Ecopedological explorations of three calcareous rich fens in the Slovak Republic

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ABSTRACT

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This report presents the findings of quick surveys in three declining calcareous rich fens in the Slovak Republic to understand their origin and present state. Hypotheses were generated for further elaborated research as a base for restoration measures. Distinct sites along cross-sections were investigated by augering, soil sampling, making vegetation relevées and measuring temperatures and electric conductivities in peat profiles. Soil samples were collected for chemical analyses. Comparable processes and patterns were observed in the fens. The distribution patterns of the plant communities were strictly related to hydrological and pedological factors. The fens developed as flow-through-systems, with alternating cold discharge and warm recharge zones. Clear layers of calcite, pyrite and iron oxides alternated with organic layers in the discharge zones. Trophic levels of plant communities increased from the discharge to the recharge zones and were distinguished by distinct humus forms. Hardly any evidence was got for Fe- or Ca-bound inorganic P to explain low productivity at calcareous discharge sites, compared to recharge sites. Extremely low C/N and C/P ratio's suggested P and N immobilization by humification in these environments.

Keywords: Calcareous fen, Caricion davallianae, Flow-through-system, Humus form, Pyrite, Productivity.

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Preface

In several parts of Middle and Eastern Europe vast peat areas are threatened to extinct by economical and technological developments in the rural landscape. These areas, however, still have a high habitat- and bio-diversity and are worthwhile to be preserved.

The Slovak Nature Conservancy Council (SNC) and the Daphne Research Institute in co-operation with Wetlands International are preparing a strategy and an action plan for the "Conservation and sustainable use of peat lands in Slovakia". The World Bank is interested to participate in restoration measures by financial support from the Global Environmental Fund. To underpin restoration measures, a detailed analysis of the hydrology and peat forming processes is needed.

The Dutch Government funded the project 'Ecohydrological research as a base for restoration of calcareous fens in the Slovak Republic'. The aim of this project is to support the Slovak organisations in gathering eco-hydrological knowledge, which appeared to be rather successful in Dutch restoration projects. This project is administrated by the University of Groningen. Wageningen University and Research Institute and the Public Water Company 'Vitens Technology' participate in the project.

From June 15 – 21, 2002 a trip was organised to Slovakia to exchange knowledge between the Dutch and Slovakian counterparts and to visit the threatened areas in order to carry out some exploratory surveys. This report presents a synopsis of exploratory ecopedological surveys in three nature reserves.

Summary

The Dutch Government funded the project ‘Ecohydrological research as a base for restoration of calcareous fens in the Slovak Republic’. The aim of this project is to support the Slovak organisations in gathering eco-hydrological knowledge to underpin restoration measures. In the summer of 2002 a Dutch-Slovakian team of geomorphologists, hydrologists, soil scientists and phytosociologists visited several calcareous fens in the Slovak Republic to generate hypotheses about ecosystem functioning and the causes of the decline of these fens. The main problem of the areas is the extinction of the specific plant communities and the overgrowth of shrubs and trees.

In this report we present our findings of quick surveys in three areas: Belianske Lúky (near Spišská Bela), Pastiersko (near Strba) and Abrod. The hypotheses are a starting point for further elaborated research to the causes of the decline of the fens.

In the three areas distinct sites along cross-sections were investigated by augering, soil sampling, making vegetation relevées and measuring temperatures and electric conductivities in peat profiles. Findings were discussed in the field. Soil samples were collected for chemical analyses. The location of the sites was recorded with a GPS receiver.

Belianske Lúky

The area forms the biggest spring-fed fen system in Slovakia with an extraordinary high value for biodiversity. The main problem of the area is the overgrowth of shrubs and trees as can be deduced from historic aerial photographs.

The morphology of the area is influenced by glaciation and fluvial processes. Post-glacial erosion of moraine sediments cover all lower parts by so-called fluvioglacial sediments. The whole area is intensively tilted by tectonic activity in the past, which caused the formation of several Holocene river terraces. Older terraces are covered by fluvio-glacial sediments. Terraces consist of silty, sandy to gravely parent material. Water flows from the next older terraces through tiny aquifers, consisting of alluvial sediments (coarse sand and gravel) in between the flysch bedrock and the covering fluvioglacial sediments, to discharge spots. Once peat formed at these spots, the peat may have expanded unilateral, i.e. even uphill from the major discharge area. Sites with discharging groundwater are characterised by calcite deposits in small pools with open water and a submerged vegetation of Characeae. They are surrounded by plant communities of the Caricion davallianae with a low productivity. Downstream the springs soils were non-calcic, but showed a high base saturation and their vegetation mainly consisted of more productive *Calthion* communities. The trophic gradient was mirrored by a transition of mesimor to saprimoder humus forms, both with low C/N and C/P ratio’s, indicative for intense humification and rapid nutrient cycling. There was no evidence for inorganic phosphorus being bound by iron or calcium. Locally the humus forms revealed a distinct influence of drainage by the presence of strongly humified Oh-horizons.

Strba

The Štrba fen is a part of a small scale catchment area bordered by two small brooks and the watershed about 1 km upstream. The source of the brooks was close to the watershed. In whole Slovakia it is unique for its preserved state. Several endangered species were recorded.

Geologically the area belongs to the same geological unit as Belianske Lúky. The bedrock consisted of flysch, which appeared as an alternation of sandstones and calcareous claystones. No clayey fluvio-glacial sediments were present. Essentially the same sequence of peat profiles, plant communities and bio-geochemical processes could be detected as in Belianske Lúky. The cross-section featured a distinct discharge zone, which was confirmed by low temperatures of the peat profile. It was hypothesized that peat formation expanded down hill from this (primary) discharge area. This discharge caused small pools, in which calcite was precipitated. Distinct pyrite layers could be distinguished. Ecological implications of pyrite formation in calcic environments and the origin of pyritic sulphur is not yet clear. The fen hydrologically could be characterised as a 'cascading-flow-through-system with alternating discharge and recharge zones. Mesimors and saprimoders were the humus forms typical for the discharge and recharge zones respectively. No clear differences in C/N and C/P ratio's, nor inorganic P fractions could be assessed in soil horizons of the different sites along the cross section. Evidence was got that N and P were strongly immobilized by humification in the peat profiles of the discharge zones.

Abrod

It was assumed that the whole fen area was severely affected by drainage activities in the surrounding areas during last decades. The peat was strongly humified and homogenised with mineral bleached sandy particles. The pH of the upper peat layer was approximately 7. The fen was bordered by intensively used arable land where huge sprinklers for irrigation were installed. Our rough impressions allowed only to hypothesize that the main cause of the deterioration of the fen had to be searched beyond the borders of the fen. The water balance of the fen probably was affected severely: less supply by groundwater discharge and more loss by drainage through the ditch. No soil chemical observations have been made.

From our survey we concluded that in the visited fens essentially identical processes could explain essentially comparable patterns in soil and vegetation development. Geo(morpho)logically determined very localized discharge was conditional for peat growth, gradually extending downslope. Finally hydrological flow-through-systems developed, with low productive *Caricion davallianae* plant communities in the calcic discharge zones featuring mesimor humus forms, alternated by more productive *Calthion* communities in non-calcic recharge zones, featuring saprimoder humus forms. Enhanced aerobic or anaerobic decomposition of peat might explain the more productive plant communities. We got hardly any evidence for Fe- or Ca-bound inorganic P that might explain low productive sites near discharge zones. On the other hand extremely low C/N and C/P ratio's suggest a strong immobilisation of N and P by humification as an explanation for low productivity.

1 Introduction

Calcareous fens are becoming a rare phenomenon. In The Netherlands they have nearly disappeared. Due to a high precipitation surplus most soils are decalcified and consequently calcareous parent material occurs only at greater depth in the Netherlands. Therefore calcareous fens used to be bound to brook valleys where aquifers discharged base rich groundwater. By human interference in the hydrological cycle through drainage activities and the pumping of drinking water rich fens are almost extinct. If present, calcareous fens are mostly known as spring mires, restricted to tiny spots in forested areas. In Central and Eastern Europe they still can be frequently met thanks to the ample presence of calcareous soils and the absence of a yearly precipitation surplus. These areas can be found among others at the foot of the High Tatra in the Slovak Republic.

Next to teaching the Slovak counterparts eco-hydrological and eco-pedological survey methods, it was our aim to learn ecopedological processes in order to understand the abiotic conditions of calcareous fens in relation to future restoration projects. Our main purpose was to understand the functioning of calcareous fens in their hydrological setting by the analysis of morphological and soil chemical features of humus profiles. We are particularly interested in their trophic status as conditioned by hydrology and biogeochemistry and in the understanding of the processes that are responsible for their extinction. This knowledge is a prerequisite for restoration measures.

In this report we present our findings of short surveys in three areas that were visited by a team of scientists representing several disciplines: geomorphology, hydrology, soil science and phytosociology. Information was collected by augering, soil sampling, making vegetation relevées and measuring temperatures and electric conductivities in peat profiles. 'In situ' discussions between the different disciplines appeared to be very fruitful in generating hypotheses about decisive processes controlling local ecosystem development. Our findings and hypotheses intend to launch further elaborate studies by the Slovakian counterparts to get more knowledge of processes that resulted in the decline of calcareous rich fens and to learn about future restoration measures.

2 Methods

2.1 Approach

Three areas were visited during our trip (Figure 1). For each of the areas there was approximately one day available for exploratory surveys. After a short introduction we explored the fens by walking around and augering to get an impression of the geo-morphological, pedological and vegetational variability. Upon this first impression we decided for a further exploration along a chosen cross-section, covering the main transitions. Distinct sites along the cross-section were investigated by groups composed of different scientific disciplines: pedologists, geomorphologists, hydrologists and vegetational scientists. At several sites soil samples from distinct soil horizons were collected for chemical analyses.

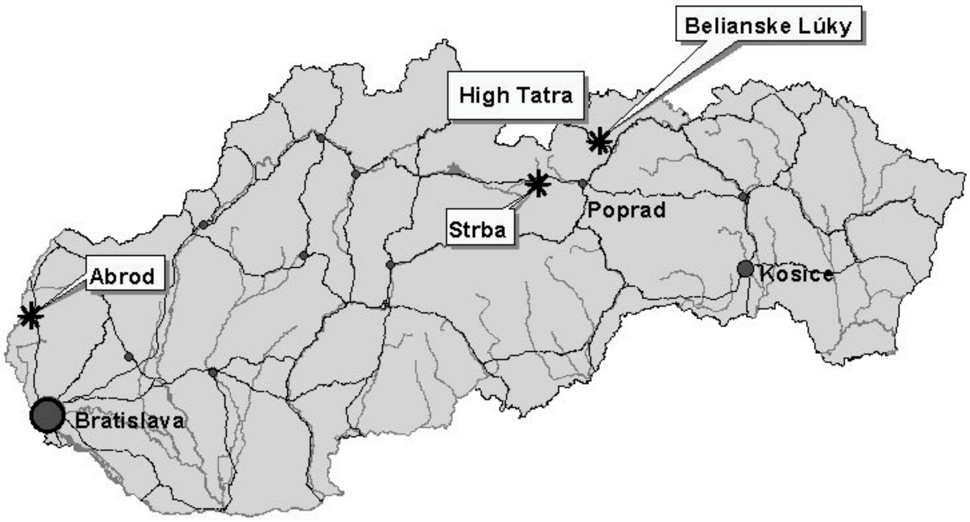

Figure 1 The three areas we visited during our trip

We recorded the location of the sites with a Garmin Etrex GPS receiver at an accuracy of 5 to 10 meters (< 15 m). The co-ordinates were recorded as latitude/longitude in decimal degrees and later transformed to the JSTK system which is used in former Czechoslovakia. A list of the sites is given in appendix 1.

2.2 Areas studied

Belianske Lúky

Belianske Lúky is a National Nature Reserve covering 100 ha and is a wetland of international importance bordering the small river Biela (Figure 2). It is positioned North of Poprad near the village of Spišská Bela. The area forms the biggest spring-fed fen system in Slovakia with an extraordinary high value for biodiversity. The main problem of the area is the overgrowth of shrubs and trees (Figure 3). The hydrology of the fen has probably also been influenced by upstream drainage systems which are abandoned now.

In this fen system we started with a general geo-morphological survey (3.1.2), and laid out a cross-section for more detailed geo-morphological and pedological explorations (3.1.3).

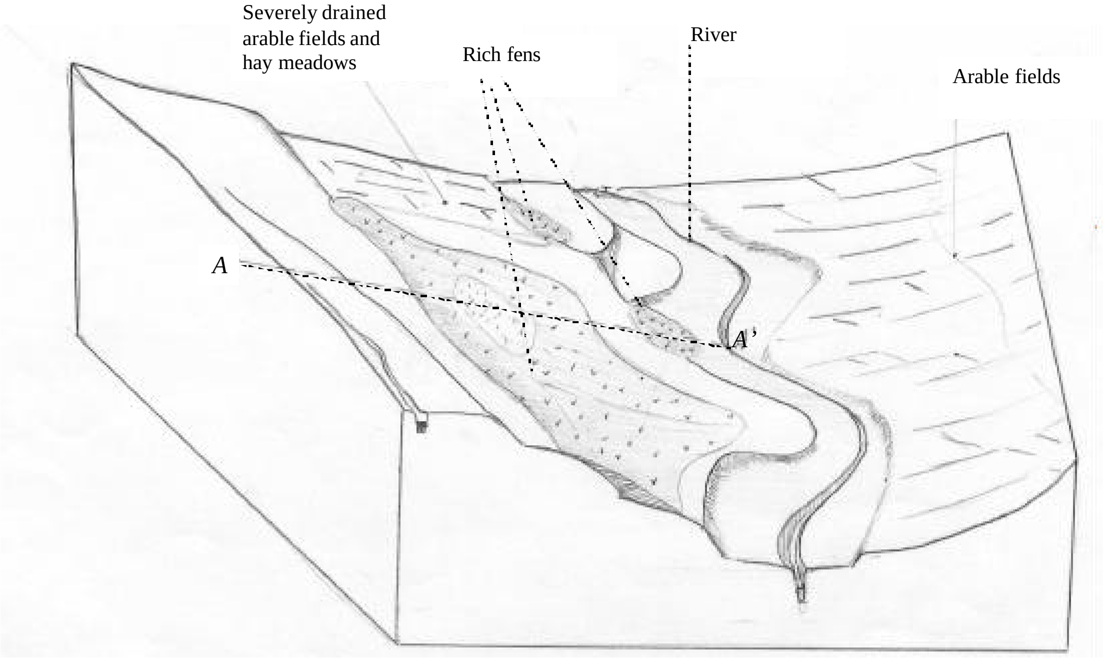

Figure 2 Schematic landscape section of the Belianske Lúky reserve

Figure 3 Shrubs and trees (Betula and Pinus) invade a rich fen with Eriophorum latifólium (site 78).

