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

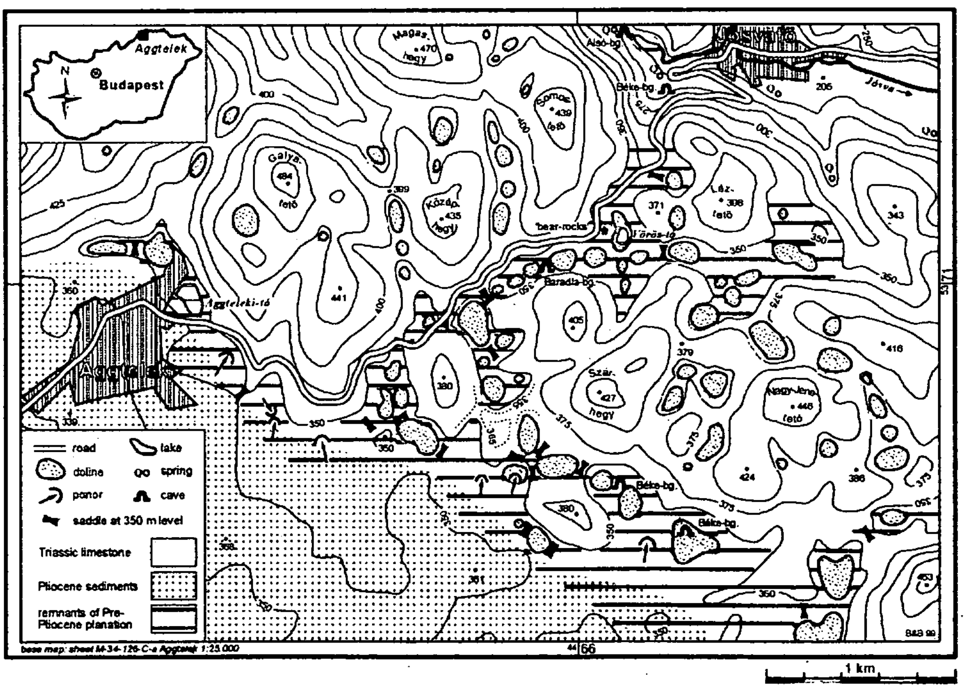

Fig. 1 Simplified geology and geomorphology of the SW Aggtelek karst

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

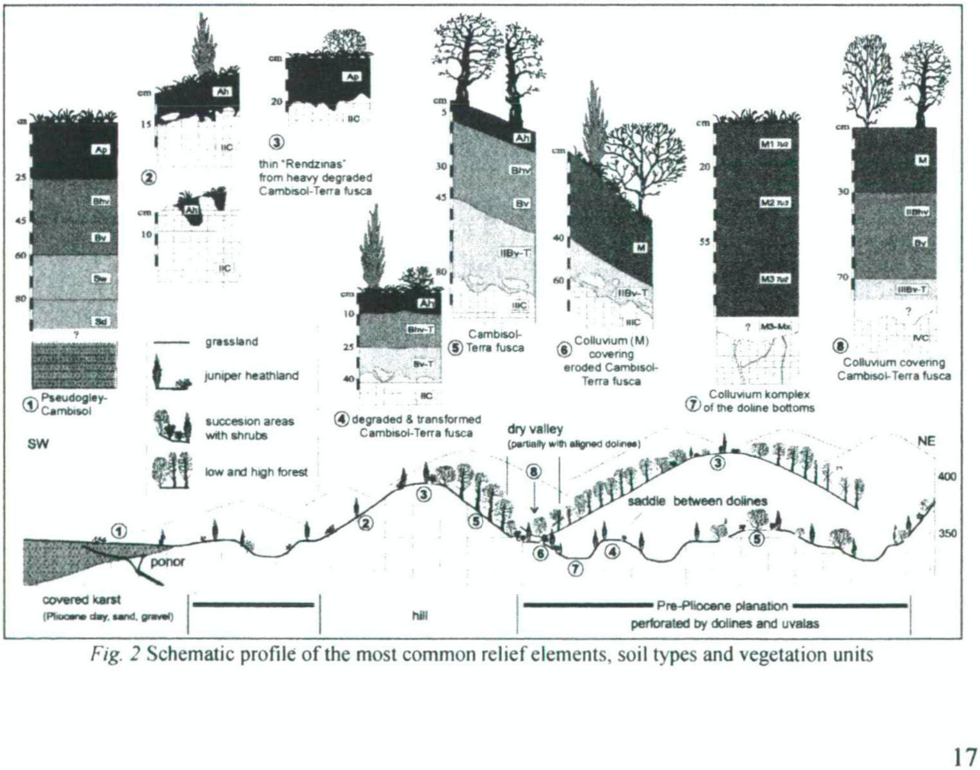

Fig. 2 Schematic profile of the most common relief elements, soil types and vegetation units

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

