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Microtopography of subalpine mires in the Krkonoše Mountains, the Sudetes*

Mikrotopografie subalpinských blatišť v Krkonoších (Vysoké Sudety)

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Long-term observation suggests that biotic decomposition of necromass effectively counteracts the processes of peat accumulation in mire complexes consisting of bog and fen components. Both aerial photography and ground surveying from the period 1936 to 1989 indicate that, over six decades, changes in the string-and-flark microtopography, and the size and outline of mire pools have been only insignificant. A hypothesis is presented that, on sloping mires, extension of the flarks along contour lines is affected by small differences in saturation/desiccation regime of the microhabitats at variously orientated banks. Intermittent flooding and drying differentiates the rates of (1) biomass primary production, (2) accumulation of organic sediment, and (3) biotic decomposition.

Introduction

In the Krkonoše/Karkonosze Mountains (Sněžka Peak 1605 m, 50°44' N, 15°44' E) the two summit plateaus above the timberline comprise large mires whose floristic composition, peat stratigraphy, hydrology and phytosociology were object of numerous investigations (Rudolph et Firbas 1927, Zlatník 1928, Tolpa 1949, Jeník 1961, Ferda et Mejstřík 1964, Hadač et Váňa 1967, 1968, etc.). Since the early explorations, researchers are attracted by conspicuous microrelief of these peatlands, which profoundly differs from that encountered in mires of other Central European mountains. A pioneer study by Rudolph, Firbas et Sigmond (1928) clearly described and mapped hummocks and hollows in the mires of the Eastern Krkonoše, and compared their patchiness with the string-and-flark pattern of some Scandinavian peatlands. Early recognition of the unique composition of Krkonoše mires was facilitated by several Scandinavian monographs, particularly by that published by Auer (1920).

Biogeographically, mires of the Krkonoše represent subarctic/subalpine outliers characterized by a remarkable encounter of alpine species, such as *Pinus mugo*, and nordic plants, such as *Rubus chamaemorus* (Hadač et Váňa 1967, Soukupová et al. 1991). On a schematic map of European peatlands produced by Eurola et al. (1984), mire complexes of the Krkonoše would belong to the „zone" of ombrotrophic montane bogs. However, according to their floristic composition and microtopography these mires reflect an

* The easternmost chain of Hercynian mountains is preferrably named in English "the Sudetes", but less appropriate German-derived versions also occur.