Štrba

The official name of the Strba fen is Pastiersko (folk expression for pasture). This fen is positioned in the cadastral area of the village Strba (S-W from the village). It belongs to a complex of three fens, laying close to each other. All three fens were proposed for preservation about the year 1980. Up to now only one of these fens (Pastierske: 1,5 km north of Pastiersko) was designated as nature reserve. Location Pastiersko consists of a large complex of fen communities. In whole Slovakia it is unique for its preserved state. Several endangered species were recorded, e.g.: *Dactylorhiza incarnata* subsp. *incarnata*, *Dactylorhiza incarnata* subsp. *pulchella*, *D. majalis*, *D. lapponica*, *Gymnadenia densiflora*, *Pedicularis palustris*, *Menyanthes trifoliata*, *Primula farinosa*, *Triglochin palustre*. Despite an untouched water regime this fen complex is endangered by progressive succession. (authors - Díte D. a Vlcko J.)

Pastiersko is a small triangular shaped area characterised by a spring-fed rich fen. It is positioned between two brooklets, bordering the reserve and meeting each other at the Western point. Upstream the reserve is bordered by an agricultural field for hay making (Figure 4).

In this area two cross-sections were led out crossing each other. Pedological explorations by augering were accompanied by temperature measurements in the peat profile up to a depth of about 1 m. Soil samples of distinct horizons were collected at sites where the humus profile was described carefully.

Abrod

Abrod is a National Nature Reserve of 92 ha designated in 1964 for rich fen protection. This reserve is situated in the Borska lowlands belonging to the Morava flood plain 65 km north of Bratislava (Figure 5). It has been recognised as a unique botanical and zoological location since 1923. Vegetation maps from 1962-66 and 1996-2002 respectively show a significant increase in plant species diversity (app. 200 species more in the registrations from 1996-2002). Out of the approximately 500 plant species, 180-200 are protected to some degree. Moreover, an astonishing 862 species of beetles live on the site (Danish report).

On early aerial photographs a distance of 1.6 km to the Morava river could be observed and flooding of the lower parts of the reserve were reported from time to time (Danish report). No proper documentation of the hydrological conditions of the site is available before the 1960s. In the 1970s dikes were constructed to prevent floodings from the Morava river. The distance is now much shorter between the site and the river.

Previously Abrod was surrounded by grasslands and pastures (Danish report). Spring floods occurred every year but they were coped with. Intensive drainage was then introduced to create suitable conditions for intensive agriculture. Due to climatically induced summer droughts it is now necessary to irrigate. As a result of drainage the surroundings could not longer function as a source of groundwater supply, which probably caused a general fall of the groundwater table and subsequent mineralization of the peat. Consequently, a large area of the reserve is eutrophied now. Small parts are probably still supplied with calcareous groundwater. The groundwater table is gently sloping down in western direction to the Morava river. The mean amplitude of the groundwater level varies from a few dm's in the western part up to more than a metre in the eastern part of the reserve.

At this area there was only time for a quick scan and some augering. No data were collected.

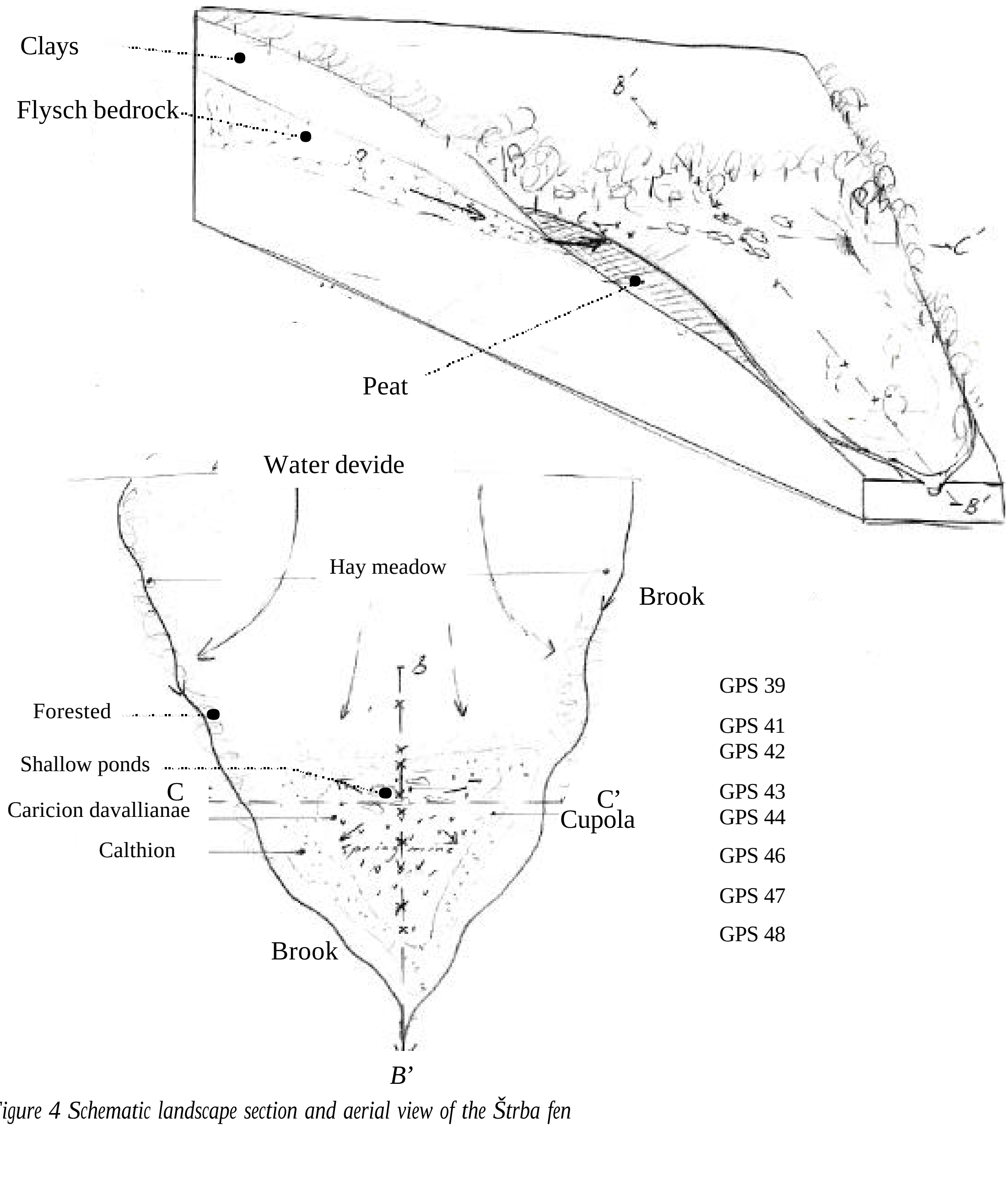

Figure 4 Schematic landscape section and aerial view of the Štrba fen

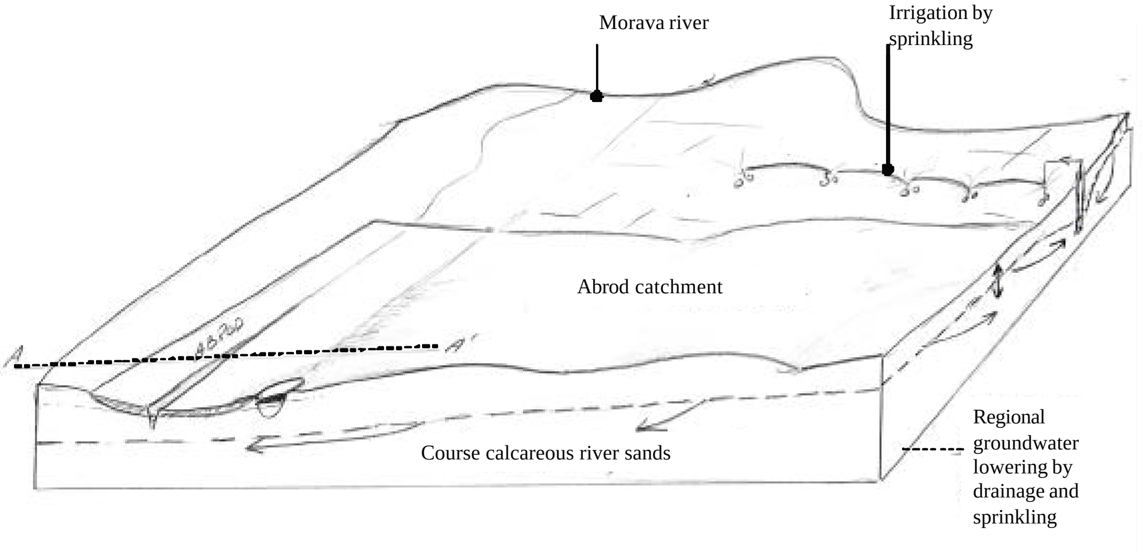

Figure 5 Schematic landscape section of the Abrod fen

2.3 Soil and humus form descriptions

Along the cross-sections, sites were selected by geo-morphological and vegetational criteria to describe the soil and humus profile. The soil was investigated to a depth of 75 – 100 cm where gravel and boulders prevented further augering. The humus profile was investigated to a depth of ca. 40 cm with a monolith-sampler. Horizons of the humus profile were described according Klinka et al. (1981) and Green et al, (1993), (Appendix 2). Soil pH was recorded using pH indicator strips (Merck, spezialindikator pH 2.0-9.0). pH-values indicated by these strips are comparable to pH-KCl analysed in soil samples.

2.4 Measurements of temperature profiles

Daily and annual fluctuations of the temperature at the soil surface cause a flow of heat between this surface and deeper strata, where the temperature is more constant. Any vertical flow of water contributes to this heat transportation, so that accurate measurements of temperature profiles in the soil enable an estimation of the vertical component of water flow. Van Wirdum (1991) developed a method to estimate the water flow in a soil profile by comparing the expected temperature profiles, based on the heat capacity and thermal diffusibility of soils and the mean annual temperature with the measured temperature profile. Differences can be attributed to water flow.

Measurements of temperature profiles were carried out with a gauge ("Prikstok"), provided with a temperature sensor and an electric conductivity (EC) sensor. The gauge can be inserted in the soil by hand to a depth of 2 m. Each 20 cm the temperature and EC was recorded.

2.5 Soil sampling and chemical analysis

At selected sites soil horizons were sampled with the monolith sampler for chemical analyses. At very wet sites with peaty soils, where the monolith sampler could not be used, we cut the samples out of the peat with a knife. Samples per horizon were split in two and send to different laboratories. The results were compared.

In the laboratories the pore water was separated from the solid phase by vacuum extraction with a Buchner funnel. Both pore water and solid phase were analysed on chemical variables.

By lack of cooling facilities the soil samples could not be stored properly before they were transported to the laboratories. It took one or two weeks before the samples arrived at the laboratories, so some variables might have been influenced by exposure to high temperatures or to oxygen intrusion. By expert judgement the results of both laboratoria were combined to a single dataset that looked most reliable.

Solid phase
The solid phase was analysed on (Buurman et al.1996):
- pH-KCl
- lime (% $CaCO_3$)
- Loss on Ignition (LOI)
- Pyrite (FeS_2)
- Exchangeable Ca, Mg, K, Na, Fe, H (Bascomb, pH=8.1)
- Oxalate extractable Fe, Al, P
- Total P, N (after Kjeldahl-destruction)

Pore water
The pore water was analysed on:
- pH, EC
- Ca^{2+}, Mg^{2+}, K^+, Na^+, Fe^{2+}
- Ortho-P
- Chloride
- Sulphate
- Alkalinity

2.6 Vegetation

In the direct surroundings of each auger hole (radius approx. 5 m) the dominating plant species that were easily recognisable were recorded. The coverage per plant species was not estimated.

3 Results and discussions

3.1 Belianske Lúky

3.1.1 Geology

Belianske Lúky belongs to the Tatra – mountain system. The core of the High Tatra mountains was formed from cristalline rock – granites. The core area is bordered, especially on the east part, by mountains consisting of mesosoic limestones. This limestone part of the Tatra-mountain is present upstream the studied area. At Belianske Luky the underlaying bedrock is flysch, consisting of alternating layers of sandstone and claystone. The morphology of the area is influenced by glaciation and fluvial processes. Despite the mountain glacier didn't reach the area, subsequent post-glacial erosion of moraine sediments cover all lower parts by so-called fluvioglacial sediments. They are present as a layer of various thicknesss (max several meters) on the flysch rocks. The whole area is intensively tilted by tectonic activity in the past, which caused the formation of several river terraces. Older terraces are covered by fluvioglacial sediments, which was observed during the field survey.

3.1.2 Geo-morphological survey

Figure 7 shows an overview of the Belianske Lúky area, with the location of the geo-morphological survey and the more detailed cross-section (A-A'). The reserve is gently sloping down to the bordering river Biela in north and north-eastern direction. During a guided tour on June 17th it appeared that the vegetation communities of prime interest (wet, high base saturation, high species density) occurred primarily on the transitions from higher to lower terraces (apparent discharge areas).

Figure 6 Outcrop of sedimentary bedrock in the Biela river

A quick survey revealed that terraces composed the major geo-morphological landscape units. We noticed sedimentary bedrock in the stream (Figure 6). The sediment layers were tilted into almost vertical position. (see figure 9). The present stream is cut about 3 to 4 m deep into the youngest terrace (floodplain). We walked perpendicular to the river from the floodplain to the older terraces (Figure 8). The two youngest terraces consist of silty, sandy to gravely parent material. Stretches of gravely or finer material within the Holocene terraces, parallel to the river, point to a braided river system at the time of deposition. The next older terraces all consisted of glacial till (an unsorted tight mixture of silt, sand, gravel and boulders).

