resources, coupled with specific concern over an apparent increase in the magnitude and frequency of flooding at Marble Arch Caves, prompted Fermanagh District Council, as show cave owners, to commission a hydrological and environmental investigation. At an early stage of the research it became apparent that the problems were a result of land use changes in the caves allogenic catchment and that the only way in which effective control of land use could be exercised was through land ownership. Following consultations, the Council identified a key portion of the caves catchment and proposed that it be purchased and established as a natural history park. This marked the start of a major initiative designed both to protect the caves catchment and to protect the blanket bog on Cuilcagh Mountain, a priority habitat under the European Union Habitats Directive. The initiative culminated with the formal opening of the Cuilcagh Mountain Park in June 1999 although work to restore the bog, and to ensure the wider area is managed in a sustainable manner, is ongoing.

Introduction

Approximately half of Ireland is underlain by Carboniferous Limestone (*Fig. 1*) but around 75 % of this is lowland karst much of which is covered by thick superficial deposits such that the limestone has little surface expression. Of the upland karsts, the Burren in County Clare bears a strong imprint of glaciation whereas the northwest plateau karsts, of which Cuilcagh is one, are more typically fluviokarstic (*Williams, 1970*). Cuilcagh Mountain lies some 20 km southwest of Enniskillen in County Fermanagh (7°.48'.17" W, 54° 13' 26" N; *Fig. 1*). Cuilcagh summit (667 m) is the highest point in the county, and the summit ridge forms the border with County Cavan and the Irish Republic. The upper slopes contain a complete representation of the Carboniferous Leitrim Group, some 580m of strata being present. This includes rich fossiliferous sequences containing an outstanding range of goniatites, brachiopods, and other fauna. The spectacular summit gritstone edge and pavement, consisting of the Lackagh Sandstone Formation (also known as the Millstone Grit), is unique in Northern Ireland. The underlying sequences, principally of sandstone, shales and mudstones, are some 320 million years old and are of Upper Visean and Lower Namurian ages (Geological Survey of Northern Ireland (GSNI), 1998). The rocks beneath the Leitrim Group are the Dartry Limestone Formation, which has a maximum thickness of 320 m. The Dartry limestone consists of two main lithological divisions, micritic mud mounds and well-bedded cherty limestones. Most of the formation is composed of mud mound accumulations of the Knockmore Member, which form several knoll shaped hills. The well-bedded cherty limestones are best observed on East Cuilcagh where they comprise most of the formation; elsewhere they overlie the Knockmore Member. Underlying the Dartry Limestone Formation is the Glencar Limestone Formation, a shaley limestone which completes the Upper Limestone succession of Co. Fermanagh.

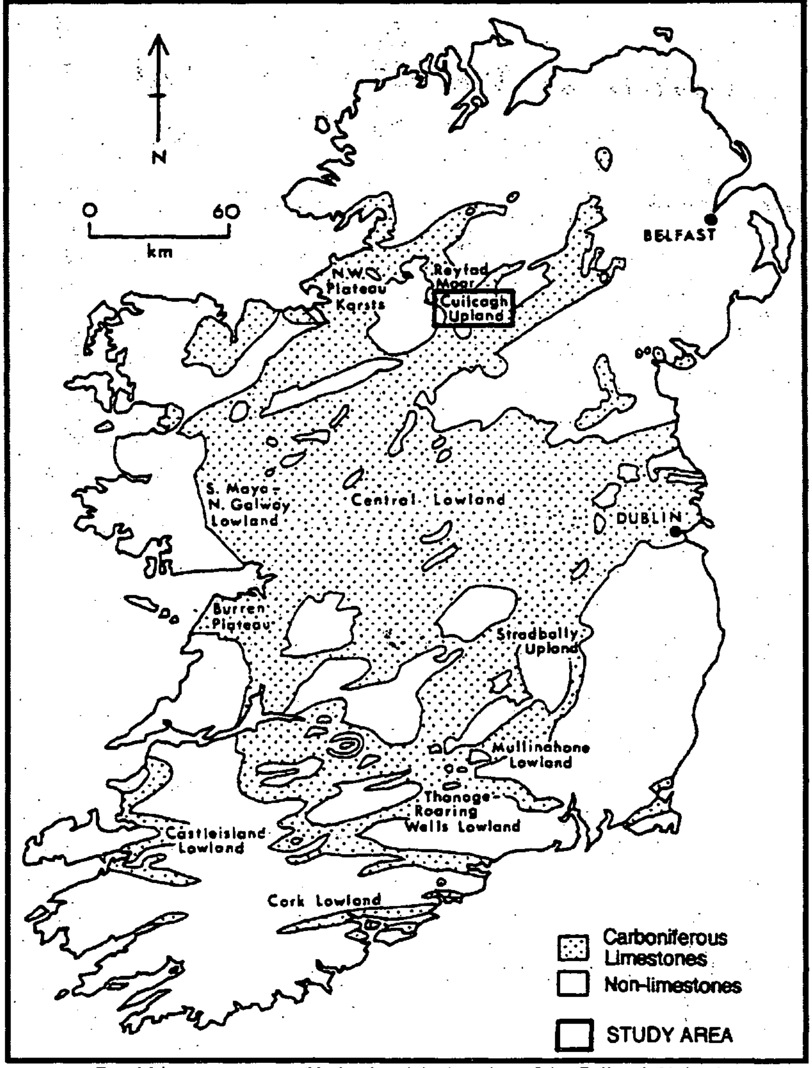

Fig. 1 Limestone areas of Ireland and the location of the Cuilcagh Upland

The border location of the Cuilcagh area has meant that there has been little economic investment, whilst civil unrest during the 1970's and 1980's restricted development of the tourism potential of the scenically beautiful countryside. In an effort to encourage tourism and economic development, Fermanagh District Council (FDC) opened part of the Marble Arch Caves to the public in 1985 and since that time it has attracted over 600,000 visitors from all over the world. Poor soils associated with impermeable boulder clay and a high annual rainfall make agriculture in the uplands unprofitable (in the absence of subsidies), and rough grazing, mainly by sheep, is the major land use. However, in the 1980's Cuilcagh was designated an European Community 'Less Favoured Area' and the availability of agricultural grants and subsidies at a higher rate than for other, more productive, environments led to an increase in stocking density and to sheep being kept on the mountain throughout the year. The peat on the mountain had traditionally been cut by hand for fuel but the 1980's also saw the arrival of machines that made it possible to increase the scale and extent of extraction. Thus, the opening of the caves was accompanied by a marked increase in human activity in their catchment.

During the late 1980's there was a perceived increase in the magnitude and frequency of flooding at the caves and this, together with a general concern over damage to the area's environmental resources, prompted the council to commission a hydrological and environmental investigation. At an early stage of the research it became apparent that, in the absence at that time of any statutory protection for the environment, the only way in which effective control of land use could be exercised was through land ownership. The 1990's saw a series of measures designed primarily to protect the surface environment but also serving to protect the allogenic catchment of the Marble Arch Caves and other caves on the mountain. This paper describes the Cuilcagh environment, the human impacts and the development of environmental protection.

The natural environment of Cuilcagh Mountain

Climate

The climate of Cuilcagh is influenced by the proximity of the Atlantic Ocean, the predominant southwesterly winds bringing in moisture-laden air. As this air passes over areas of high relief, such as Cuilcagh, adiabatic cooling occurs, resulting in condensation and precipitation. Mean annual rainfall increases with altitude from 1270 mm at the Marble Arch Caves to over 2000 mm on the higher slopes and monthly totals range from 10 mm to over 360 mm. The mean annual potential evapotranspiration is c. 570 mm and *Walker* (1998) found water year runoff totals from a small, essentially natural, catchment ranged from 1230 - 1473 mm over the period October 1993 - September 1996.

Landforms

Although the Cuilcagh upland is best known for its karst there are two other main landform assemblages in the area, the boulder fields and mass movements which characterise the summit area and the peat land of the mid-slopes (*Fig. 2*).

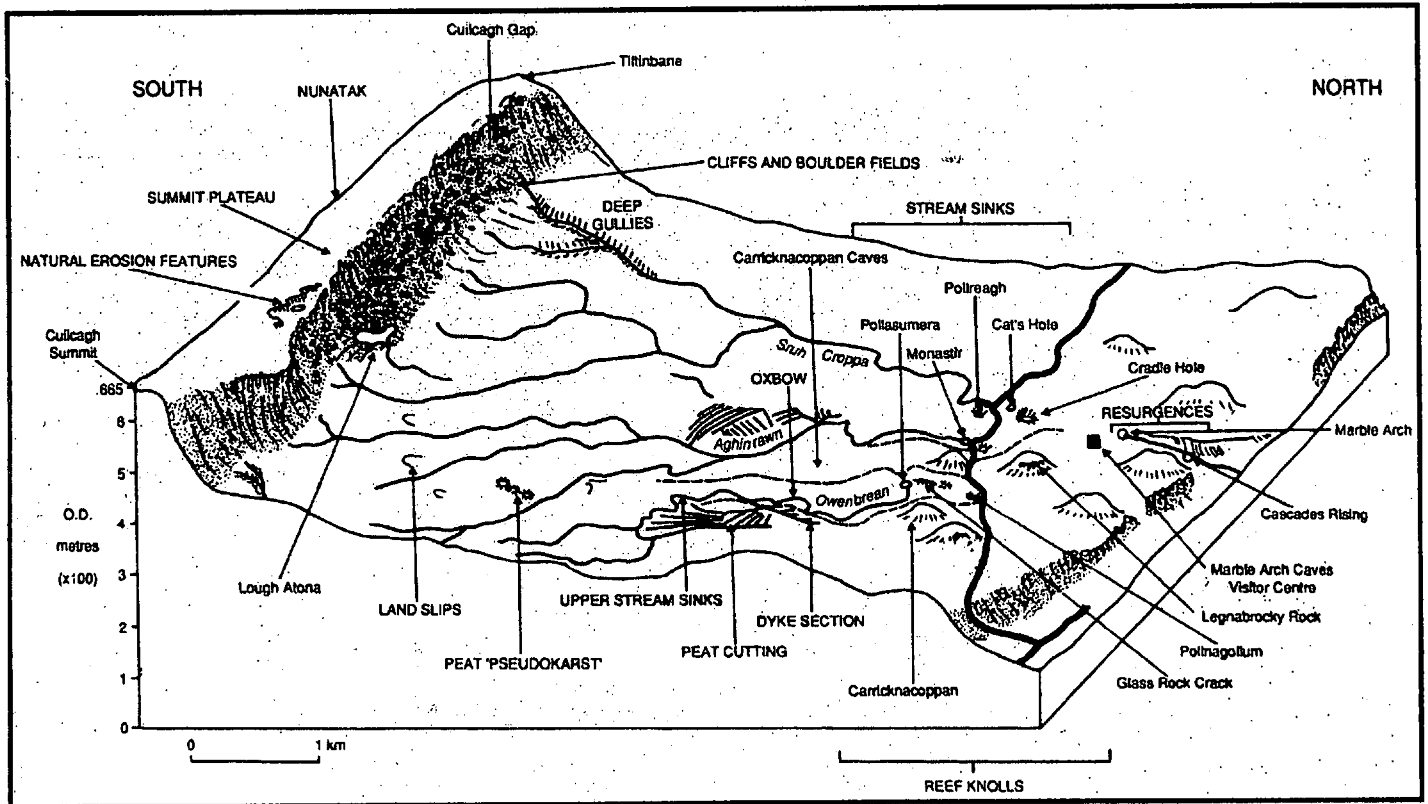

Fig. 2 Landform assemblages on Cuilcagh Mountain

Boulder fields and mass movement

The summit ridge of Cuilcagh Mountain is formed of massive Namurian sandstones and gritstones. The edge of the ridge is characterised by cliffs up to 30 m in height, and in several places large, intact blocks have slid forwards and are separated from the edge by deep rifts. The slopes below are littered with boulders up to 10 m in long axis that are associated with large scale mass movement from the edge of the ridge.

Peat landforms and drainage

The middle slopes of Cuilcagh Mountain are underlain by sandstones and shales with thin interbedded limestones. These are overlain by thin boulder clay deposits which in turn are covered by one to three metres of peat forming one of the best examples of a mountain blanket bog ecosystem in Northern Ireland. Of particular geomorphological interest are the extensive areas of piping and associated pseudokarst landforms including depressions with a long axis of up to 10 m and depths of up to 2.5 m. The majority of the pipes are large features (>20 cm diameter) and contain perennial or seasonal streams which in some cases flow on bedrock floors. They are found both on the gently sloping benches and on the steep slopes at the edge of the benches. Preliminary studies suggest that some have their headwaters in areas of permanent pools on the bog surface and that some at least have formed where peat has grown over the top of small stream channels. *Neild* (1993) has undertaken a study of piping erosion on Cuilcagh but further work is required to determine the extent and nature of the pipe networks and the processes responsible for their formation. In the higher parts of the peat bog there are a number of mass movement features (commonly known as 'bog-flows') which, in the absence of any evidence of past human activities, are presumed to be of natural origin. Rainfall increases with altitude and this may result in greater saturation and higher pore pressures in the peat. Where throughflow lubricates the base of the peat, rotational slumping is likely to result and this is thought to have been the cause of a large flow that occurred in the upper Owenbrean catchment in August 1992 and sent a large body of liquid peat several kilometres downstream and through the Marble Arch Caves (*Walker & Gunn, 1993*). The causes of bog flows on Cuilcagh are currently being studied by *Katie Kirk* (Huddersfield University) as part of a PhD research programme.

Karst landforms and drainage

The sandstones, shales and bog country form the catchment of three large rivers, the Owenbrean, Aghinrawn and Sruh Croppa, which flow down the northern slopes of Cuilcagh Mountain (*Fig. 3*). Each river sinks after crossing onto the limestones and flows through the large and extensive passages of Marble Arch Cave before rising at the head of the Cladagh Glen. The lowest sinks of each river are at Pollasumera, Monastir and Cat's Hole but all three are dry for part of the year, their respective rivers sinking at more recently developed sites some distance upstream. In the case of the Sruh Croppa and Aghinrawn water tracing has shown that the upstream and downstream sinks are associated with the same drainage system, but part of the Owenbrean's flow is captured by the adjoining Cascades catchment via sinks in its bed at c. 500 m and c. 1400 m above Pollasumera (*Gunn, 1997*). Marble Arch cave is the fourth longest in Ireland (c. 6500 m) and some 450 m of it forms the only show cave in Northern Ireland. There are three other major cave systems on the mountain, Shannon Cave (c. 2500 m), the Prod's Pot-Cascades system (c. 4100 m) and Tullyhona Cave (c. 1500 m), and several other smaller sinks, cave passages and risings (*Jones et al., 1997*).

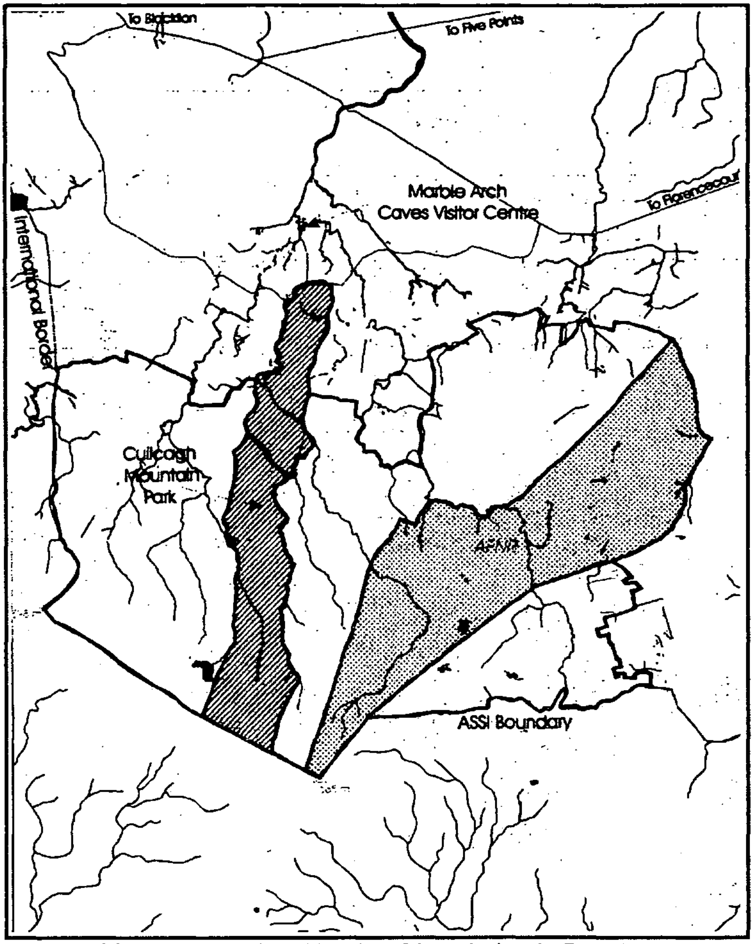

Fig. 3 The drainage of Cuilcagh Mountain and location of the Aghatirourke Forest Nature Reserve (stippled) and Cuilcagh Mountain Park within the ASSI

In addition to the caves, the lower slopes of the mountain are associated with some of the finest examples of upland karst topography in the British Isles (*Gunn, 1995*). Major sites include the impressive stream sinks of Monastir and Pollasumera at the end of blind valleys, large collapse dolines at Pollreagh and Pollawaddy, a large karst window (Cradle Hole) and the Marble Arch itself, a remnant section of passage isolated by collapse. In addition, there is a series of mud reef knolls and several small areas of limestone pavement. The Dinantian Dartry Limestone Formation has been extensively karstified and there is a complex underground drainage system with over 50 springs (*Gunn, 1982, 1997*). These include a range of flow types, from short residence-time systems dominated by concentrated allogenic recharge from sinking streams, to longer residence time springs fed entirely by diffuse autogenic recharge.

Biological Resources

Despite the relative wilderness of much of Cuilcagh Mountain, there are no wholly natural habitats or ecosystems on the surface. Humans have had a marked impact on the vegetation and ecosystems of the area, both through modern land uses, and as a result of more ancient agriculture and settlement. Perhaps the least affected areas are the caves but even those passages which have yet to be entered by humans are likely to have been impacted indirectly by surface activities. The biological interest of the area relates to the size, quality and diversity of the habitats, in addition to the presence of particular plant and animal species of note. The distribution of vegetation types is determined largely by geology, slope, drainage and nutrient conditions. Three broad categories can be identified: the montane grassland of the summit slopes (including a fine example of *Racomitrium* moss heath and a well-developed oceanic montane bryophyte flora); the second largest expanse of intact blanket bog in Northern Ireland covering the gentle middle slopes; and limestone grasslands. The area also supports an important upland bird community, including a significant breeding population of Golden Plover *Pluvialis apricaria.*

Anthropogenic impacts on Cuilcagh Mountain

The Cuilcagh environment has a long history of human-induced change dating back several thousand years to the first land clearance which may have had an influence on the original development of blanket bog. However, during the 1980s and early 1990s there was a marked increase in damaging activities, particularly: land drainage, mechanised peat cutting, burning and increased stocking densities. In addition, physical damage to the surface was identified as resulting from agricultural operations, primarily use of All Terrain Vehicles, and from recreational activities. The primary impacts were on the mid-slopes of the mountain where blanket bog forms most of the caves' allogenic catchment.

Drainage

A number of drainage channels were excavated into the blanket bog during, and possibly prior to, the 1980's. Some were associated with peat cutting but the purpose of others is uncertain. A recent mass movement has been tentatively linked to drainage channel construction (*Dykes & Kirk,* in press) but dip-well measurements in two instrumented catchments (see below) found that the ditches had less effect on the water table than had been expected.

Mechanised peat cutting

The introduction of Scandinavian compact harvesting technology to Ireland in the 1970s revolutionised peat extraction for fuel in upland areas. Chain cutters mounted on large, four wheel drive tractors, allowed cutting of blanket mire in previously inaccessible areas and in areas where hand cutting had been the only option. They were first used on Cuilcagh in the mid 1980s and have affected over 155 ha of which c. 50 ha are currently active and the remainder dormant. The cutover areas vary in size from a few square metres to almost 20 ha and this, together with the intensive nature of the processes involved, means that the impacts on the environment are diverse and both direct and indirect. None of the cutting has planning permission and it is assumed that the cutting is being undertaken for domestic consumption under existing turbary rights. The cutting has a profound visual effect and the ecological destruction is equally obvious. However, the hydrological and geomorphological impacts were previously unknown.

To obtain information on the hydrological impacts of mechanised peat extraction on upland blanket bogs a small catchment was divided into two sub-catchments, the upper (c. 302,300 m^2) being essentially natural although subject to sheep grazing, while the lower (c. 393,400 m^2) was more heavily grazed and included an area of c. 151,700m^2 from which the vegetation, and with it most of the acrotelm, had been removed prior to machine cutting 4-5 times between 1988 and 1992. Drains, around 1m deep, were installed at 20 m intervals prior to cutting but it was found that they did not significantly alter the water table relative to the control sub-catchment (*Walker, 1998*). Analysis of rainfall and runoff data for the water years 1993-4, 1994-5 and 1995-6, suggests that the total discharge from the cut-over area has been increased by 11 %, mainly due to an increase in winter baseflows (*Walker & Gunn, 1998*). This is linked to the destruction of the vegetation. Peat extraction has dramatically increased peak instantaneous discharge, particularly in summer when peak discharge is more than doubled. The average increase over 148 paired storm events, was found to be 80 %. The response to rainfall events from the cut-over area was quicker and the recession faster, producing an even more flashy hydrograph than that typically seen from peat catchments.

Burning

Burning, like drainage, is associated with agricultural land use, and has been employed extensively on Cuilcagh to improve grazing for sheep, by encouraging regeneration of ageing dwarf shrubs. However, burning can result in severe damage to the bog, particularly to sphagnum species, and results in an increase in storm runoff.

Stocking density

The availability of subsidies, principally headage payments, led to a marked increase in the number of sheep on the mountain, many remaining for the whole year with supplementary feeding in winter. In some areas there was damage to the bog species from overgrazing but a more widespread problem resulted from the wet blanket bog, and particularly the Sphagnum bog mosses, being very sensitive to physical damage by trampling. Consequently a relatively small number of livestock can cause severe damage to the surface of the peat and to the bog vegetation. Cattle cause more damage than sheep but were only grazed over small areas of the mountain. Hydrologically the impacts were accelerated runoff leading to erosion.

Physical damage

Physical damage to the bog results from the concentration of activity in specific areas. In addition to the problems resulting from overstocking, widespread damage has been caused by the use of All Terrain Vehicles, principally small four wheel drive quads, by farmers for access to their land, generally for stock handling purposes. A less significant impact has been localised damage to a long-distance footpath by walkers.

Environmental Protection

Northern Ireland has lagged behind the remainder of the United Kingdom in the protection of sites of biological and earth science interest and in the early 1990's there was no statutory protection of any of the features of scientific interest on Cuilcagh Mountain. General planning law might have given some protection but was not enforced. The reasons for this are beyond the scope of this paper and related to the governance of Northern Ireland, the development of legislation for nature conservation, and the allocation of responsibility for implementing this legislation. The following section briefly describes developments as they relate to Cuilcagh Mountain and the Cuilcagh karst. *Table 1* summarises the chronology of events.

Table 1 Chronology of significant events in the protection of the Cuilcagh environment

Date	Event
1990	Initial suggestion that a Cuilcagh Natural History Park (CNHP) be established.
Feb 1993	Fermanagh District Council (FDC) seek funding from European and other United Kingdom government sources for the purchase of approximately 12 km^2 of land to establish CNHP (unsuccessful).
May 1993	West Fermanagh and Erne Lakeland Environmentally Sensitive Area designated by the Department of Agriculture for Northern Ireland (DANI).
Feb 1994	Application made by Royal Society for the Protection of Birds (RSPB), supported by FDC, for Community Financial Aid to support "Conservation of Active Blanket Bogs in Scotland and Northern Ireland". Approved for period Oct 1994 - Dec 1996. Included purchase of land to establish CNHP.
Sept 1994	A portion of Cuilcagh Mountain designated an Area of Special Scientific Interest (ASSI) under Article 24 of the Nature Conservation and Amenity Lands (Northern Ireland) Order 1985.
Feb 1995	ASSI Confirmed.
March 1995	Cuilcagh Mountain ASSI recommended to UK government as a possible candidate Special Areas of Conservation (cSAC). Subsequently included in the list of cSAC submitted to the European Commission by the UK Government. The reason for its inclusion is that Cuilcagh Mountain supports an active blanket bog habitat, identified on Annex I of the EC "Habitats Directive" (92/43/EEC) as a priority habitat.
March 1996	FDC / EHS / DANI commission Strategic Management Review to assist the Council in its aim of conserving the active blanket bog on Cuilcagh Mountain. Review undertaken by Professor John Gunn who put forward proposals for re-orientating the Cuilcagh sub-project.
Dec 1996	LIFE committee accept proposals with minor amendments and approve the re-orientated project for the period to 30 September 1998.
July 1997	As part of the re-orientated LIFE Contract, and with additional financial support from the National Heritage Memorial Fund, the EHS, and the University of Huddersfield, FDC enter into an agreement with Legnabrocky Townland landowner for: a long-term (99 year) lease on c. 28 ha of severely degraded, machine-cut, bog and c. 237 ha of active blanket bog; a 25 year lease on c. 0.7 ha of limestone grassland around Monastir cliff and an access agreement for the area of limestone grassland between the Marlbank road and the main leased area.
Dec 1998	Whole of the Cuilcagh Mountain ASSI designated as a Ramsar site under the *Convention on Wetlands of International Importance especially as Wildfowl Habitat.*
June 1999	Cuilcagh Mountain Park (CMP) formally opened to the public.
April 2000	CMP to be enlarged by addition of Aghatirourke Forest Nature Reserve.

The Cuilcagh Mountain Park

In 1993, a desire to protect the catchment of Marble Arch Caves and the wider Cuilcagh environment led Fermanagh District Council (FDC) to seek funding from

European and other United Kingdom government sources for the purchase of approximately 12 km^2 of land to establish a Cuilcagh Natural History Park (CNHP). This bid was unsuccessful but in 1994 an application was made to the European Community 'LIFE' Fund by the Royal Society for the Protection of Birds (RSPB), supported by FDC, for Community Financial Aid to support "Conservation of Active Blanket Bogs in Scotland and Northern Ireland". The project, which was approved for the period October 1994 - December 1996, comprised a Scotland Sub-project run by the RSPB and a Northern Ireland Sub-Project run by FDC. The aim of the Northern Ireland Sub-Project was to establish the CNHP, with a primary focus on the conservation of active blanket bog, and through this to protect the allogenic catchment of the caves.

Subsequent to the original bid for funding the West Fermanagh and Erne Lakeland Environmentally Sensitive Area scheme was formally launched (see below), and although this has had many positive benefits it did result in an initial setback for the LIFE project as landowners were unwilling to sell their land at the prices recommended by the District Valuer. As a result FDC were unable to purchase the land necessary for setting up the CNHP, as originally conceived. A Strategic Management Review was commissioned to assist the Council in its aim of conserving the active blanket bog on Cuilcagh Mountain and proposals were made for re-orientating the Cuilcagh sub-project (*Gunn, 1996*). The Council, and the LIFE Committee, accepted these proposals with minor amendments and the re-orientated project was approved for the period to 30 September 1998. In July 1997, as part of the LIFE Contract, and with additional financial support from the National Heritage Memorial Fund, the Environment and Heritage Service, and the University of Huddersfield, Fermanagh District Council entered into a long-term (99 year) lease on 265 ha of blanket bog in the Aghinrawn catchment, including c. 28 ha of severely degraded, machine-cut, bog (*Fig. 3*). The area was included in the original CNHP proposal but to distinguish the new project from that originally proposed it was decided to give the area the title "the Cuilcagh Mountain Park" (CMP). A management plan was prepared *(Gunn & Walker, 1999*) and the Park was formally opened in June 1999.

In 1998, as part the LIFE contract, restoration work commenced on the tract of machine-cut peat in the CMP, the aim being to re-establish a regenerating, self-sustaining bog ecosystem with the appearance and composition of a 'natural' bog. No further peat-cutting is permitted in the Park and the grazing density has been reduced. A track and path have been constructed to provide access to the summit of the mountain and opportunities to observe a range of lithologies and landforms.

The West Fermanagh and Erne Lakeland Environmentally Sensitive Area Scheme

In May 1993 the Department of Agriculture for Northern Ireland (DANI) established the West Fermanagh and Erne Lakeland Environmentally Sensitive Area (ESA) which includes the whole of Cuilcagh Mountain. The scheme is voluntary, farmers within the area being offered a ten year agreement with the opportunity to withdraw after five years if they so wish. Levels of payment are tiered and reflect the conservation value of habitats on the farm. Unfortunately, the specific requirements and particular importance of active blanket bog did not become widely recognised until the mid-1990's and at the time that the ESA scheme was launched they were not well understood. In contrast, there was a widespread concern over the decline in heather moorland and the need for positive management of this habitat. Consequently the blanket bog on Cuilcagh was classified in the

ESA scheme as heather moorland. Properly controlled grazing was seen as the key to successful heather management with DANI prescriptions specifying: (a) a stocking density limit of ten ewes, or one cow, per five hectares, (b) exclusion of stock from November 1st to February 28th. The stocking levels are now considered to be too high for active blanket bog and it is probable that in the future the Scheme will be revised to include a specific 'blanket bog' category with lower stocking levels. Although the ESA Scheme does not have a specific commitment to blanket bog it has been very successful in enhancing nature conservation in general on Cuilcagh and the majority of farmers on the mountain have entered the scheme.