	extremely stable			*very stable*			*stable*		*unstable*				*counted transparent minerals*
Heavy minerals	*Z*	*T*	*R*	*An*	*Ky*	*Sil*	*Ep*	*St*	*Hbl*	*Gr*	*rest*	*opaque*	
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.

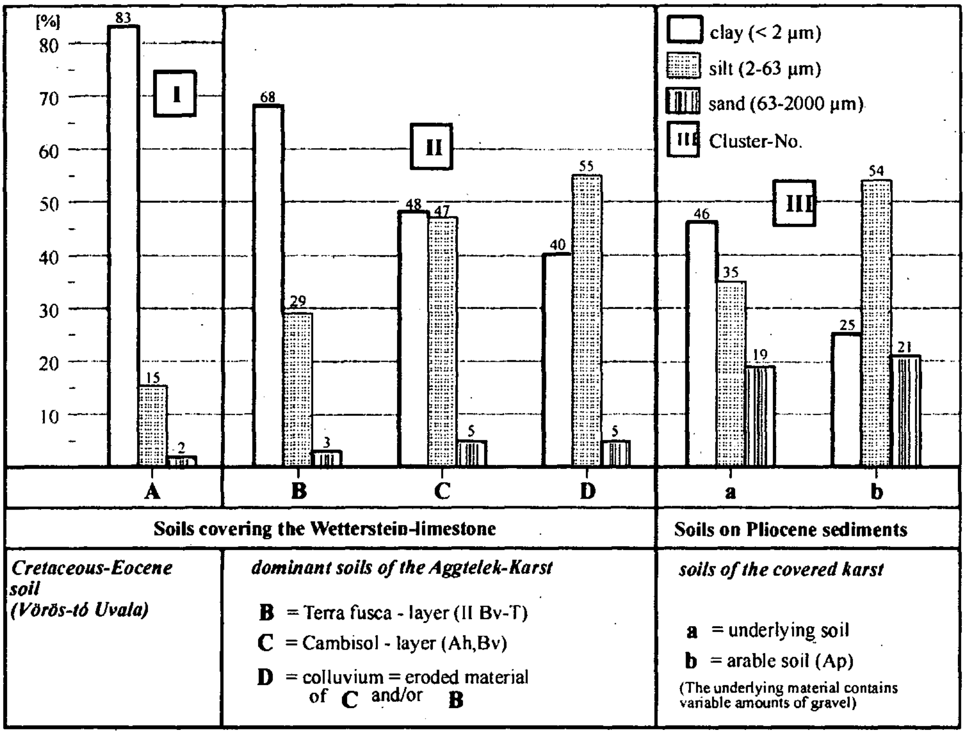

Fig. 5 Grain size distribution in the different soil types

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.