Most arable fields are located on the two youngest terraces I and II. The Caricion davallianae and derived communities (wet, high

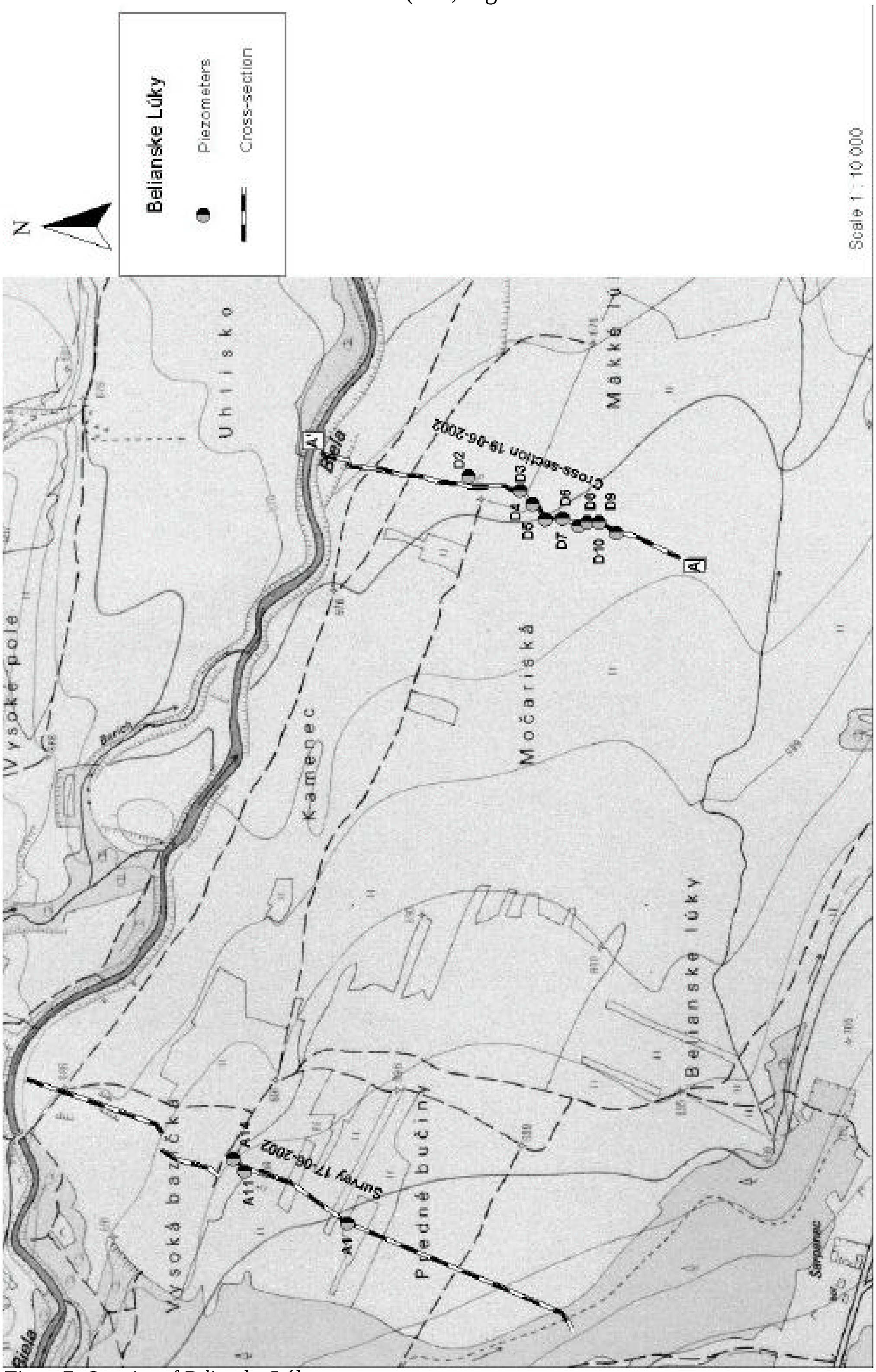

Figure 7. Overview of Belianske Lúky

base saturation) occurred primarily on the transitions from higher to lower terraces. We expect water to flow from the older terraces through preferential paths (primarily gravel and alluvial sediments) under the glacial till to the next lower ones (Figure 9). After discharge, water will in part be retained by the peat, while an excess of water will drain through natural brooklets and ditches. It became not clear which of these streams were naturally formed or man made. These brooks and ditches were observed to stream largely parallel to the river. However, a brook may cross a terrace (about diagonally) and continue parallel to the river onto a next lower terrace. While crossing a terrace a gully is created and an alluvial fan is deposited on the next lower terrace.

Figure 8. Overview of river terraces from north to south. The Biela river flows through the trench in the fore-ground

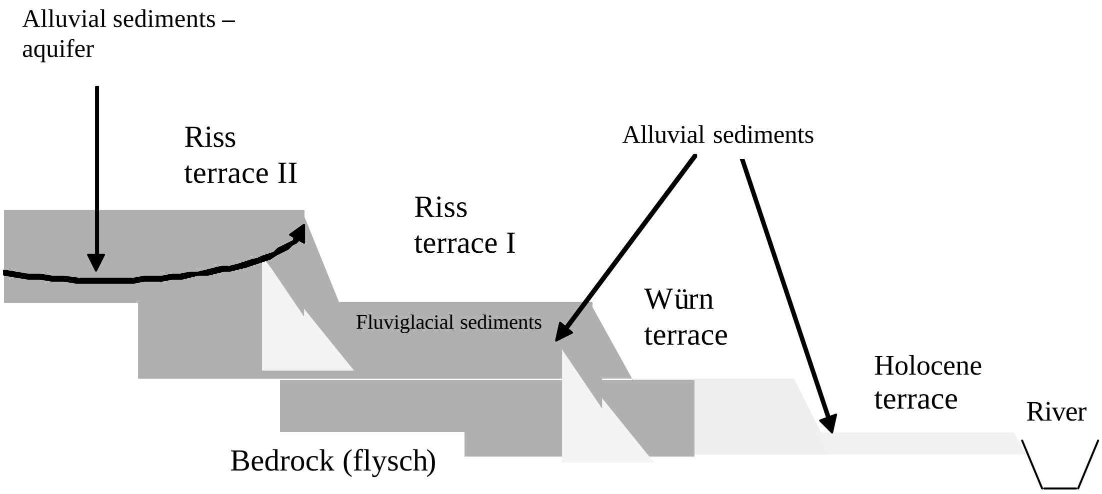

Figure 9 Geo-morphological cross-section of the Belianske Lúky reserve

3.1.3 Cross-section data

On June 19th the cross-section A-A' was investigated in more detail by pedological analyses of the soil and the humus forms in order to further explore the hypothesis that we conceived on 17th. The locations of the described sites are given in figure 10.

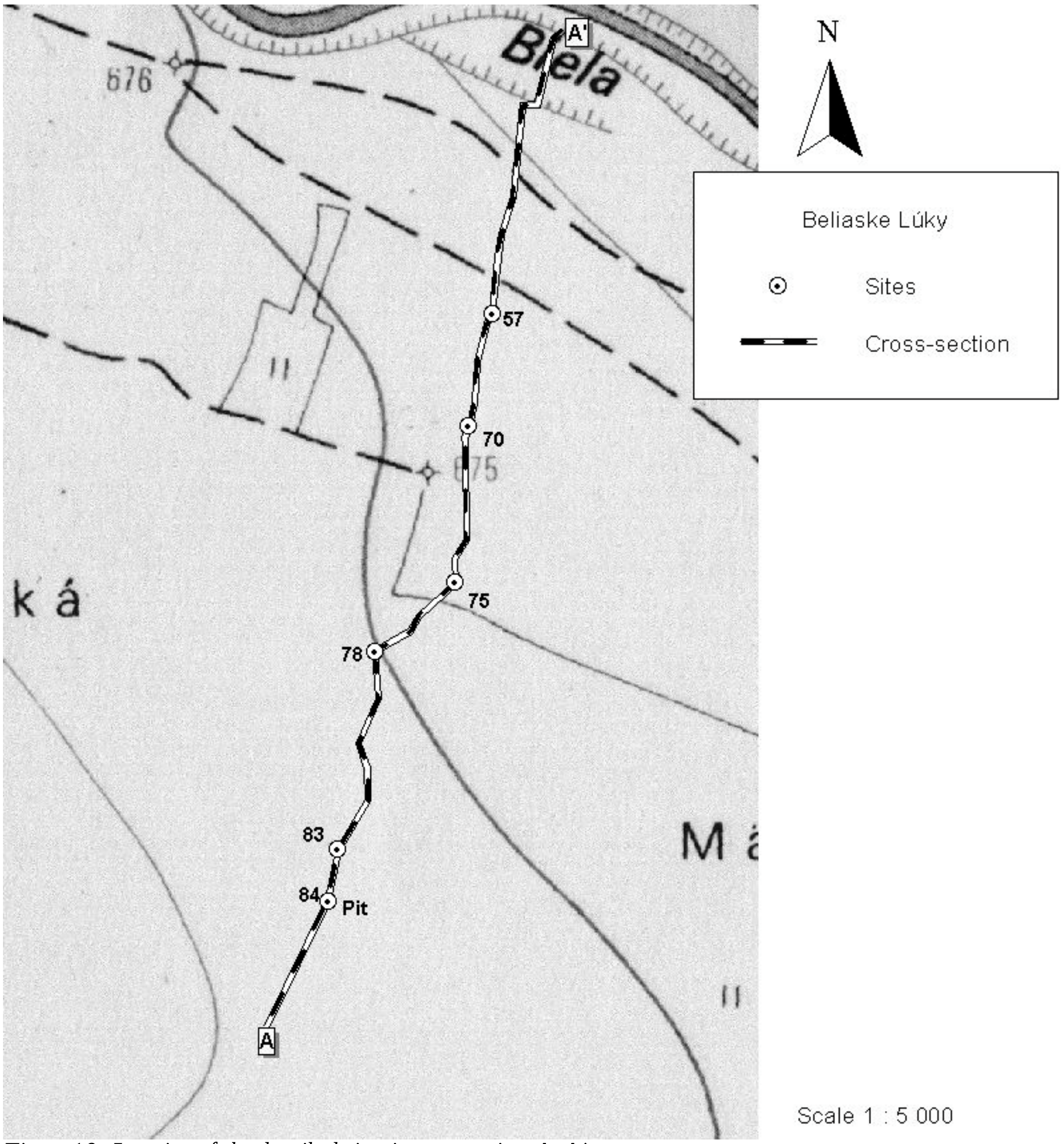

Figure 10. Location of the described sites in cross-section A-A'

Soil and humus form

At sites marked with an asterisk soil samples were collected.

Site GPS 57		Alluvial fan on Holocene terrace Humus form: Vermimull
Ap	0 – 20 cm	silty clay loam, very stony, sharp angular at 5 cm pH=5.5 at 15 cm pH=6.5
B	20 – 30 cm	silty clay loam,very stony, sharp angular
2B	30 – 55 cm	silt loam, few stones, small FeIII mottles
2Bg	55 - 110	silt loam, few gley mottles at 110 cm: pH=7.5, lime, severe stoniness

Site GPS 70		Spring fen on terrace escarpment (± 30 m west of GPS 57, Figure 11) Humus form: Saprimoder
Oh	0 – 20 cm	clayey peat, audible lime at 1 and 20 cm at 3 cm pH = 7.5; 10 cm pH = 7; 20 cm pH = 7
Om	20 – 30 cm	Moderately decomposed peat
2OC	30 – 60	gradual peat to silt loam (glacial till)
2C	60 -	badly sorted glacial till

Figure 11. Narrow zone of Caricion davallianae/Eu-Molinion in a spring fen at site 70

Site GPS 75 (=D3)*		Fluvioglacial sediments with alluvial cover (Figure 12) Humus form: Tenuic saprimoder
Oh	0 – 10 cm	clayey peat, at 2 cm pH = 6.5
2Ahg	10 – 23	silt loam, pH = 6.0
2ACg	23 – 70	silty clay loam, stoniness, pH = 5.5
2C	70 -	silty loam, fluvioglacial sediments, reduced with FeIII mottles, no lime, very stony

Figure 12. Calthion vegetation on a Tenuic Saprimoder humus form at site 75

Site GPS 78 (=D5)*		Spring fen on terrace escarpment Humus form: Mesimor
Oh	0 – 12	peat, at 5 cm pH = 6.0
Om	12 – 90	peat, at 20 cm pH = 6.5, temp = 10.8 C at 50 cm pH=6.5, at 80 cm pH= 7
2C	90 -	silt loam fluvioglacial sediments, reduced without mottles, no lime very stony

At the end of the cross-section, near site GPS 78, we dug a pit. The fluvioglacial sediments consisted of clumps of loam, gravel and boulders up to 40 cm in diameter. After enough fluvioglacial sediment was excavated, the water was scooped out of the pit. A 60 x 70 cm^2 area filled with water to a height of 16 cm in 10 minutes. This is equal to an inflow of 6.7 litres per minute.

Vegetation

In Appendix 3 the plant species recordings at the different sites are presented. According a rough interpretation of the undoubtedly incomplete inventory of species, distinct plant communities on the level of order could be observed: *Arrhenatherion* (site 57), *Calthion* (site75), *Eu-Molinion* (site 70) and the *Caricion davallianae* (site 70, 78, 83).

Soil chemistry

At two sites distinct horizons were collected for chemical analyses. The results were compared and are presented in appendix 4.

The first profile (M75) represents a transition of organic soil towards mineral soil, with a substantial part of mineral particles and 30% of organic carbon in topsoil

(Appendix 4; Table 1). The soil is slightly acidic. Calcium is the dominant cation and the base saturation reaches 75% in topsoil. The second profile (M78) consists of peat with 70% of organic carbon. The topsoil is neutral and subsurface horizon slightly acidic. Base cations share 84% of the exchange sites in the topsoil and 71% in the subsurface horizon. The major exchangeable cation is Ca.

Despite the fact that no calcium carbonate was analytically detected, the pH of the soil pore water and the calculated calcite saturation indices (Appendix 4; Table 3) show supersaturation or equilibrium with calcite. In the vicinity of the studied profiles accumulation of calcium carbonate in the topsoil was observed.

A strong negative correlation was found between amorphous Al and Fe ($R2=0.99$, $P<0.01$), which could be explained by the different origin of Al and Fe. Aluminum is derived from silica minerals and thus positively correlated with the mineral phase and negatively with organic matter. Amorphous Fe precipitates from groundwater rich in Fe^{2+}. Because the wet conditions favour also the accumulation of organic matter, it is clear that amorphous Fe content was positively correlated with the organic matter content. The mineral soil (M75), with the highest aluminium levels showed very low C/P ratio's, pointing to P-immobilisation by humification. The peat profile with wet conditions and high iron contents showed distinctly higher C/P ratio's suggesting a lower P-availability for incorporation in organic matter by humification. Although amorphous iron oxides were amply present to bind phosphates in this peaty profile (M78), a periodical release of iron bound P might occur by dissolution of iron oxides through reduction and a subsequent loss of P by convective subsurface transport. C/N ratio's of both sites were comparably low, indicative for intensive humification processes.

Pyrite was not detected in the samples. However, in other observed profiles with calcium carbonate accumulation in the topsoil, its presence was likely because of H_2S odour and a dark black colour.

The soil water was mainly composed by calcium and bicarbonate as dominant ions, which was indicative for discharging groundwater passed through calcareous sediments in the subsoil. The low sulphate concentrations were indicative for strongly reduced discharging groundwater at site 78.

3.1.4 Eco-pedological system: hypothesis

The observations by augering and digging the pit confirmed the hypotheses that we conceived on June 17th. Water is flowing from the next older terraces through tiny aquifers consisting of alluvial sediments (coarse sand and gravel) in between the bedrock and the covering fluvioglacial sediments to discharge spots (Figure 9,13,14). Most of the water will surface near the slope of one to another terrace. Once peat formed at these spots, the peat might have expanded unilateral, i.e. even uphill from the major discharge area. This last phenomenon might be caused by hydrological backstopping of the peat (low permeability) and by the ‘sponge’ properties of peat itself.