The Cuilcagh Mountain ASSI / SAC / Ramsar Site

In September 1994, some 2745 ha of Cuilcagh Mountain was designated an Area of Special Scientific Interest (ASSI), the designation being confirmed in February 1995 (*Fig. 3*). The primary selection feature was the blanket bog habitat and the ASSI boundaries were drawn so as to include all active, largely undamaged, bog. Five other selection features were identified for the area: montane heath habitat, oligotrophic lakes, Golden Plover, rare plant assemblage and earth science interest in the exposures on the upper slopes and karst features lower down. In practice the ASSI only encompasses a small part of the Cuilcagh karst but provides protection for a large part of the allogenic catchment. The whole of the ASSI was subsequently included in the list of candidate Special Areas of Conservation (SAC) submitted to the European Commission by the UK Government. The reason for its inclusion is that Cuilcagh Mountain supports an active blanket bog habitat, identified on Annex I of the EC "Habitats Directive" (92/43/EEC) as a priority habitat. The bog extends across the international border and has been included in the list of Special Areas of Conservation (SAC) submitted to the European Commission by the Irish Government. In December 1998 the whole of the Cuilcagh Mountain ASSI was designated as a Ramsar site under the *Convention on Wetlands of International Importance especially as Wildfowl Habitat*. The site qualifies under criterion la of the Ramsar Convention by being a particularly good representative example of blanket bog, a globally restricted biotope and under criterion 2a of the Ramsar Convention by supporting an appreciable assemblage of rare, vulnerable or endangered species.

The Aghatirourke Forest Nature Reserve

The Forest Service own the Florence Court Forest Park which includes a large area of land on Cuilcagh. The Aghatirourke Forest Nature Reserve (AFNR), which forms the upper part of the Forest Park, contains c. 25 % of the active blanket bog on the mountain, all of which is within the SAC / ASSI (*Fig. 3*). Fermanagh District Council has entered into an agreement with the Forest Service to lease the land from April 2000, the intention being that it should be managed, promoted, and form part of, the Cuilcagh Mountain Park.

Discussion

In many karst areas that have substantial allogenic catchments a major difficulty for managers is to find ways to protect the karst from impacts resulting from land use in the allogenic catchment. The reason for this is that while the scientific value of the karst is usually easy to recognise, the allogenic catchment may have relatively little scientific value and hence not be worthy of protection in its own right. The Cuilcagh karst is therefore unusual in that while the majority of the limestone area has no statutory protection, the allogenic catchment has (*Fig. 3*). The highest level of protection is given by the Cuilcagh Mountain Park (CMP) where action is being taken to reduce runoff and erosion from the cutover area by a programme of drain-blocking, habitat restoration. Elsewhere in the CMP, and throughout the ASSI / SAC, there is a requirement to enhance the conservation status of the blanket bog and this is being met partly through the controls on stocking density that form part of the ESA scheme. The result should be greater growth of sphagnum and an expansion of the area of flow-bog, bringing the majority of the allogenic catchment back towards a 'natural' condition. However, it is still unsatisfactory that the autogenic catchment, and the caves themselves, have no statutory protection. While the boundaries of the SAC cannot extend beyond the bog, as this is the priority habitat, there is a need for an enlarged ASSI to take in the earth science interest elsewhere on the Mountain. The principal karst landforms on Cuilcagh are limestone pavements, closed depressions (dolines), stream-sinks and caves. An Earth Science Conservation Review (ESCR) of the karst geomorphology of the Cuilcagh / Marlbank area was undertaken by *Fogg & Kelly* (1995). Some 15 individual 'Units' were identified in five main areas and each could potentially be notified as an ASSI. However, this is akin to trying to identify particular strokes of genius on a large work of art and it is also the case that at least some of the areas outside of the proposed individual ASSI sites form part of the hydrological catchment of those sites that are proposed for designation. Elsewhere in the UK there has been a general presumption against designating karst systems at catchment level, although there is at least one precedent for this approach in the Castleton Caves SSSI, Derbyshire. In the case of Cuilcagh there are large areas of overlap between the existing ASSI and features likely to be included in future earth science ASSI. In addition, much of the area which is of value because of its karst landforms supports limestone grassland, another habitat of Special Scientific Interest. Hence, there is the potential for a large ASSI extending from the Marble Arch Caves to the Cuilcagh summit ridge and covering a wide range of biological and earth science interest. UNESCO are currently considering proposals to establish a Network of GEOPARKS and if a large ASSI were to be designated then it would be a prime candidate for inclusion in the list.

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LANDSCAPE CLASSIFICATION AND KARST MANAGEMENT AT JENOLAN CAVES, NEW SOUTH WALES, AUSTRALIA

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Summary
Land classification is a widely used tool for defining management units to which differing management strategies may be applied. The complexity of limestone terrain requires that any land classification scheme must be a hierarchical one so that land managers can gain information at an appropriate spatial scale for a given task. A suitable scheme would be from (large area >10,000ha) bioregion>land provinces>land systems>land units (small areas < 1ha). Map generalisation must proceed by amalgamating land units over increasingly broader spatial scales. There will be an appropriate scale for major plant communities, for faunal functional groups and for individual species habitat suitability. The critical question is identifying that appropriate scale which accounts for the most meaningful detail while still being achievable in terms of field survey and data handling. This is the SLAP principle - Simplify as Little As Possible - which is a corollary to the KISS principle. In this particular land mapping sequence the minimal mapping unit (MMU) would be at the land unit scale, a homogeneous area of terrain and vegetation clearly identifiable and having ecological significance; for example, the limestone ledge land unit which is an important habitat for the endangered brush-tailed rock wallabies and occurs on steep cliffs. These units can be clearly identified on the ground and are visible on high-resolution aerial photography. The key question for this study is whether or not we can scale up to lower resolution imagery (such as airborne video or Landsat TM) and still reliably identify these MMUs. Other land units of greater spatial extent (for example, tall forest communities in gullies) are still clearly identifiable on Landsat TM imagery although some aliasing of their boundaries occurs due to the lower (25m) resolution.

Introduction

Karst is a complex and highly variable landscape, operating within a variety of scales. Landscape classification is a tool, which allows managers to deal with this complexity, by defining land units at various scales, to which differing management strategies can be applied. The challenge in developing a landscape classification model for karst is to identify that appropriate scale which accounts for the most meaningful detail, while still being achievable in terms of field survey and data handling. This is the SLAP principle - Simplify as Little As Possible. At the same time, the model must simplify the details enough to make meaningful statements about the nature of the landscape.

What is Landscape Classification?

Landscape classification is essentially a mapping technique, and has been in use in Australia since at least the 1950s. Patterns in the landscape are defined by an hierarchical process involving the identification of land classes. Each class level is identified at a particular scale, e.g:

large scale (> 10 000 ha) > medium scale > small scale (< 1 ha)

At the smallest scale, land classes are distinctive, homogenous (uniform) environments (eg. gently sloping red earth plain on limestone with *Eucalyptus* woodland) At the largest scale, the land classes are heterogeneous (varied), but are broadly linked by an underlying similarity (eg. Southern Highlands of Eastern Australia).

Landscape classification helps to make sense of complex environments by providing uncomplicated information in the form of maps. Supporting documentation may include tables defining the characteristic features of a class. With few exceptions (eg. *Godwin 1991*), the technique has not been specifically applied to karst. However, there are wide range of potential applications for karst managers.

Applications of Landscape Classification

Landscape classification can provide a framework for a variety of applications including:

1. Land capability assessment
    - Risk assessment and monitoring
2. Gap analysis
    - Threatened species habitat identification and assessment
    - Integrated catchment management

Identifying links between surface & underground environments.

The framework afforded by landscape classification provides a spatial context for understanding the environmental relationships of particular areas. At smaller scales, the distribution of related areas can be identified, so it is then possible to determine for example, the distribution and extent of landscapes, which are susceptible to accelerated erosion. Such information is useful in assessing the type of land use suitable for an area, and assists in identifying sites which need to be prioritised for risk assessment and monitoring.

As another example, site records for rare and threatened species can be incorporated into the classification. Patterns of distribution of sites within land classes can be determined, and predictions of the locations of populations outside of known distribution areas can be determined. This provides a basis for gap analysis. Under-representation of a rare and threatened species habitat within the reserve boundaries, or gaps in management knowledge can be identified. This may provide a basis for requisition policies and recovery plans (in the case of under-representation), or a focus for surveys and monitoring programs.

These types of applications apply to any landscape, but there is one application, which may prove particularly useful to karst. By linking cave maps to land class maps (eg. by using overlays in GIS models), it may be possible to provide useful information about interrelationships between the surface and subterranean environments. For example, if a cave system is largely located within a single land class, energy inputs into the cave can be predicted, which will have implications for managing cave fauna. In addition, previously unknown hydrological links between surface and subsurface flows may be detected by this application of landscape classification.

Benefits of Landscape Classification

Aside from a wide range of applications, landscape classification has many benefits for the karst manager.

It provides a means by which to make sense of complex environments.

Natural environments are by nature heterogeneous (variable), and it is often difficult to identify interrelationships within a landscape without an understanding of the component parts of the landscape, and how those component parts are distributed.

It provides a rational and cohesive framework for collecting and analysing environmental data.

The landscape classification provides a means of partitioning environmental data in a logical, step-wise manner. It also provides a spatial context for understanding the dynamics of a particular site, species, landform or ecosystem at various scales.

It provides a biophysical basis for assessing resources.

Natural landscapes operate independently of political and cadastral boundaries. Landscape classification provides a more meaningful ecological basis for understanding the environment.

It allows the adoption of a uniform management approach.

At the finer scales of the classification hierarchy, the distribution of land classes becomes increasingly patchy. By using a landscape classification map, related areas can be identified, and uniform management policies can be applied.

It allows for rapid and cost-effective assessments.

Having identified a group of homogenous land classes, verification of the mapping predictions only requires limited field assessment of a representative set of sites. This reduces the time spent in the field and the costs of the field survey, and means that information is available for decision-making soon after the mapping is completed.

Landscape Classification Hierarchy for Jenolan Caves

Class Definition

Classes are typically defined according to a set of characteristic attributes, including:

- climate
- geology, geomorphology
- soils
- vegetation
- hydrological regime

At each scale of the landscape classification hierarchy, the level of detail in the class descriptions changes accordingly. Hence large-scale classes require very broad descriptions, and small-scale classes are highly detailed. For Jenolan Caves four class levels have been determined as shown in *Fig. 1*. These are:

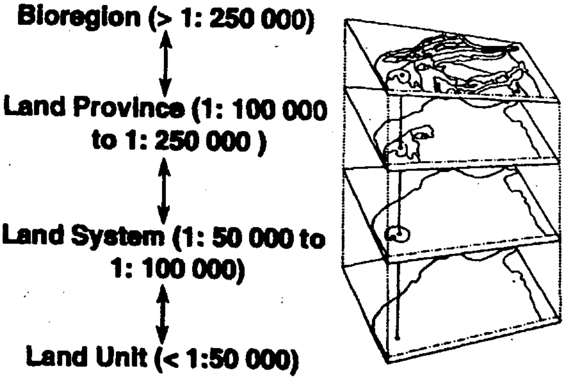


Fig. 1 Landscape classification hierarchy for Jenolan Caves

To date, efforts at Jenolan have concentrated on defining Land Unit boundaries. As the Jenolan mapping project is using a bottom-up approach to classification, intermediate land class boundaries will result from the amalgamation of these fine-scale land units.

Bioregions

The Bioregion is the broadest delineation of the land classes applied to Jenolan, and is mapped at scales greater than 1: 250,000. Boundaries for units within this class are defined by uniform geology, climate and landforms. A Bioregion boundary has already been determined by external agencies for Jenolan Caves Reserve. Jenolan is encompassed by the South Eastern Highlands Bioregion, the boundaries of which occur outside of the reserve. The Bioregion is described as:

> *Steep dissected and rugged ranges extending across southern and eastern Victoria and southern NSW. Geology predominantly Palaeozoic rocks and Mesozoic rocks. Vegetation predominantly wet and dry sclerophyll forests, woodland, minor cool temperate rainforest and minor grassland and herbaceous communities.*
>
> (*Thackway 1996*).

Knowledge of the attributes of the Bioregion provides a regional context for understanding the characteristics of Jenolan Caves, and the external processes influencing the reserve.

Land Provinces

Land Provinces are mapped at broad to intermediate scales (1: 100 000 to 1:250 000). They are delimited by a finer scale separation of geology and landform characteristics than those identified for a Bioregion. In addition, information about broad soil and vegetation patterns are also utilised. As an example, a Bioregion dominated by igneous rocks with (1) high altitude inland ranges with rainforest on shallow soils, (2) a coastal plain blanketed by alluvials with open sclerophyll woodlands and (3) medium altitude coastal ranges with sandy soils and vine forests, would be divided into three provinces.

Land Systems

Land Systems are mapped at intermediate scales varying between 1:10 000 to 1: 100 000. The separation of Land Systems is on the basis of fairly uniform geological and landform elements with related suites of soils and vegetation patterns found within a provincial boundary. For example, if the coastal plain (described above as Province 2) contained (a) transitional foothills, ranges and isolated peaks of igneous rock with clay loams and closed forest; (b) coastal alluvial plains on an igneous base with sandy soils and open forests and woodlands and (c) subtidal/intertidal lowlands with sandy clays and mangrove, saltmarsh and aquatic plant communities, then three land systems would be described.

Land Units: The Minimum Mapping Unit (MMU)

It was earlier stated that the challenge in developing a landscape classification model for karst is to identify that appropriate scale which accounts for the most meaningful detail, while still being achievable in terms of field survey and data handling. For Jenolan Caves Reserve, this has been identified as the Land Unit. The Land Unit is mapped at scales of 1:10 000 or less.

A Land Unit is defined as an homogeneous area of terrain and vegetation which is clearly identifiable, and which has ecological significance. Class boundaries are defined primarily on uniform topography with a distinctive soil and water regime and plant community. From the example of the previous section, a Land Unit might be the mangrove communities of Land System 3. An example from Jenolan Caves Reserve is the Limestone Ledge Land Unit. This is identified by the presence of steep cliffs & bluffs in limestone, with shallow stony soils and a Bursaria low shrubland, and is an important habitat for Brush-Tailed Rock Wallabies. Some further guidelines for developing a landscape classification are provided in Appendix One.

Scale-dependent Limitations of Landscape Classification

The determination of the MMU for any landscape classification is critical. This will allow managers to determine if commercially available data is adequate for their purposes, or whether customised data needs to be obtained. Most State government agencies will provide data at the Land Province scale i.e. 1:100 000 to 1:250 000. While this may be adequate for regional studies, the generalisations inherent in such data may make them inappropriate or inaccurate for analysis at the Reserve scale. Thus the successful mapping of a reserve probably requires customised data, for which managers need to determine a minimal mapping unit (MMU) which provides meaningful data while still being achievable in terms of time and cost.

The minimal mapping unit is the smallest object that must be mapped in a hierarchy. A rule of thumb is that the MMU is four times the resolution of the data needed. Thus if you want to map spatial objects that are 20m by 20m (0.04ha), then the data you use must have a resolution of 5m by 5m. From this it is apparent that on an aerial photograph with a resolution of 0.5m you can map to ~5m^2 while if you are using a Landsat TM satellite image (resolution 25m), you can map down to about 1ha (100 by 100m). This may be adequate for a whole Reserve, but will fail to detect small land units such as individual vegetated limestone ledges.

There are a large number of image products available for mapping (*Table 1*), with the newest possessing both high spatial resolution and ability to sense beyond the visible light wavelengths. In particular, the use of near infra-red light (NIR) allows calculation of various indices of vegetation health which have wide applications in forest inventory, weed detection, and survey of algal blooms.

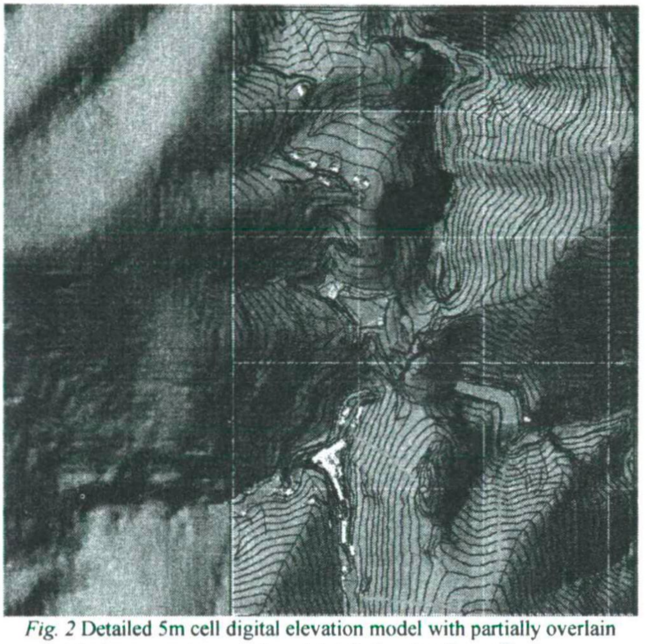


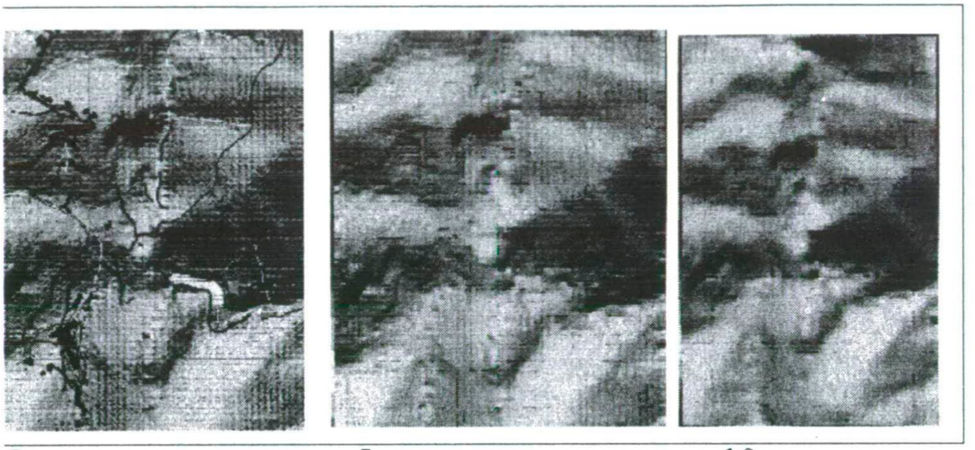
Fig. 2 Detailed 5m cell digital elevation model with partially overlain drainage, contours and road detail, Jenolan Caves Reserve

Table 1 Readily available sources of digital image data and their characteristics.

Data Source	Spatial resolution	Spectral resolution	Repeat cover	MMU
Landsat TM	25m	7 band B G R NIR NTIR 2xTIR	16 days	1ha
Spot XS	20m	3 bands BG R NIR	26 days; +5 off-nadir	0.6ha
Spot Pan	10m	1 band in visible BG to R	26 days; +5 off-nadir	0.2ha
Airborne Multispectral Video System	1m	4 bands B G R NIR	On demand	$20m^2$
Digital Colour Air Photos	0.5m	natural colour or false infrared	On demand	$5m^2$

Uses and abuses of DEMs

One of the most useful items of data that can be obtained is a digital elevation model (DEM). DEMs are the building blocks of topographic maps, as well as much else. The original data are spot heights from aerial photography, on an irregular grid. From these, a triangular interpolation network can be built to account for variations in terrain complexity. Areas of low relief are next masked out to avoid spurious pits and pinnacles. For Jenolan, the final surface was interpolated using a cubic spline technique to give a 5m horizontal resolution cellular DEM (*Fig. 3*) with data range from 663 to 1233m.



2m 5m 10m

Fig. 3 Comparison of DEMs with differing spatial resolution, Jenolan Caves Reserve

From DEMs the following products can be derived:

- Contours at any desired interval
- 3-D terrain models
- Topographic profiles
- Slope maps
- Aspect maps
- Maps of specified altitude ranges

These can be used to display other data or as input layers to a GIS. Commercially available DEMs (such as those supplied by AUSLIG or the State mapping agencies) are usually derived from existing topographic maps or stereo satellite images. They have a large cell size (typically 25m) and from them one can generate 20m contours at best. But this resolution may be inappropriate for detailed work, as the MMU from these will be 1ha. Determining the appropriate cell size for a DEM relies on spatial analysis of the terrain and some knowledge of the limitations of the initial data set. One technique that is widely used is that of spatial autocorrelation (*Worboys, 1995*). This rather weighty word relies on the assumption that the elevation within a single cell will rely to a greater or lesser degree on the adjoining cells. We would normally expect that in a normal landscape the value of a point elevation on a slope would relate closely to those above and below it. That is, there is significant spatial correlation in the landscape. In karst terrain, as we know, this assumption is not always valid because of the presence of dolines, pinnacles and cliffs which create local anomalies in elevation.

We measure this using a statistic called Moran's I, which measures the statistical relationship between each cell and those surrounding it, over successively larger distances. From it we can estimate the distance at which Moran's I significantly reduces in value. This

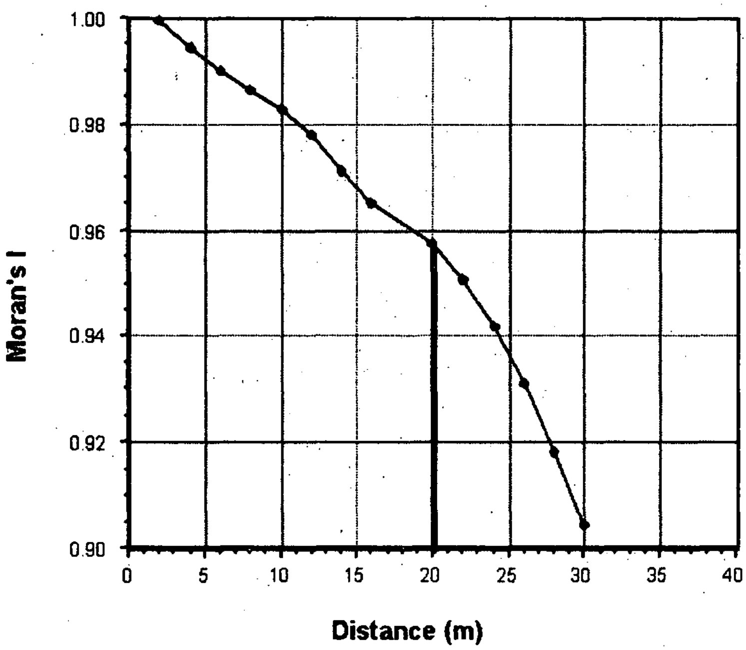


Fig. 4 Results of Moran's I analysis for Jenolan DEM

can be used to estimate an MMU and thus the resolution of the data we need to adequately account for the local variability in the karst terrain. In *Fig. 4*, this has been carried out for the Jenolan DEM. The graph defines a MMU at 20m, implying that we need a data resolution of 5m. This is unavailable from State data, but by using digital aerial photography at a scale of 1:12,500 we can achieve it.

Once we have our DEM, we can classify it according to slope angle to identify flat spots which correspond to limestone ledges. Or we can use it to produce a map which shows areas visible or invisible from a given point or line on the terrain (the military notion of live and dead ground). This *viewshed* can be used to assess the visual impact of new buildings, carparks or even aerial cable-cars. We can combine it with other data on vegetation type to predict where rare plants of known preference might occur. The applications are limited only by our imagination.

Conclusions

Land classification provides a means of understanding landscape patterns and processes and can be of value to managers in providing a transparent and objective framework for management actions. Land classification rests on an hierarchy of mapping units from land province to land unit. For most karst systems, the land unit will be the appropriate mapping scale and for this data will need to be at a scale around 1 : 10 000. For many reserves one may need customised data rather than the generic data that are available through State agencies. Digital elevation modelling provides a highly valuable product, which can be translated into other forms such as slope, aspect etc. Careful attention needs to be paid to the resolution of the DEM so that the complexity of karst terrain is faithfully rendered.

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Appendix One: Guidelines for Mapping

Prior to commencing a landscape classification- mapping project it is vitally important to determine:

- the applications of the final landscape classification for your situation;
- the benefits you expect from your landscape classification, and;
- the minimum mapping unit (MMU) that will satisfy your needs and expectations.

The following guidelines provide a good basis for planning landscape classification mapping:

Collect & collate all available information of land attributes (geology, soils, vegetation). This may be available in the form of published maps, reports, databases, etc.

Acquire the best available field mapping topographic base. Normally satellite imagery, airbourne video and/or aerial photography. May need to be customised if commercially available data is not at an appropriate scale.

Conduct a brief field survey to identify likely land units & land systems matching imagery with ground truthing. A familiarisation process that will allow better interpretation of the available imagery. Allows the assessment of areas, which are obscured on the imagery.

Conduct an interpretation of available imagery to create a preliminary landscape classification. The first stage of mapping, where the number of land classes and their distribution and boundaries are provisionally determined.

Conduct field mapping and survey to refine class boundaries, and acquire ecological data. Carry out routine mapping, confirming land class boundaries and modifying them as required. A draft map, complete with supplementary information should be completed by the end of this stage

Construct GIS data layers or hard copy maps. The final landscape classification map can now become the basis for management of the reserves.

Modified from *Gunn et al.* (1988)

Generally, the MMU which can be shown on a map is the Land Unit. However, while Land Units are essentially homogenous, minor variations may be present that may have ecological significance. The best approach for recording such variations is to provide a series of profile diagrams. For the Limestone Ledge Land Unit, the profile diagrams may show the variations in ledge shape, slope and height as illustrated below. Profile diagrams are not included on the land classification map, but can be appended to the map as tables. Generalised profile diagrams can also be used to help readers interpret Land Unit and Land System information on the final map (see *Laut et al.* 1977).

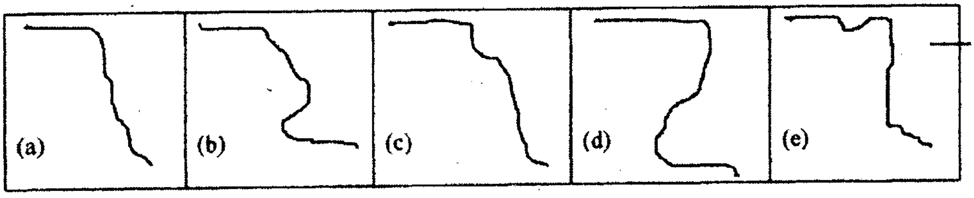

Fig. 5 Examples of profile diagrams for Limestone Ledge Land Unit, Jenolan Caves Reserve.

MANAGEMENT FOR ENVIRONMENTAL AND SOCIAL SUSTAINABILITY AT JENOLAN CAVES, NEW SOUTH WALES, AUSTRALIA

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Summary
Jenolan Caves have been open to the public since the 1850s, and at one time were Australia's premier tourism destination. In about 1993, the administration decided that the continuing increase in visitor numbers represented a significant threat to the environmental quality of the site.

Accordingly, a meeting of karst and tourism professionals was set up to advise on action, and as a result, a continuing program of both environmental and social monitoring was established under the oversight of a supervising committee.

This paper will describe the innovative managerial arrangements, which are in place and the processes being utilised. Results to date will be outlined.

The Jenolan Caves

The Jenolan Caves are located in a deep valley in the Western side of the Blue Mountains, and contained in a relatively small area of impounded karst. The karst has an extremely complex geological history, with two periods of major folding, a number of faulting events, at least three periods of palaeokarst deposition, with evidence of hydrothermal activity, and of sulphuric acid erosion. The main cave system comprises over 20 kms. of passages contained within a one km. length of the limestone body, and a complex series of different tourist routes have been provided (*Hamilton-Smith & Osborne 1998*).

The Caves are said to have been discovered in 1838, and in 1866, the Jenolan Caves Reserve was proclaimed. This was one of the first wild-land reservations in Australia, and in 1872 was certainly the first to be placed under conservation regulations. The Reserve quickly became an important tourist destination, and by the end of the 19th century, was probably one of the best-known and most often visited attractions in Australia. It was also the site of a remarkable series of innovations. The beauty of the caves was safeguarded by erection of wire screening, visitors were shown the caves by magnesium light (first used at Jenolan, later elsewhere in Australia, but not generally in other countries), the first use of electric lighting in caves anywhere in the world (1880), and Australia's first hydro-electric generating system (1889).