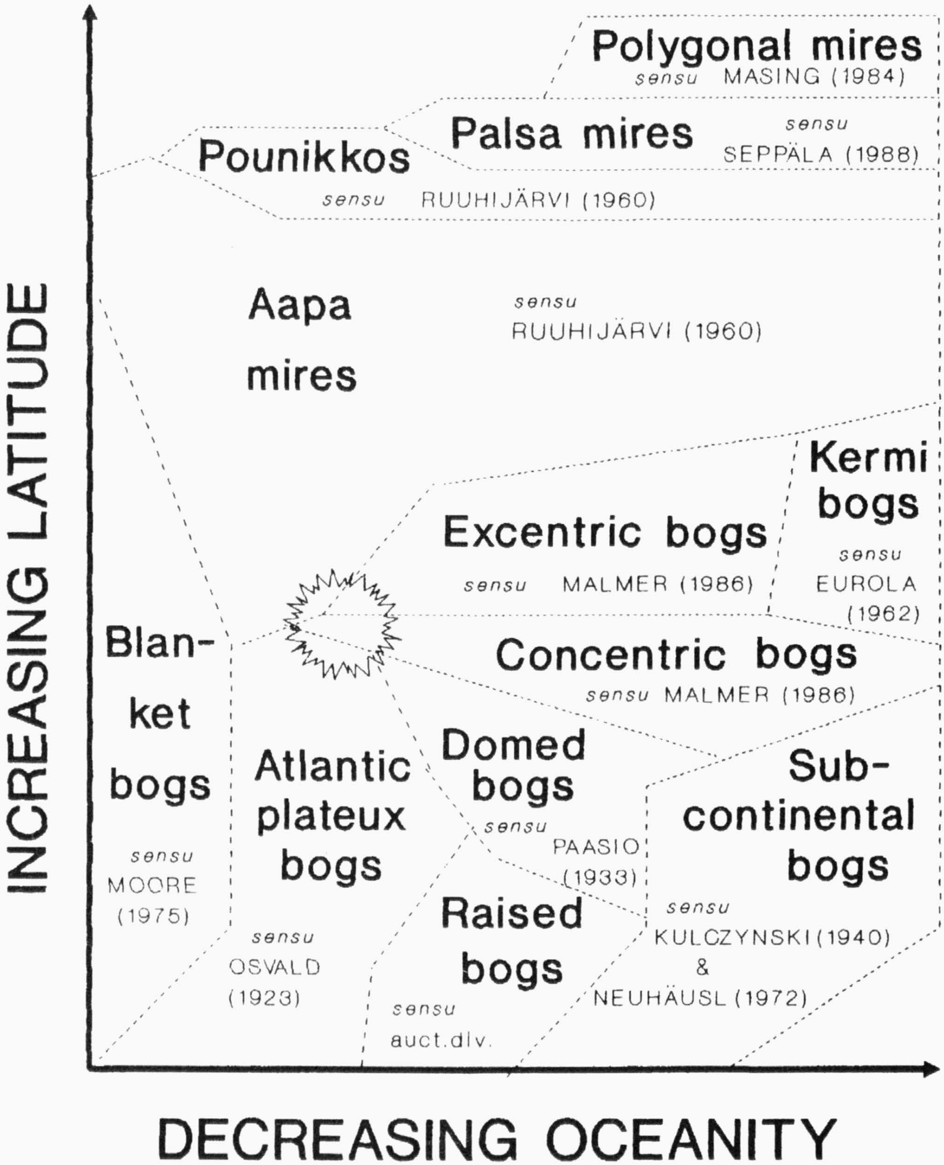

Fig. 1. - A tentative model of „zonal“ distribution of mire complexes in boreal and subarctic Europe, along the latitudinal and longitudinal gradients; the ragged circle marks the „extrazonal“ position of the subalpine/subarctic mires in the Krkonoše.

outstanding „extrazonality" which can best be illustrated by a simplified geographical model showing their situation in the close neighbourhood of nordic peatland types (Fig. 1).

In terms of the current phytosociology, mires of the Krkonoše consist of oligotrophic bog communities belonging to the *Oxycocco-Sphagnetea*, and of minerotrophic fen communities classified as the *Scheuchzerio-Caricetea fuscae* (see a survey in Hadač et Váňa 1967, 1968). These communities vary along environmental and biotic gradients, and create the „vegetational gradients" (sensu Malmer 1986), „mixed mires" (sensu Sjörs 1990) or „mire complexes" (sensu Masing 1984).

Situated near the highly polluted „dirty triangle" of Central Europe, the Krkonoše display a number of indicators pointing out serious human-induced changes in natural ecosystems, and indicating invasion of alien plants. Acid rain, heavy metals and nitrogen deposition threaten particularly the ecosystems of the summit area. Both national parks (Krkonošský národní park on the Czech side, and Karkonoski Park Narodowy on the Polish side) and respective UNESCO bilateral biosphere reserves, suffer from rapid decline of forests and krummholz, by encroachment of ruderal biota, and by losses of indigenous species (Jeník et Štursa 1987). Various predictions pointed out dramatic changes of non-forest ecosystems in the nearest future. Similar alterations should be expected in the area of „mixed mires" whose existence and internal balance depend on a lower status of nutrient supply - a positive factor in particular with regard to ombrotrophic bogs.

In the highly polluted Krkonoše, changes in the deposition of acid rain and nitrogen oxides could affect the rate of peat accumulation/disintegration, and ultimately alter the microsite pattern and microtopography of mire complexes. In expectation of these processes we have attempted to answer the following question: Are there any significant structural signs of major changes within these subalpine peatlands? Inevitably, such a simple question brings about further theoretical issues referring to natural growth/decay processes controlling the hummock-and-hollow pattern in these ecosystems.