Putting results together, the distinct plant communities and humus forms, can be positioned in the cross-section studied according the hydrological induced pedological processes as presented in Figure 13, 14.

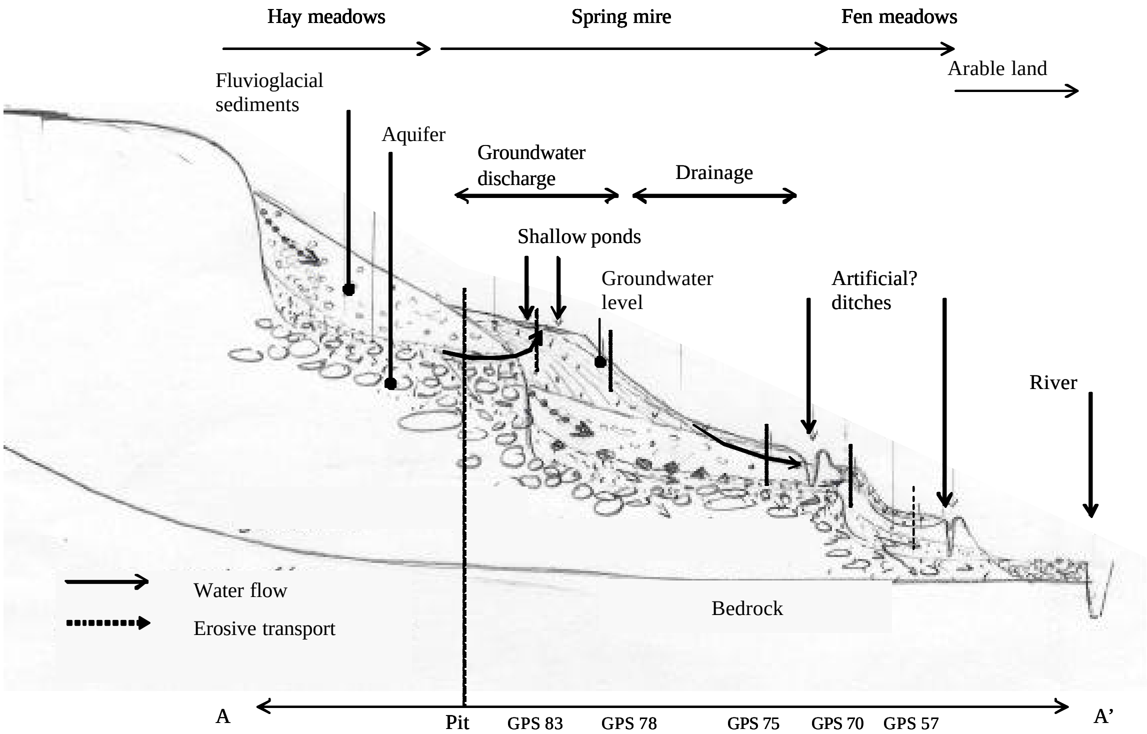

Figure 13 Geo-morphological and hydrological features of the cross-section A-A’ in Belianske Luke with tentative distribution of plant communities

At site 57 the vegetation was composed of rather common species pointing to a fertile, well drained *Arrhenatherion* community, used as a hay meadow. Organic matter was humified and the humus form was a *Vermimull*. Site 70 harboured species belonging to both the peat forming *Caricion davallianae* (*Eriophorum latifolium*, *Epipactis palustris*, *Gymnadenia conopsea*, *Carex flacca*) and the *Eu-Molinion* (*Molinia coerulea*, *Cirsium rivale*, *Carex panicea*, *Briza media*) community, pointing to a transition from wet to dryer, but still base rich and mesotrophic conditions (Figure 13). Due to somewhat drained conditions the peat was decomposed with very few recognisable plant residues (dominant Oh horizon), resulting in a *Saprimoder* humus form. The vegetation of site 75 (Figure 12 and 14) was predominantly composed of species of the *Calthion* community (e.g. *Myosotis palustris*, *Luzula multiflora*, *Lychnis flos cuculi*, *Caltha palustris*, *Polygonum bistorta*, *Cirsium rivale*). This community indicateed moist to wet conditions with ample supply of nutrients by mineralisation of organic matter. This site seemed to represent the fringe of a spring mire, which source was some 100 meters uphill and seemed to be influenced by an artificial ditch, intended to ameliorate the soil for agricultural purpose. The influence of the ditch was expressed in the humus form, which had only a thin Oh-horizon on a mineral subsoil, and is a *Tenuic saprimoder.* Most of the peat was mineralised and there was no accumulation of organic matter. Sites 78 and 83 were characterised by species of the peat forming community of the *Caricion davallianae*, with typical species as *Carex flava* and *Carex davallianae*. These sites represented the core of the spring fen. *Pinguicula vulgaris* and *Juncus alpino-articulatus* were indicative for calcareous spring fens with very stabilised discharge of groundwater at site 83. We did not make a humus profile description at this site, but at comparable sites in Belianske Lúky and Štrba, the humus form was a *Calcic saprimoder*, which was characterised by an Og-horizon, consisting of anaerobic decomposed mesotrophic peat, overlain by a Ck-horizon, largely consisting of travertine (calcite) (Figure 18). Site 78 was slightly drained as can be deduced from several species that occurred in the *Calthion* community (*Polygonum bistorta*, *Luzula multiflora*, *Trollius europaeus*). In the top part of the humus profile, the peat was decomposed, whereas from 12 cm below the surface, the peat is only partly decomposed (Om-horizon), due to anoxic conditions and a low temperature of the discharge water. The humus form is a Mesimor.

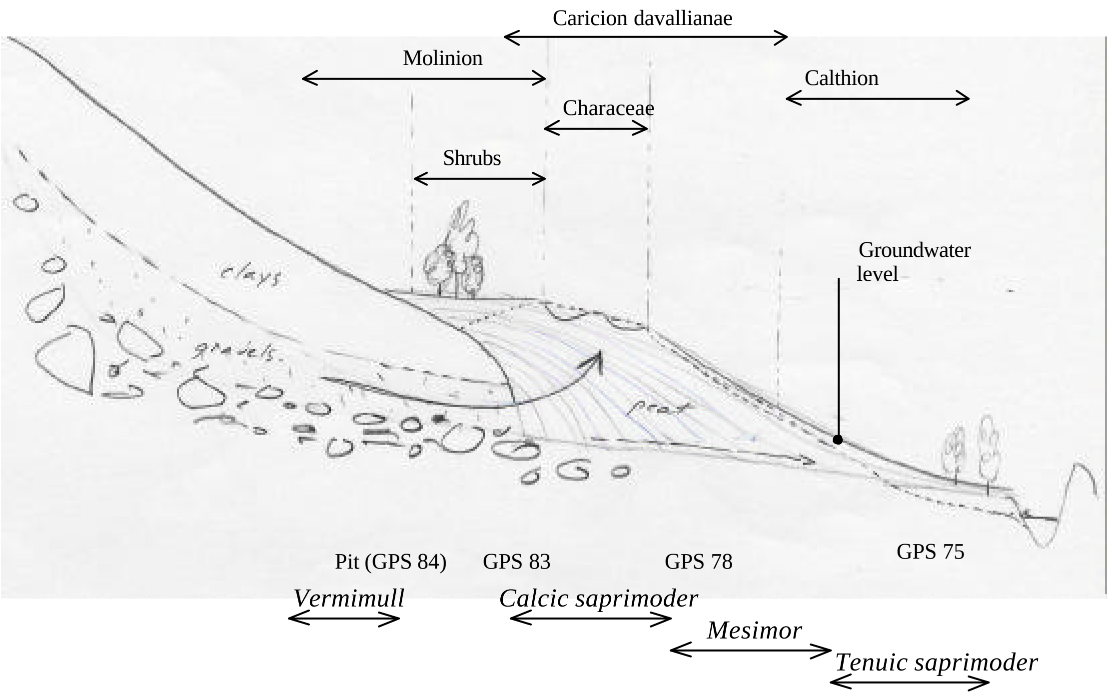

Figure 14 Tentative distribution of plant communities and humus forms in the transition zone between two terraces

3.2 Štrba

3.2.1 Geo(-morpho)logy

The Štrba fen is located just upstream of the mergence of two small brooks (Figure 15 and 16). The fen seems to be a part of a small scale catchment area, which is bordered by both brooks and the watershed about 1 km upstream from the point where the brooks merge. The source of the brooks is close to the watershed.

Geologically the bedrock of the fen belongs to the same geological unit as Belianske Lúky (Late Cretaceous and Paleogene of the Inner Carpatians). At both locations, the bedrock consisted of flysch, which appeared as an alteration of sandstones and calcareous claystones. No clayey fluvioglacial sediments were present. Although we didn't find calcareous layers in the bedrock at the sites during our field observations, they can be expected in deeper layers and thus formation of calcium-carbonate saturated local underground water can be explained.

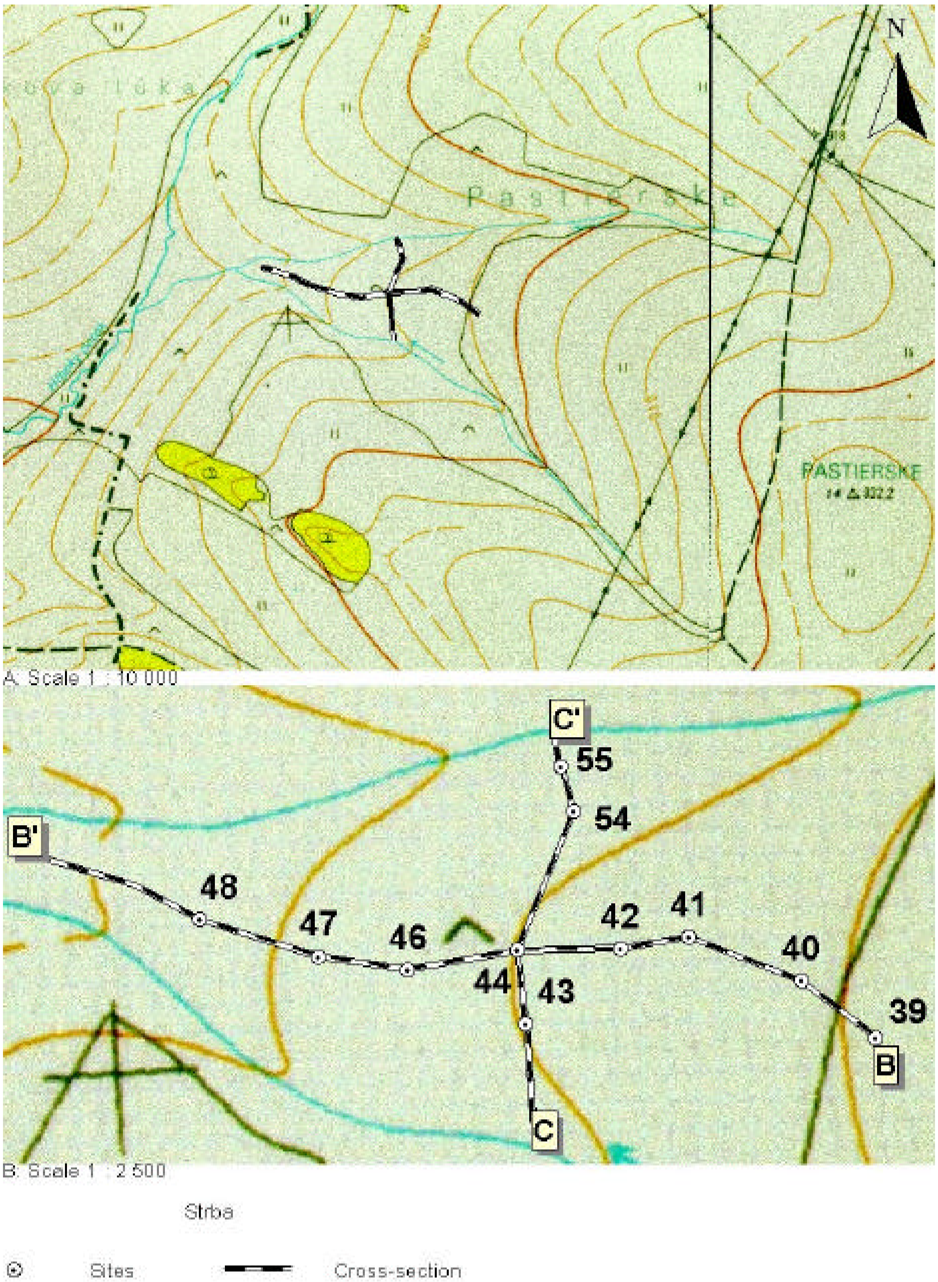

Figure 15 Location of the sites in Štrba

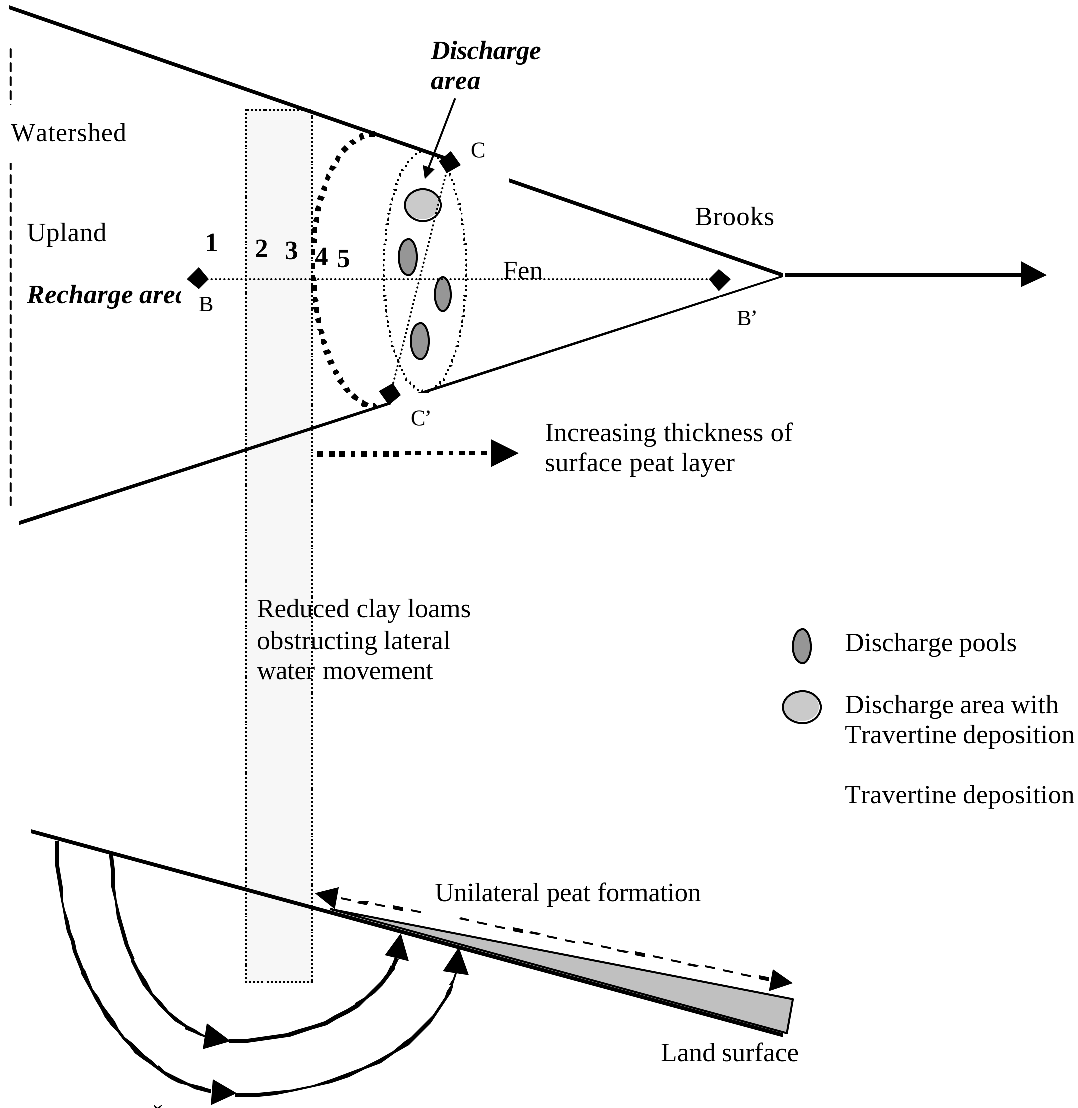

Figure 16 The Štrba rich fen system

3.2.2 Cross-section data

Along the cross-sections the soil was described and the plant species occurring in a radius of ca. 5 m from the auger hole were recorded. Close to the auger hole a temperature and electric conductivity profile was measured with a 'prikstok'.