The reserve was, for many years, managed by various government departments, and in 1988 the first formal plan of management was prepared and formally approved in 1989. Following this, the Jenolan Caves Reserve Trust was established as a corporation under the provisions of the Crown Lands Act and regulations with specific responsibility for the management of Jenolan, and now three other caves reserves in New South Wales. As visitor numbers increased, so the location within a deep and precipitous valley served to generate considerable problems in both visitor access and maintenance of environmental quality.

Accordingly, the Trust became concerned about the potential impacts of increasing visitor numbers, particularly after undertaking a study of future development options, and in 1994 commissioned a further study by Manidis Roberts Consultants (1995) into how the 'carrying capacity' of the reserve might best be determined. This study involved a three-day workshop, comprising experts in karst research, cave management and visitor management. A program for action, based in the *Visitor Impact Management* process (*Graefe et al 1990*) was proposed. This proposal was adopted and immediately implemented by the Trust. Then in due course the Social and Environmental Monitoring (SEM) Committee was appointed by the trust to maintain an oversight of this program and first met in May 1996.

Structural Arrangements

The Board of the Trust has a number of smaller sub-committees, and of these, the conservation sub-committee provides for oversight of and liaison with the SEM Committee. The SEM Committee itself includes both persons with long experience and knowledge of caves and karst management and those without such experience but considerable other relevant expertise. These structural arrangements are summarised in *Fig. 1*.

The Committee meets twice in each year, and one or more members of the Conservation Sub-committee always attend at least part of each meeting. Two staff members, the karst resources manager and assistant, who have the responsibility for actual operation of the research program, also attend each meeting.

The role of the committee is to:

- maintain a program of evaluating both the quality of visitor experience and the quality of the environment
- maintain a continuing review of the quality of the resulting research and of any other submitted reports
- produce an annual independent *State of the Environment* Report
- identify implications for management and budgetary decision-making

The transparency and accessibility of the evaluation process is maintained in a number of ways. The annual State of the Environment Report is published in the statutory annual report of the Trust, and in effect, constitutes an audit of both the quality of the bio-physical environment and the visitor experience. A quarterly newsletter is published and regular 'fact-sheets' reporting progress are made readily available, particularly to staff. Members of the committee and the two staff concerned also have close liaison with staff and other stakeholders, and two stakeholder workshops have been held.

This degree of structural integration and the continuing openness of communication both serve to enhance understanding and implementation to an unusual degree. However, there is another less explicit but important integration process. The level of expertise represented amongst the members of the SEM Committee means that any research or monitoring is soundly based from both conceptual-theoretical and practical-methodological perspectives. Members of the committee are also in a position to alert all concerned of the implications of other research throughout the world.

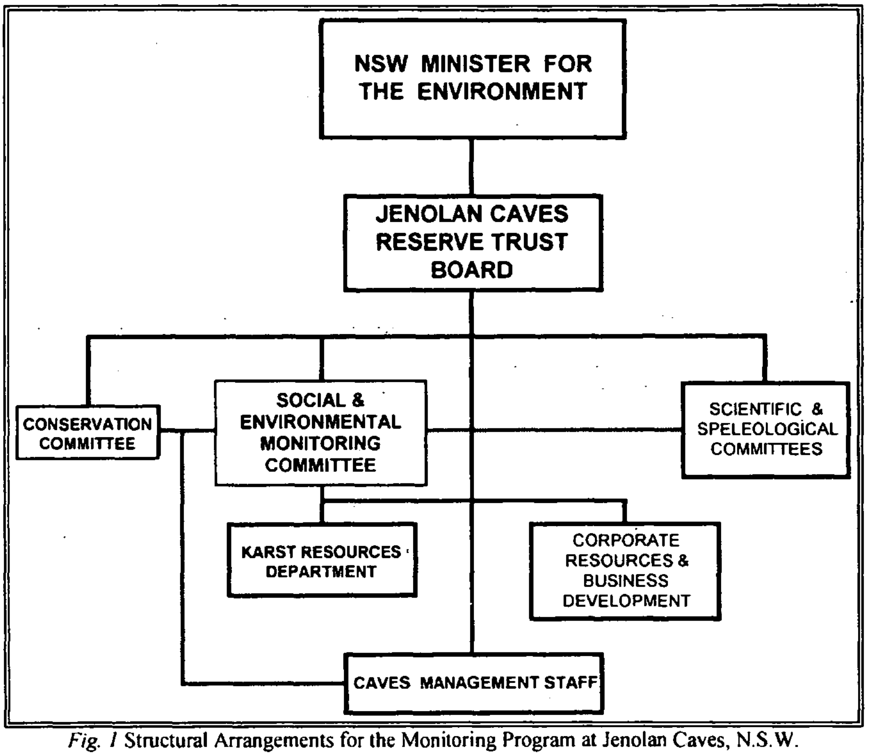

Fig. 1 Structural Arrangements for the Monitoring Program at Jenolan Caves, N.S.W.

The actual work program has evolved as a shared responsibility with broad involvement. The core-monitoring role rests with the staff of the Karst Resources Department. However, some members of the committee also make a significant contribution to the work program, either in conjunction with staff or through their personal research activities. As a number are from universities, they have been able to enlist post-graduate students to pursue topics of concern to the evaluation program.

The Work Program

VIM, and indeed all of the quality maintenance models, assume that the major issue in sustainability is one of visitor impacts. Our experience has led us to the broader conclusion that we must consider any processes which threaten the quality of the environment and/or the visitor experience. Thus in looking at the ecology of the surface environment at Jenolan Caves, probably the most damaging threats are due to invasive species (weeds, pathogens and feral animals) together with the impact of the old-time pathways which were inappropriately located and built with poor design and construction techniques.

So this wider view of the task, which arises out of sustainability concepts, is one way in which the Jenolan process has evolved to be holistic rather than fragmented.

The key elements of the VIM process include:

- the establishment of precise objectives for management of both the environment and visitor experience
- identification of indicators which serve to measure the extent to which objectives are being achieved
- measurement of these indicators
- development of appropriate managerial responses to revealed problems

The VIM framework (and that of other similar models) also appears to assume that it is a relatively easy task to define specific and precise objectives. In fact, this can only be done effectively with a good understanding of the social and natural systems, and at least in Australia, we often lack an adequate basis for doing this.

Some environmental properties can be clearly defined and readily measured. At Jenolan Caves these include, for instance, the composition of the air within the caves, the quality of the water, evaporation rates within the cave and the deposition of dust within the cave. However in endeavouring to capture, for instance, the less tangible characteristics of the recreational experience and to recognise the role of the recreating person in individually shaping that experience, while maintaining fidelity to the reality of experience, an insistence on precise definition of objectives may prove truly troublesome. A similar problem arises in a number of environmental issues, for instance, endeavouring to establish the desired ecological balance in an already badly damaged vegetation community.

At the same time, there has also been a long debate about the appropriateness or otherwise of insisting upon clearly defined objectives. *Wholey et al* (1975) and many others argue that evaluation is impossible without clearly defined and measurable objectives; *Nienaber and Wildavsky* (1973: 11) present a powerful critique of the objective-based approach. They argue that:

. . . objectives are not just out there, like ripe fruit waiting to be plucked; they are man-made, artificial, imposed on a recalcitrant world. Inevitably they do violence to reality by emphasising certain activities (and hence organisational elements) over others.

Scriven (1972, 1993) presents a similar argument, together with a clearly defined conceptual approach to goal-free evaluation, which has since been further developed by many others.

The approach at Jenolan has therefore been that, where necessary, rather than striving to delineate precise objectives (which are all too likely to be flawed), issues for concern are defined, the state of these issues is identified and monitored (which in itself may assist to develop an adequate understanding for the definition of objectives) and at the same time, students and others are encouraged to undertake basic research upon the issue concerned.

There is a special problem in the social arena, where managers only define their objectives for visitor experience in terms of providing opportunities and all too rarely define even the range of opportunities in clear terms. Although there is an available and well-developed technology for defining 'customer satisfaction' and other characteristics of the visitor experience, this is only useful at the broad level, and makes only a limited contribution to the kind of understanding of visitor experience which is desirable. The committee continues to pursue the investigation of this area.

Aspects of the work program

Air quality and vehicle pollution

One of the concerns which attracted considerable attention at the beginning of the program, and was assumed to be potentially extremely damaging, was the impact of exhaust and dust emissions from motor vehicles. Research and monitoring showed that although there were high pollution levels in the Grand Arch (an immense cave passage through which all traffic passes) even these are short lived due to the winds which clear the air constantly, but see below re traffic access. The exhaust fumes and dust (from tires and brake pads) only penetrated a short distance into the other cave passages, and were deemed not to present a major threat.

However, this research led to two other important findings. The first was that there was a relatively stable thermocline and associated change in humidity at the furthest point to which external dust and fumes entered the cave. Temperature differences as high as 4° C has been recorded on either side of the thermocline. This appears to protect the cave from external pollutants (*James at al 1998*). Monitoring of the thermocline has now commenced in order to more fully understand its dynamics, and to assess the impact of visitor parties passing through it.

The second was that there were a number of locations in the cave with high concentrations of zinc and cadmium resulting from both leeching of galvanised metal structures, and even more strongly from the former practice of in-cave fabrication of handrail systems. Cadmium, a virtually ubiquitous impurity in zinc, has a highly toxic impact on micro-biota and hence upon the integrity of the cave environment. For this and other reasons, in-cave fabrication is now avoided and the galvanised structures will be progressively replaced with stainless steel.

Vehicular traffic

Although pollution as a result of the heavy vehicular traffic proved to be less important than anticipated, a comprehensive assessment of the traffic situation showed that the geological instability of the current major traffic route to the caves dictates that the road should be replaced at the earliest feasible date. Further, the impact of motor vehicles within the tightly constrained space of the pedestrian precinct at the caves offices is such as to adversely affect the visitor experience. Finally, the current impacts upon the Grand Arch and its fauna are certainly undesirable, and should be eliminated. It has therefore been decided to proceed with the development of an alternative access means, probably by a cable car system.

Cave climatic conditions

Climatic conditions within the cave areas visited by tourists have been regularly monitored, and a major research study of the total climatic systems of the cave completed by *Michie* (1997). Although the results of monitoring still demand further analysis, it appears that although each visitor party causes a rise in cave temperature, this does not exceed 0.5°c and so falls within the normal range of seasonal variation. A similar variation occurs in carbon dioxide levels, and again, *given the current size and timing of visitor parties*, does not seem to be a cause for alarm. However, a full integration of the measurements of carbon dioxide, temperature and humidity is required before the effects of climatic variation can be fully assessed.

However, the problem of dust is a very different matter. Although there are some natural sources of dust, the great majority is borne into the cave on visitor's footwear and clothing, shed as lint from clothing and skin flakes from visitors. It has a marked negative impact upon the quality of speleothems appearance, causing surface dulling and discoloration. It also changes the bio-ecology of the cave, providing food input to both Collembola and other small invertebrates and to microbiota, and hence having significant chemical effects.

It is a matter for very serious concern, and Jenolan initiated regular washing as one response to this problem (*Bonwick & Ellis 1985*). Recent assessment by *Spate & Moses* (1994) has demonstrated that this in itself has an impact upon the surface of speleothems, and so, although it may be necessary, it should be carefully controlled and minimised. Techniques have now been developed for simple monitoring of dust and lint deposition, and it is planned to establish controlled experiments on means to minimise the problem.

Integrity of the surface environment

Threats to the integrity of the surface environment involve a number of issues, including the impact of invasive species, land stability problems resulting from the long period of human interference, and impacts upon water quality as a result of increased sedimentation and both chemical and biological pollution.

The three current major projects of the monitoring program involve the establishment of a comprehensive water quality monitoring program, the development of an environmental risk management strategy, and the development of a detailed land system analysis as a basis for land management initiatives (*Gillieson & Thurgate*, this meeting).

Quality of visitor experience

Two preliminary studies of the quality of visitor experience have been carried out. *Veldman* (1997) concentrated upon bus tour parties, and found a reasonably high level of self-reported satisfaction amongst visitors. However, the study also revealed a significant number of problems in visitor service from both bus operators and the caves experience. *Campbell* (1998) examined a random sample of visitors, most of whom were independent travellers who had arrived in private cars. This study provided a preliminary identification and analysis of the psychological components of the visitor experience, demonstrated that many visitors felt too crowded and were most dissatisfied with local food services, and pointed to a need for greater diversity of tour experiences.

A recent stakeholder meeting identified further monitoring of visitor experience as a high priority for action.

Summarising the Current Process

In conclusion, we can now summarise the overall process which, has been developed at Jenolan, and which although it has evolved from the VIM process described above, has adapted it to the Jenolan situation.

It now consists of seven steps. The first of these consists of preliminary investigation of apparent issues or threats, and in the example above of assessing the impact of motor vehicle emissions, the preliminary investigation indicated that although there was clearly a heavy environmental impact upon the Grand Arch, that resolution of this problem could only be resolved as part of a wider traffic access problem. On the other hand investigation of cave climate led to the conclusion that the most critical immediate issue was that of dust, although other issues (temperature, carbon dioxide levels and humidity) require continuing monitoring to ensure that they remain within an acceptable range.

From that point, each of the critical threats which have been identified are monitored in the most effective way, the results of monitoring analysed, and ultimately, proposals for action are presented to the Trust Board. The on-site research and monitoring is supported by appropriate theoretical and conceptual insights and a knowledge of other relevant research elsewhere in the world which is provided by the SEM Committee. The total process is summarised in *Fig. 2*.

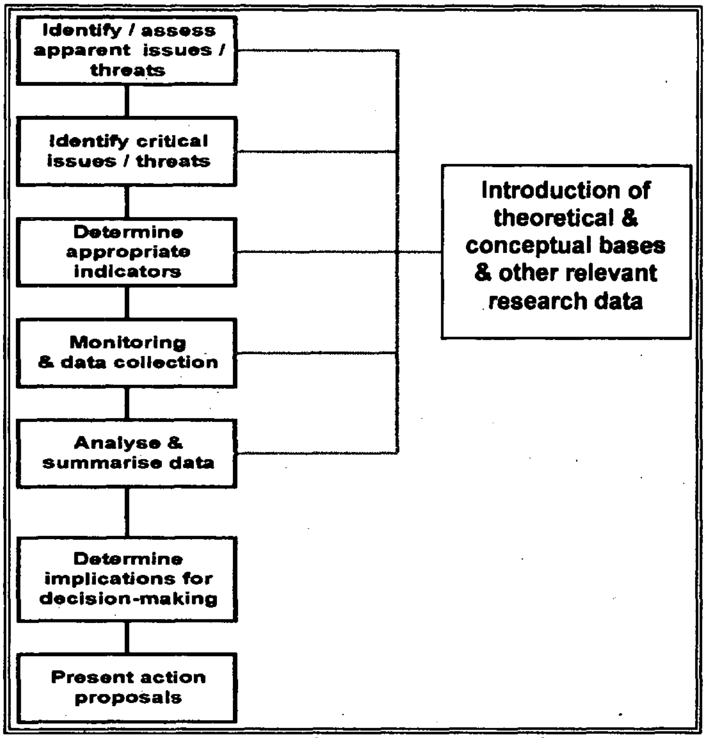

Fig. 2 : A Summary of the Monitoring process at Jenolan Caves, N.S.W.

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KARST CAVES IN THE IRKUTSK AMPHITHEATRE, RUSSIA: ECOLOGICAL CONDITION AND PROBLEMS OF CONSERVATION

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Summary

The ecological state of the 75 best known caves in the Irkutsk amphitheatre was analysed in terms of changes to the natural state of the underground systems, anthropogenic rubbish and changes to air quality. The ecological states of all the studied caves have been altered. To assist in establishing measures for conservation of the caves, three categories were defined: strict, moderate and limited conservation.

The Irkutsk amphitheatre

Karst rocks occupy some 50 % of the Irkutsk amphitheatre, a total of more than 400,000 km^2. Dissolved rocks are disposed in all stratigraphic stratums and geostructural elements of two main karst regions, the Siberian Platform and its mountain range. Karst is developed in carbonate and sulphate rocks and salts of Lower Cambrian, dolomites and limestones of Ordovician, Silurian and Devonian of Platform and Precambrian rocks of mountain regions - crystalline marbles, limestones and dolomites. Depending on geological, geomorphological and hydrogeological conditions, karst occurs on the surface of the earth or revealed at depths of more than one kilometre.

More than 200 caves have been discovered in the Irkutsk amphitheatre, the longest being the 30 km Botovskaya /1/ in the Zhigalovsky Region (Here and in the rest of the text the number /X/ corresponds to that shown on *Fig. 1*). The deepest pit is the 144m Kurtujskaya /56/ in the Cheremkhovsky Region. Urungaiskaya /67/ and Spirinskaya /69/ caves in the Nizhneidinsky Region have underground lakes, Trofimovskaya /75/ in the Nizhneudinsky Region has cascades and Argaracan /3/ in the Kachugsky Region and Mechta /9/ in the Olkhonsky Region have huge ice fields.

Ecological state of caves in Irkutsk amphitheatre

It is possible to divide the processes which are changing the appearance of the caves into two groups: natural and artificial. Collapse is the main natural process in the caves of the Irkutsk Amphitheatre. Two caves, Big and Small Nizhneudinskie were formed from the one underground cavity - Nizhneudinskaya as a result of collapse of its ceilings. That is why the researches very often is writing about a single Nizhneudinskaya cave [1-3]. The same process has shortened the length of Hudugunskaya /63/ cave from 2.5 km twenty years ago to less than 1 km. Constant collapses are observed in Mechta /9/, Zagadaj /18/ and Bolishaya Onotskaya /57/.

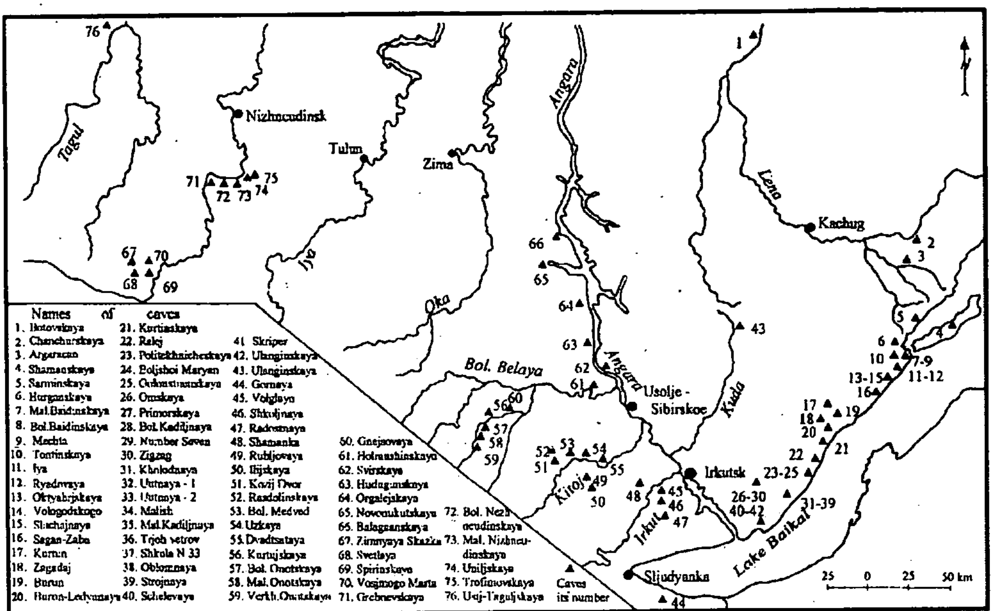

Fig. 1 Caves of the Irkuts Region

Artificial processes are due to different kinds of human activity. As a result of the building of a hydroelectric power station on the River Angara cave Balaganskaya (Meljhetuiskaya /66/) with unique ice crystals, and wave cut caves on the west shore of Lake Baikal, were irrevocably lost. In connection with the extraction of the limestone, underground cavities with priceless archaeological materials are blocked up in Bolishaya Kadilinaya (west Baikal). The entrance to Rasdolinskaya pit (Bezdonnaya Yama) /52/ (Angarskiy Region) has been filled by bulldozers several times. In November 1999 42 old gas ballons were threw down in this cavity by the Angarsk Chemical Plant.

Between 1993 and 1998, with the support of the Russian Society of Nature Protection, the exploration of the ecological state of the 75 best known caves in the region (*Fig. 1*) was organised. According to our research, inhabitants, schoolchildren, caving and unorganised tourists are the main visitors to the caves. The single excursion (tourist) speleological route through Mechta /9/ in Malomorskaya is inoperative at the time of writing. Three groups of intensity of visits to caves were distinguished: weak, middle and high (*Table 1*).

The underground cavities of the Irkutsk amphitheatre are characterised by considerable violations of their ecological state by human activity. These violations included: changes to the natural state of underground systems, anthropogenic rubbish and changes to air quality.

Table 1 Visits in caves of the Irkutsk amphitheatre

Number of regions	Number of the caves in regions	Visitors in caves	Intensity of the visits	Breaching index of the ecological state of the caves		
				changing of the natural state	antropogen rubbish	changing of the air
1	2,3	inhabitants speleologists	weak	-	1	-
2	4-16	inhabitants speleologists tourists	high	3	3	1
3	17-21	inhabitants speleologists	weak	-	-	-
4	22-42	inhabitants speleologists tourists	mean	1	2	-
5	45-48	inhabitants speleologists	mean	-	-	-
6	49-55	inhabitants speleologists tourists	high	-	2	1
7	56-60	inhabitants speleologists	high	3	3	-
8	61-66	inhabitants speleologists	weak	-	2	-
9	67-70	inhabitants speleologists	weak	-	-	-
10	71-75	inhabitants speleologists tourists	mean	-	2	1

The changes of the natural state included:

- violations of underground systems: creating additional entrance(s), re-equipment of natural entrance, widening of cavity size for access.
- deformations of cave sediments: water-chemical - damage and destruction of stalactites, stalagmites, etc.; cave ice - damage and destruction of long standing ice crystals, ice stalactites, stalagmites, ice fields; water-mechanical, biogenic and anthropogenic - presence of geological, palaeontological and archaeological prospect-holes. (Classification of cave sediments was carried out according to *Sokolov- Maksimovich* [4]).

Anthropogenic rubbish includes:

- food wastes, food packages, used equipment.
- mould which is formed usually at low parts of underground systems after human visits.
- inscriptions by paint on cave walls and ceilings.

Changes of air included the smell of rotting organic material and of oil.

All violations of ecological state in caves were graded as: weak - 1, middle intensity - 2, considerable - 3 points (*Table 1*). According to our data, only a few caves, which are situated in the least accessible regions or which were opened not more 10 years ago, are characterised by absence of violation to ecological state. For the majority, considerable changes to the natural state of underground systems and accumulations of anthropogenic rubbish were noted and in several caves changes to air quality were noted.

The Irkutsk amphitheatre was divided into ten ecological-speleological regions (*Fig. 1, Table 1*). The caves in Region 1 (north part of considered area) are in relatively good condition as they can only be entered in the winter season as the underground systems are surrounded by swamps and are on the border of a separately conserved area, the Baikalo-Lenskiy reserve. The underground systems of Region 2, the west shore of lake Baikal, in front of Olkhon Island have the most violations of ecological state as it is a popular area for summer tourism. Underground systems of Region 3 (valley of River Buguldeika) are practically without changes under anthropogenic pressure, because the majority of caves were opened not more than 10 years ago. Region 4 is one of the oldest speleological region in the Irkutsk amphitheatre, but the only access to this area is by water from 1986 tourists were limited by a conserved regime of nature. Some caves situated in the boundaries of the zone of ecological safety of Irkutsk Town form Region 5. These caves are used usually for training young cavers. Volglaya Cave /45/ is a component of the ecological path which is elaborated for the ecological museum in Bolishoi Lug Village. The underground cavities of Regions 6 (valley of River Kitoy) and 7 (valley of River Bolishaya Belaya) are visited rather intensively. Caves of Region 7 are easy accessible and convenient for visits by unprepared groups; as a result there is frequent deformations of cave sediments with flowstone often broken. In recent years, the activity of visitors in Region 8 (valley of River Angara between the Town Usolie-Sibirskoe and settlement Ust-Uda) has been lowered, chiefly in consequence of flooding by the water of Bratsk reservoir of the main site, Balaganskaya Cave /66/. Underground cavities of Region 9 are in an inaccessible area, the East Saiyan mountain (in upstream of valley of River Uda) and are therefore characterised by weak changes of ecological state. The caves of the River Uda valley near Nizhneudinsk Town wêre included in Region 10. This area is situated some distance from the larger towns in the Irkutsk Region but the caves are very picturesque and have a long history.

2. Conserved caves of the Irkutsk amphitheatre

Designation of caves as State Nature Monuments is a widespread method of cave conservation. The majority of caves have scientific, aesthetic, instructive and sport importance. There are 34 conserved caves in the Irkutsk amphitheatre. With the aim of devising measures for conservation of their natural state, three categories have been identified. The first category comprises caves with strict conservation, where only specialists should be allowed to work on the permission of Russian Society of Nature Protection. These should include underground systems with items of collection value, that is, palaeontological remains, archaeological cultural stratums (in the case of the latter, these caves should have the double status of geological and archaeological monuments) and fauna. It should not be permitted to publish the geographical position of these caves for reasons of conservation. The second category, with moderate conservation, should include underground cavities of great scientific importance and should only be accessible for scientific excursions and research. In these caves, scientific experiments have been undertaken and unique ice or dripstone formations adorn the walls, ceilings and floor. The third category, with limited conservation, should include caves with recreational and sport value and for these purpose they can be visited.

2.1 Caves with strict conservation

In the Irkutsk amphitheatre eleven caves in limestones, marbles and dolomites of the Archean, Proterozoic and Lower Cambrian have been included in this category (see *Table 2*). The Boljshaya and Malaya Nizhneudinskaya caves are situated at 250 metres above water edge of the River Uda, at the level of its 14th terrace that has been dated back to the Pliocene [5]. These underground cavities were first described in 1875 by the Polish geologist *I.D. Chersky* [1-2]. He found the remains of fossilised Quaternary fauna in the sediments of Malaya Nizhneuidinskaya including Rhinocers antiquitatissen tichorhinus, Antilope borealismihi, Myides brantii and Egnus hemionus. An expedition of the Palaeontological Institute of Academy of Sciences of the USSR worked in the caves in the 1930's. In the course of the work, new bone material was found, confirming and adding to Chersky's conclusions [3]. A number of things indicate that the Boljshaya and Malaya Nizhneudinskaya caves could have served as a refuge for stone age people. In the deposits of Malaya one, the wooden end of a harpoon, covered by a thick crust of limestone, was found and some of the fossil animal remains showed signs of damage caused by human [6].Apart from the scientific value, the cave's aesthetic significance should not be overlooked. This is particularly true for Malaya cave. A number of transparent ice stalagmites, 0.5 metre high, are situated near its entrance, and its walls are covered by micro waterfalls. A small ice crust is noted in the Boljshaya cave.

Palaeontological material, witnessing to the fact that the area to the west of Baikal was inhabited by an animal of the wide open steppe, Egnus hemionus Pall, was revealed in Malaya Kadiljnaya cave/35/ [7]. Archaeologists have found the remains of New Stone and Iron Age cultures in sediments of a number of underground cavities in Baikal area including stone and bone instruments, household tools and fragments of clay pottery with a variety of ornaments in the Hurganskaya /6/,Boljshaya Kadiljnaya /28/, Tontinskaya /10/, Boljshaya and Malaya Baidinskaya caves /7-8/ [7-8].

Boljshaya and Malaya Baidinskaya caves are characterised by their underground ice fields. Starting from 1995 the melting of this ice has been observing, in average an intensity is reaching of 10 cm per year in Boljshaya Baidinskaya and 1 cm in Malaya. The remains of malacofauna, revealed in the lower part of underground ice field in Boljshaya Baidinskaya cave, witness to the ice's formation in the Pleistocene-Holocene [9]. Insects of Class Entognapha were found in Primorskaya /27/, Trjoh vetrov /36/ and Oblomnaya /38/ caves.

2.2 Caves with moderate conservation

Eleven caves have been allocated to the category of moderate conservation. These were formed in limestones, dolomites and marbles of the Archean, Proterozoic and Lower Cambrian (see *Table 3*). Argaracan Cave, discovered by the geologist G.P. Vologodsky and A.P. Vagina in 1968, is one of the largest caves in the Region. Its underground cavern is of the complicated multi-level cavity kind. The first level is characterised by the presence of an ice field with area 35 m^2 and thickness 2 m. The ice is of congelation genesis. At present, observations are being conducted for the dynamic of underground icing, according to bench marks. Towards the end of winter crystals of sublimation ice up to 8-10 cm in cross section are formed near the entrance. On the second level of the underground cavern, stalactites, stalagmites and draperies of pink, white, red and brown colours are wide spread. There are also small lakes with calcite formations. The walls and floor of the third level are covered by liquid clay of a red-brown colour, and in some places rock slide deposits occur.

Hudugunskaya cave /63/ is an example of an underground cavity aligned along systems of tectonic fissures. The majority of passages lie in two main directions, 40-50 degrees and 300-320 degrees. Because of collapses, the length of this underground cavity has decreased from 2.5 to 1 kilometre during the last twenty years.