<u>Soil type</u> 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) IIBv IIIBv-T	 + + (4,5 - 5 - 35) + (4,1 - 2 - 47) + (4,4 - 1 - 65)	Profile 8 = very high	 80 cm 100 cm 90 cm
Colluvium covering eroded Cambisol-Terra fusca **(succesion area, shrubs)** M IIBv-T	 + + + (5,5 - 5,5 - 44) + + + + (6,5 - 2 - 64)	Profile 6 = very high	 55 cm 40 cm
Degraded Terra-fusca **(Juniper heathland)** Ah / Bhv-T Bv-T	 + + + (5,4 - 7 - 55) + + + + (5,7 - 3 - 72)	Profile 4 = high	 45 cm 40 cm
Cambisol-Terra fusca **(Forest)** Ah / B(h)v IIBv-T	 + + (4,8 - 6 - 45) + + (4,6 - 1 - 76)	Profile 5 = very high	 60 cm 70 cm
Soils on Pliocene sedim. *Pseudogley-Cambisol* **(farmland, grassland)** Ap Bv Sw	 + (5,3 - 4,5 - 22) + + (5,7 - 3 - 30) + (4,9 - 2 - 44)	Profile 1 = intermediate (no filtering at runoff events)	 95 cm 75 cm 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

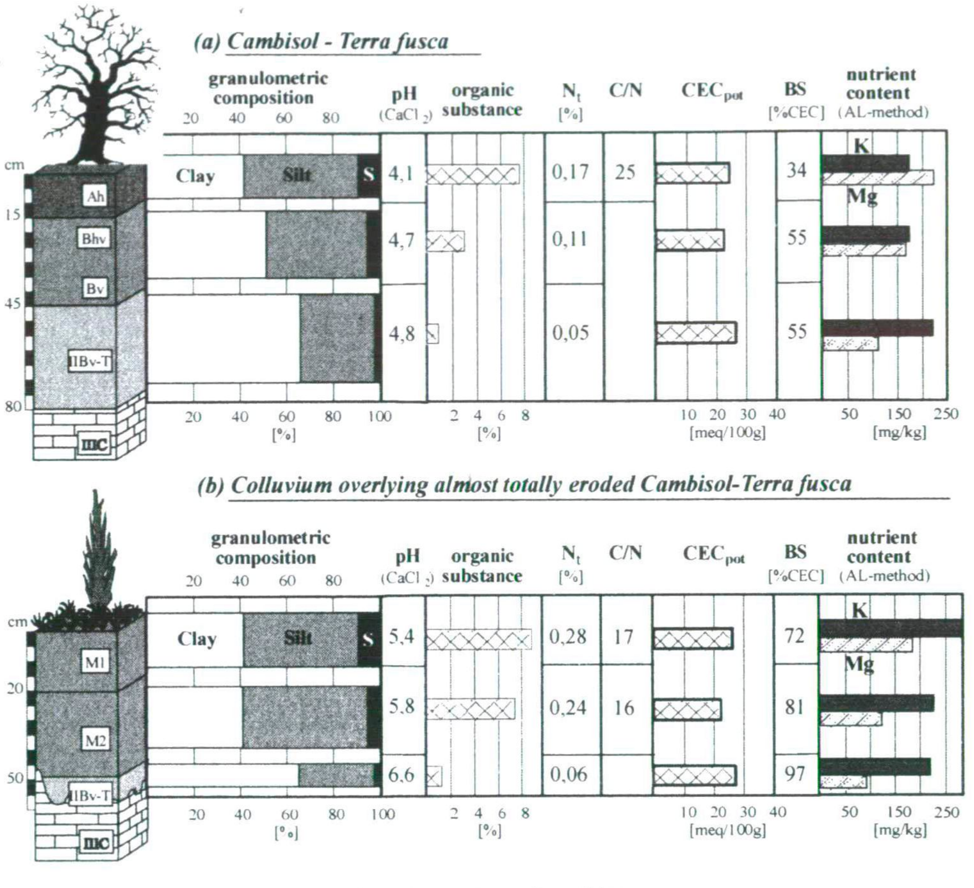

Fig. 9 Comparative soil qualities
(a) profile beneath forest cover and unaffected by man
(b) profile resulting from human activities

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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