Soil
Along a short cross-section representing the transition zone between the upland area and the fen the soil was described following the numbers in Figure 15 and 16.

Site 1	(GPS 39)	*Pseudo gley Cambisol*
Ap	0 – 30 cm	silt loam, pH 4.0 - 4.5
Bg	30 – 110	clay loam, weathered flysch (sand/silt stone), FeIII mottles, no lime
B	110 – 140	clay loam, weathered flysch (sand/silt stone) FeIII mottles, audible lime

Site 2	(GPS 40)	
Ah	0 – 20 cm	clay loam
Bg	20 – 80	silt loam, increasingly reduced with depth
	80 – 85	rock fragments

Site 3	(GPS 41)	
A	0 – 15 cm	peaty clay
Bg	15 – 50	clay loam, reduced matrix with FeIII mottles
	50 – 60	clay loam, reduced, rock fragments

Site 4	(GPS 43, near cupola)	
O	0 – 20 cm	clayey peat, FeIII mottles
2C	20 – 30	peaty clay, increasingly reduced with depth
	30 – 40	clay loam, reduced with few FeIII mottles

Site 5	(GPS 44)	*Stagno gley Planosol*
O	0 – 40 cm	peat, partly decomposed
2Cg	40 – 130	silty clay, reduced with FeIII mottles, Mn mottles,no lime
2Cg	180 – 200	less mottling, stoniness, no lime

Humus forms

The humus forms were described along cross-section B-B'. The first three profiles consisted mainly of mineral material, the other five profiles consisted entirely of peat within 40 cm. Site 39 were situated in a hay meadow, sites 40 and 41 in a woodland at the transition form the recharge area to the discharge area. Sites 42 through 48 were situated in the fen area, where site 44 is at the centre of the discharge area with shallow ponds where travertine was precipitated. Between site 45 and 46 the slope of the fen was somewhat steeper and site 47-48 were positioned in a lower part of the fen.

At sites marked with an asterisk soil samples were collected.

GPS. 39

High, on meadow.

Humus form: *Rhizomull*

Depth (cm)		Horizon code	pH	Remarks
0	0.5	Mm	4.0	
0.5	1.5	Mh		
1.5	10	ACg(p)	4.2	
10	30	ACg	4.2	More compact, iron nodules

GPS. 40

Just in the bushes, near the ridge that is the border between woodland and meadow.
Humus form: *Rhizomull*

Depth (cm)		Horizon code	pH	Remarks
-2	-1.5	L	4.5	
-1.5	0	F		
0	10	AC	4.5	Very little organic matter, weathered horizon? No $CaCO_3$ present in topsoil
10	?		4.5	Little more compact than previous horizon.

GPS. 41

In the woodland.
Humus form: *Tenuic saprimoder*

Depth (cm)		Horizon code	pH	Remarks
0	5	Oh1	5.5	Peat, about 80% organic matter
5	10	Oh2		Clayey peat, about 50% organic matter
10	15	OA1	7.0	About 25% o.m., 20% clay
15	20	OA2		About 20% o.m., 20% clay
20	?	C	7.0	Reduced clay

(mineral material within the first 40 cm)

(no mineral material within the first 40 cm.)

GPS. 42*

Top part of the rich fen (Figure 17).
Humus form: *Mesimor*
Piece of profile in Box A9, Of+Om1 and Og1 were sampled

Depth (cm)		Horizon code	pH	Remarks
-5	-3			Moss, green
-3	0			Moss, brown
0	4	Of	7.5	
4	6	Om1	7.3	Brown peat
6	7			Wavy thin layer, slightly greyish, dark peat
7	20	Og1	7.5	Pitch black FeS
20	70	Om2		Brown peat, more recognisable parts.
70	100	Og2		A little clay, clayey peat
100	150	Om3		Brown moss and sedges
150	180	Og3		Again more clayey with thin claybands
180	?			Clay, no mottles, pieces of siltstone

GPS. 44*

Travertine pool (Figure 18).
Humus form: *Calcic mesimor*
Ck1 and Om were sampled

Depth (cm)		Horizon code	pH	Remarks
0	8	Ck1		With travertine nodules, formed on peat
8	20	Om		Moss and sedges
20	?	Ck2		Again travertine in peat

GPS. 46*

Halfway the slope.

Humus form: *Calcic saprimoder*

Depth (cm)		Horizon code	pH	Remarks
0	6	Og1	8.0	Locally $CaCO_3$ near surface
6	25	Og2	7.5	Sampled horizon
25	?	Om	7.5	Brown peat, some $CaCO_3$

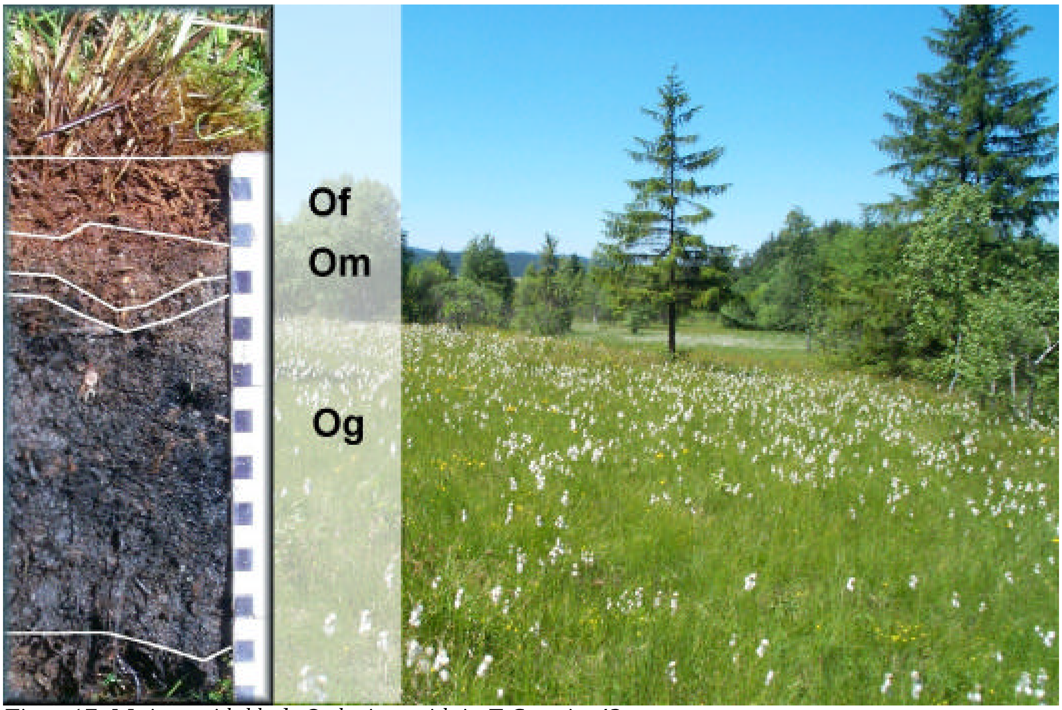

Figure 17. Mesimor with black Og-horizon, rich in FeS at site 42

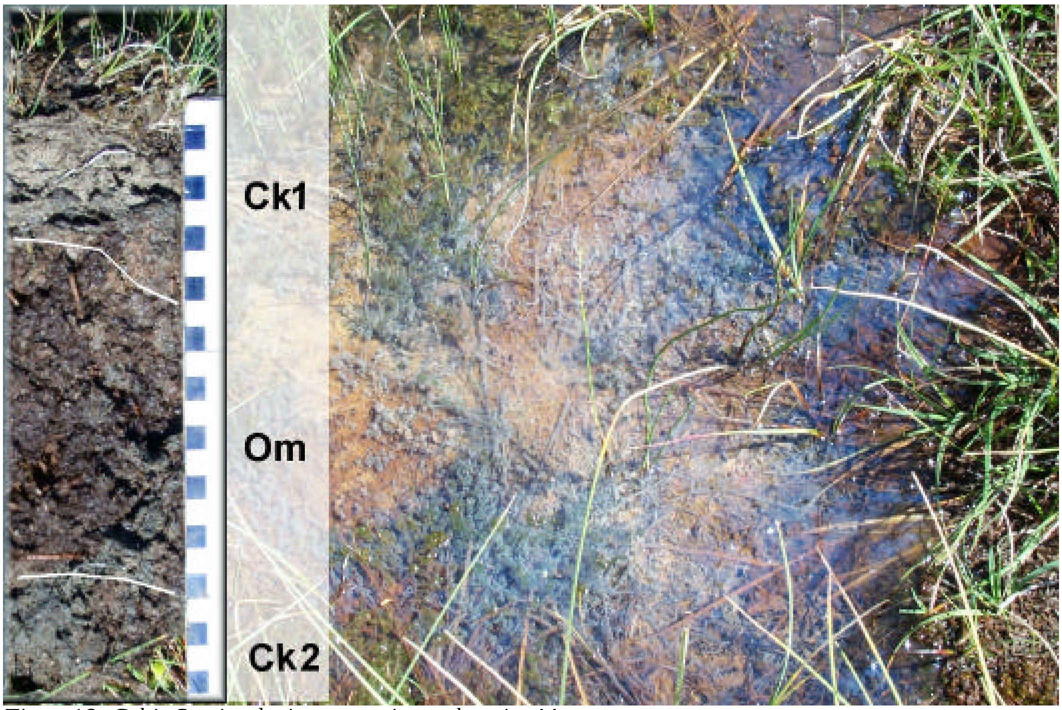

Figure 18. Calcic Saprimoder in a travertine pool at site 44

GPS. 47

Humus form: *Calcic saprimoder*

Depth (cm)		Horizon code	pH	Remarks
0	8	Omg1	8	Black, a little more grey in the upper few cm.
8	12	Omg2	7	Brown, mainly organic matter (gyttja), maybe some clay. Question: does the brown colour indicate a change of environment?
12	?	Og	7	Black (also FeS?)

GPS. 48*

Humus form: *Calcic saprimoder*

Og1+2 and Og3 were sampled

Depth (cm)		Horizon code	pH	Remarks
0	2	Og1	8.0	Whitish layer, very calcareous. This layer differs in thickness over a very small distance!
2	10	Og2	7.5	Black, with thick roots
10	?	Og3	7.0	Red, with black mottles (FeS?)

The sites 39 and 40 are dry in the summer, but iron mottling in the top soil pointed to wet conditions in winter and spring. At site 39 a thin mat of dead roots (Mm- and Mh-horizon) pointed to a somewhat hampered decomposition of organic matter. pH values were low (4.0 – 4.2), as a result of eluviation of basic cations. Dry conditions in summer and low pH-values are unfavourable for earthworms, that play an important role in decomposition of organic matter. The humus form at both sites was a *Rhizomull*. At site 41 the influence of groundwater was more apparent, although the decomposed state of the 20 cm thick peaty top layer indicated some drainage.

The clay loam subsoil was reduced, but iron mottles gave evidence of aeration to 50 cm at some time. The relatively low pH value of the Oh-horizons might be the result of infiltration of rain- or melting water in the top 10 cm. If any $CaCO_3$ was present in this profile, it has been washed out from the top. The humus form, a *Tenuic saprimoder*, illustrated the transition between wet and slightly drained conditions.

The humus profiles in the fen (42 through 48) all showed evidence of permanent wet conditions. Peat forming processes are dominant. Both low temperatures and anoxic conditions, decrease the speed of decomposition of organic matter which depends on the activity of anaerobic bacteria. In Om-horizons the organic matter is moderately decomposed. In site 42, this was the dominant horizon within 40 cm, and therefore the humus form was a *Mesimor*. If organic matter is decomposed under anaerobic conditions to a degree that most plant residues are unrecognisable, the horizon is coded a Og-horizon. Humus forms with a dominant Og-horizon are called *Saprimoder*. Often, these Og-horizons are coloured black from sulphide, as a result of reduction of sulphates by anaerobic bacteria. The question remains where these sulphates come from? Is their presence 'natural' (i.e. transport by groundwater flow) or artificial by atmospheric sulphate deposition. In the top part of the profile, $CaCO_3$ (travertine) might have precipitated. This was the case in all profiles at sites 42 through 48, and therefore a *Calcic* phase of the humus form *mesimor* or *saprimoder* was distinguished. At site 44 the precipitation of travertine was so abundant, that the horizon was considered a mineral Ck-horizon. The processes that caused the sequence of horizons in these profiles are related to the discharge of ground water, rich in calcium and iron. This is illustrated in figure 19.