Mechta Cave /9/, formed in crystalline limestones and marbles along tectonic and lithogenetic crevasses, was discovered in the 1960s. It is characterised by its 200 m^2 underground ice field. Exotic ice formations occur here. They have the names "Ded Moroz" (Father Frost), "Snegurochka" (Snow Maiden) and "Raketa" (Rocket). Red-brown and, in places, snow-white corallites are widespread on the walls and ceilings. All galleries of the inner cave are littered with rock slide deposits with some blocks as large as 4 x 2 x 1.5 m.

Unique needle crystals of pseudomorphs of quartz on aragonite have been revealed in the Boljshaya, Malaya and Verkhnyaya Onotskaya caves /57-59/. Cave "Jewels" in the forms of oolites, from a few millimetres to 5 cm in size, have been found on the bottom of a lake with a depth of 20 cm, in Rasdolinskaya pit /52/. In the opinion of S.A. Kokorina [10], these "jewels", which have a specific weight of 2.856, are formed of manganese calcite $[CaMn(CO_3)_2]$.

Classic "sugary" ice stalagmites up to 1.5 m tall occur near the entrance of Zagadaj cave /18/. A geological prospecting hole in clay which was dug in one of the cave's halls is more than 8 m deep. The lakes of the Zimnyaya Skazka /67/ and Spirinskaya /69/ caves represent a single hydrodynamic system. Bench marks are situated here. Deposits of the lower level of Politekhnicheskaya cave /23/ are full of mammalian bones. Further palaeontological exploration is required to determine the category of conservation for this underground cavity.

2.3 Caves of limited conservation

The largest horizontal cave in the Region - cave Botovskaya, and the deepest pit, Kurtujskaya, were included in this group (*Table 4*). Botovskaya cave is a cavity of the carcass kind with alternation of narrow passages and small grottoes. Aragonite crusts were found in this cave. A feature of the Kurtujskaya pit is a sheer 50 m shaft, the deepest in the study area. Five caves on the west shore of lake Baikal have become widely known: Iya, Ryadovaya, Oktyabrjskaya and Vologodskogo /11-14/ which are on a karst plateau at 250 m above lake level and Sluchajnaya /15/, 4 km from the plateau. All these cavities are used as tourist caves. Iay cave had an ice field, whose size in November 1977 was 226 sq.m, in July 1997 complete thaw of it was registered. Other caves of limited conservation are Vosjmogo Marta /70/ and Svetlaya /68/ where thread like crystals of ice are observed in winter.

Conclusions

The ecological state of underground systems in the Irkutsk Region has been derogated by anthropogenic pressure. Hence, it is necessary to accelerate the process of awarding to caves the status of State Nature Monument and of determining a conservation category for every cave. These processes have been delayed by a lack of local knowledge and of specialists. For this reason, it would be desirable to conduct scientific expeditions, possibly international, in order to appreciate the scientific value of the caves and to suggest recommendations for the conservation of their natural state. This is urgently required, as the caves of Baikal west shore are the most frequently visited. Moreover, from the 5th of December 1996 Lake Baikal was inscribed in the World Heritage list.

Acknowledgements

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HUMAN ACTIVITY AND CONSERVATION IN THE GÖMÖR-TORNAI KARST, HUNGARY

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Summary

The caves of the Gömör-Tornai karst, in the Hungarian-Slovakian border territory, were declared as part of the World Cultural and Natural Heritage by the World Heritage Committee of UNESCO by its resolution of 06.12.1995. This resolution, however, concerns only the caves and does not automatically include the overlying karst planinas or the allogenic catchment despite the fact that without special protection of the whole karstic environment, the caves themselves cannot be properly defended from harmful effects. A morphological, hydrological and ecological study of the Gömör-Tornai karst has demonstrated the adverse consequences of human activity and raised the question: "Is it possible, and are we able to regulate the different economic activities"?

Introduction

The caves on the Gömör-Tornai karst rising on the Hungarian-Slovakian border territory were declared as part of the World Cultural and Natural Heritage by the World Heritage Committee of the UNESCO by its resolution of 06.12.1995. This resolution however concerns only the caves and does not expand automatically on the karst planinas hiding the caves although without the special protection of the whole karstic environment, the caves themselves cannot be defended from harmful effects. With the morphological, hydrological and ecological study of the Gömör-Tornai karst, the burdening consequences of human activity can be revealed. I searched the answer to that question, whether the protection given to the Gömör-Torna karst at present is enough to ensure the equilibrium and the survival of the karst on the long run. Is it possible, and are we able to regulate the different economic activities conducted on the karst, can the view points of the economy (agriculture, industry, transport, pipeline transportation, quarrying, cement and lime production) be brought to agreement with those of the karst planinas and caves, and where can the borderline between the different interests be drawn.

During my research I tried to give an answer to that question how the progress can be maintained on the karstic territories at the present level of regulation of nature protection. The long time protection of the natural values and caves considered as part of the World Heritage make the evaluation of the ecological hazard sources necessary on both side of the border. With my geomorphological, hydrological and ecological researches I would like to call attention on the sources of hazards on the protected territories of the Gömör-Tornai karst and its environment.

Dangers from transport routes

The main transport roads and rail as well as the oil and earth-gas pipelines cross the Gömör-Tornai karst situated between the Gömör and the Abaúj-Torna basins. The main source of danger is the "Friendship oil-pipeline" which lies about 1-5 kms from the border. Starting from the Torna valley it continues upwards, turns at Szilice and runs near the Szilice ice-cave, descends to the bottom of the Borzova-polje and finally cuts the western edge of the Szilice-plateau and reaches the Sajó valley (*Fig. 1*). The fracture or leakage of the oil pipeline would endanger the whole subsurface waters of the karst plateau. If the pipeline would break between the Torna valley and Szilice, the oil would cause natural disaster at the Western part of the Alsó mount. The oil would appear in the main spring of the Torna valley, in the Sólyom spring. As the border in this area lies in the centre of this narrow plateau, the oil damage would reach Hungary as well and it cannot be abandoned that the oil would appear in the upper springs of the Ménes valley (Lizina springs). This could have consequences in the international law. If the break in the pipeline would occur North of Szilice the oil could be observed in the Sajó valley (Fehér s., Pisztráng s., Nagykő s., Vár s.). The waters of these springs are being collected by the Rožnava - Moldava n. Bodvou - Košice (Rozsnyó – Szepsi - Kassa) water-pipelines, thus the oil would endanger the water supply of these cities. If the break would occur South from Szilice, then it would appear in the Fekete-spring at Gombaszög, ruining the natural beauty of the Gombaszög cave and the Szilice ice-cave. If the break would happen near Ardo the infiltrating oil would spoil the drinking water of the Buzgó spring at Lekenye (*Orvan, J. 1979.*). However

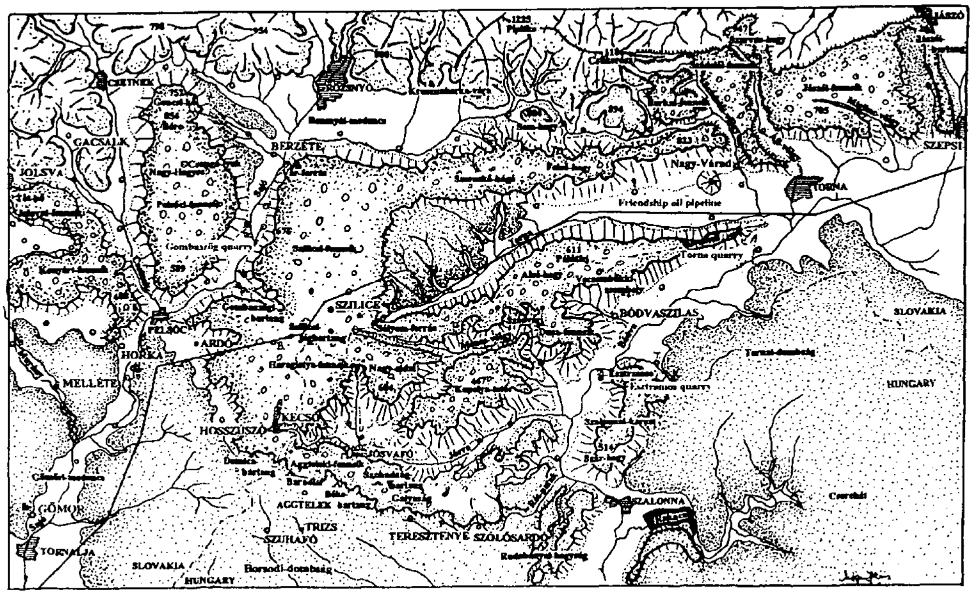

Fig. 1 The "Friendship Oilpipeline" on the plateaus of the Gömör-Tornai karst

the water of this spring is still not captured. The oil, not speaking about the above mentioned springs would reach the deep karst-water circulation zone and could endanger further territories.

It would be important to abolish the route of the so-called "Friendship-pipeline" which crosses the Szilice plateau, and this is the vital necessity of both countries. Without a very high cost a new trail can be founded through the Szoroskő pass or through a tunnel-system built under the plateau.

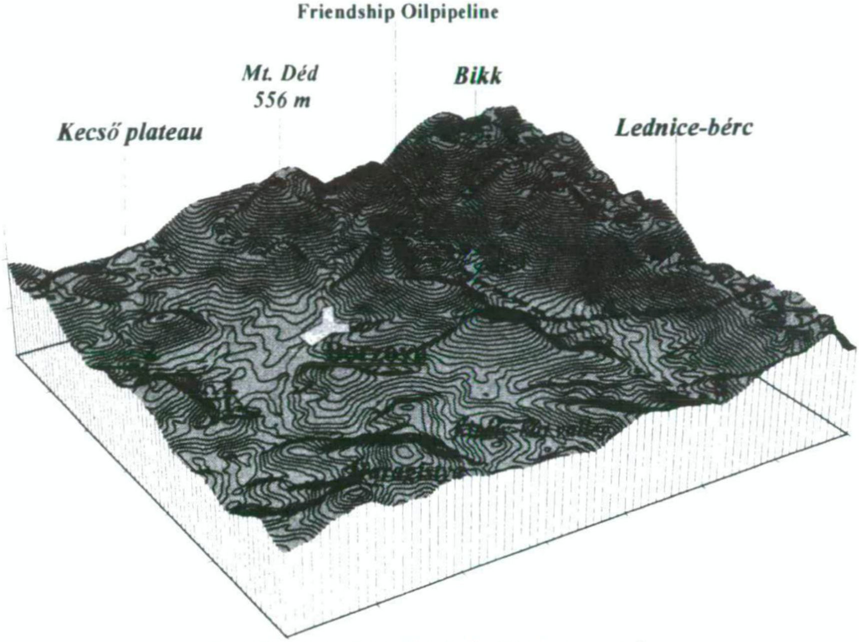

Fig. 2 The "Friendship Oilpipeline" in Borzova polje
(1.Milada cave, 2. Matilda cave, 3. Szilice ice cave, 4. Vörös-kő swallow hole, 5. Paskó-tó spring)

Dangers from quarrying

Another source of danger are the quarry's found on the territory of the Gömör-Tornai karst in the neighbourhood of the National Park and the Slovakian Karst Nature Reserve. Out of the three main quarries the Esztramos in Hungary has stopped to function so its caves escaped destruction. Serious natural damage is caused on the whole of the karst and to Hungary as well by the Torna quarry (*Fig. 1*), which destroys the Eastern edge of the Alsó-hegy. At the quarry close to the border there are explosions daily, disturbing natural life at the National Park of Aggtelek. The operation of the quarry at Torna should be limited. It should be examined whether international law allows a country to conduct an economic activity endangering nature through sound and dust effect close to the border of another country in such a sense that the neighbouring country can only share the disadvantages. With the process of privatisation quantity restrictions should be established so that the Alsó hegy does not fall victim to any personal or lobby interests.

Dangers from urban development

During the Middle Ages on the plateaus of the Gömör-Tornai karst many small villages were formed, but among these only two survived on the Szilice plateau, Szilice and Borzova (*Fig. 1., Fig. 2.*). There is no solution to the transportation of the refuse and rubbish in the villages situated on the karst plateaus. The rubbish is heaped up in the dolines close to the swallow holes. The water flowing down the swallow holes continuously spoils the water of the Kecső and Fekete springs. Though there is no industrial activity in the two villages, but the remains of chemicals accumulating in the agriculture and in the households, together with solid waste and outlet water spoil the karst waters after reaching the karst, and endanger the caves which are part of the World Heritage - among them the Szilice ice cave and the well known Gombaszög cave as well. The storage, cleaning and transportation of the wastewater of the two villages with competence are among the primarily important tasks.

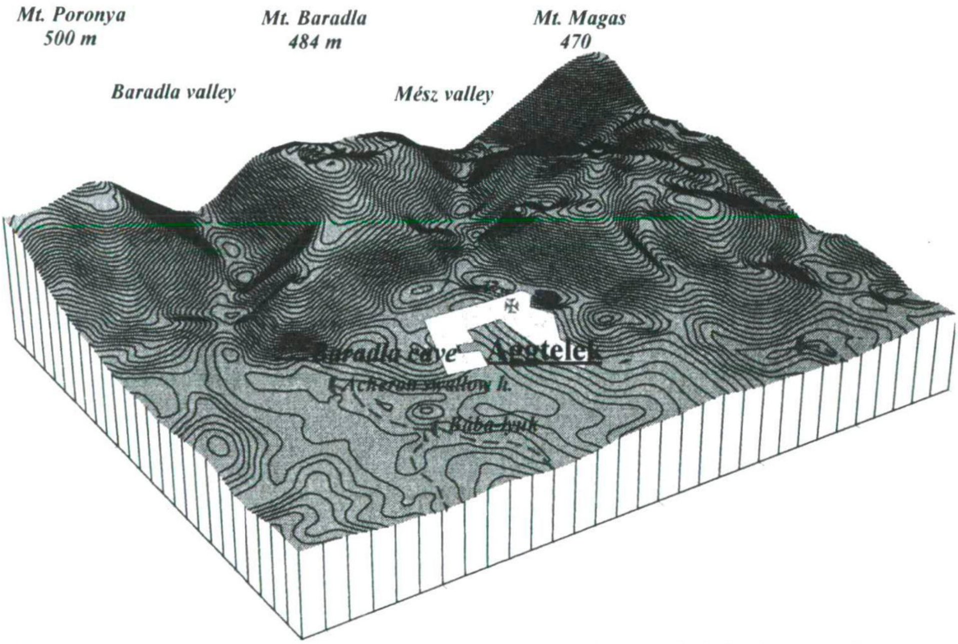

Fig. 3 The entrance and the surrounding topography of the Aggtelek cave and relationship to swallow hole location

Dangers from tourism

The great number of tourist visiting the caves cause an ever growing environmental burden. It is a difficult task to give a solution to the growing demand of water and drainage problems at the entrance of the Domica and Baradla caves, where a big number of swallow holes open and conduct the waters into the cave system. A major ecological hazard is caused by the buildings established for the reception of tourist groups in the village of Aggtelek and its environment lying on the side of the swallow holes of the cave system. In the past years an average of 150-200 000 visitors arrived at the Aggtelek cave. The tourists move in a somewhat narrow circle around the entrances of the cave system, as the establishments for accepting visitors were constructed here, such as the hotel, the motel, the camping site, restaurants, snack bars, shops – together producing a concentration of natural damage. The collection and transportation of solid waste materials produced by the above mentioned establishments at the entrance of the Aggtelek cave has been solved already, but the conducting and cleaning of outlet water still awaits a solution. The surface water system heading towards the Aggtelek cave entrance and the swallow holes opening on the edge of the Aggtelek plateau (*Fig. 3*) make the special treatment and storage of wastewater necessary. The ultimate solution would be the transportation of communal waters to the outside of the Baradla-Domica water shed.

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AN ECOLOGICALLY BASED, COMPUTER ASSISTED, FOREST REHABILITATION PROJECT IN THE AGGTELEK NATIONAL PARK, HUNGARY

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Summary
In 1996. reformation of the forest laws in Hungary provided opportunities for a new type of silviculture which is free from conflicts with environmentalists. Both the environmental and the silviculture laws state that forests in nature reserves should be protected. This paper describes a planning method which is based on forestry and ecological factors and uses the Arc/Info GIS software. The aim was to optimise the segments of functionally and environmentally protected landscapes and the result is a vegetation pattern which can be implemented by forestry managers. The advantages of the process are that the data used in the project can easily be modified and completed and that the method can be used to construct „economic forests". The technique could be used in other areas by taking the local characteristic features into consideration.

Introduction

The reformation of law in 1996 meant a great leap forward forming a new type of silviculture which is free of conflicts with the environmentalists. Both the environmental and the silviculture law state that forests in nature reserves should be ranked among protected ones and steps should be taken for the sake of the cause. That is why such a projects are needed which are based on forestry and ecological principles neglected in the past.

Object

This project can be used in other areas as well by taking the local characteristic features into consideration. However, I thought that I can give a clearer description of the project by using it in a particular model area where the above mentioned facts are everyday problems.

Aggtelek National Park (ANP) is situated in North Hungary. Thus, in north the National Park borders with the Slovak Karst Protected Landscape Area in the Slovak Republik. Considering the geology, landscape geography and cultural history, these two protected areas form an integral unit and both were declared as biosphere reserves in 1979 (UNESCO's Man and Biosphere Program). The caves of Slovak Karst and Aggtelek Karst were inscribed in UNESCO's World Heritage List in 1995. ANP's area has being protected by law since 1978 and had been declared as a National Park in 1985. There are three kinds of protected areas in ANP, their names are zone A (the most protected part), B and C. (*Fig. 1*) *(Salamon 1998)*

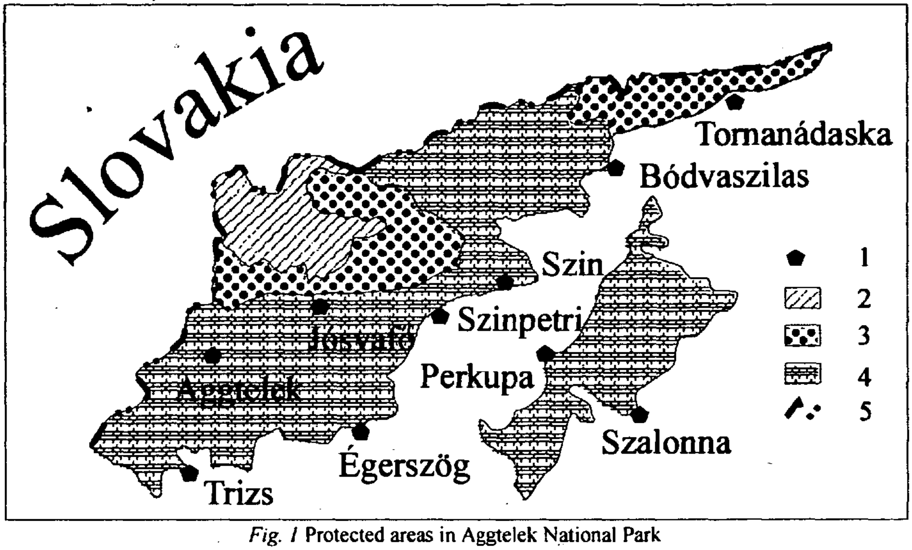

Fig. 1 Protected areas in Aggtelek National Park
(1.: settlement; 2.: zone A; 3.: zone B; 4.: zone C; 5.: border line)

I have chosen a 190 ha area of the most protected part of the zone A of Aggtelek National Park. There are very poor, poor and average qualified stands with lot of foreign species. (*Fig. 2*)

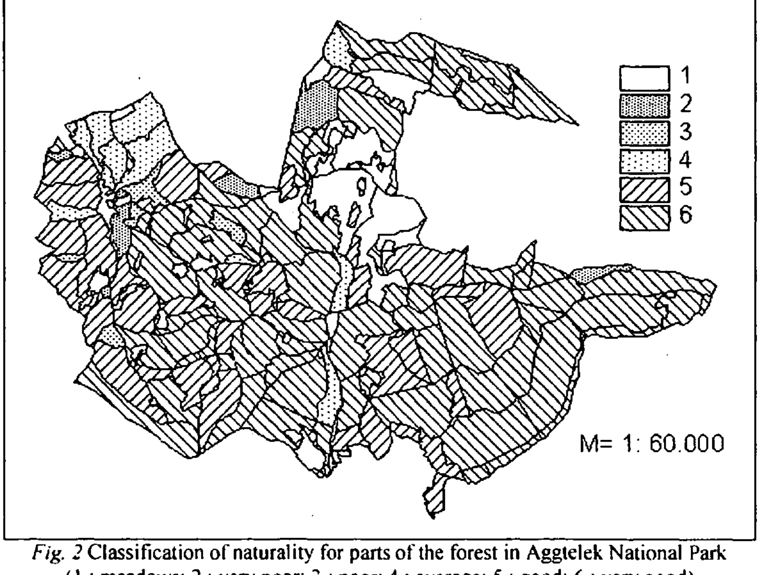

Fig. 2 Classification of naturality for parts of the forest in Aggtelek National Park
(1.: meadows; 2.: very poor; 3.: poor; 4.: average; 5.: good; 6.: very good)

This is a natural zone where according to the conception of 1998 the aim of silviculture is to maintain and restore those forests which are free of foreign species, which peculiar to a given habitat and have similar association in age and species to the original forest.

Besides in karstic areas it is very important to save or restore the soil since together with subsoil water pollutants can easily get into the karst system destroying its ecological condition. In order to solve this problem it would be advisable to form deciduous forest associations peculiar to the area.

My aim was to make a method in order to form the most appropriate forest associations.

The adopted influential factors

The most important influential factors in terms of forest associations were thought to be: Forest climate, Height above sea level, Aspect, Slope, Genetical soil conditions, Depth of soil and Physical soil conditions (*Fig. 3-9*).

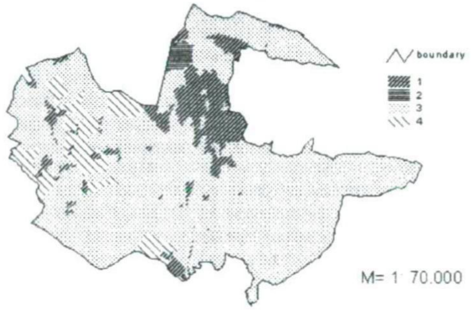

Fig. 3 Forest climate types in zone A
(1.: meadows; 2.: beech; 3.: hornbeam; 4.: turkey oak)

Fig. 4 Height above sea level in zone A
(1.: 200-300 m; 2.: 300-400 m; 3.: 400-500 m; 4.: 500 m <)

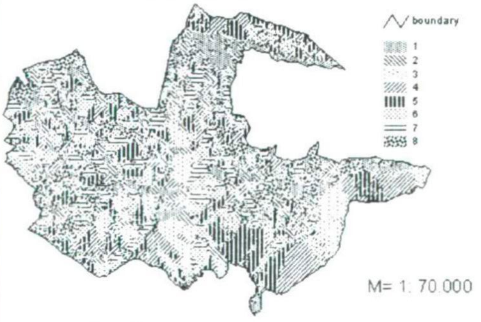

Fig. 5 Aspect categories in zone A
(1.: NNE; 2.: ENE; 3.: ESE; 4.: SSE; 5.: SSW; 6.: WSW; 7.: WNW; 8.: NNW)

Fig. 6 Slope categories in zone A
(1.: 0°-5°; 2.: 5°-25°; 3.: 25°<)

Fig. 7 Genetical soil conditions in zone A
(1.: meadows; 2.: skeletal soil, bedrock; 3.: rendzina; 4.: brown earth; 5.: brown forest soil; 6.: alluvial soil)

Fig. 8 Depth of soil in zone A
(1.: meadows; 2.: 0-20 cm; 3.: 20-40 cm; 4.: 40-60 cm; 5.: 60-100 cm)

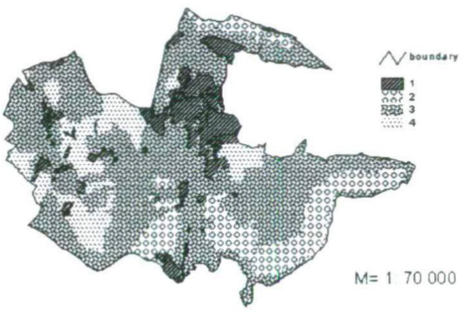

Fig. 9 Physical soil conditions in zone A
(1.: meadows; 2.: fragmentary; 3. adobe; 4. clayey)

The planning method

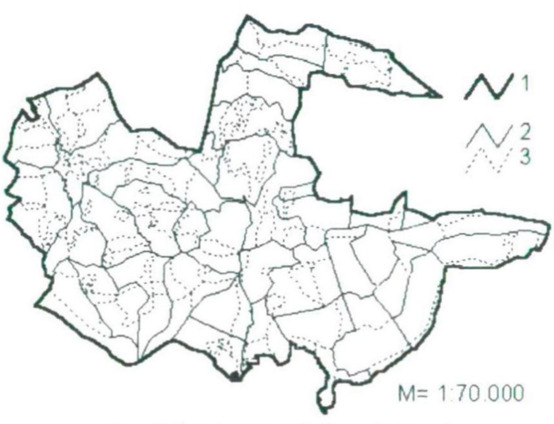

Fig. 10 Forest parts and pieces in zone A
(Boundary of zone A(1), forest parts(2) and forest pieces(3))

The question has arisen how to operate with different local data. I solved the problem with Arc/Info software using GIS. (Geographical Information System). I worked out the value of height above sea level, aspect and slope factors by using a digital elevation model. The model was constructed by the program itself from the contour lines of a digitalised topographical map, scale of 1:10.000. In all three cases I reclassified the values (which were automatically counted from the model) by using values appropriate to the type of habitat. Then I transformed the values into polygons. The values of the other factors were collected from the current forest plans and systematised by a database-operating program. Then I digitalised the barriers of forest spieces and parts on the basis of a forestry map.

The data in tabular form were coordinated to the digitalised polygons. Following this process I could use each factor type as a polygon, I could make operations with them and could easily represent them. If I indicated each factor type with different order of numbers and then added the layers containing polygons, I could get each combination of numbers which are peculiar to the type of habitat. When I added the layers, I used the „overlay" GIS function. (*Fig. 11*) Later I determined the forest associations fitting to each combination. This was the result of the project. (*Fig. 12*)

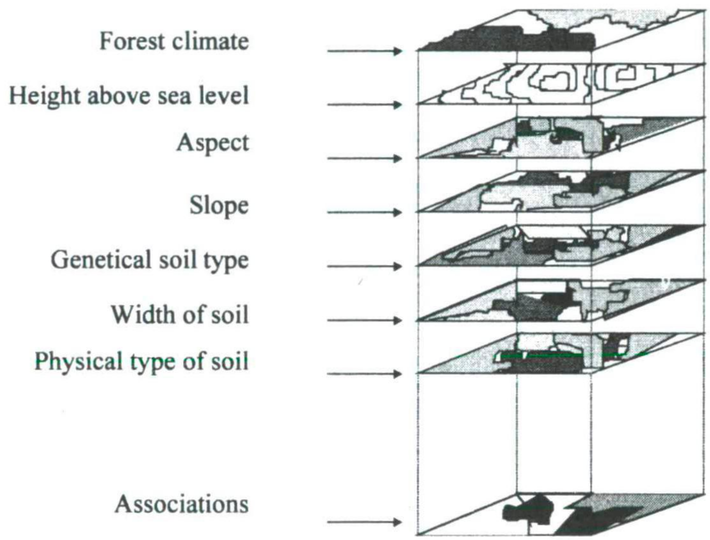

Fig. 11 The overlay GIS function

Summary

The method supports sustainable silviculture and its necessity is stated by law. The aim is to optimalize functionally the environmentally protected landscape segments. The result of the project is a vegetation pattern which can be carried out by the forestry itself. (*Fig. 12*). The advantages of the process is that the data used in the project can easily be modified and completed as well. The method is useful for constructing the so called „economic forests". Besides that, build upon the digital database we can make quickly and easily very accurate and smart thematic maps. (*Fig. 2-10, 12*).