Materials, methods and terminology

The subalpine mires of the Krkonoše consist of 20 separate sections covering a total area of 86 ha (Očadlík et Fuksa 1968). In the course of about sixty years, these mires were repeatedly surveyed, photographed and mapped at various scale; a number of data refers, particularly, to the largest mires on the upland plateaus.

Among the available documents, there is a valuable large-scale ground plan covering an area of 320 by 350 m, and two detailed cross sections mapped and drawn by Rudolph, Firbas et Sigmond (1928) in the Eastern Krkonoše. We have used these detailed illustrations for the comparison with the current situation.

A set of aerial photographs (1936, 1958, 1989) has been provided by the Military Topographic Institute in Dobruška, Czechoslovakia (Figs 2 and 3). These pictures enabled us to (1) distinguish objects well below 1 m in size, (2) trace boundaries between various vegetation types, (3) estimate changes in the area of open water bodies and outline their shoreline, and (4) identify growth or decline of individual clusters of krummholz and spruce. Taking into account the less suitable period of photographing (July) and varying technical factors that operate during individual photographic operations, the accuracy of this unintentional „monitoring" is limited (Višňovský et Čihal 1985); greater differences in momentaneous saturation and moisture of individual patches of the mire have slightly obscured the resolution of boundaries in the available aerial photographs. [As confirmed by Tomaszewska (1988), October is the most favourable month for

„phytosociological photointerpretation" of peatlands.]

With regard to the Western Krkonoše, we have studied the largest complex called Pančava Mire, and made measurements of a sample area with distinct string-and-flark microtopography in its SW corner. In 1992, all major mire pools were measured, their littoral vegetation mapped, and current situation compared, on the spot, with the enlarged aerial photographs (Fig. 6, Table 1); using an aerocartograph (Višňovský et Čihal 1985), on successive photographs the position of boundaries of various vegetation types could be compared with reasonable accuracy.

In 1991 and 1992, our observations referred to various stages of hummocks and hollows occurring on the flat and sloping surface. Distinction has been made between surface features pointing out (1) progressive growth of biomass and accumulation of necromass and (2) processes of disintegration, decomposition and erosion of the necromass and peat. The senior author (J. J.) exploited earlier observations in the Krkonoše, which started in 1952 and lasted, with irregular interruptions, for about four decades.

Nomenclature of vascular plants, cryptogamic plants and plant communities follows the phytosociological monograph by Hadač et Váňa (1967, 1968).

Pančava Mire in the Western Krkonoše

Pančava Mire (in Czech: Pančavské rašeliniště) is a peatland complex about 26 ha in size, situated at an average altitude of 1300 m (Figs 4 and 5), and exposed, both in the past and at present, to western precipitation-rich oceanic air currents. According to palynological analyses (Firbas 1952:129) deposition of peat started here in the Boreal period; after its optimum growth in the humid Atlantic, this mire started to decline and nowadays represents "a ruin of the past raised bog, eroded underneath and on the surface by water" (Rudolph et Firbas 1927:91). Mejstřík et Straka (1964:44) write about "subalpine raised bog, partly extinct or in a stage of stagnation"; with regard to the mire pools, the latter authors (op. c.: 42 and 44) mention a process of successive infilling.

Table 1. - Size and morphometric notes on the mire pools in the Pančava Mire; for their situation see Fig. 2. n.e. - not examined.

No.	Length	Width	Note
1	23.6	18.2	E: steep bank, NW: bare ground
2	11.2	9.5	N: sinked bank
3	26.15	21.8	S: erosive inlet
4	7.5	4.0	thick moss mat
5	13.5	8.8	becoming closed by krummholz
6	12.4	9.3	to S 15.7 m long desiccating bay
7	9.0	6.7	all banks steep, 3 islets
8	27.4	22.7	the largest, E: narrow outlet
9	n.e.	n.e.	few open water, mostly desiccating
10	14.9	13.8	rounded, closed by krummholz
11	9.7	7.0	N bank with a bench
12	n.e.	n.e.	shallow, broad desiccating margins
13	3.9	3.3	unidentifiable on aerial photograph