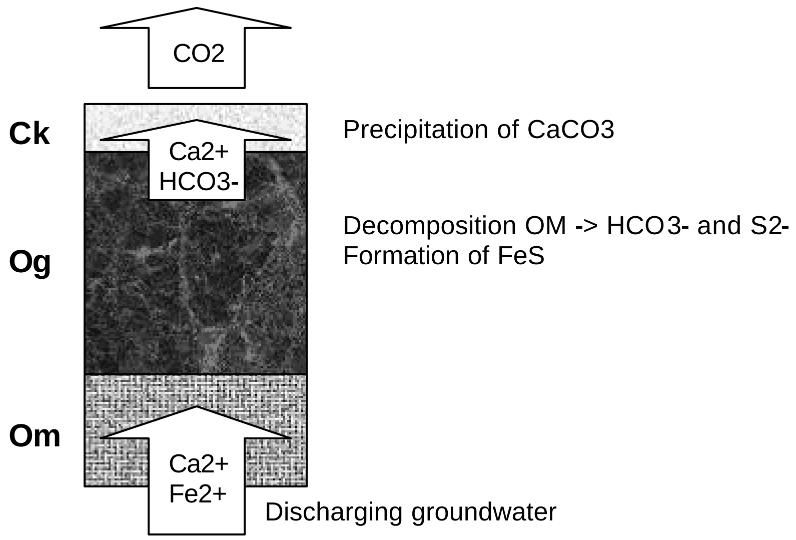

Figure 19 Main processes in a Calcic saprimoder

In site 44, a second Ck-horizon was observed underneath a Om-horizon. This can be ascribed to a sequence of peat formation and travertine precipitation. After a period in which travertine is precipitated (Ck2), peat growth must have increased, forming an Om-horizon. After peat growth has decreased again, a new Ck-horizon was formed. Although precipitation of travertine is most clearly recognisable in the shallow pools in the discharge area, we also observed it among the peat forming mosses and sedges in the area.

Temperature profiles

Along cross-section B-B', near the sites of the humus form descriptions temperature profiles of the peat soil were recorded (Appendix 5). Another profile was measured on the top of the travertine cupola with discharging groundwater. Figure 20 shows that site GPS 44 and 45 represent the extreme profiles, although they were positioned close to each other.

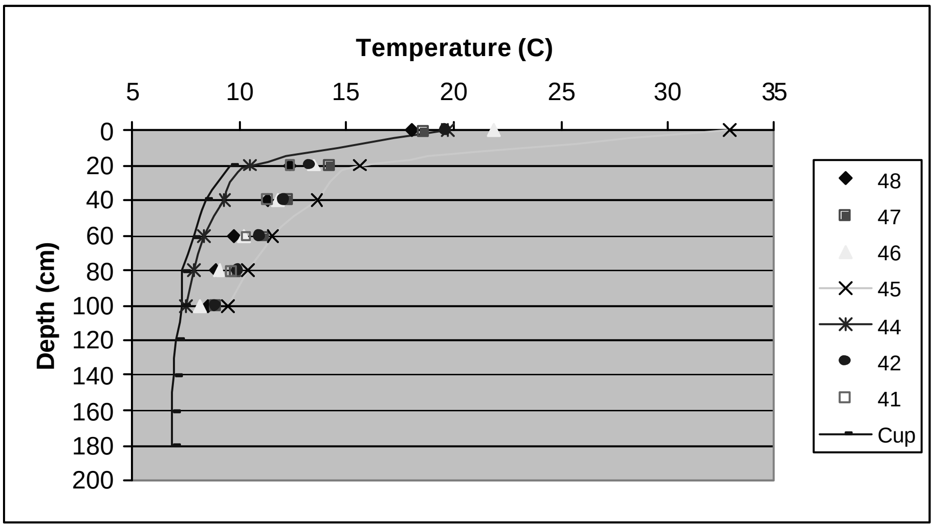

Figure 20 Temperature profiles of sites in the cross-section B-B'

At site 44 a steep slope of the temperature profile could be observed, increasing from 7 to 10°C at a depth of 10 cm and to 20°C at soil surface. At site 45 the temperature increases from 10 to 15°C with a surface temperature of even 32°C. The temperature profile of site 44 is very similar to the one of the travertine cupola where artesian water seeps out of the top. The temperature of the discharging groundwater appeared to be approximately 7°C.

Electric conductivity

The measurements of EC resulted in very heterogeneous profiles both in depth and in spatial distribution (Appendix 5). The data collected with the field equipment are not comparable with those from the gauge.

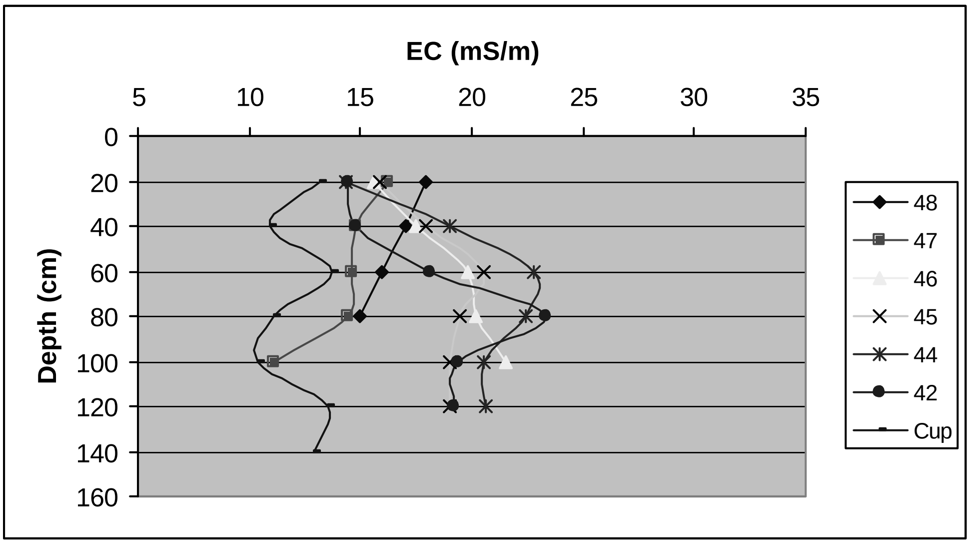

Figure 21 Electric conductivity recordings at several depths of the sites along cross-section B-B' at Štrba

The recordings from the deepest layers mostly show a discontinuous behaviour, which has to be ascribed to the transition of peat to mineral soil. In figure 21 the surface and the deepest recordings are skipped. The profiles of site GPS 47, 48 and the cupola were more or less comparable and could be distinguished clearly from the rest. The first group showed decreasing EC-values towards the soil surface whereas the other sites had increasing values. It is striking that the EC profile of the cupola is quite different from those of the other sites in the same discharge zone. The interpretation of the EC recordings is hardly possible without further hydrochemical speciations.

Vegetation

In Appendix 3 the plant species recordings at the different sites are presented. According to a rough interpretation of the undoubtedly incomplete inventory of species, distinct plant communities on the level of order could be observed: *Arrhenatherion* (site 39), *Calthion* (site 47, 48, 54, 55) and the *Caricion davallianae* (site 43, 44, 46). At sites 42 and 99 a transition of *Caricion davallianae* to *Calthion* occurs and site 41 is developing into shrub vegetation, as can be derived from distinct *Franguletea* species overgrowing the original *Calthion* vegetation

Soil chemistry

Soil samples from the Strba fen were taken from 4 peat profiles. All profiles were highly calcareous (see Appendix 4, Table 1), with increasing carbonate contents towards the soil surface and a slightly alkaline pH, buffered by $CaCO_3$. In the pools and in the cupola, almost pure calcium carbonate was present. The content of organic matter (C_{ox}) showed a strong negative correlation with the carbonate content, indicating that these are major components of the peat. C/N and C/P ratio's were low, indicating retention of N and P by humification. Especially at the discharge site 44 extraordinary low ratio's were measured, indicating immobilisation of N and P by intense humification, leaving hardly any inorganic P.

Calcium was the major cation on the exchange complex. Base cations occupied 70 – 80 % of the exchange sites. The cation exchange capacity correlated well with the content of organic matter, where the majority of exchange sites is present.

The profiles in the upstream part of the fen were characterised by a high content of iron sulfides (further in the text mentioned as pyrite). This points to sulphate reduction by an intensive activity of sulphate-reducing bacteria according to equation (1):

$$SO_4^{2-} + 2CH_2O \leftrightarrow H_2S + 2HCO_3^- \qquad (1)$$

Iron sulfides are then formed by reaction of H_2S with Fe^{2+} in anaerobic environment. Interesting is the distribution of pyrite and iron oxides (analyzed as oxalate-extractable Fe). In profiles of the upstream part of the fen (42 and 44), more iron oxides were present in the topsoil then in deeper horizons and - vice versa - more pyrite was found in deeper horizons then in the topsoil (Figure 22, 23). In profiles from the slope (46) and in the lower part of the fen (48), no pyrite was detected and higher contents of iron oxides was detected in the profile then in topsoil.

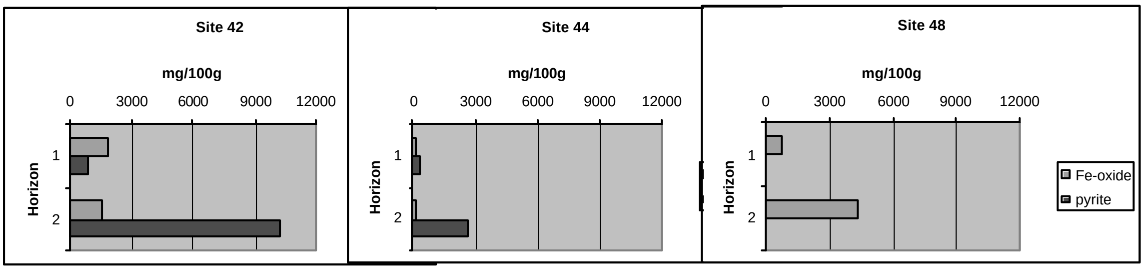

Figure 22 Distribution of iron oxides and pyrites in the soil profile at site 42, 44 and 48

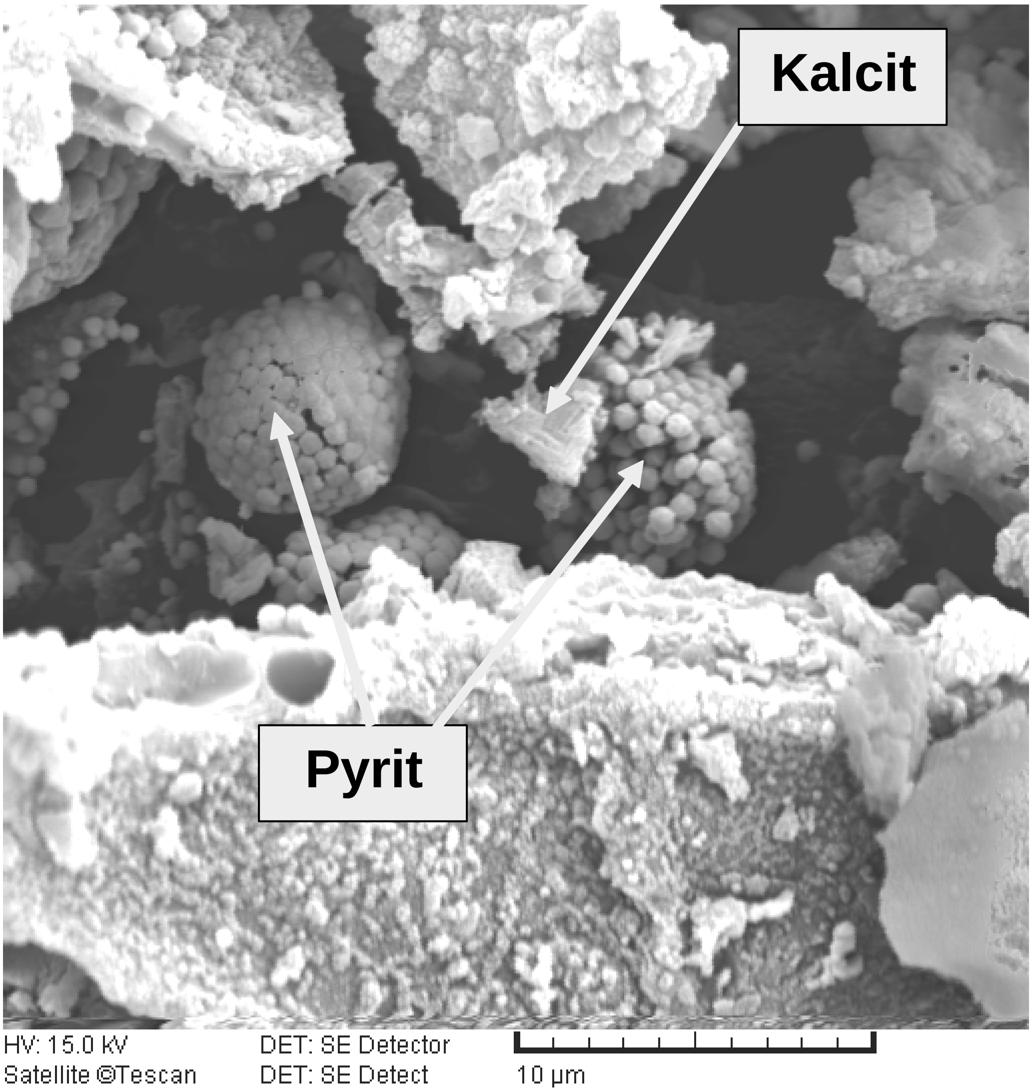

Figure 23 Scanning electron microscope photo of a soil sample from site 44 at Strba (analysed by Dr. Dlapa, Gemini, Bratislava)

The different distribution of pyrite and iron oxides pointed to different hydrology and redox conditions at the sites. In the upstream part, where groundwater discharges into the fen, the water table will be very stable throughout the year and anaerobic conditions will persist. In ample presence of sulphates these conditions favour the formation of pyrite close to the soil surface. The source of the sulphates is not known. Both atmospheric deposition during the last century and transport by groundwater flow might explain the origin of sulphur in pyrites.

In the downstream part the soil chemical observations can be explained in two ways (Fig 24): 1) due to a bigger amplitude of the groundwater level and seasonally aerobic conditions iron oxides accumulated in the upper soil horizons, while pyrites could only be formed in the deeper horizons of the profile; 2) the groundwater that superficially flows downstream was depleted of sulphates, which precipitated in the upstream part of the fen. In this case, pyrite will not be present throughout the profile of the downstream parts of the fen. The second explanation seemed to be more likely, because in samples from the downstream part of the fen we didn't notice a smell of H_2S, which was very intensive in samples from the upstream part.