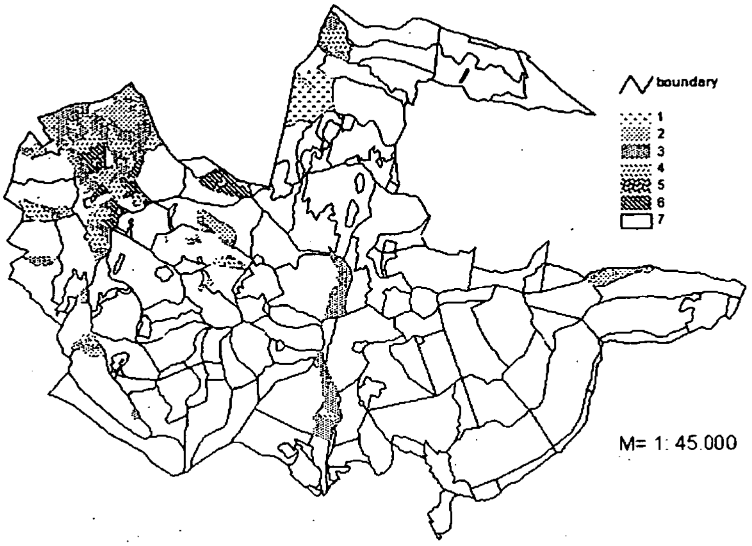

Fig. 12 Optimalized associations for the planned forest parts in zone A
(1.: mixed beech; 2.: hornbeam with beech; 3.: oak with hornbeam; 4.: oak with hornbeam and turkey oak; 5.: linden-ash forests; 6.: oak with turkey oak; 7.: not planned parts)

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THE PLANNED LANDSCAPE PROTECTION AREA IN THE WESTERN MECSEK HILLS, HUNGARY

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Summary
The Duna-Dráva National Directorate (Hungary) is planning to establish a new landscape protected area in the Western Mecsek Hills. This nature reserve would incorporate almost the whole karst surface and a large limestone area on 8000 hectare. We hope that this landscape protection will help to protect not just the karst phenomena but the landscape, the unique flora and fauna, and it will help a facility for recreation. This poster try to represent mostly the speleological and karstmorphological values.

Why do we need a new nature reserve?

The eastern part of Mecsek Hills is under nature protection as Kelet-Mecsek Tájvédelmi Körzet (Eastern-Mecsek Landscape Protection Area) since 1977 because of its flora and wildlife. Now we are working to prepare a new nature reserve in Western Mecsek Hills, which is partially karstland. The planned landscape protection will contain almost the whole karst and the sandstone surfaces. The total area of the planned nature reserve is approximately 8.000 ha, out of it the area of karst surfaces is altogether 5.000 ha. In this poster we would like to show the natural values of this karstland.

On the karst surface there are several kinds of karst phenomena (caves, dolinas, sinkholes...) and natural forest with unique flora. The karst is important water source of some settlements on the edge of hills. Every year more and more tourists visit the Abaliget-cave, our study trails and the peaceful hills and valleys. To preserve the naturalness and clearness of this land for the next generations the best way is to establish a huge, contiguous nature reserve.

The present state

Now there are four smaller nature reserve in Western Mecsek Hills: Melegmány Nature Reserve (on karstland), Jakabhegy Nature Reserve (on sandstone), the surface of Abaliget-cave and Pintér-kert (botanical garden on limestone). We have three study trails: Jakabhegy-hill study trail, Abaliget-cave study trail, and the Tettye-hill study trail. There are more than hundred known caves, four of them (Abaliget-, Kőlyuk-, Vízfő- and Mészégető- cave) are strictly protected. In Abaliget village there is the only one show cave of South-Transdanubia, the Abaliget-cave, every year visited by more than 50,000 people. The cave is under reconstruction.

The caves

The Mecsek Mountains is situated on the southern part of Transdanubia. It has a very complex geological structure. The western part of the mountains is built up of Middle Triassic well karstified limestones and dolomites. The karst area is about 35 km^2. In the southern neighbourhood of the limestone, Lower Triassic red sandstone and aleurolite areas can be found. They are source areas of small water courses which reach the limestone and disappear in sinkholes and re-emerge in springs on the edge of the hills. The subsurface streams could have carved several caves, but unfortunately just a few have been explored. The largest one is the Abaliget-cave which is about 1.5 km long and the main passage of the cave is utilised as a show cave. In one branch nice helictits are visible. Under the surface there are several hidden caves, waiting for exploration. Behind the 21 meters deep siphon of Vízfő-cave there is an unexplored cave which is maybe five or six kilometres long. We know several potholes, but they are not too deep and often filled by sediment. The deepest cave in Mecsek is Spirál-cave which is a sinkhole on the catchement area of Vízfő-spring. Its total depth is about 100 meters.

The Tettye- spring made a freshwater limestone hill on the southern foot of Mecsek and there is a more than 100 meters long cave in this rock. In the caves of the southern Miocene limestone the evidence of man from the Iron age was found. Some caves contain fossils mainly from the Pleistocene age (e. g. mammoth bones).

The surface karst phenomena

On the karst surface of Western Mecsek Hills we can find lots of dolinas, their diameter is between 10 and 50 meters and some of them deeper than 10 meters. The bottom of few dolinas are covered by clay so we can see small lakes in these dolinas. Dolinas have special climate as it is indicated by the vegetation. The former surface streams carved valleys into the limestone. Due to the surface sedimentation some valleyfloor covered by beautiful freshwater limestone steps as it visible in the Melegmány and Magymély valleys. In the deep, young, erosion formed valleys sometimes we can see waterfalls, when the streams flow over the sinkholes. On the southern slopes there is karrenfield which is hardly covered by soil.

The karstwater

The karstwater has been very important source of drinking water for ages. The annual yield of the biggest karst spring is app. 2 million m^3/ year. Four karst springs are utilised as water supply. The Tettye spring have been utilised to supply the town of Pécs since the end of last century. In the eighties, when the utilisation was the most intensive, more than 1.5 million m^3 water was used as drinking water. Unfortunately, the utilisation of spring caves caused several irreversible changes in the caves, dripstones and other speleothemes has been destroyed, passages has been enlarged and lot of concrete had been carried into the caverns. The karst springs have an another importance, because two of them supplies the artificial lake system in the Orfű valley. The lakes and holiday resorts are the one of the biggest recreational centre of Baranya county. We are sure that the nature reserve will help to preserve or improve the water quality. Researches show, that the landuse has great influence on water quality. We studied the Vízfő spring, which catchement area covered by forest and Mészégető spring of which catchement area partially used as vineyard and holiday estate.

The sandstone surface

The sandstone Jakab Hill is the highest point of Western Mecsek Hills (592 m). On the top of the hill we can find the ruin of a Celtic earthwork and tumulus, inside the earthwork we can see a newer ruins of a monastery from the 13th century. On the steep southern slope we find the famous viewpoint of Zsongorkő, from where almost the whole plain of Dráva river is visible. Another geomorfological interests is the Babás Szerkövek, the natural sculpture from sandstone formed by the wind. The soil has low pH values, so there is special flora, its rare and protected plant is *the Vaccinium vitis-idaea.*

The flora and fauna

Almost the whole Mecsek Hills are under the influence of submediterranean climate consequently the Mecsek has unique flora in Hungary. Almost the whole planned landscape protection area (insist on the karst) is covered by forest. On the steep southern slopes we find karst brush forest with *Quercus pubescens, Fraxinus ornus* and *Cotinus coggigria* with several protected species (*Ophris cornuta, Adonis vernalis, Orchis purpurea...*). The top of the hills and the northern slopes are covered by oak and beech forests, the most common tree species are *Quercus petrea, Quercus cerris, Fagus sylvatica, Carpinus betulus.* In the deep valleys the *Fraxinus excelsior* and *Acer platanoides* are abundant. Bellow the trees we can see several submediterranean species, e.g. *Ruscus aculeatus, Thamus communis, Orchis simia, Asperula taurina, Convulvulus cantabrica* in the cool vallyeflors the *Phyllitis scolopendrium, Lunaria rediviva, Stachys alpina* are often visible. In the future the national park directorate have to defend the protected plants against the flower collecting tourists and we would like to minimise the amount of non-native coniferous species.

The caves are good habitats for several bat species, the Abaliget-cave is the most important bat hibernating and propagation place in South-Transdanubia (some species: *Rhinolphus ferrumequinum, Myotis dasycneme, Myotis daubentoni....*) In the grasslands along the streams we can find the nests of *Crex crex*, the lake system at Orfű village can provide habitat for *Lutra lutra.* Rare insects are *Rosea alpina, Isophya costata* and *Cordulegaster boltonii.*

THE GEOMORPHOLOGICAL VALUE OF DOLOMITE SURFACES IN THE BALATON-UPLAND NATIONAL PARK, HUNGARY

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Summary

The environmental sensitivity of karstic areas is well known. These areas could be important from environmental protection considerations and the value of the karstic landscape could be increased by its typical geological and geomorphological formations, by its flora and fauna. In Hungary the limestone areas have received considerable attention but the other karstic rock, dolomite, is less well studied. The dolomite areas possess the above-mentioned features, but show significant differences from limestone karstic areas due to the different mineral composition of the rock. The typical erosional processes on dolomite surfaces are not sufficiently well known but this knowledge is indispensable to environmental evaluation of these areas.

Geological situation

In the Balaton-Upland region, besides the Triassic dolomite, one can find limestone and non - carbonate rocks on the surface. Three main tectonic lines meet here, therefore, the tectonic structure of the area is complex, signed by preformed shallow valleys and large depressions (*Fig. 1*). The first scientist, who wrote a genetical analysis about this area, was Jenő Cholnoky, one of the best-known Hungarian geomorphologist of the first part of the 20th century. He explained these valleys and depressions as deflational landforms (1938). According to Márton Pécsi, periglacial climate caused the formation of dolomite's rubble and powder. In his opinion derasional valleys and their systems construct the surface.

Jakucs (1971) said, that dolomite rubbles are the result of karst solution. According to this theory the dolomite falls apart because it consists soluble carbonate minerals too. We think that all these processes have influenced the formation of the landforms, so it is the object of further investigation to determinate which process had bigger importance on the studied dolomite area.

Morphology

The primary surface of the Balaton-upland is divided into residual areas by swallow valleys and depressions. The tops of residual areas are in the same altitude. Residual areas, valleys and depressions are the macroforms of the landscape. The macroforms are divided by minor forms (e.g. monadnocks, dolines, deflated soilness marks). Their diameter ranges from few millimetres to several meters. On several places they appear as single forms, but usually they occur in groups. The most important factors of denudation are the following: The dislocations and joints are very important, as they preform and divide the area. The surfaces, which are broken by tectonic lines, separated into ridges by valleys. Wider plateaus exist between the valleys, which were formed not too close to each other. On the steeper slopes secondary valleys were formed, which divide surface into smaller parts. This is the formation of cons (monadnocks). On the less steep surfaces dolines and other depressions (such as the bottom of valley on a plateau and some ridges) occur. Any part of a valley and any depression could be transformed into the great depression system with varied layout. The area of the higher (residual) areas is decreasing, because the lateral growth of the lower areas. All the forms covered by shallow, lithomorphic soil with typical vegetation, with the exception of the deflated ones. Under the soil one can find autochthonous dolomite rubble layers in various depths. These layers are usually deeper in the valleys and depressions. We think that the depth of this autochthonous dolomite rubble cover is in connection with the intensive karstification. The development of depressions (dolines and some valleys) is in a close connection with the karstification process.

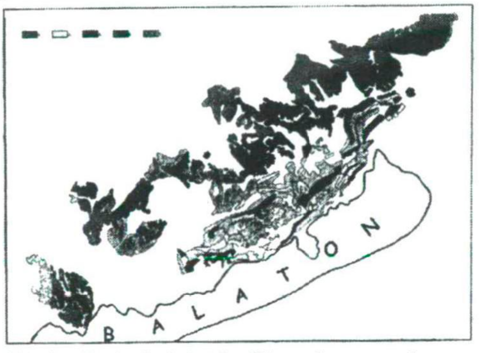

Fig. I. a Geological sketch of the carbonate-rock areas
1.: Main Dolomite (Upper - Triassic), 2.: "Megyehegy" dolomite (Lower - Triassic), 3.: Dolomite with cellar structure (Lower - Triassic), 4.: Other carbonate assise with dolomite, 5.: Other carbonate assise without dolomite

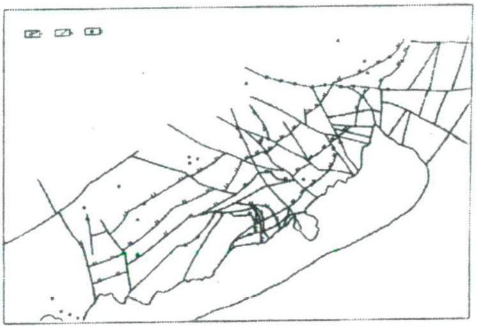

Fig. I. b Tectonic sketch of the Balaton-Upland area
1.: Upthrusts, 2.: Other dislocation faults, 3.: Dolomite-mines

Fig. I. c The most important geomorphological elements and their areal extent
1.: Tabular faulted mountains, 2.: Exhumed peneplane, 3.: Front of the Pediment

The microforms on dolomite are especially important. The karren forms on dolomite are smaller than on limestone rocks. They have little significance in aspect of surface forms. The following locally characteristic forms can be found on the studied surfaces: micropits, kamenitzas. Fracture-controlled linear forms are microfissures, splitkarren, grikes, cutters and karren caverns.Hydrodynamically-controlled linear forms can't be find because especially the heads of the layers have been uncovered, therefore, the extension of dolomite surfaces is relatively small. Some embrional forms can be seen on the area, formed by mixture corrosion or other solution processes on several sites, where dolomite outcrops.

Some aspects of landscape protection

In the Balaton-upland area, which was declared as a National Park recently, the following dolomite areas protected because of their significant natural values: Kis-Bakony Hill, Babuka Hill, Várhegy Hill, near the settlement of Hegyesd, Dolomite hills in the Pécsely-basin, Dolomite hills near Balatonfüred, Dolomite hills near Balatonalmádi and the Vilonya-plateau. Besides their typical forms, these territories represent important botanical values: the different vegetation types show very mosaic pattern and they are rich in species, therefore, they recorded as such a ecosystem that deserves the highest degree of protection by the World Strategy for Environmental Protection. The human pressure on the area is ambivalent. As the dolomite surfaces are less useful, the significant human effects arise just in some points, therefore, natural areas could maintain in significal extension.

The most harmful human activities are: overgrazing; plantation of non-native forests (Pinus nigra stands); stone mining and the usage of mine pits as rubbish dumps; besides the degradation of soil and vegetation on shooting-ranges and military-grounds, these areas are contaminated by special rubbish and pollutant materials; -unfortunately, in the neighbourhood of the popular visitor sites the rubbish catering is not satisfactory and the tourists eager to pick up protected flowers as well.

The Balaton-Uplands National Park

The Balaton-Uplands National Park was established in 1997 in the richest region in terms of culture, scenery and history of Hungary. It extends over 56 000 hectares. The natural and cultural values of the landscape can be protected successfully through large-scale zone division, i.e. having on a protected area a stepped structure and taking into consideration the interests of inhabitants, farmers and holidaymakers. There are three zones within the Balaton-Uplands National Park:

1. Zone I.: Core area (strictly protected area). An area which has retained its original condition protecting major natural values, untouched and to be visited freely via designated paths, though occasionally with permission only, with no farming.
2. Zone II.: Managed natural zone. Hardly disturbed area, close to its natural condition, requiring natural management methods, to be visited freely.

3. Zone III.: Tourist or buffer zone. The outer protection belt encompassing the settlements within the National Park, the vine hills, the mass tourism sites, the places exhibiting the values and offering repose to hikers (*Fig. 2*).

It can be stated that there is no perfect resolution for the protection of the dolomite's special geomorphological values of this National Park. In some cases the frontiers of the National Park were designated valuable geomorphological areas, not managed as a unit, and the protection is extended just over part of them. On the non-protected areas, we noticed numerous harmful effects that basically influences naturalness.

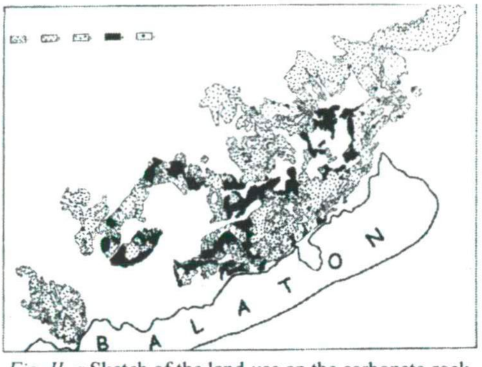

Fig. II. a Sketch of the land-use on the carbonate-rock areas
1.: Forests, 2.: Grass-land (pasture, common or gun-range), 3.: Vine-culture, 4.: Arable, 5.: Dolomite-mines

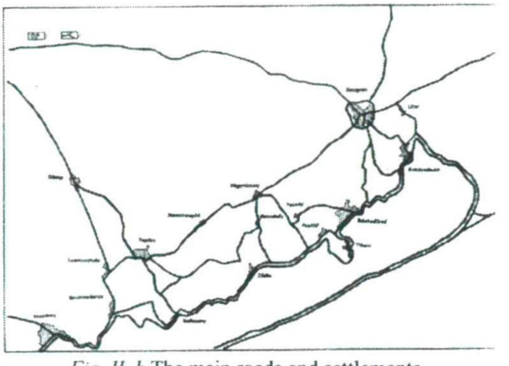

Fig. II. b The main roads and settlements
1.: Roads, 2.: Settlement

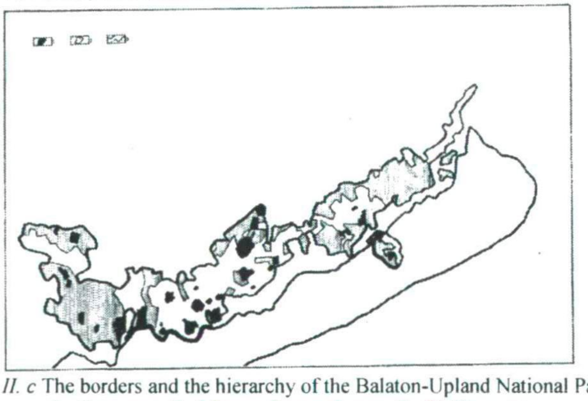

Fig. II. c The borders and the hierarchy of the Balaton-Upland National Park
1.: Core-area, 2.: Managed natural zone, 3.: Buffer zone

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A SCIENTIFIC RESEARCH AND ACTION PROGRAMME FOR THE PROTECTION OF THE HYDROTHERMAL CAVES AND SPRINGS OF THE BUDAPEST (RÓZSADOMB) KARST

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Abstract
The last few decades have seen the rapid, and ever increasing, development of Budapest. As a result the balance and stability of the natural and man-made environment have broken down. Some processes on the surface have seriously damaged the subterranean natural heritage, the stability of the caves and the quality of the thermal water. This paper describes a several-year-long series of complex research activities aimed at the protection of Budapests hydrothermal caves and thermal springs.

Introduction

Budapest, situated on the two sides of the River Danube, in a scenic setting of hills and lowlands, boasts one of the most beautiful natural environments of all capitals. Because of its geological and hydrogeological conditions, it is justly called a spa, with thermal baths and caves. Hot and tepid springs that discharge along a tectonic fault by the Danube have been known and utilised since the Roman times. The large and internationally well-known thermal caves, more than half of which were discovered in the last 15 years, are made up of passages created by the ancestors of these springs. The last few decades have seen rapid, and ever increasing, development of Budapest. As a result the balance and stability of the natural and man-made environment have broken down. Some processes on the surface have seriously damaged the subterranean natural heritage, the stability of the caves and the quality of the thermal water. Some other processes and phenomena are considered to be a potential threat. For this reason, the area and the Phare-supported large-scale scientific research and action programme have become a focus of public interest.

Scientific and action programme for the protection of hydrothermal karst areas of Budapest

The programme includes the following topics:

1. The preferably full-scale provision of public utilities in the urban area over the most endangered, most valuable, strictly protected hydrothermal caves which are also the richest in formations and the most sensitive to pollution. To this end, trunk sewers with a diameter of 50 and 60 cm have been laid to support the efforts of the municipalities of the capital and the district, with the precondition that the municipalities in turn oblige the local population to connect their sewers to the trunks.

2. Complex geological research and drilling activities in the Rózsadomb area:

1. Deepening of deep drills and the establishment of groundwater observation wells.
2. Geological, petrophysical, tectonic and paleokarst analyses and evaluations.
3. Measuring of superficial water absorption capacity.
4. Analysis of water infiltration and concomitant phenomena.
5. Analysis of migrations (the movement of dissolved materials from the surface to the karst system).
6. Measuring of the water absorption of caves.
7. Hydrochemical, microbiological and isotope analyses.
8. Temperature profiling in order to detect any water seepage from the thermal springs towards the Danube.
9. Cave mapping.
10. Examination of cave stability and security.
11. Examination of cave minerals and their contamination

3. Special microclimatological research both in the caves and on the surface in order to prepare medicinal utilisation as well as to monitor the compliance with the requirements and the interactions.

1. A comprehensive survey of the characteristics of cave airspace and the situation of Hungarian cave therapy.
2. Pollen analyses.
3. Ion analyses.
4. Radon analyses.
5. A complex chemical and bacteriological examination and analysis of dripping water and air in caves.
4. The establishment of a complex monitoring system on the surface of the Rózsadomb thermal karst, in the Pál-völgyi Cave and in the area of the foothill József-hegyi springs (set up at springs and in deep drills).
5. The reconstruction of the Szent Iván Cave (Cave Chapel) in Gellért Hill.

During the special microclimatological research, answers were sought to numerous questions that, according to our knowledge and the literature, had never been treated before, neither in Hungary, nor any other country. For example:

- Is it possible to plan and use the same cave (and the same passages of that cave) at the same time or consecutively for both touristic and medicinal purposes?
- Is it possible to carry out medicinal activities in caves under urban areas, where the chemical and bacteriological parameters of the dripping and infiltrating water is not always perfect?
- How do the consequences of superficial contamination affect the quality of the cave's air?

- Is there any correlation between the health conditions of the patients and the parameters of the special microclimatological research?
- How does the air quality of a given part of a cave limit the number of patients and the duration of the treatments?
- In order to purify the air and aerosol matter in the caves, how long regeneration periods must intervene between the touristic and the medicinal uses?
- What factors other than the so-called 'cave healing factors' may cause the efficiency of cave therapy?
- Is there any of the natural parameters in the given cave that might damage the health of the patients treated there or the staff working there?
- What is the current potential of the medicinal use of caves in Hungary for the population suffering from chronic respiratory diseases due to environmental pollution?
- As a parameter never examined before in Hungary or in any other country, what are the relations between the air plankton composition of the cave and of the surface above, with special regard to pollens and fungus spores?

All of the above questions have been positively answered by those serial measurements whose results have been recently published in various forums. These results will not be treated here in detail but a number of the above questions will be answered by the more recent studies published here. [1]

The research programme covered primarily the Rózsadomb thermal karst area, including its surface and caves. How have these caves that are justly nominated to the UNESCO Natural and Cultural World Heritage list evolved? How far can we consider this geologically complex, 'multi-storey' system as the standard example of researching environment pollution and protection, nature conservation and water quality protection? How can we further exploit the potential of this now irrefutably efficient medicinal cave system that has cured thousands of children infected by the pollution of a metropolis right under the increasingly developed greenbelt surface zone of the same metropolis?

The research site extends on the surface to about 10 km^2. The number of known caves underneath now exceeds seventy, and the total length of known passages is over 30 km. József-hegyi springs, with the greatest discharge among all thermal spring groups in Budapest, discharge at the foothills, yielding medicinal waters of 20-50 °C.

Problems

The thermal springs and caves situated under Budapest city centre offer unique opportunities for touristic and medicinal use, but at the same time cause problems that are not known to occur anywhere else and have therefore never been researched. These problems include:

- static (engineering geologic) and stability (environmental geologic) questions: what damages may any defects in public utilities cause in this particular geological environment? (breaking or leaking of water pipes, defects of gas pipes or sewers)

- special conditions to lay down public utilities
- the introduction of a zonation system restricting and/or prohibiting new constructions in the research site
- the effects of seepage of chemicals used to defreeze winter roads on the water quality of thermal springs (with special regard to the sodium and chloride ion concentrations)
- continuous chemical and bacteriological analysis of dripping water in caves: the infiltration of pollutants from the surface to the interior of the karst (the direction and intensity of contaminations)
- the correlation of chemical and bacteriological pollution (significance analysis)

KARST GEOMORPHOLOGY AND HYDROLOGY

THE INFLUENCE OF THE SOIL ZONE ON KARST CORROSION AND KARREN DEVELOPMENT

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Summary

Over the past two decades investigations have been directed to revealing the significance of soil zone processes on the evolution of surface karren. The soil fill was removed - as perfectly as it was possible - from two similar karren and the floors of both karren were sealed by cement. In order to reduce the effect of the cement it was covered by synthetic resin and the original soil was refilled into one of the karren while the other remained soil free. Thus measurements refer to so-called 'bare' karren, 60 per cent free from soil cover, and to so-called covered karren with a complete soil cover. The amounts of runoff from and infiltration into karren are lower than the precipitation amount on the surface both for bare and for covered karren. The deficit in the first case (through wetting and evaporation) is 23 per cent, while in the second 45 per cent (through wetting, evapotranspiration and pore water). In bare karren, infiltration occurs in pulses and ends abruptly; water from further minor events cannot reach the joints of the bedrock. The beginning of infiltration into covered karren is 1-5 hours delayed on average compared to that of bare karren, but attenuation is prolonged and in a rainy period moderate infiltration can be continual. The amount of dissolved carbonate from bare karren is usually proportional to the amounts of precipitation and infiltration. Solution takes place due to runoff from snowmelt, early summer precipitation maximum and autumn secondary rainfall maximum (at most 1500-2000 mg per two weeks), while minima are observed in the drier intervals in between. The amounts of dissolved carbonate from covered karren show greater annual variations. Maxima are over twice those for bare karren. Our observations support the conclusion that the trend of maximum solution, which reflects the joint impact of soil moisture, soil temperature and CO_2 production in the soil, controls the carbonate concentration of infiltrating water and the daily amplitude of this variation is 35-45 mg/l. During continuous infiltration there is an average of 100-110 mg/l carbonate concentration in covered karren areas.

Introduction

It has been shown that soil cover and soil deposits washed into karst passages play a significant part in the solution of karstic rocks, in the geomorphic evolution of karst terrains and development of karst features. This factor, is manifested in variable manner and degree in karst corrosion and influences the development of various karst features in all sites where soil cover or its redeposited remnants are present. Over the past two decades investigations have been directed to revealing the significance of soil on the evolution of surface karren. Focusing on the measurement of the growth and broadening of kluftkarren, a field observation station was set up in a doline on a plateau at 600 m altitude in the Aggtelek Karst, northeast Hungary. It is located on a heavily karstified doline slope of N exposure. In two parallel kluftkarren of similar size, the rainwater runoff from karren crests and peaks is received by a subsurface container system. The amount of infiltration, dissolved carbonate contents and other physical and chemical parameters are recorded on the spot or measured in the laboratory. The bottoms of the karren were originally covered by 5-10 cm deep black rendzina soils. The sides and karren crests were overgrown sporadically by bryophytes and lichens and in the karren locally monocotyledonous and dicotyledonous plants lived. A rich bacterium and Actynomyces flora thrived in the black rendzina. The 5-8 most active groups of them were identified and also investigated in other stocks. Field measurements were performed in two phases. The first lasted from March 1980 to September 1982 for 861 days, with observations at two-week intervals by installed mechanical and electronic recorders. Infiltrating water was collected for 14 days and measured and sampled. Some of the results are presented in the first part of the paper. The second phase began in January 1997 and lasted to the present day and a continuation is planned for the future. Here electronic sensors and data loggers were employed at the field station. Thus continual data collection was achieved and short-term (one-hour) changes of parameters affecting solution could be measured and details of the process of corrosion could be revealed. The first results of the second phase of investigations are presented at the end of the paper.

As the primary objective of the experiment was to study the influence of soil zone processes on karst corrosion, the soil fill was removed - as perfectly as it was possible - from two similar karren and the floors of both karren were sealed by cement. In order to reduce the effect of the cement it was covered by synthetic resin and the original soil was refilled into one of the karren while the other remained soil free. Thus measurements refer to so-called 'bare' karren, 60 per cent free from soil cover, and to so-called covered karren with a complete soil cover.

In the present study two groups of factors of karren development were identified and measured:

A) triggering factors

- rainwater runoff on karren surfaces, eventually infiltrating. It was recorded in two-week intervals in the first phase and conducted under the surface through a cup meter and sampler set up in a closed space, providing electric impulses, and collected in a container in the second phase.
- amount of debris produced by mechanical weathering and reaching the karren and, mixed into the black rendzina, dissolved. Its amounts can be regarded equal in both karren and thus was disregarded in comparison.

B) influencing factors

- temperatures of soil and infiltrating water;
- soil moisture content (per cent);
- CO_2 contents of infiltrating water, which is a decisive factor in hydrogen carbonate solution, irrespective of its origin (microbial decomposition, root respiration or microclimatic water). In the analysis of CO_2 bound, equilibrium and aggressive CO_2 forms were distinguished and this allowed the measurement of dissolved carbonates and, with respect to the aggressivity responsible for further solution, the calculation of potential solution capacity.

Results

The amounts of runoff on and infiltration into karren are lower than the precipitation amount on the surface both for partly bare and for covered karren. The deficit in the first case (through wetting and evaporation) is 23 per cent, while in the second 45 per cent (through wetting, evapotranspiration and pore water). The minimum amount of precipitation to be taken into account in karren development is >1 mm at 8°C mean annual temperature and 0.02 mm per min minimum rainfall intensity. If rainfalls have parameters below the above limits, no infiltration is fed even on bare karren and they increase the precipitation deficit. The values tend to rise in the growing season and decrease at temperatures below freezing point. Over a 861 day period, 55 per cent of the precipitation infiltrated into bare karren surfaces and 23.3 per cent into covered karren. The seasonal variations of runoff-infiltration are shown in Fig. 1. In bare karren, infiltration amounts increase from April to the regular maximum in June-July and a secondary minimum is observed in August-September, a secondary maximum in October and a regular minimum in winter. There is no infiltration in winter when temperatures are below 0°C but some precipitation from frontal events may infiltrate. Infiltration shows a similar curve for covered karren but its amounts are, on average, 25 per cent less than for bare karren. Here it is typical that maxima are two-three weeks later than those on bare karren surfaces and infiltration begins with delay compared to the advent of the rainy season but with a great intensity. Infiltration on covered karren surfaces depends on the weather of the one or two weeks before the precipitation event and on the soil moisture conditions.

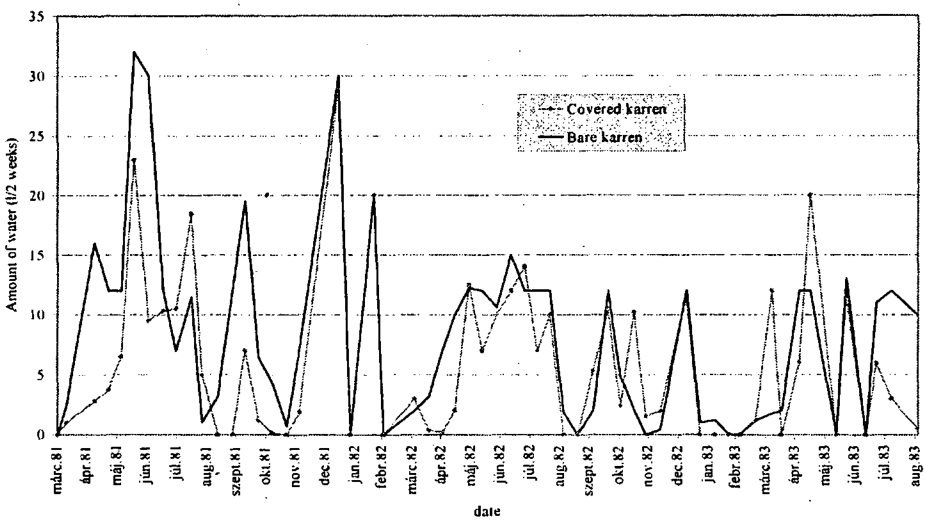

Fig. 1 Runoff water (infiltration) from the karren, 1981-1983

In bare karren infiltration occurs in pulses and ends abruptly; water from further minor events cannot reach the joints of the bedrock. The beginning of infiltration into bare karren precedes the infiltration of soil solution. The beginning of infiltration into covered karren is, on average 1-5 hours later than that of bare karren but attenuation is prolonged and in a rainy period moderate infiltration can be continual (see *Fig. 2*, 12-17 July).

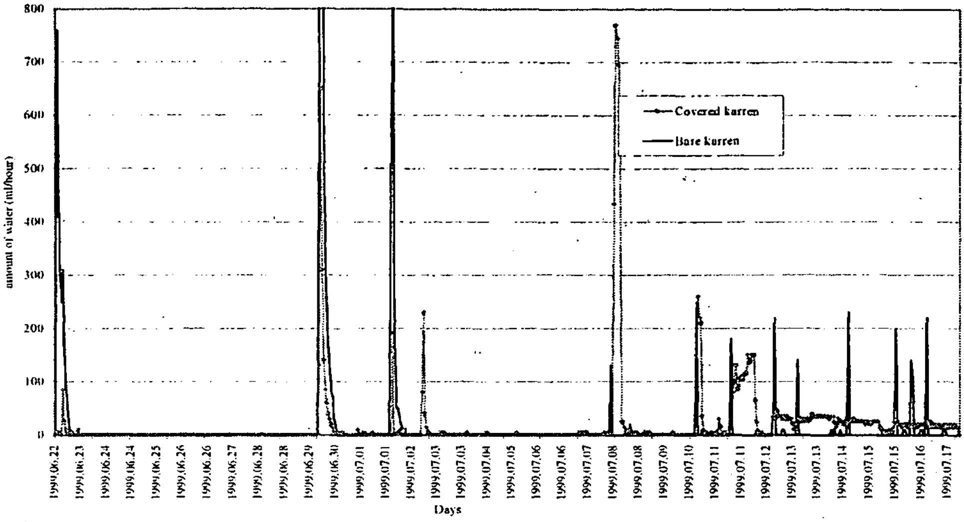

Fig. 2 Runoff water (infiltration) from the karren, Summer, 1999.

When the soils are moist (96-100 per cent soil moisture) even small rainfall amounts infiltrate. Where there is a clay cover infiltration is initially rapid but with swelling it slows down and attenuation is prolonged. The change of infiltration and soil temperature is particularly characteristic in covered karren (*Fig.3*).

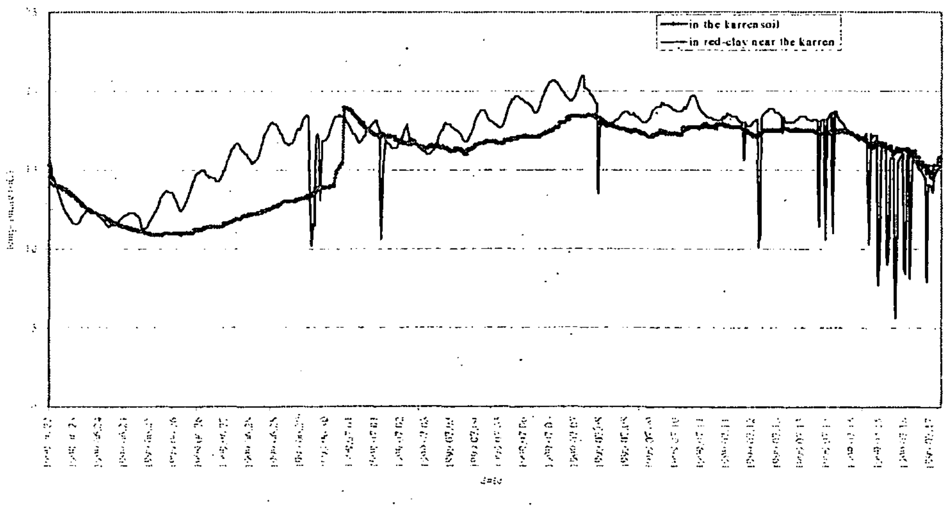

Fig. 3 Soil temperature

In non-frontal weather conditions, the soils of karren covered by black rendzinas shows a sinusoidal daily temperature curve, e.g. in summer 3-4°C daily variation is observed. Intensive infiltration after rainfall events cools the soil down by 7-8°C on average. Cooling is simultaneous with the beginning of intensive infiltration and during prolonged low-intensity infiltration soil temperature resumes its normal daily curve. This indicates that infiltrating water does not cool down soil particles for a long time and thus soil microbial activity and CO_2 production is not reduced but, with the increased CO_2 solution by cold water, the solution capacity of infiltrating water grows (*Fig. 4*).

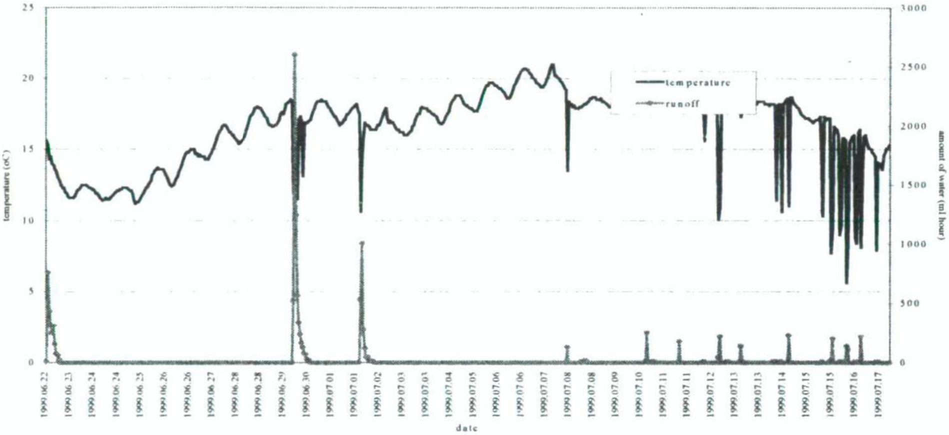

Fig. 4 Surface temperature and runoff water from the bare karren

The influence of infiltration on temperature cannot be observed so clearly where the soil cover is clayey. The carbonate solution capacity of infiltrating water, assuming prevailing hydrogen carbonate corrosion, corresponds to the amount of dissolved CO_2. The annual curve of solution on bare karren (*Fig. 5*) is more moderate than on covered karren.

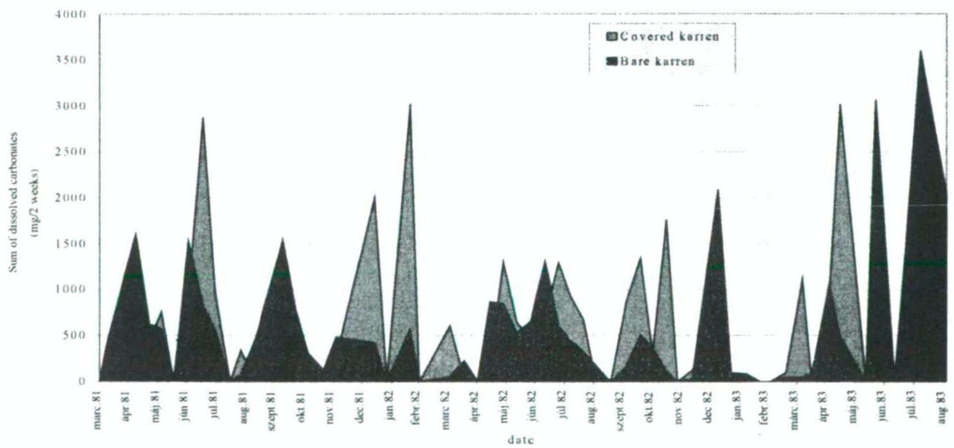

Fig. 5 Sum of dissolved carbonates in water draining from the karren, 1981-83.

The amount of dissolved carbonates in water draining from bare karren is usually proportional to the amounts of precipitation and infiltration. Solution takes place due to runoff from snowmelt, early summer precipitation maximum and autumn secondary rainfall maximum (at most 1500-2000 mg per two weeks), while minima are observed in the drier intervals in between. In covered karren, the amounts of dissolved carbonates show greater annual variations. Maxima are over twice those for bare karren. Corrosion in covered karren is not a linear function of precipitation but adjusts to interactions of soil biological activity and infiltration. Consequently, optimum solution is not always controlled by precipitation amounts and extreme values may occur in any month (including February). It is characteristic that during frozen soil conditions and in totally dry periods corrosion stops entirely. Continual observation allowed the formulation of several relationships between infiltration and carbonate solution (*Fig. 6*).

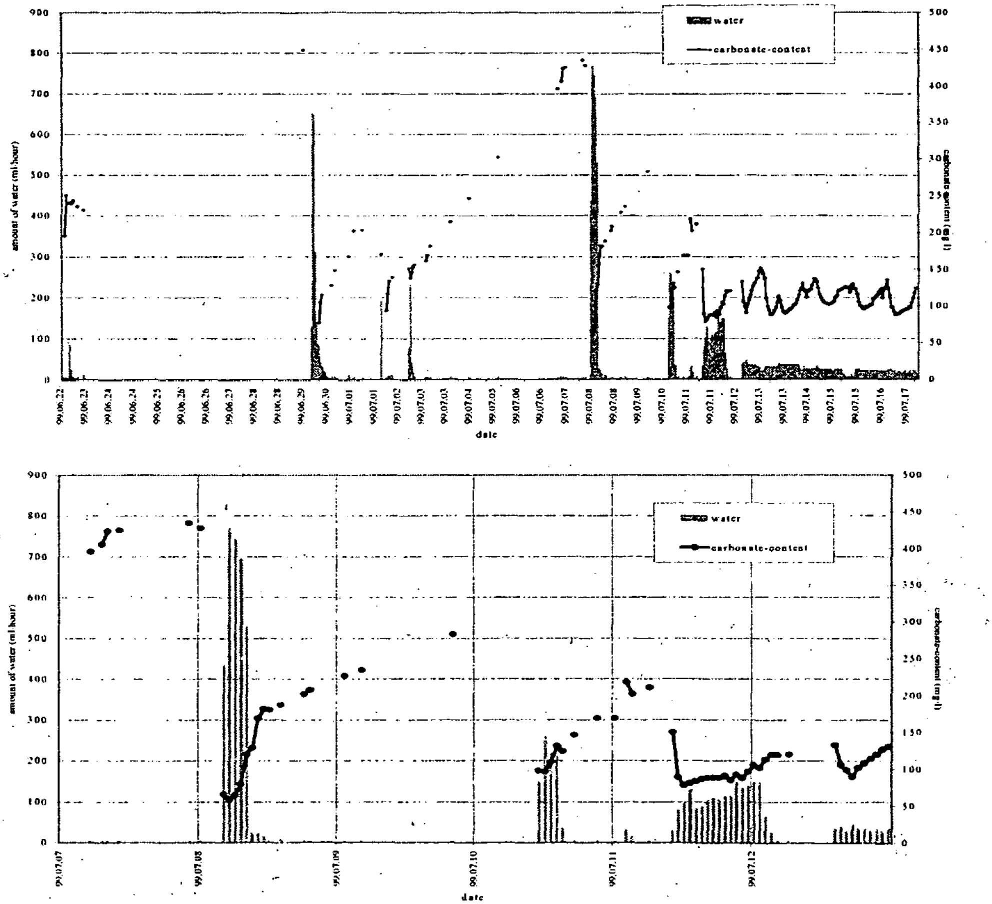

Fig. 6a-6b Amount of water draining from the covered karren and its carbonate-content
A: 22.06. - 17.07.1999, B: 07.07. - 12.07.1999.

There is generally an inverse relationship between the amount of infiltration and the carbonate content of water. In the various phases of infiltration during a rainfall event, however, this means a regularly changing relationship. Within a phase of infiltration:

1. At the beginning of rainfall, the carbonate concentration of infiltrating water is reduced to its minimum, 50-80 mg/l.
2. During a prolonged rainfall event, the initially low carbonate content increases slightly (to 80-130 mg/l).
3. During the infiltration of minor rainfalls after a major event, carbonate content reaches 2-8-fold higher values than the minimum, 130-450 mg/l.
4. In the case of uniform and prolonged infiltration, carbonate content shows a daily cycle with an amplitude of 80-140 mg/l.

Detailed study of uniform infiltration allows three conclusions to be drawn (*Fig. 6b*):

1. With the intensification of infiltration, the concentration of dissolved carbonates increases in the water and the other way round.
2. The relationship between the amount of infiltration and carbonate concentration is inverse but not linear.
3. Uniform, constantly low-intensity, infiltration involves constant carbonate concentration if factors achieve an equilibrium under optimum solution conditions.

The variations of major factors of solution, temperature and infiltration, soil moisture content and the resulting level of biological activity in the soil, that cumulate in the potential carbonate solution capacity of water are shown by the curve of carbonate concentration observed for constant low infiltration (*Fig. 7*). During uninterrupted but slight infiltration, the carbonate concentration of water shows a sinusoidal curve. Concentration changes in a daily cycle, probably influenced by root respiration and temperature. The regular daily cycle of concentration is disturbed temporarily by cooling during infiltration but when infiltration acquires its normal rate, the trend of concentration is restored.

Conclusions

The observations support the conclusion that the trend of maximum solution, which reflects the joint impact of soil moisture, soil temperature and CO_2 production in the soil, controls the carbonate concentration of infiltrating water and the daily amplitude of this variation is 35-45 mg/l. During continuous infiltration there is an average of 100-110 mg/l carbonate concentration in covered karren areas. The results from the total measurement period indicate that in bare karren the further potential solution capacity due to increased infiltration with reduced dissolved carbonate amounts promotes karren deepening, while in covered karren, the increased solution under the soil points towards karren widening. Summarising, the deepening rate of bare karren is 1.3 mm per ka, while the deepening rate of covered karren is 1.0 mm per ka.

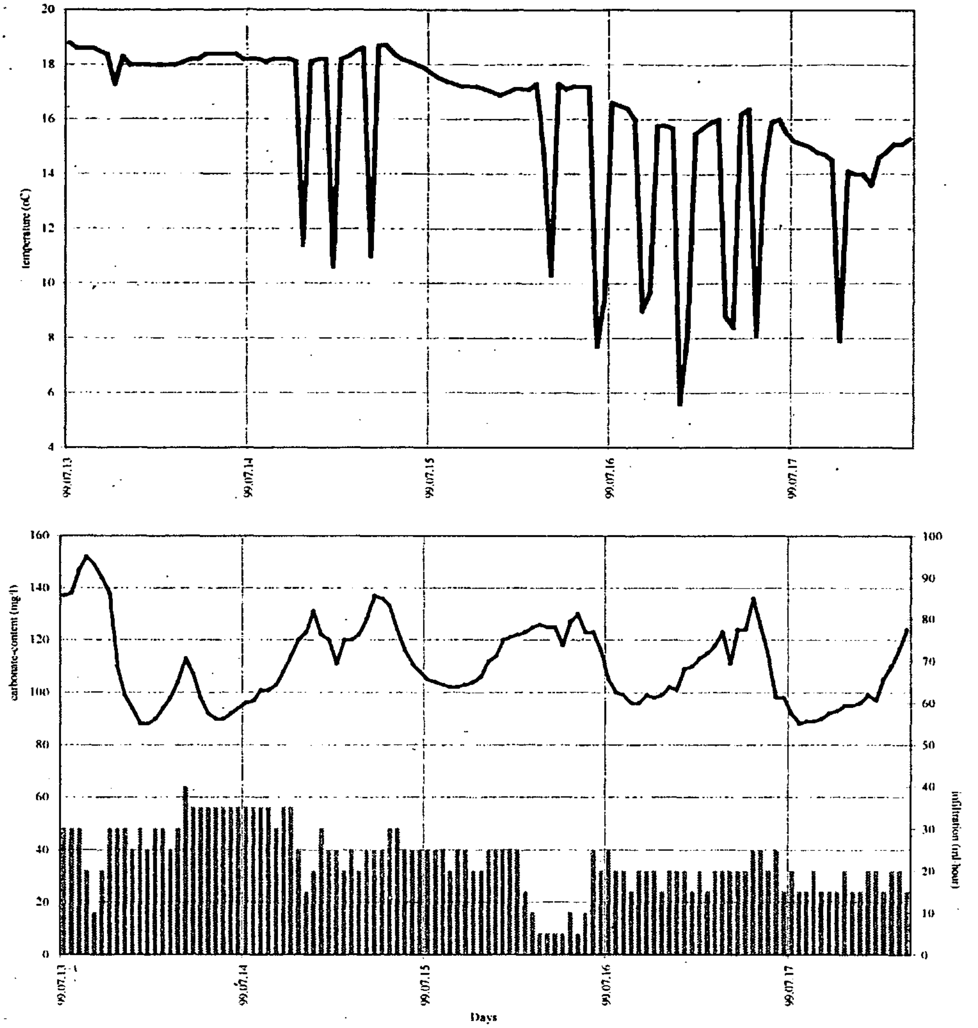

Fig. 7 Soil-temperature, carbonate-content and infiltration from the covered karren.

Acknowledgement

Thanks to Professor John Gunn for making many improvements to the English text.

VARIANCES OF KARST CORROSION ON THE BASIS OF DIFFERENCES IN THE SOLUTION OF Ca- AND Mg-CARBONATES

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Summary

In this paper, we present results from the analysis of water samples collected by the karst corrosion measuring system installed at the Aggteleki Karst (NE-Hungary). The measurement sites are located to allow a good observation of vertical changes in solution. The water samples come from a rock surface covered by soil, from the uppermost and lowermost (at bedrock) ground level of the soil-fill of a doline, and from water dripping from the ceiling of Béke Cave which is located at the karstwater-table below the doline above mentioned. We collected the water samples monthly and analysed them in terms of $CaCO_3$ and $MgCO_3$ contents. We tried to explain the seasonal variations in the solution of the examined carbonates, and the solutional differences between the measurement sites. The total carbonate-content of the water samples shows great fluctuations during the year, but is not dependent on the annual course of temperature. We measured the highest values in early autumn. The dissolved carbonate-content of the water samples of the cave is, naturally, much higher (210-220 mg/l) than that of the water samples collected near the surface (30-80 mg/l). This fact indicates that the water infiltrating through the soil has significant agressive CO_2-content when it arrives at the soil-bedrock boundary. The dissolved $CaCO_3$ content is, on average, 2.5-5 times greater than the dissolved $MgCO_3$ content and the ratio of the above carbonates increases from the surface towards the cave as a consequence of the fact that the dissolved $MgCO_3$ content of infiltrating water comes from the soil. Two periods of the year (early summer, autumn) are characterised by lower $MgCO_3$ solution and abundant precipitation. Since this decrease during these periods is not significant from the point of view of $CaCO_3$ solution, the qualitative changes in solution can be well characterised by the ratio of the amounts of dissolved $CaCO_3$ and dissolved $MgCO_3$. Summing up, it seems that precipitation is an important factor of karst corrosion not only quantitatively but also qualitatively, changing the ratio of dissolved carbonates.

I. Introduction

The main goal of our investigations was to get a better understanding of vertical changes in karst corrosion processes (such as dissolution and precipitation of carbonates). For this reason, a measuring system was installed at the Aggteleki-Karst, NE-Hungary (*Zámbó, 1986., 1997.*). For the present examinations, water samples have been collected for 4 years (since 1996) from several characteristic points along a vertical profile from the karstified surface to the ceiling of Béke Cave. The measurement points are shown in *Fig. 1.*

We collected the water samples monthly, and analysed them in terms of dissolved $CaCO_3$ and $MgCO_3$ contents. The precipitation during the investigated period (average of the year 1996-97) is presented in *Fig. 2.* Its tendency and the total amount correspond well to the averages of longer periods. The climate is temperate-cool, Dfx according to the Köppen-system.

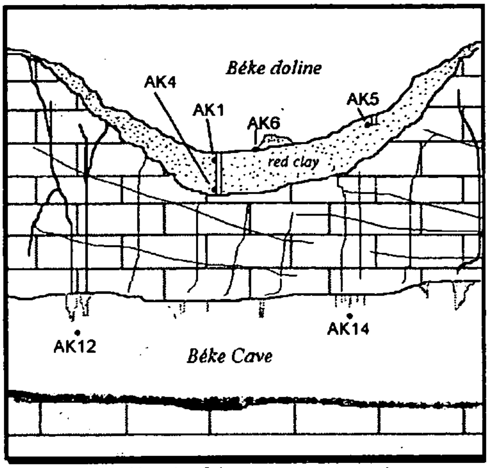

Fig. 1 Sketch of the measurement points (AK6: Limestone rock surface partially covered by moss [Bryophyte]; AK1: below 0.5 m thick red-clay soil; AK5: below 0.5 m thick red-brown earth; AK4: below 9.5 m thick red-clay soil-fill of a doline [at soil-bedrock boundary]; AK12: 2 medium stalactites in the Béke Cave [at karstwater table]; AK14: a group of small stalactites in the Béke Cave [at karstwater table])

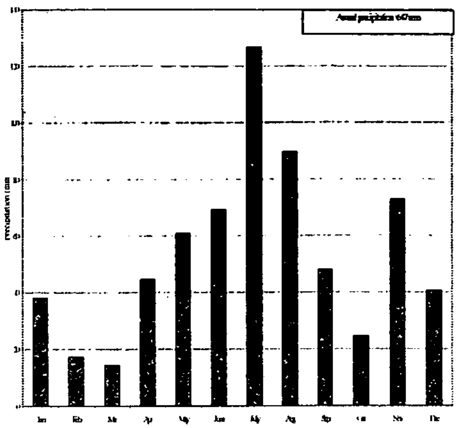

Fig. 2 Precipitation at Aggtelek (averages of the years 1996-97)

II. Results

The monthly averages of the different parameters over the 4-year long investigation period are shown on *Fig. 3, 4a, 4b and 4c*.

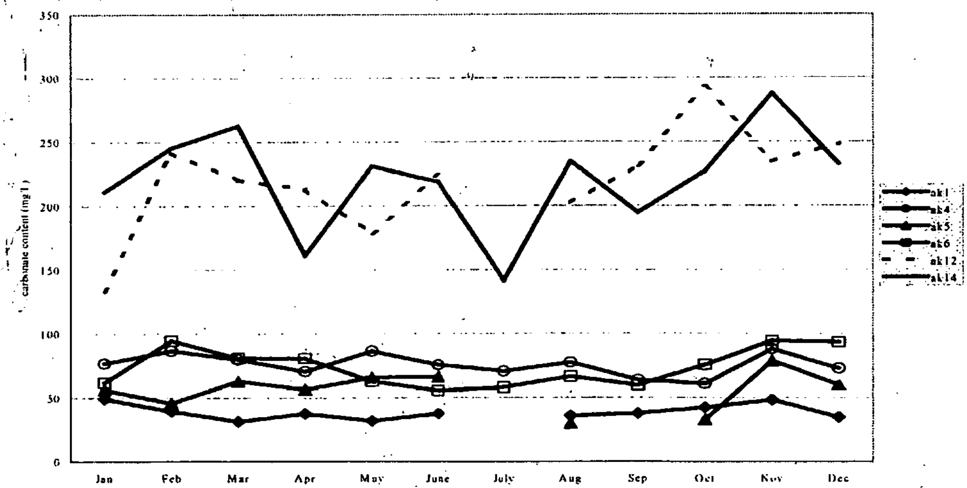

Fig. 3 Total dissolved carbonate-content of water samples

In the water samples (*Fig. 3*) from near the surface the total dissolved carbonate-content shows only slight fluctuations during the year, but vertical changes are recognisable. The lowest carbonate concentrations are at the uppermost ground level of the soil (AK1 - below red-clay: 30-50 mg/l; AK5- below red-brown earth: 30-80 mg/l. These differences according to soil types correspond to our earlier experimental results on small soil samples in laboratory conditions (*Zámbó, 1998*). Below the 9.5-m thick red-clay soil the carbonate concentrations are greater (AK4: 60-95 mg/l). The total dissolved carbonate-contents of the dripping waters in Béke Cave are much higher (AK12, AK14: 140-300 mg/l) than of the other measurement points, and their changes are in inverse ratio to the amount of precipitation. The highest concentrations are in accordance with the driest months at AK12, where the medium speleothems have wider feeding fissures. At AK14, where infiltrating water arrives trough narrower fissures the highest carbonate-concentrations are a month late compared with the most arid month.

The annual course of $MgCO_3$-dissolution (*Fig. 4b*) is less uniform than that of $CaCO_3$-dissolution (*Fig. 4a*), and the differences between the samples near the surface and from the cave are also less significant looking at the $MgCO_3$-dissolution. The correlation coefficients between precipitation and dissolved carbonate-contents are low, but some trends seem likely:

- the dissolved $CaCO_3$ content slightly decreases with increasing precipitation;
- the dissolved $MgCO_3$ content better decreases with increasing precipitation;
- as a result, the ratio of dissolved $CaCO_3$ to dissolved $MgCO_3$ (*Fig. 4c*) increases with increasing precipitation (in the cases of AK4 and AK14, the correlation coefficients between this ratio and the precipitation are equal to 0.66, in the other cases the value of r is lower.) Similar phenomenon was measured in karstwater-sources, where peak discharges were characterized by high $CaCO_3/MgCO_3$ ratio in the karstwater (*Maucha, 1989b, Ovstedal-Lauritzen, 1989*). In laboratory conditions *Mándy* (1954) suggested that an increase in the temperature of the solvent cause an increase in the $CaCO_3/MgCO_3$ ratio, but in natural conditions, the differences in temperature are not high enough to explain this phenomena.

These facts can be explained by the followings:

- the dissolved $MgCO_3$ content of infiltrating water comes mainly from the weathering in the soil and at the surface;
- during intense rainfall (or snowmelt) the infiltration is very rapid and the dissolved CO_2-content (which comes principally from the soil-air) can't follow this rapid change immediately which results that the concentration of aggressive CO_2 decreases, thus the concentration of dissolved carbonates also decreases. It seems that the Ca2+-ions get to the solution more quickly than Mg^{2+}-ions, which can explain why the ratio of dissolved $CaCO_3$ and $MgCO_3$ increases with precipitation. Since the infiltrating water has no more CO_2-source after penetrating in the bedrock, the dissolution from there prefers the $CaCO_3$ to the $MgCO_3$, thus

in the dripping water samples of the cave the dissolved $CaCO_3$-content is much greater (3-14 times) than the dissolved $MgCO_3$-content. This demonstrates that the "time" factor has a very important role in karst corrosion (*Jakucs, 1977*).