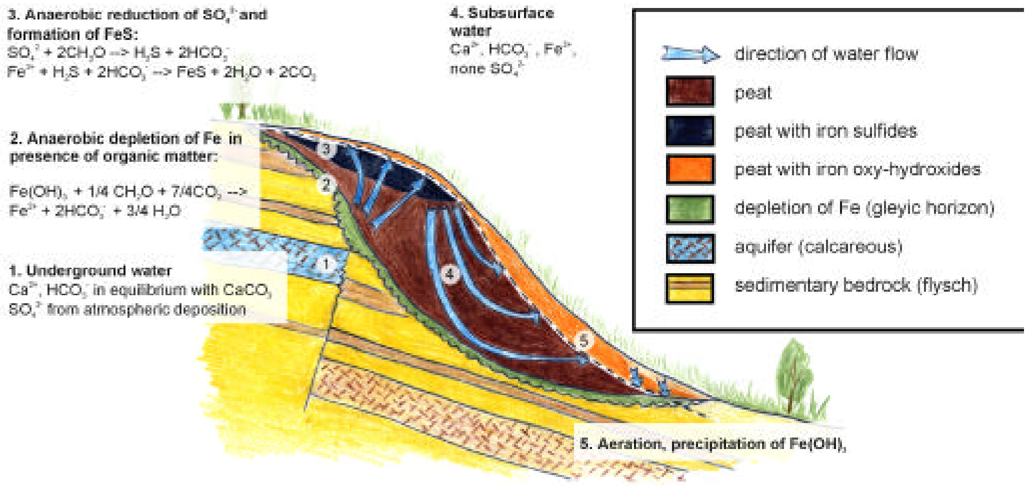

Figure 24 Hypothesized soil chemical processes and their spatial distribution in a cross-section of the Strba fen system

Another interesting phenomenon was the accumulation of carbonates in the topsoil. According visual observations, carbonates were only present within the upper 40 cm. The profile at site 44 even showed two calcic horizons separated by a pyrite layer, pointing to some periodicity in soil processes. At greater depth all the profiles were without $CaCO_3$, until a depth of about 1.5 m, where again highly calcic layers were observed in some profiles. Formation of pyrites might have contributed to the carbonate accumulation. During the pyrite formation, alkalinity is produced by reduction of sulphates and Fe oxy-hydroxides:

$Fe(OH)_3(s) + SO_4^{2-} + 9/4\ CH_2O(s) \rightarrow FeS_2(s) + 2HCO_3^- + ¼\ CO_2 + 11/4\ H_2O$
Because formation of calcium carbonate can be written as:

$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3(s) + H_2O + CO_2$$

Combination of both equations gives:

$$Fe(OH)_3(s) + SO_4^{2-} + 9/4\ CH_2O(s) + Ca^{2+} \rightarrow$$

$$FeS(s) + CaCO_3(s) + 5/4\ CO_2 + 15/4\ H_2O$$

It is obvious, that in a solution with a near calcite equilibrium formation of pyrite will cause supersaturation of calcite, which will precipitate immediately after loss of CO_2, or free H_2S (in case of lack of Fe) and after water loss due to evaporation. It also appeared that calcite precipitation occurred especially on the leaves and stems of Chara-species, abundantly growing in the open water pools. So, submerged plants might affect calcite precipitation by the uptake of bicarbonate as a carbon source. Calculations of SI by ECOSAT showed that in all samples, water was supersaturated with respect to calcite (Appendix 4, Table 3).

3.2.3 Eco-pedological system: hypothesis

The heavy textured subsoils (Figure 16: sites 1 through 5) prevent lateral flow of water from the upland area to the fen. Water is therefore hypothesised to infiltrate in the upland recharge area and to surface in a 'discharge belt' in the fen area (see upper and lower panel of Fig 16). The water probably flows through the fractured under laying Flysch bedrock. Water was observed to surface on top of a small (0.5 m height above surrounding surface, 4 m diameter at base) mound consisting of a granular type of Travertine (Fig 25). In the same 'discharge belt' several pools were found. The quality of the fen will largely depend on the quality of the discharge water, which in turn depends on the quality of the water infiltrating in the upland area.

The temperature profiles gave more insight in groundwater flows through the fen. From the temperature recordings it can be deduced that heat transport to the subsoil was prevented by cool upward flowing groundwater, discharging in the small pools near site GPS 44 (Fig 26). At 20 cm depth the temperature was only about 10°C. The temperature profile of this site was very much alike as the profile that we measured in the cupola. So it seemed plausible that the low temperatures near the soil surface were indicating a distinct discharge of cool groundwater (7°C) in this zone. We hypothesize that peat formation expanded down hill from this (primary) discharge area This discharge caused small pools where the groundwater was stored. The temperature of the open water in the pools was about 20°C and locally increased to 30°C. In these pools travertine was precipitated. In contrast, the temperature at a depth of 20 cm of the neighbouring downstream site GPS 45 was more than 15 °C. The temperature profile of this site indicated a better heat transport than at all other sites investigated, suggesting heat transport by downward water flow. So it seemed likely that the discharging groundwater infiltrated the fen again about 20 m further down the cross-section (Fig 24, 26). The temperature profile of site 48 gave some evidence that a second (secondary) discharge zone existed there. Consequently the fen hydrologically could be characterised as a 'cascading-flow-through-system.

Temperature differences between the discharge and infiltration zone might have important consequences for temperature dependant processes as calcite precipitation and peat decomposition processes (see 3.2.2).

Figure 25. Travertine Cupola near site 43

By the synthesis of the different data we have made an interpretation of the distribution of the plant communities in the fen in relation to pedological and hydrological factors (Figure 26, 27). From the pools in the discharge zone a concentric pattern of plant communities with increasing trophic levels could be observed, suggesting a low nutrient availability in the discharge zone. This zonation was mirrored by a pattern of mesimor (Om-horizons, poor decomposition) humus forms in the centre and saprimoders (Og-horizons) to the periphery of the fen.

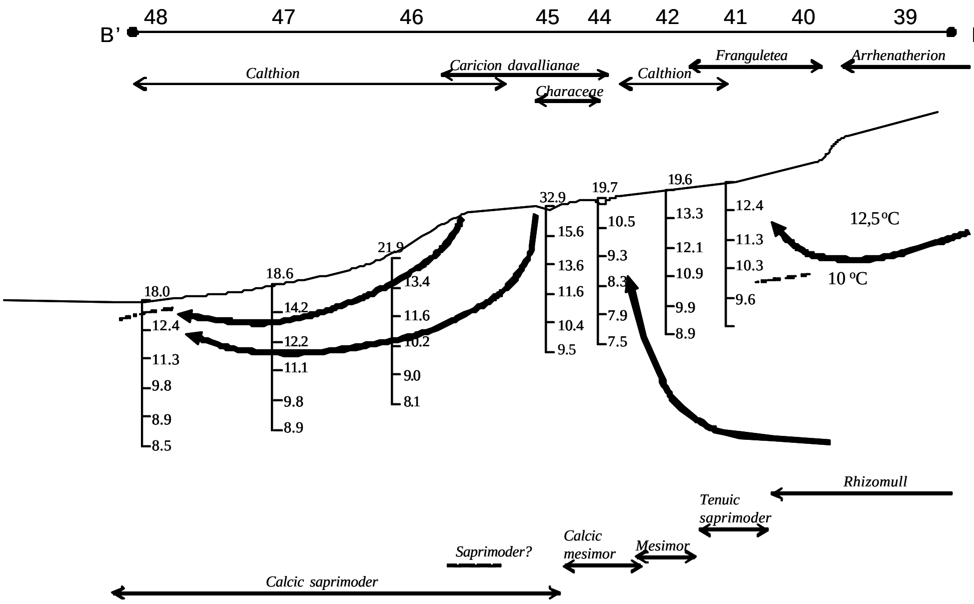

Figure 26 Temperature profiles, the 10 and 12,5°C isotherm and derived water flows in the B-B' cross-section of Štrba. The distribution of plant communities and humus forms has been indicated tentatively

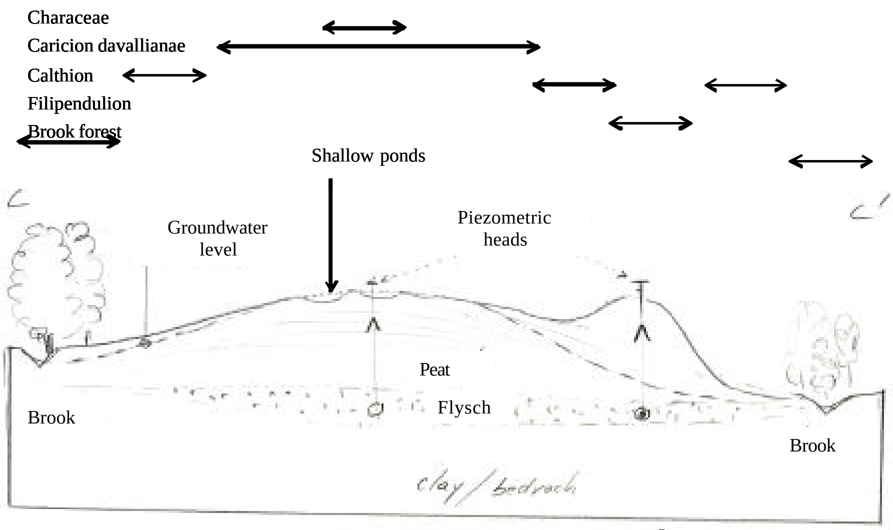

Figure 27 Tentative distribution of plant communities in cross-section C-C' of the Štrba fen

It is hypothesized that two processes might account for the low productivity in the discharge zone: 1) a complex interaction between iron, sulphate and calcium chemistry, resulting in the formation of insoluble Fe-P or Ca-P complexes and a phosphorus restricted productivity and 2) a strong immobilisation and restricted plant availability of both N and P through humification by specialized micro-organisms, adapted to extreme calcic environments. The higher productivity of the *Calthion* plant communities to the margins of the fen might be associated with lower mean groundwater levels and periodically aerobic conditions.

The layered character of the soil profiles are suggesting the occurrence of cyclic processes in organic matter decomposition, pyrite and calcite formation, that might be driven by climate or hydrological changes.

3.3 Abrod

3.3.1 Some impressions

We visited Abrod only for a couple of hours. We only did some random augering, just to get an impression of the thickness of the peat layer, the depth of the groundwater table and the mineral subsoil.

We got the impression that the whole fen area was severely affected by drainage activities in the surrounding areas during last decades. The peat was strongly humified and homogenised with mineral bleached sandy particles. The pH of the upper peat layer was approximately 7. The water level of the drainage channel crossing the fen was not detectable ?

At the north east side the fen was bordered by a vast area of afforested sandy dunes (Figure 5). A small lake, probably formed by sand-mining, was positioned in the transition zone between the fen and the dune area The water level of the lake was significantly higher (meters ?) than the surface of the downwards laying fen. Along all other sides the fen was bordered by intensively used arable land where huge sprinklers for irrigation were installed.

3.3.2 Eco-pedological system: hypothesis

Our impressions allowed only to hypothesize which hydrological alterations might have caused the present deteriorated status of the fen. We think that the main cause of the deterioration of the fen must be searched beyond the borders of the fen. We assume that the subsoil of this flood plain is build up of calcareous sandy and clayey layers, providing the region with aquifers. Both the withdrawal of groundwater from the aquifers for irrigation and an overall drainage of the region might have caused a decreased groundwater supply by discharge to the fen. On the other hand the ditch crossing the channel definitely will drain the fen. Consequently the water balance of the fen probably is affected severely: less supply by groundwater discharge and more loss by drainage through the ditch (Figure 27).

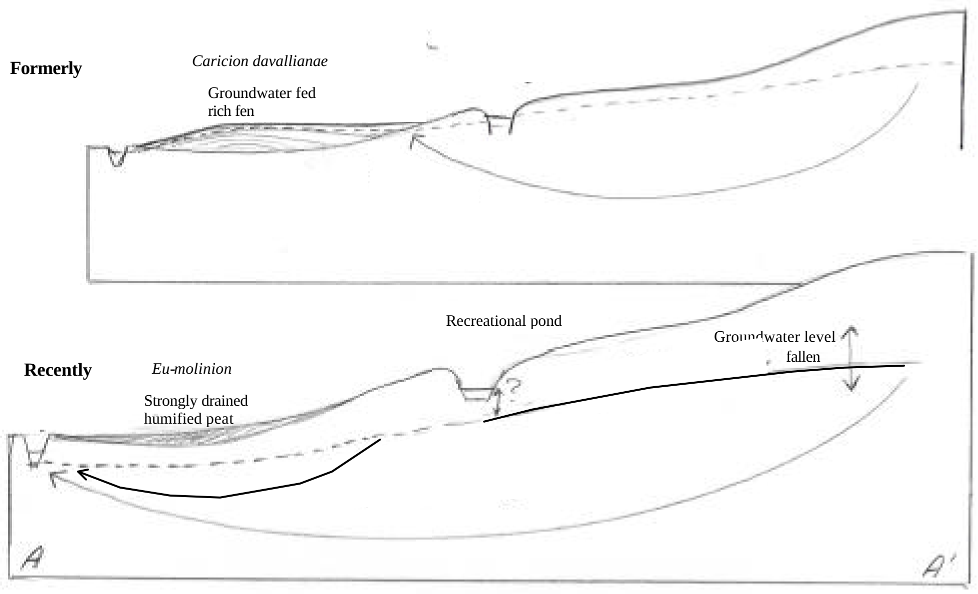

Figure 27 Assumed levels of groundwater and hydrological position of the Abrod fen in the cross-section A-A' (see Figure 5)

4 Conclusions

Our surveys in Beliansky Luky and Strba aimed to understand processes controlling the development of calcareous rich fens. In both fen systems comparable processes and patterns were observed. From our survey we concluded that:

- The distribution patterns of the plant communities in the fens are strictly related to hydrological and pedological factors. At geo(morpho)logically determined spots tiny shallow aquifers discharge groundwater to the soil surface where calcite layers, iron oxides and pyrites were deposited in alternating layers;
- Peat formation expanded down hill from the discharge areas. Finally a flow-through-system developed, with alternating cold discharge and warm recharge zones in the fen system;
- From the discharge zones a pattern of plant communities with increasing trophic levels can be observed, suggesting a low nutrient availability in the discharge zone, increasing to the periphery of the fens;
- In discharge zones mesimor humus forms developed, pointing to hampered decomposition of organic matter; recharge zones are generally characterised by saprimoders indicative for intensive anaerobic decomposition; towards the fringes of the fens saprimoders featured thin Oh-horizons, indicative for aerobic decomposition, suggesting some impact of drainage by ditches or brooks;
- Saprimoders showed low C/N and C/P ratio's, suggesting rapid nutrient cycling by decomposition and intensive humification, favouring the development of *Calthion* plant communities; mesimors were characterised by extraordinary low C/N and C/P ratio's, suggesting both P and N immobilisation by humification, with hardly any evidence for Fe- or Ca-bound inorganic P. Typical plant communities of mesimors appeared to belong to the low productive *Caricion davallianae.*