Figure 4a: Total dissolved Ca-carbonate contents of the water samples

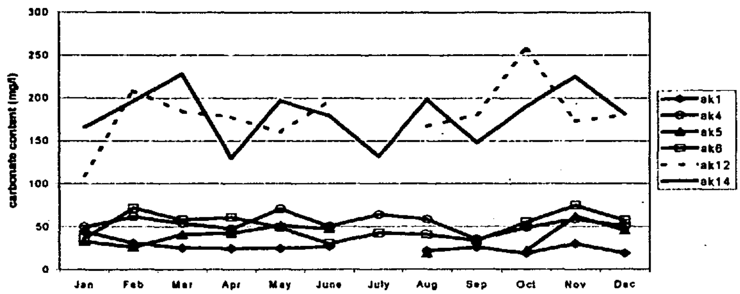

Figure 4b: Total dissolved Mg-carbonate contents of the water samples

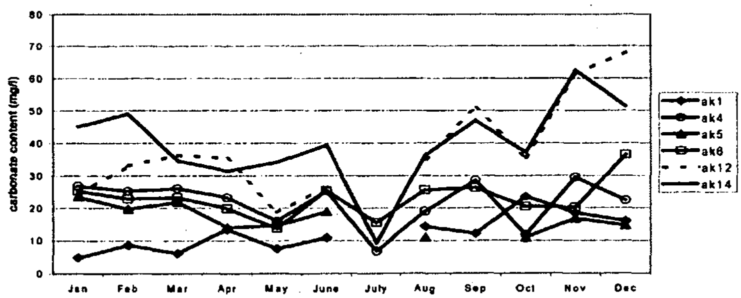

Figure 4c: Ratio of dissolved $CaCO_3$ and $MgCO_3$ in the water samples

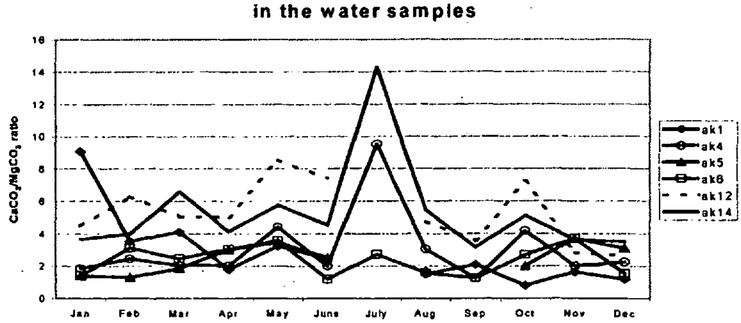

Fig. 4a,b,c Changes of the $CaCO_3$ and $MgCO_3$-content and their ratio in the water samples

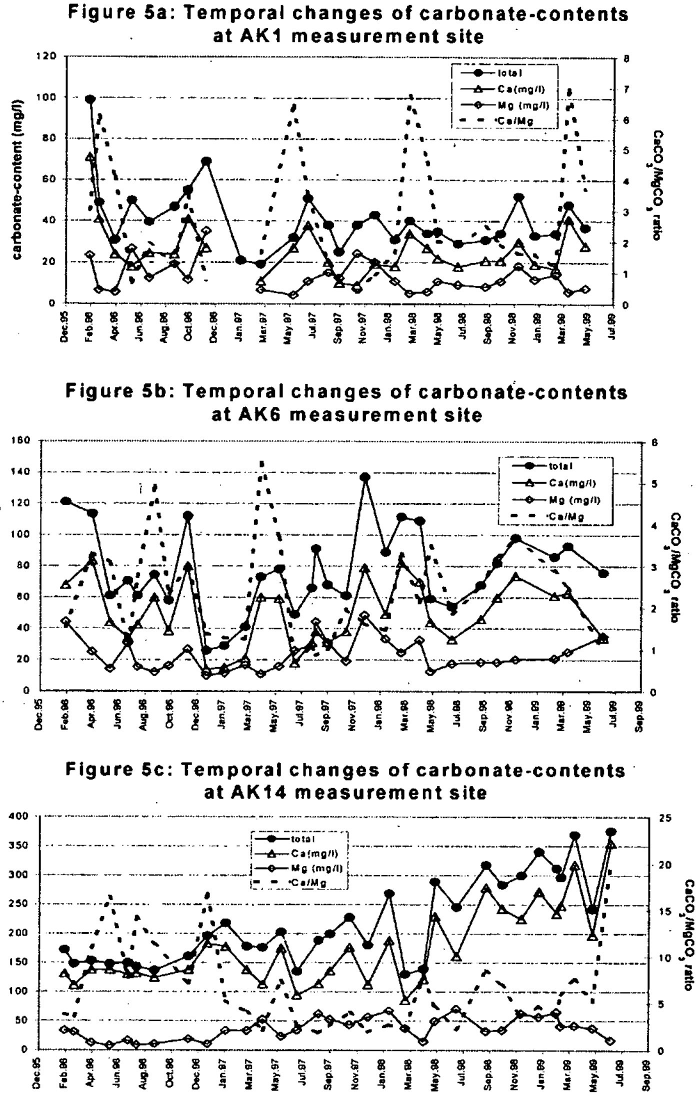

Fig. 5a,b,c Temporal changes of carbonate-contents at different measurement sites

In *Fig. 5a* the significant fluctuations in the ratio of dissolved $CaCO_3$ and $MgCO_3$ are well manifested: during the rapid and cold infiltration after snowmelt this proportion increases as explained above. Thus, a relative growth of $MgCO_3$ content in the soil is realised. A maximum in the total dissolved carbonate-content is also observable in late autumn. This is likely to be a consequence of constant high soil moisture (long but quiet rainfalls in November) and abundant rotting organic material.

In the case presented in *Fig. 5b* the corrosion attacks the rock surface so the runoff water dissolves directly the rock material, i.e. the ratio of dissolved $CaCO_3$ and $MgCO_3$ is rather a function of the rock composition and the temporal variations are less significant. It means also, that the dissolved $CaCO_3$ and $MgCO_3$ contents change in a parallel way.

In the dripping water from the group of small stalactites (*Fig. 5c*) the seasonal variations in the dissolved carbonate-contents are in a month late referring to the water samples collected from the soil, i.e. a local maximum in the ratio of dissolved $CaCO_3$ and $MgCO_3$ is in late spring (as a result of the decrease in the dissolved $MgCO_3$ content).

In *Fig. 6* a direct factor of corrosion process, the amount of water (runoff at the rock surface and infiltration in the cave) is presented. It is demonstrated here, that after rainfall the runoff water percolates through the soil and can fast arrive at the karstwater table if the infiltration passes in large fissures (AK12). But a great volume of water is transported through narrow fissures (AK14), which delays the beginning of the intense dripping in the cave with 1-1.5 month and makes the duration of abundant infiltration longer (2-3 months). The highest infiltration periods are in early spring in accordance with the measurements of *Maucha* (1989a).

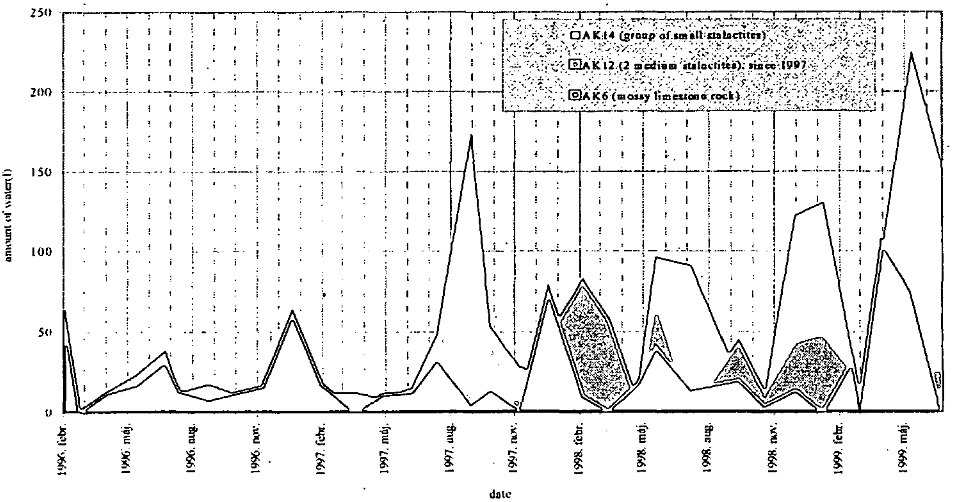

Fig. 6 Amount of water at different measurement sites (AK12 has been working only since 1997)

To get the amount of total dissolved material, the concentration values must be multiplied with the amount of water. Taking these calculations into account, the denudation dynamics can be studied (*Fig. 7*). Since the fluctuations in the carbonate-concentrations are less than in the amount of water, the main dynamics of the sum of dissolved carbonates is determined by the temporal variations of precipitation. The consequence of this dynamics is that the precipitation of carbonates in the speleothems is also dependent on the amount of infiltration. In our data this relationship is demonstrated for a time-resolution of 1 month, but this relationship is valuable for annual data, too, and this fact is responsible for the varied ring structure of speleothems which makes the reconstruction of paleoclimate possible.

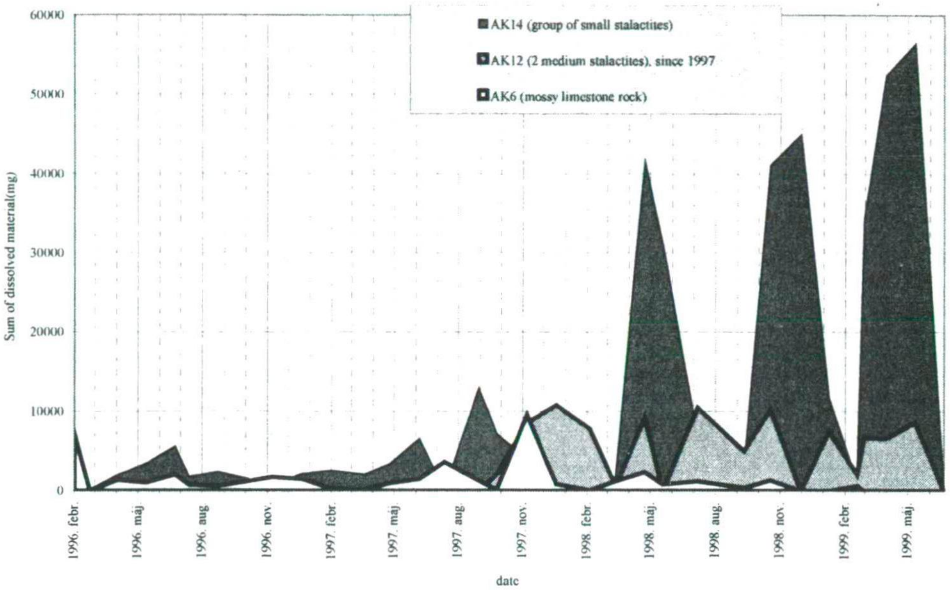

Fig. 7 Sum of total dissolved material at different measurement sites (AK12 has been working only since 1997)

III. Conclusions

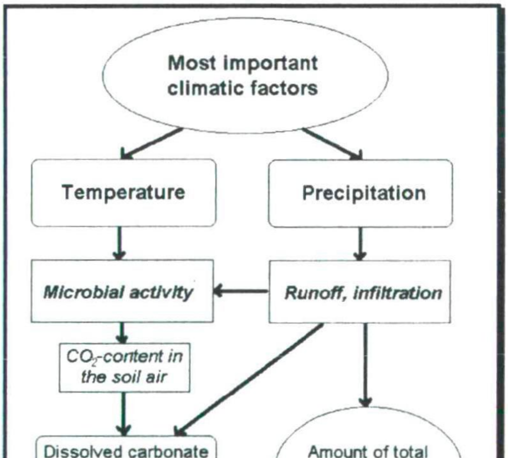

Fig. 8 Sketch diagram of karst corrosion processes

The most important climatic factors and their (in)direct regulative effects for the karst corrosion processes are presented in a simplified arrow-box diagram (*Fig. 8*).

- The total dissolved carbonate-content increases with depth, but soil type and vegetation can vary this trend.
- The highest total dissolved carbonate-concentrations are in the driest months.
- The narrow fissures cause a 1-1.5 month delay in the concentration and infiltration values.
- The ratio of dissolved CaCO3 and MgCO3 increases with increasing precipitation. (These qualitative changes would be also examined in the ring structure of speleothems.)
- In the denudation dynamics precipitation is the most important

climatic factor because the carbonate-concentration changes are less than the variations in the infiltration. (Looking at the temperate climate characteristic to Aggtelek.)

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INTERANNUAL VARIATION OF LIMESTONE SOLUTION RATES IN JAPAN

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Summary

The solution rates of four tablets made from limestone obtained in Kozina (Slovenia), Guilin (China), Chichibu (Japan), and from the rock at the observation point were measured in seven limestone areas in Japan from 1993 to 1997. Solution rates in the air 1.5m above the ground show a high correlation with (water surplus (WS) - water deficit (WD)) by Thornthwaite's method. The solution rates of limestone tablets in soils show values 1.5 to 5 times higher than those in the air. The solution rates of limestone tablets in the A_3 and B_2 horizons show high correlation with annual precipitation. High solution rates in soils must be related to high CO_2 values under humid and warm periods. In 1993, when cool and humid summer prevailed in almost all parts of Japan, the trend of solution rates increased in accordance with (WS-WD), having the largest range during the five years. In 1994, when an extremely hot and dry summer prevailed, the solution rates increased in accordance with (WS-WD), having with the lowest range during the five years. Solution rates of limestone tablets in the air at each point increased with increasing (WS-WD) during the five years. However, it is interesting to note that the solution rates of limestone increased sharply by the amount of 1,000-1,600mm of (WS-WD). Lithologically, Guilin and Slovenia tablets belong to one group, and Chichibu and Akiyoshi tablets belong to the other group. The group of Guilin and Slovenia show high solution rate under the wet condition and low solution rate under the dry condition but the group of Chichibu and Akiyoshi show low solution rate under wet conditions.

Introduction

Many research workers, who have been interested to karst, have tried to clarify rates of solution and main factors for karstification. Measurements of solution rates using limestone tablets were tried by *Trudgill* (1975) and Jennings (1977). The Commission of International Speleological Union has measured solution rates of limestone tablets from the stand point of global comparison using the Slovenian Cretaceous limestone since 1980 (*Gams, 1985*). Similar limestone tablets made of Guilin Permian limestone were measured in China (*Yuan, 1991*). The solution rates of Slovenian Cretaceous limestone in Japan was measured from 1989 to 1990 by *Urushibara* (1991). Not only the solution rates of Slovenian Cretaceous limestone, but also those of Guilin Permian limestone and Japanese limestone have been measured since 1992. The results of these observation during the three years, 1993, 1994 and 1995, were published *elsewhere (Urushibara-Yoshino et al., 1998)*.

Five years results were also published in Japanese (*Urushibara-Yoshino et al., 1999*). In this study, the effective factors for annual solution rates of limestone in Japan are discussed using measured values.

Study Areas and Methods

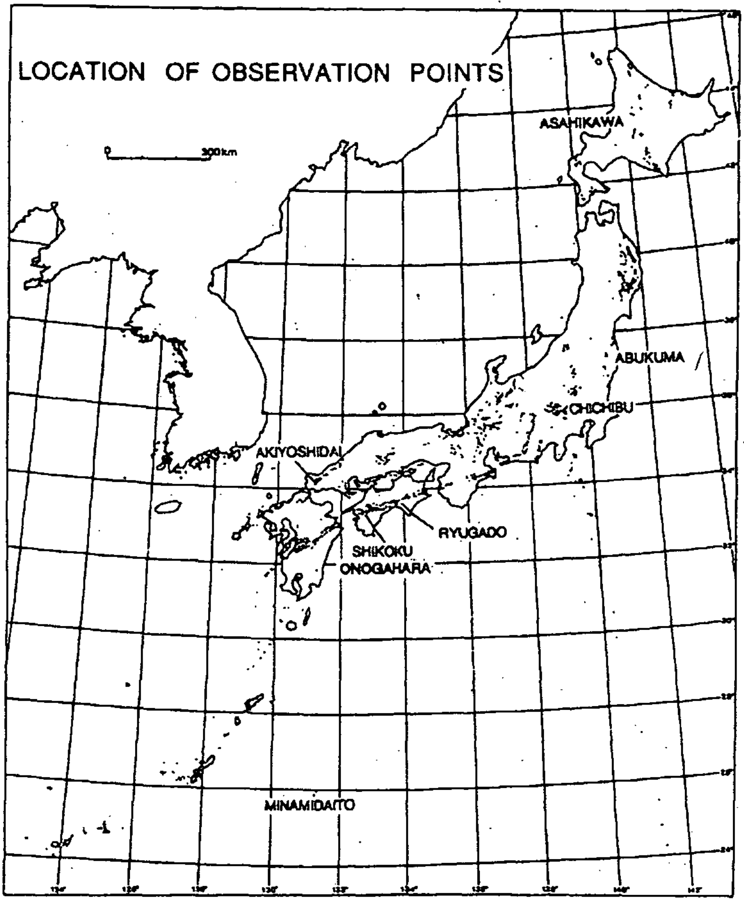

Fig. 1 Limestone areas and location of observation points in Japan.

Limestone areas occupy only 0.44% of the all land in Japan (*Urushibara, 1996*). However, the areas are distributed from north to south under a wide range of different climatic conditions. The seven limestone areas were selected from north to south, namely Toma, Abukuma, Chichibu, Akiyoshidai, Shikoku, Ryugado and Minamidaito. The locations of these points are shown in *Fig. 1* and their environmental conditions in *Table 1*. The tablets were made from Slovenian Cretaceous limestone, Guilin Permian limestone, Chichibu Triassic limestones and the local limestone at each location in Japan and were

40mm in diameter with a thickness of 4mm. They were set in the open air 1.5m above the ground and in the soils at the A_3 horizon and B_2 horizon. Their depth was different because of the different depth of horizons. The weights of the tablets ranged from 12.5g - 13.5g. Once a year during the five years, the tablets were cleared and weighted. The results of weight loss had shown in 10^{-4}g to 10^{-5}g then, calculated as the solution rate for the year. By microscopic observation, the upper surfaces of tablets corroded more than the lower surfaces at all observation points. Therefore, because of differential solution between the upper and lower surfaces, the loss of thickness was not calculated but only the loss of weight was measured.

The CO_2 concentrations in soils were paid attention in the present study, because the solution rates are extremely high in soils. In this study, the CO_2 in A_3 and B_2 horizons, where the tablets were set, was measured in at least 4 seasons at each localities. The three methods, Non Dispersive Infrared Gas Analyzer, Gastec and Dräger method (*Miotke, 1974*) were *examined (Urushibara-Yoshino et al., 1998)*. To further understand the solution processes of limestone, the water balance in 1993, 1994, 1995, 1996 and 1997 was calculated by the methods of *Thornthwaite* (1948), because it considers the water balance including soil moisture. During the five years measured, the summer of 1993 was very cool and wet, and the summer of 1994 was extremely hot and dry. In June - August, 1994, monthly mean air temperature was the highest in the whole Honshu area during the last 100 years observation period, according to meteorological data.

Table 1 Environmental conditions of the observation points.

Observation points	Location	Elevation	Stratigraphy and Ecological Condition
Asahikawa (Toma)	43°49'30"N 142°37'50"E	220m a. s. l.	Permian limestone mixed forest with needle trees and desidual trees
Abukuma	37°20'30"N 140°40'40"E	640m a. s. l	crystallized limestone by Cretaceous metamorphism deciduous forest and grassland
Chichibu	35°57'30"N 139° 6'10"E	960m a. s. l.	Trias limestone deciduous forest and grassland
Akiyoshidai	31°14'50"N 131°17'40"E	240m a. s. l.	Carboniferous and Permian limestone mixed forest with evergreen and deciduous forest, and grassland
Shikoku (Onogahara)	33°28'24"N 132°52'51"E	1200m a. s. l.	Permian limestone deciduous forest and grassland
Ryugado	33°54'54"N 133°44'53"E	280m a. s. l.	Trias limestone evergreen forest and grassland
Minamidaito	25°50' 7"N 131°14' 1"E	14m a. s. l	Quaternary limestone subtropical evergreen trees and grassland

Solution rates of limestone tablets

In comparing the solution rates of the four limestone tablets (Slovenian limestone, Guilin limestone, Chichibu limestone and local limestone tablets) set in the air, in the A_3 horizon of soils and in the B_2 horizon of soils at each observation points, the following results were obtained. The mean solution rates of four limestone tablets were considered as the best estimate of solution rate at each position at each observation points. The solution rates at 1.5m above the ground were higher in southern Honshu and Shikoku and lower in

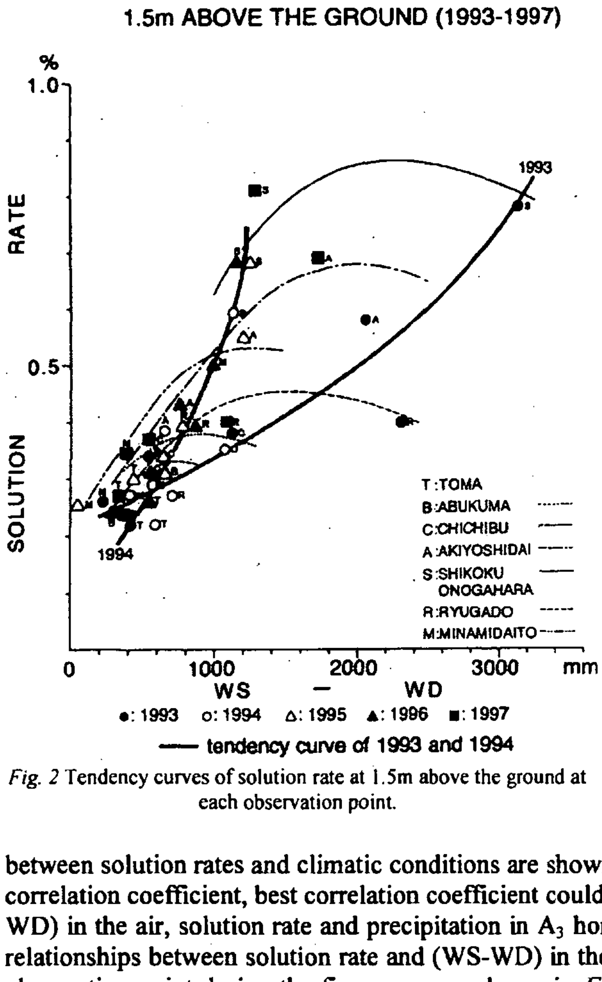

Fig. 2 Tendency curves of solution rate at 1.5m above the ground at each observation point.

northern Honshu and Hokkaido. The solution rates in southern Japan are generally higher than those in northern Japan. However, they are not the highest in Minamidaito in air, because of dry periods that appear during summer. The inter-annual fluctuations of the solution rates in Japan are very clear from 1993 to 1997. Extremely high solution rates appeared in 1993, a very wet and cool summer, and the smallest in 1994, an exceptionally dry and hot summer. As an example of these two years, mean annual solution rate at the three points (Toma, Akiyoshi, Minamidaito) in 1993 and 1994 are shown in *Table 2*. Original weight of tablets was in the range of 12.5g-13.5g as mentioned above. Therefore, the mean annual solution rate of four tablets at various situation of the location was used for the discussion of differences location to location and year to year fluctuations. The relationships between solution rates and climatic conditions are shown in *Table 3*. Showing the matrix of correlation coefficient, best correlation coefficient could be obtained solution rate and (WS-WD) in the air, solution rate and precipitation in A_3 horizon and B_2 horizon. The trends of relationships between solution rate and (WS-WD) in the air 1.5m above the ground at each observation point during the five years are shown in *Fig. 2*. The solution rate increases in accordance with (WS-WD) at values lower than 1000-1600mm for each point. However, they decrease slightly at the higher values over the maximum points. The maximum solution rates are different at each location, but appear within the range of 1000-1600mm of (WS-WD). At the observation points of Shikoku, Akiyoshidai and Ryugado the maximum values are higher than those of the other four points.

Comparing the values year by year, it is clearly shown that the solution rates at the seven observation points increase in accordance with (WS-WD). In 1993, with cool and humid summer, the trend shows the largest (WS-WD) during the five years. In contrast, it shows the lowest (WS-WD) in 1994 with extremely hot and dry summer during the five years. Under the influence of monsoon climate in Japan, solution rate of limestone shows values higher than 0.5%, when (WS-WD) over 1000mm. In the range of (WS-WD) from 0 to 1000mm, the solution rate increases with positive relation taking the values of 0.2 to 0.5% with (WS-WD).

Table 2 Annual solution rate (%) in Toma, Akiyoshi and Minamidaito.

TOMA (ASAHIKAWA)

	1993	1994
AIR	**0.2173***	**0.2228**
A3 HORIZON	**0.4056**	**0.4651**
B2 HORIZON	**0.5476**	**0.6341**

AKIYOSHIDAI

	1993	1994
AIR	**0.5834**	**0.3782**
A3 HORIZON	**2.8828**	**1.2498**
B2 HORIZON	**2.6578**	**1.3951**

MINAMIDAITO

	1993	1994
AIR	**0.2623**	**0.2660**
A3 HORIZON	**1.0407**	**1.2819**
B2 HORIZON	**1.3714**	**1.2984**

* 0.2173% : mean solution rate of 4 tablets

Table 3 Correlation matrix for 5 years (1993-1997) between solution rates of limestone tablets and climatic factors

	PREC.	WS	WS - WD	P - E
1.5m ABOVE THE GROUND	r = 0.695	r = 0.744	r = 0.749	r = 0.745
A_3 HORIZON	r = 0.485	r = 0.426	r = 0.409	r = 0.406
B_2 HORIZON	r = 0.562	r = 0.436	r = 0.418	r = 0.416

CO_2 in soils

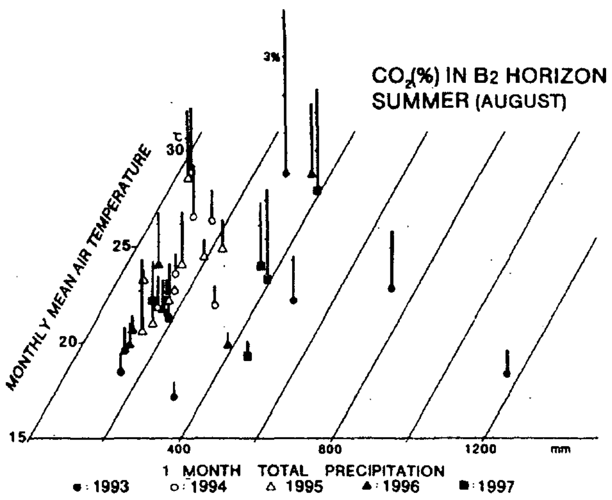

Fig. 3 Soil CO_2 in the B_2 horizon, monthly mean air temperature and one month precipitation prior to measurement, August 1993-1997.

In this part of the study, carbon dioxide concentrations in the A_3 and B_2 horizons measured at the seven points are discussed. The CO_2 in the B_2 horizon shows higher values than the A_3 horizon in almost all cases, even though A_3 horizon is the most productive horizon. The detailed results from 1993 to 1995 have been reported in *Urushibara-Yoshino* (1998) and *Urushibara-Yoshino et al.* (1999). It is considered that CO_2 gas accumulated and was retarded longer in the B_2 horizon than in the A_3 horizon. Therefore the solution rates in

B_2 horizon were higher than that of in A_3 horizon in almost all cases. Carbon dioxide concentrations of the B_2 horizon in summer (August) are shown in *Fig. 3*. In summer, CO_2 concentrations show higher values, when monthly mean air temperature is over 22 and monthly precipitation before the measurements are lower than 400mm. A monthly precipitation higher than 400mm is less effective for increasing CO_2%. In winter (February), observation point at Minamidaito shows a high CO_2 value from 1 to 2%, because of higher monthly mean air temperatures over 17. However, the other points show lower CO_2 less than 2,000ppm with reduced temperature, because of less assimilation and less CO_2 production. It can be summarised that these high CO_2 contents in the B_2 horizon during the warm period can support higher solution rates of limestone tablets in soils. However, the solutional activity in winter is extremely small, because of low CO_2 in B_2 horizon.

Solution of tablets at Location Akiyoshi

The tablets at Location Akiyoshi show typical results of solution rate from year to year and lithological differentiation as mentioned above. Therefore, as examples of the results measured at Locations Akiyoshi, the four tablets are taken for discussion. The climatic condition from 1993 to 1997 at Location Akiyoshi are shown in *Table 4*.