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Danish report

Appendix 1 Co-ordinates of the visited sites

SITE	Latitude	Longitude	JTSK-X	JTSK-Y
001	20.3752	49.2114	4454600	5453459
002	20.3741	49.2197	4454527	5454377
003	20.3730	49.2205	4454450	5454464
004	20.3728	49.2208	4454436	5454501
005	20.3745	49.2207	4454559	5454489
006	20.3778	49.2210	4454799	5454518
007	20.3855	49.2161	4455352	5453976
008	20.3873	49.2168	4455488	5454049
009	20.3927	49.2155	4455879	5453904
010	20.3916	49.2142	4455798	5453755
011	20.3766	49.2242	4454717	5454876
012	20.3763	49.2235	4454692	5454803
013	20.3760	49.2229	4454671	5454736
014	20.3756	49.2221	4454639	5454649
015	20.3756	49.2220	4454636	5454639
016	20.3753	49.2219	4454614	5454624
017	20.3749	49.2219	4454588	5454628
018	20.3747	49.2217	4454571	5454602
019	20.3745	49.2212	4454555	5454542
020	20.3743	49.2210	4454540	5454524
021	20.3748	49.2208	4454579	5454497
022	20.3747	49.2208	4454573	5454497
023	20.3744	49.2206	4454553	5454475
024	20.3744	49.2206	4454550	5454475
025	20.3744	49.2203	4454547	5454442
026	20.3742	49.2200	4454536	5454414
027	20.3741	49.2198	4454529	5454393
028	20.3731	49.2189	4454455	5454287
029	20.3710	49.2154	4454296	5453907
030	20.3709	49.2153	4454287	5453890
031	20.3709	49.2152	4454292	5453877
032	20.3706	49.2152	4454272	5453880
033	20.3704	49.2151	4454257	5453871
034	20.0372	49.0533	4429749	5436134
035	20.0364	49.0514	4429688	5435920
036	20.0321	49.0519	4429375	5435978
037	20.0289	49.0515	4429141	5435937
038	20.0284	49.0509	4429101	5435877
039	20.0299	49.0507	4429214	5435846
040	20.0295	49.0509	4429186	5435867
041	20.0290	49.0510	4429144	5435883
042	20.0286	49.0510	4429118	5435879
043	20.0281	49.0507	4429083	5435851
044	20.0281	49.0509	4429079	5435879
045	20.0280	49.0509	4429073	5435875
046	20.0275	49.0509	4429038	5435871
047	20.0271	49.0509	4429005	5435876
048	20.0264	49.0510	4428960	5435890

SITE	Latitude	Longitude	JTSK-X	JTSK-Y
049	20.0261	49.0511	4428936	5435903
050	20.0255	49.0513	4428889	5435917
051	20.0252	49.0512	4428866	5435906
052	20.0251	49.0512	4428862	5435905
053	20.0250	49.0511	4428857	5435903
054	20.0284	49.0514	4429100	5435931
055	20.0283	49.0516	4429096	5435947
056	20.0370	49.0530	4429733	5436098
057	20.3919	49.2177	4455824	5454146
058	20.3925	49.2178	4455864	5454157
059	20.3925	49.2194	4455870	5454333
060	20.3924	49.2193	4455864	5454328
061	20.3923	49.2189	4455854	5454285
062	20.3922	49.2189	4455844	5454284
063	20.3921	49.2184	4455837	5454224
064	20.3920	49.2182	4455830	5454198
065	20.3920	49.2180	4455828	5454184
066	20.3919	49.2176	4455820	5454140
067	20.3918	49.2174	4455814	5454114
068	20.3918	49.2172	4455812	5454087
069	20.3917	49.2170	4455805	5454064
070	20.3917	49.2170	4455808	5454072
071	20.3919	49.2170	4455825	5454064
072	20.3917	49.2169	4455805	5454061
073	20.3917	49.2164	4455807	5453997
074	20.3916	49.2162	4455799	5453984
075	20.3916	49.2161	4455800	5453968
076	20.3913	49.2159	4455775	5453946
077	20.3912	49.2158	4455769	5453936
078	20.3909	49.2157	4455746	5453923
079	20.3909	49.2154	4455748	5453892
080	20.3907	49.2151	4455735	5453862
081	20.3908	49.2150	4455741	5453845
082	20.3908	49.2148	4455741	5453824
083	20.3906	49.2145	4455722	5453792
084	20.3905	49.2142	4455716	5453758
085	20.3899	49.2134	4455674	5453675
086	20.3898	49.2132	4455664	5453653
087	20.3761	49.2121	4454667	5453534
088	20.3744	49.2099	4454537	5453295
089	17.0056	48.5344	3648238	5379935
090	17.0034	48.5344	3648075	5379929

Appendix 2 Humus form horizons

Code	Suffix	Description
L	-	Undecomposed litter
F	-	Partly decomposed plant residues
	m	by mycogenous activity
	z	by zoogenous activity
	a	both zoogenous and mycogenous activity
H	-	Well decomposed (humified) plant residues
	r	recognisable residues present
	h	no or very few macroscopic residues
	w	woody residues recognisable
Ah	-	Mineral horizon enriched with humified organic matter by bioturbation
	e	with eluvation features (micropodzol)
	g	with gley features
E	-	Main eluvation and iron depleted horizon
B	-	Horizon with iron and humus illuvation
O(A)	-	Wetland horizon predominantly composed of organic matter (O) by prolonged water saturation or mixed up with mineral particles (OA) by (bio)turbation
	f	undecomposed peat with plant residues that are easely recognisable
	m	partly decomposed peat
	h	well-decomposed eutrophic peat
	g	anaerobically decomposed, mesotrophic peat (gyttja)
	d	aerobically decomposed oligotrophic peat (gliede)
M	-	A matted horizon composed of root residues
	f	undecomposed dead roots
	m	partly decomposed root residues
	h	strongly decomposed (humified) root residues

Appendix 3 Vegetational composition

Belianske Luke					
	Site (GPS)				
	57	75	70	78	83
Plant species	Arrhenatherion	Calthion	Eu-Molinion	Caricion davallianae	
Dactylis glomerata	x				
Ranunculus repens	x				
Symphytum officinale	x				
Rumex acetosa	x	x			
Anthriscus sylvestris	x				
Chrysanthemum leucanthemum	x				
Plantago lanceolata	x				
Vicia cracca	x				
Veronica longifolia ?	x				
Rhinanthus spec.	x				
Festuca pratensis	x				
Galium palustre	x	x			
Achillea millefolia	x				
Trifolium pratensis	x				
Crepis paludosa	x	x			x
Molinia coerulea		x	x	x	
Cirsium rivale		x	x		
Gymnadenia conopsea		x	x		
Briza media		x	x		
Orchis maculata			x		
Epipactis palustris			x		
Sanguisorba pimpinellifolia			x		x
Orchis majalis		x		x	x
Eriophorum latifolium		x	x	x	x
Equisetum palustre		x		x	x
Equisetum fluviatile		x		x	
Trollius europaeus			x	x	
Triglochin palustris			x	x	x
Carex flacca			x	x	x
Primula farinosa			x	x	x
Carex panicea			x	x	x
Potentilla erecta			x		x
Carex davalliana				x	x
Galium uliginosum				x	x
Carex flava				x	x
Menyanthes trifoliata				x	x
Salix repens					x
Juncus alpino-articulatus					x
Pinguicula vulgaris					x
Polygala spec.					x
Myosotis palustris		x			
Angelica sylvestris		x			
Luzula multiflora		x		x	
Lychnis flos cuculi		x			
Ranunculus acris		x			
Juncus subuliflorus		x			
Valeriana dioica		x			
Polygonum bistorta		x		x	
Filipendula ulmaria		x			
Galium verum		x			
Peucedanum palustre		x			
Caltha palustris		x			
Geum rivale		x			

Strba											
	GPS-site										
	44	43	46	42	99	47	48	55	54	41	39
	Caricion davallianae										
				Calthion palustris							
										Franguletea	
											Arrhenatherion
Plant species											
Eriophorum latifolium	x	x	x	x	x	x	x	x			
Carex panicea	x	x	x	x							
Carex rostrata	x			x	x					x	
Potentilla erecta		x	x	x	x		x				
Carex davalliana	x	x	x		x						
Equisetum fluviatile			x	x		x					
Pinguicula vulgaris	x	x									
Triglochin palustris	x	x									
Eleocharis quinquefolia	x										
Primula farinosa		x									
Juncus alpino-articulatus		x									
Carex rostrata		x					x				
Pedicularis palustris				x							
Galium uliginosum											
Molinia caerulae						x					
Lathyrus pratensis						x					
Maianthemum bifolium						x					
Pyrola rotundifolia					x						
Succissa pratensis								x			
Equisetum palustre	x			x				x	x	x	
Crepis paludosa				x	x	x	x	x	x	x	
Caltha palustris						x				x	
Carex paniculata		x			x	x	x	x	x		
Valeriana officinalis							x				
Angelica sylvestris						x					x
Filipendula ulmaria					x		x	x	x	x	
Trollius europaeus										x	
Polygonum bistorta				x							
Valeriana dioica						x				x	
Orchis majalis				x						x	
Melampyrum nemorosa.					x		x	x	x	x	
Sanguisorba officinalis			x		x						x
Salix cinerea										x	
Salix pentandra										x	
Geum rivale										x	
Betula pubescens										x	
Alnus glutinosa										x	
Phleum pratensis											x
Ranunculus acris											x
Campanula spec											x
Lychnis flos cuculi											x
Rumex acetosa											x
Rhinanthus serotinus											x
Dactylis glomerata											x
Trifolium repens											x
Trifolium pratensis											x
Alopecurus pratensis											x
Poa pratensis											x
Luzula multiflora											x
Festuca pratensis											x
Centaurea pratensis											x
Chrysanthemum leucanthemum											x

Appendix 4 Results of chemical analyses of soil and soil solution

Table 1

Location	site	Depth [cm]	Horizon	pH_{KCl}	$CaCO_3$	C_{ox}	Exchangeable cations pH 8.1						CEC	Pyrite (as FeS_2)	Fe_{oxalat}
							Ca^{++}	Mg^{++}	K^+	Na^+	Fe^{++}	H^+	sum		
					%	%	cmol+/kg							mg/100g	
Štrba	42	0-6	Of+Omm	7,4	55	22	69	12	0,4	0,7	0,71	24	106	879	1852
Štrba	42	7-20	Og	7,2	25	43	104	17	0,2	0,7	0,87	29	152	10201	1578
Štrba	44	0-8	1C1	7,6	85	10	29	4	0,1	0,2	0,05	11	45	399	134
Štrba	44	8-20	Om	7,3	45	35	88	13	0,2	0,6		23	125	2595	129
Štrba	46	8-20	Og2	7,5	15	47	123	24	0,4	0,5	0,42	43	191	<dl	1934
Štrba	48	0-10	Og1+2	7,6	50	31	93	20	0,4	0,4	0,29	25	139	<dl	785
Štrba	48	10-20	Og2	7,3	8	27	103	14	0,2	0,3	0,30	45	162	<dl	4245
Belianske Lúky	M75	0-10	Oh	6,5	0	31	80	8	0,2	0,4	0,23	30	118	<dl	1602
Belianske Lúky	M75	12-20	Ahg	6,1	0	18	49	5	0,1	1,7	0,22	21	78	<dl	950
Belianske Lúky	M78	0-12	Oh	6,8	0	71	152	16	0,4	0,2	0,58	31	200	<dl	2368
Belianske Lúky	M78	12-20	Oh	5,9	0	70	144	14	0,3	0,2	0,85	65	225	<dl	2060

Table 1 continued

Location	site	Depth [cm]	Horizon	Pyrite (as FeS_2)	Oxalate extract			P_{total}	$P_{inorganic}$	$P_{organic}$ (calculated)	C/N	C/P
					Fe	Al	P					
				mg/100g								
Štrba	42	0-6	Of+Omm	879	1852	4	3	45	6	39	25	288
Štrba	42	7-20	Og	10201	1578	66	15	77	7	70	14	309
Štrba	44	0-8	1C1	399	134	12	2	161	3	158	6	32
Štrba	44	8-20	Om	2595	129	31	16	186	2	184	6	96
Štrba	46	8-20	Og2	<dl	1934	31	5	277	13	265	10	89
Štrba	48	0-10	Og1+2	<dl	785	13	4	310	14	296	12	53
Štrba	48	10-20	Og2	<dl	4245	11	1	212	4	208	16	65
Belianske Lúky	M75	0-10	Oh	<dl	1602	157	26	206	7	200	10	79
Belianske Lúky	M75	12-20	Ahg	<dl	950	201	17	172	5	167	11	54
Belianske Lúky	M78	0-12	Oh	<dl	2368	109	20	251	6	246	11	145
Belianske Lúky	M78	12-20	Oh	<dl	2060	120	18	288	4	283	10	124

Table 3 Soil water

Location	site	Depth [cm]	Horizon	EC	pH	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Fe^{2+}	SO_4^{2-}	Cl^{-}	HCO_3^{-}	P_{total}	calcite saturation
				mS/m		mg/l									
Štrba	**42**	**0-6**	Of+Omm	55	7,9	65	29	16	35	0,24	7	21	381	0,29	+
Štrba	**42**	**7-20**	Og	55	8,1	96	29	16	8	0,18	117	19	336	0,34	+
Štrba	**44**	**0-8**	1C1	58	8,1	86	30	17	7	0,09	88	20	364	0,16	+
Štrba	**44**	**8-20**	Om	59	7,9	87	27	16	4	0,12	128	16	403	0,18	+
Štrba	**46**	**8-20**	Og2	58	8,0	78	34	17	12	0,05	6	19	451	0,20	+
Štrba	**48**	**0-10**	Og1+2	49	8,2	59	27	16	18	0,10	7	17	347	0,14	+
Štrba	**48**	**10-20**	Og2	51	8,1	72	27	15	5	0,09	5	11	384	0,26	+
Belianske Lúky	**M75**	**0-10**	Oh	49	8,2	86	15	7	2	0,24	24	9	285	0,13	+
Belianske Lúky	**M75**	**12-20**	Ahg	50	8,2	48	16	13	5	0,23	43	16	295	0,58	+
Belianske Lúky	**M78**	**0-12**	Oh	59	8,4	131	22	4	5	0,26	6	7	511	0,26	+
Belianske Lúky	**M78**	**12-20**	Oh	27	7,8	45	8	4	1	1,53	7	7	169	1,00	0

Appendix 5 Temperature and EC measurements in soil profiles at Štrba

Depth (cm)	GPS-nr (Site) 48 (8)	47(7)	46 (6)	44 (5)	43 (4)	42 (3)	41 (2)	Cupola
0	18	18.6	21.9	32.9	19.7	19.6		
20	12.4	14.2	13.4	15.6	10.5	13.3	12.4	9.6
40	11.3	12.2	11.8	13.6	9.3	12.1	11.3	8.4
60	9.8	11.1	10.2	11.6	8.3	10.9	10.3	7.9
80	8.9	9.8	9	10.4	7.9	9.9	9.6	7.3
100	8.5	8.9	8.1	9.5	7.5	8.9		7.3
120								7.1
140								7
160								6.9
180								6.9

	EC (mS/m)							
0*	55.2	58.6	52.5	54.2	66.9	54.2		69.7
20	17.9	16.2	15.6	15.9	14.3	14.4	16.3	13.2
40	17	14.8	17.5	17.9	19	14.8	27	10.9
60	16	14.6	19.8	20.5	22.8	18.1	22.2	13.7
80	15	14.4	20.2	19.5	22.4	23.3		11.1
100	16.8	11.1	21.5	19	20.5	19.4		10.4
120		19.8		19	20.6	19.2		13.5
140				23.7				12.9

0* Surface temperatures were measured with field equipment