Table 4 Climatic conditions of the Akiyoshidai station from 1993 to 1997

	1993	1994	1995	1996	1997
Precipitation	2773	1411	1992	1488	2458
Annual temperature	13,1	14,3	13,1	13,2	13,7
Evapotranspiration	720,7	788,6	737,7	741,0	752,8
Water surplus	2052,3	695,5	1206,1	747,0	1705,2
Water deficit	0	40,9	0	0	0

Lithological differences

The four tablets, namely those from Regions Akiyoshi, Chichibu, Slovenia and Guilin were measured at Location Akiyoshi. The particle sizes of calcite of each tablets and geological ages are as follows:

- Tablets from Region Akiyoshi: Carboniferous, Permian; average size of calcite diameter 7.5μm; and maximum size of diameter 78.2μm.
- Tablets from Region Chichibu: Trias; average size of calcite diameter 7.5μm; and maximum size of diameter 60.9μm.
- Tablets from Region Slovenia: Cretaceous; average size of calcite diameter 4.0μm and 10.6μm; and maximum size of diameter 74.2μm.
- Tablets from Region Guilin: Devonian; average size of calcite diameter 3.6μm and 11.6μm; and maximum size of diameter 100.5μm.

Inter-annual variation of solution rate of four different lithological tablets

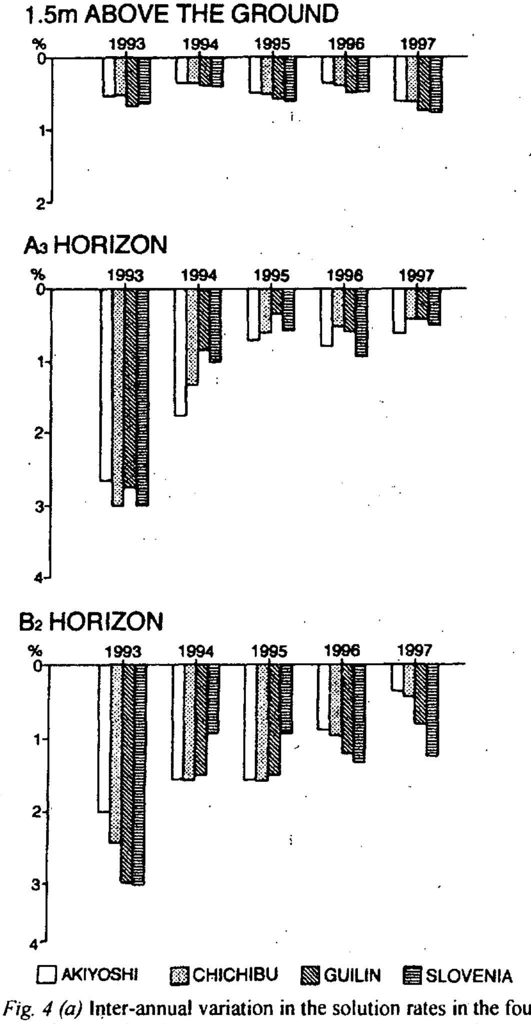

Fig. 4 (a) Inter-annual variation in the solution rates in the four tablets in the air 1.5m above the ground, and A_3 and B_2 horizons in the soils.

Four different lithological tablets, namely those from Regions Akiyoshi, Chichibu, Guilin and Slovenia, were compared by taking inter-annual variation of solution rate from 1993 to 1997.

1. In the air

Solution rates of four tablets show clear tendency in the air. The values of solution rates are in the range of 0.2% in a year. The tablets from Akiyoshi and Chichibu show similar tendency of inter-annual solution rates. The tablets from Guilin and Slovenia show higher solution rates than those from Akiyoshi and Chichibu in every year as shown in *Fig. 4 (a)*. Especially, the tablets from Guilin and Slovenia show greater solution rates in 1993, wet year. In the air, inter-annual solution rates are divided clearly into two groups. The cumulative solution rates show also that the 5 years results of the tablets from Guilin and Slovenia are bigger than those of value of the tablets from Akiyoshi and Chichibu as shown in *Fig. 4 (b)*.

2. In the A_3 horizon

The maximum value of inter-annual solution rates appeared in 1993, wet year. In 1993, the solution rate of the tablet from Akiyoshi shows minima among the four tablets. The tablets from Slovenia showed maximum solution rates in 1993. On the other hand, the solution rates of the four tablets were not minima in 1994, the extremely dry year. The minimum values appeared in 1995. This tendency can be seen also in B_2 horizon. It suggests that the condition of soils or activity of organic decomposition in soils appeared slightly later than those under the conditions in the air.

In 1994 and 1995, the solution rates of the tablets from Chichibu and Akiyoshi were higher than those from Guilin and Slovenia. The solution rates were different

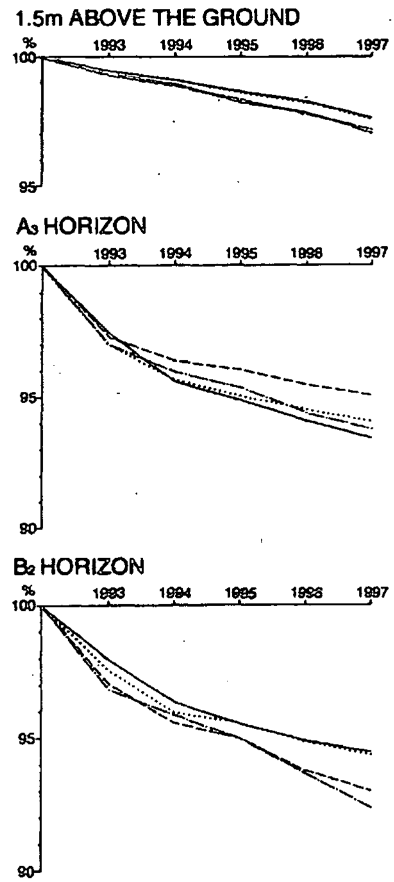

Fig. 4 (b) Cumulative solution rates of four tablets over the five years in the air 1.5m above the ground, and A_3 and B_2 horizons in the soils

lithologically; namely they show opposite tendencies in the soils at dry year, as compared with those in the air.

3. In the B_2 horizon

The maximum solution rates of the four tablets appeared in 1993. The values in B_2 horizon were 3 to 5 times higher than those in the air. The range of values of B_2 horizon was the biggest in 1993. In 1993, the groups of the tablets from Akiyoshi and Chichibu show lower rates than those from Guilin and Slovenia. The groups of Guilin and Slovenia show maximum solution rates regardless the conditions of the five years. The longer period of wet condition in B_2 horizon will be accelerated effectively for the Slovenia and Guilin tablets. In the dry year, 1994, the solution rates of the four tablets showed lower values, but did not show minimum. As same to A_3 horizon, the minimum values appeared in 1995.

Solution rates of extreme year tendency at Location Akiyoshi

The year 1993 was an exceptionally wet year, having the highest annual precipitation among the five-year period as shown in *Table 4.* The year 1993 exhibited the maximum solution rate of the whole five-year period, for the tablets set at 1.5m above the ground as well as for those set underground in the A_3 and B_2 horizons. Of the tablets suspended in the air 1.5m above the ground, the Guilin and Slovenian tablets had higher solution rates than those of Akiyoshi and Chichibu limestone. Likewise the Guilin and Slovenian planted in the B_2 horizon showed higher solution rates than the B_2 horizon Akiyoshi and Chichibu tablets. However, this difference between Guilin, Slovenian, and Akiyoshi, Chichibu tablets were not clear for the tablets planted in the A_3 horizon.

The year 1994 was a dry year; it had the least precipitation in the five-year period as shown in *Table 4*. For the tablets suspended 1.5m above the ground, the solution rates of all four types of tablets were smaller in the five-year period. For the tablets suspended in the air, the solution rates of the Guilin and Slovenian tablets were less than those of the Akiyoshi and Chichibu tablets. However, the year 1994 was not the smallest solution rate for the tablets planted in the B_2 horizons; the year 1995 exhibited the minimal solution rate in the five-year period. The measurement of the CO_2 in the soil revealed that 1995 had shorter periods of high CO_2 content. This suggests that the solution rates of 1995 reflect the CO_2 content of the soil. The 1995 solution rate of the Guilin tablets in the A_3 horizon was the smallest of the five years, while under dry conditions probably because the grain size of their calcite is smaller than that in the other types of tablet.

CO_2 effect at Location of Akiyoshi

Over the five-year period, the solution rates of the tablets planted in the A_3 and B_2 horizons were three to five times greater than those of the tablets suspended in the air. As shown in *Fig. 5*, CO_2 in A_3 and B_2 horizons had a clear relationship to daily precipitation. It can be understood that the higher solution rate was occurred due to the persistence of water contents in the soil and the development of high CO_2 contents in the wet soil. High CO_2 contents develops in the soil in the warm season, after it rained for five days consecutively with precipitation of 50mm to 100mm per day.

Especially, it is clearly shown that high CO_2 content in A_3 horizon was appeared earlier after rainfall. In contrast, high CO_2 content in B_2 horizon was appeared slowly after rainfall. The CO_2 content in B_2 horizon was higher than in A_3 horizon. It seems that the tight layer of B_2 horizon can keep CO_2 gas longer than that of A_3 horizon.

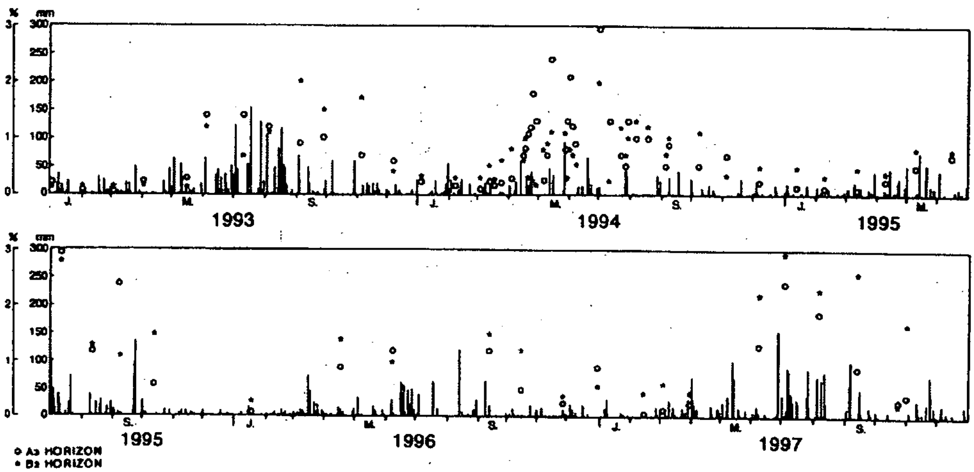

Fig. 5 CO_2 % in A_3 and B_2 horizons and rainfall at Akiyoshidai station from 1993 to 1997

Conclusions

Solution rates of four tablets made from limestone obtained in Slovenia, Guilin, Chichibu and from the limestone at each of seven observation points in Japan were measured from 1993 to 1997. The solution rates were measured for estimating karstification rate of bare karst and soil covered karst in monsoon climate in the temperate and subtropical zones. The results are summarised as follows:

- Solution rates of limestone tablets in soils are 1.5 to 5 times higher than those in the air 1.5 m above the ground. This means that karstification will progress with a high rate in the soil than on the bare karst (without soil) in Japan.
- The correlation coefficient between solution rates in the air and (WS-WD) is the highest for the five years. On the other hand, in the A_3 and B_2 horizons, correlation coefficients between solution rate and annual precipitation were highest in the five years observed.
- In the five years, solution rate of limestone at the four observation points shows inter-annual fluctuations. Especially, the solution rates in the air 1.5m above the ground show clear trend with (WS-WD). At each observation point, the solution rate increases in accordance with (WS-WD), for the range 1,000-1,600mm. Then solution rates decrease in the range above 1,600mm in (WS-WD).
- The following considerations summing up the facts obtained from the experimental measurements can be possible. The dominant solution factor is climate. The solution rates reveal inter-annual variation according to atmospheric climatic conditions. The inter-annual variation of the solution rates of tablets planted underground is a function of the rate of precipitation and the CO_2 content of the soil. The subsidiary factor for solution rate is the lithological properties of the limestone. For the limestone suspended in the air, the five year cumulative solution rates of the Guilin and Slovenian tablets were 20% higher than the Akiyoshi and Chichibu tablets. The Guilin and Slovenian tablets planted in the B_2 horizon had slightly higher cumulative solution rates than the Akiyoshi and Chichibu tablets suspended 1.5m in the air.
- From these results, Shikoku and Akiyoshidai have the best water balance condition for the solution of limestones in air in the monsoon temperate zone. Because of these situations with good water balance condition, karstified limestone plateaus with dense dolines develop relatively better in these areas of Japan. Of course, for the development of dolines, bedding planes, thickness of layers, fissure pattern in limestone also assist karstification. However, in Minamidaito island, solution rates of limestone in the air are not the highest, because of dry periods in summer. In the soils of Minamidaito, the solution rate of limestone tablets show the highest values except in 1995. This means that walls rugged karst development is possible under present climatic conditions in Minamidaito.

Acknowledgements

The 1995, 1996 and 1997 measurements of solution rate and CO_2 contents were made possible by a grant-in-aid by the Ministry of Education, Science and Culture in Japan (Leader: Kazuko Urushibara-Yoshino No.0768090). We would like to express our sincere thanks to *Prof. I. Gams and Prof. D. Yuan*, who supplied tablets of Slovenian limestone, and Guilin limestones,

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INFILTRATION IN THE TRANSDANUBIAN MIDDLE MOUNTAINS, HUNGARY

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Summary

This study confirmed the deep karst character of the Transdanubian Middle Mountains. In case of the other Hungarian karst regions which have mainly shallow character, the input is followed by the output after some months. In spite of this, the Transdanubian karst system reflects the input water only with a leeway of some years. The most intensive infiltration occurred in those cases when the precipitation was >10 mm/day, snowfall, winter half-year precipitation. The water system bled its water input; first part: during 2-2.5 months, main part: 1-2 years.

Introduction

The Transdanubian Middle Mountains are situated mainly in the northeastern parts of the Transdanubian region; however, some parts extend to north and east, towards the right banks of the Danube. In morphological sense, it covers a territory of 5200 km^2 (*Fig. 1*). In the studied area, mainly Upper-Triasic limestone and dolomite can be found. The average depth of the karst strata is 2.5 km, its surface projection is around 13000 km^2. The mentioned formations - comprising one single system - reserve most of the karst waters. Special name was introduced for this type of water in the 1950s: it was entitled as „main karst water". Other, smaller closed units have to be separated from this; the age of these separate units also differs from the mineral content of the main karst. The study deals with the „main karst water" which - because of the large extension of the karst strata - belongs to the group of the „deep karsts". The extremely large capacity of the minerals causes the fact that the amount of stored water can be measured in hundreds of km^3. This

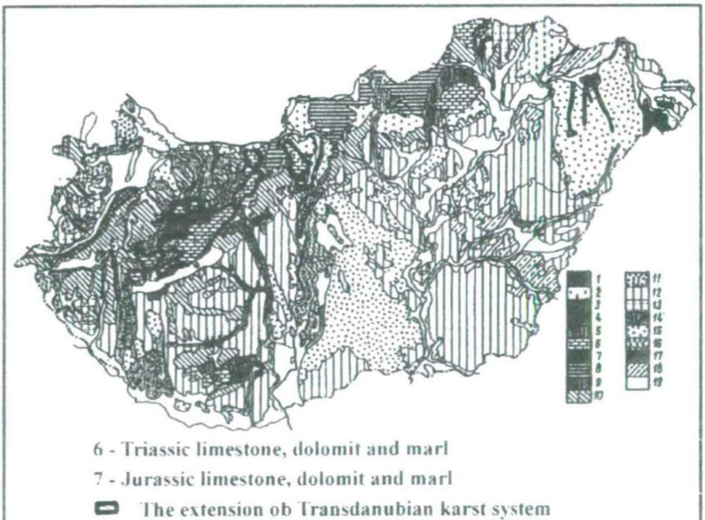

Fig. 1 Geological map of Hungary

huge quantity appears as the largest natural drinking-water body of Central Europe. Intensive exploitation of this water occurred between 1950 and 1990, which caused the 20-30 m regional decrease of the groundwater level, and the drying up of all - formerly abundant - springs of the area.

In connection with the economic decline after 1990, practically all of the significant mining activities disappeared from the area. As the very last of them, the water exploitation in Fehérvárcsurgó was halted in July, 1999. Since the only water resource of the human population of the area comes from the above-mentioned karst water, the water exploitation for human consumption has to be continued in the future. However, the amount of human consumption also decreased in the last 10 years. The intensive anthropogenic use is a good indicator of the importance of further research on karst water: the mass of natural water supply, the possible exploitation of water without the degradation of the system and also the presumable rate of regeneration of the former hydrological balance are some of the most significant and current questions in the area. (*Fig. 2.*)

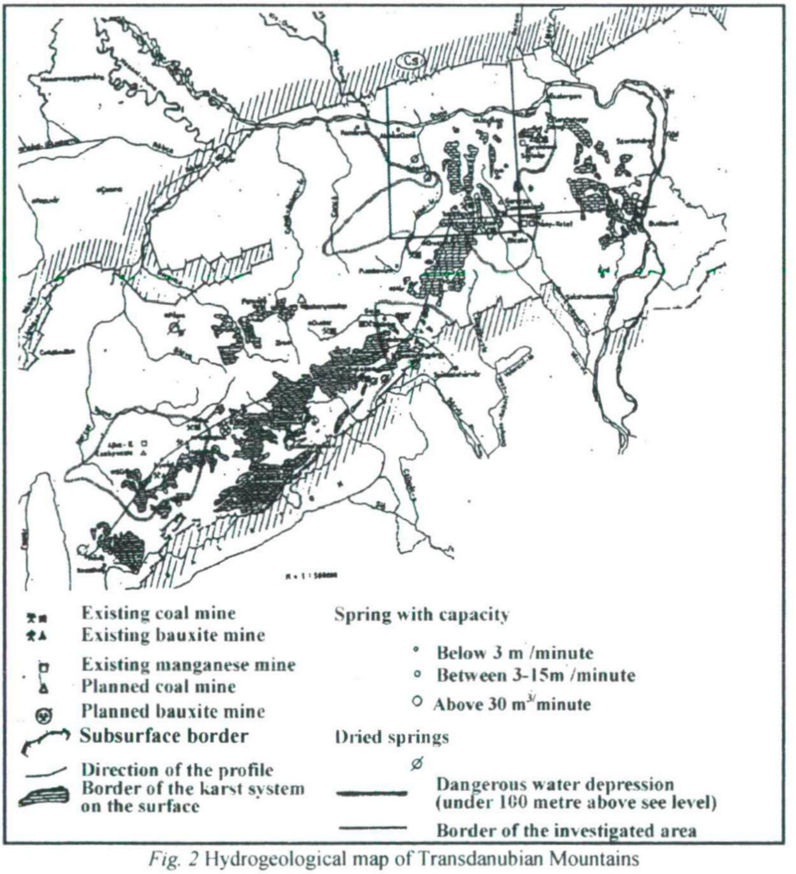

Fig. 2 Hydrogeological map of Transdanubian Mountains

The springs of the Tata area

A larger, relatively separated cell of the „main karst water" strata is the group of the springs of Tata. In this area, the original aim of the research was to present the connection between the infiltration (water input) and the runoff (water output) of the springs; and also, to draw conclusions about the functioning of the water-system. The studied springs are situated in the area of the so called „town of waters": Tata. Their runoff is around 120 m^3 in their natural conditions. The water of these springs used to be lukewarm (18-22 °C) with relatively high mineral content (H_2S, $MgCO_3$, etc.). Their curative power was well known by the Romans: even a settlement was founded by them in the close vicinity of the springs. Up to the Modern Times, springs became more and more frequently visited again, especially by tourists.

This prosperity was ended up by the new, intensive mining activity: the famous springs dried up one by one between 1949 and 1972, as the water exploitation in the area reached much larger extent then the possible infiltration. According to the changes of the last decade, from 1990, the continuous and intensive increase of the groundwater level can be followed in the area, and the renewal of the first springs will most probably occur between 2001 and 2003. Before the appearance of mining in the area, there were approximately 170 springs in and around Tata, but most of the water came from four (groups of) springs: „Nagy" (33 m^3/min), „Kis" (27 m^3/min), „Nagy-tó parti" (11 m^3/min) and the „Fényes" springs (42 m^3/min). The sustaining area of the springs was the uncovered (236 km^2) and covered (450 km^2) karst terrains in the eastern parts of the Vértes, and western parts of the Gerecse Mountains. (*Fig. 3.*)

Model

The aim of the study is to find connection between the precipitation and the runoff of the karst springs of the area (*Fig. 4*). On this way, both the input and output sides have to be counted; from their relationship, certain conclusions can be drawn about the functioning of the system.

Input side

- *precipitation*: Its quantity, intensity and the aggregate are in positive correlation with the amount of the infiltrated water.
- *vegetation overlay*: The infiltration is very much influenced by the vegetation overlay, as it decreases the runoff of the water and delays the infiltration.
- *material of the minerals*: The capacity of the pores and the rate of the cracked parts influence the infiltration (positive correlation)
- *water content of the pores*: Its task is the „pre-wetting": without this moisture, water cannot infiltrate into deeper layers.
- *Groundwater input from the surrounding areas*: In case of the cell which sustains the springs of the Tata area, water input arrives from the Bakony Mountains (15-20 m^3/min).

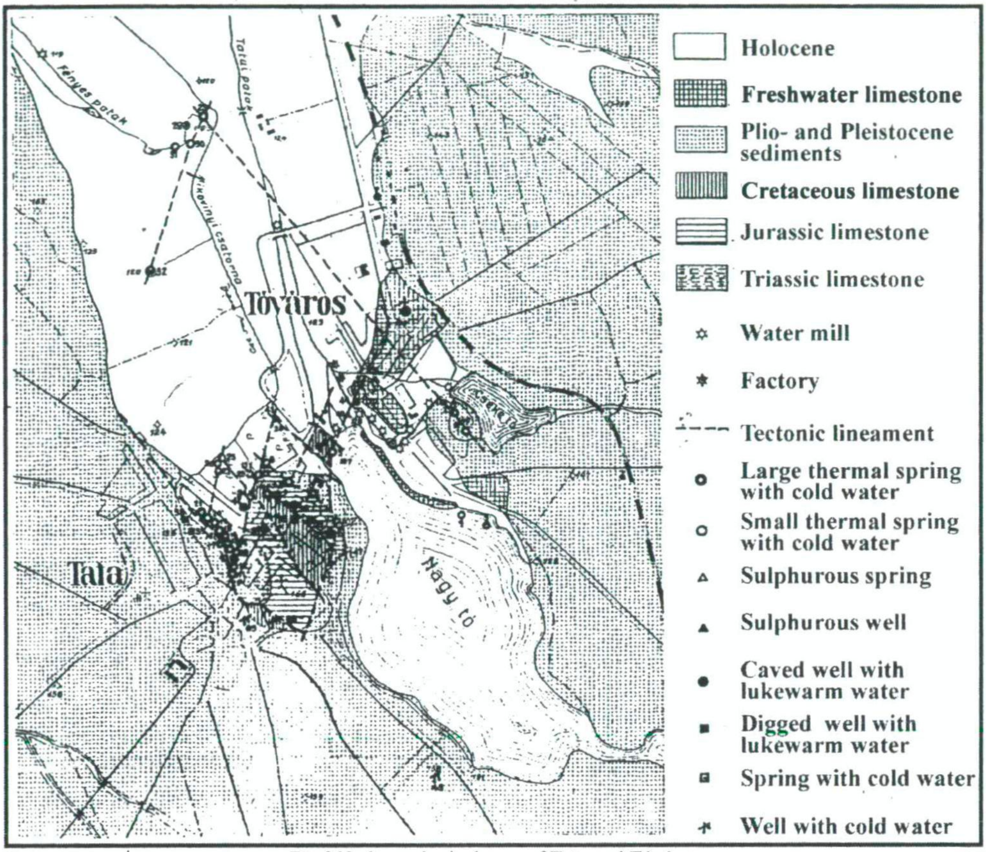

Fig 3 Hydrogeological map of Tata and Tóváros

The most important features of the present **water-system** are:

- The waterlevel is not entirely linear, but follows, more or less, the differences of the surface morphology.
- Certain rifts can be found in the mass of rock in which the watercourse is tectonically determined.
- In these rifts, the watercourse has dynamic changes: if there were significant changes in one part of the system, equalization starts immediately. For example, earlier there was a southwestern-northeastern flow in the karst system, which can be explained by the deviations of the precipitation (900 mm - 560 mm). This flow can be mentioned as an input of the studied springs.
- In spite of the uniformity of the watersystem, there exists some separated subregions such as the Tata area. This separation can be made only for some exceptional case studies: the „main karst water" comprises one solid system, and there is significant - still relatively unclear - communication between the more or less separated cells.

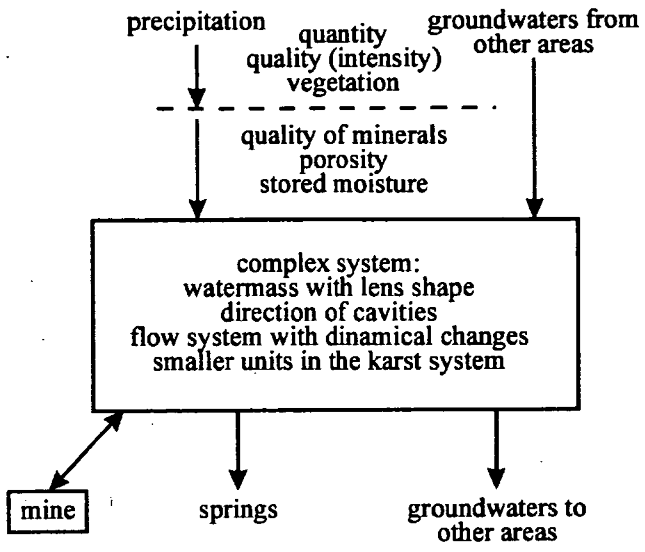

Fig. 4 The infiltration modell

Output side:

Before the foundation of mines in the region, two factors were most important:

- springs (e.g.: the springs of Tata, 175 m^3/min)
- subsurface outflow (in our case, the groundwater had its northern outflow towards the springs of Neszmély, 2 m^3/min)

Water exploitation had short history, but it was extremely influential with its 205 m^3/min consumption.

Correlation analysis:

Applied database of meteorological stations:

- fluid precipitation: Pusztamarót (340 m), Gerecse Mountains
- solid precipitation: Bakonypölöske (212 m), Bakony Mountains
- runoff of the springs: based on the data of the period between 1949 and 1954 of the afore-mentioned four springs. This period was still not influenced by the mining activity.

Linear regression:

At the beginning of the study, it was presumed that linear connection existed between the factors. Therefore, the connection between the dependent and the independent variables is y=ax+b. The statistical analysis, the linear equation of the joint line and the correlation coefficient were calculated by the application of the STATGRAPH program. (*Table 1, 2*)

Table 1 Table of calculations I.

Independent variable	Dependent variable	Correlation coefficient
1. monthly precipitation	runoff (2 months later)	0,3
2. 10 mm/day > intensity of monthly p.	runoff (2 months later)	0,4
3. 10 mm/day > int. of m. p.	runoff (3 months later)	0,1
4. 10 mm/day > int. of m. p.	runoff (1 month later)	0,0
5. winter snowfall	first runoff after melting period	0,93
6. yearly precipitation (April-April)	runoff (2 months later)	0,24
7. 10 mm/day > int. of winter p. (Oct.-May)	runoff (2 months later)	0,41
8. snowfall	runoff 2 months after melting	0,34

The following data are connected to the precipitations under 10 mm/day, fell between October and May, in the winter half-year. In case of infiltration, the winter half-year was treated as one unit, because of the organisation of the hydrological year: this begins with September, after the longer break of the summer infiltration. In case of the last precipitation data, it was compared to the two-month-later output (July is the dependent variable).

Table 2 Table of calculations II.

Independent variable	Correlation coefficient
9. previous year + two years earlier (snow 1.5*)⇒	0,67
10. previous year + two years earlier⇒	0,74
11. previous year (snow 1.5 *) + two years earlier⇒	0,74
12. previous year/2 + two years earlier⇒	0,78
13. previous year (snow 1.5 *)/2 + two years earlier (1.5 *)⇒	0,8

Conclusions

1. The correlation analysis verified the connection between the precipitation and the output of the springs only in case of winter snowfall (calculations 1-4). Stronger correlation could not be shown with the decrease of precipitation intensity or not even with the change of duration.

2.a. On the basis of one-year precipitation (calculations 5-7) the following could be concluded. The connection between the precipitation of the last year and the runoff of the springs after 2 months was also very weak. This means that the intensive precipitation did not influence the water output. As we can see, with the decreasing intensity of precipitation and the change of the measured period of precipitation, increasing connection could be indicated. On the other hand, it did not have connection with the 10 mm/day> precipitation of the winter half-year. Because of these circumstances, the precipitation database of a much longer period had to be applied for further examination.

2.b. According to the mixed database of the studied years and the database of the spring outputs 2 months after the last used precipitation data (calculations 9-13) the following could be concluded. According to the above calculations, strong correlation could be indicated only between the winter half-year and the outputs of the springs. In connection with the changes of the duration and the precipitation intensity (snowfall), much stronger correlation appeared (0.67-0.8). The strongest correlation could be indicated with the 1:1 combination of the last year precipitation and the precipitation data of the period before 2 years, also with 1.5 times counting of the snowfall data (0.8).

References

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