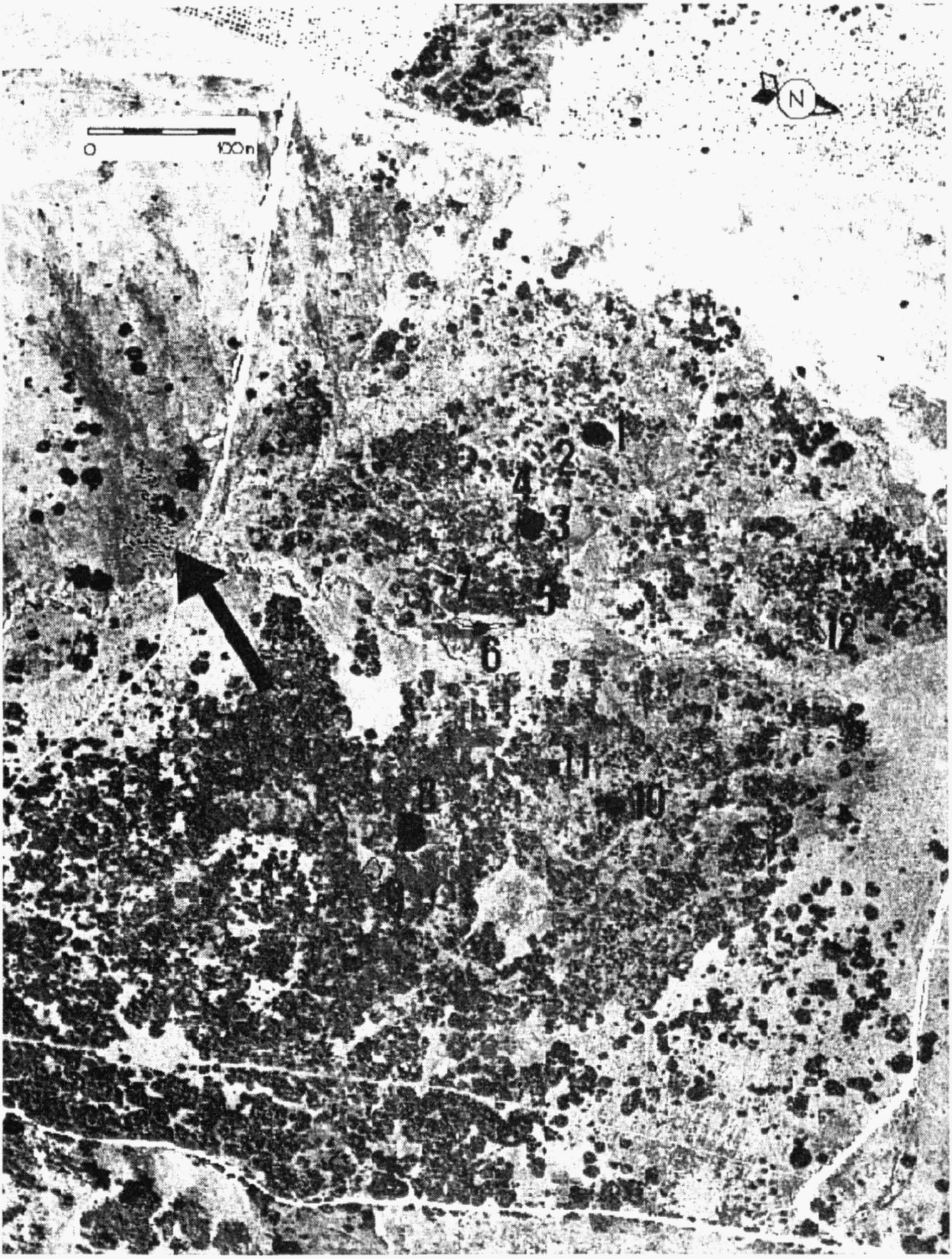

Fig. 2. Aerial photograph of Pančava Mire taken on July 30, 1958; the numbers refer to the bog pools (black spots) listed in Table 1; large arrow points out the string-and-flark system analyzed in Fig. 7.

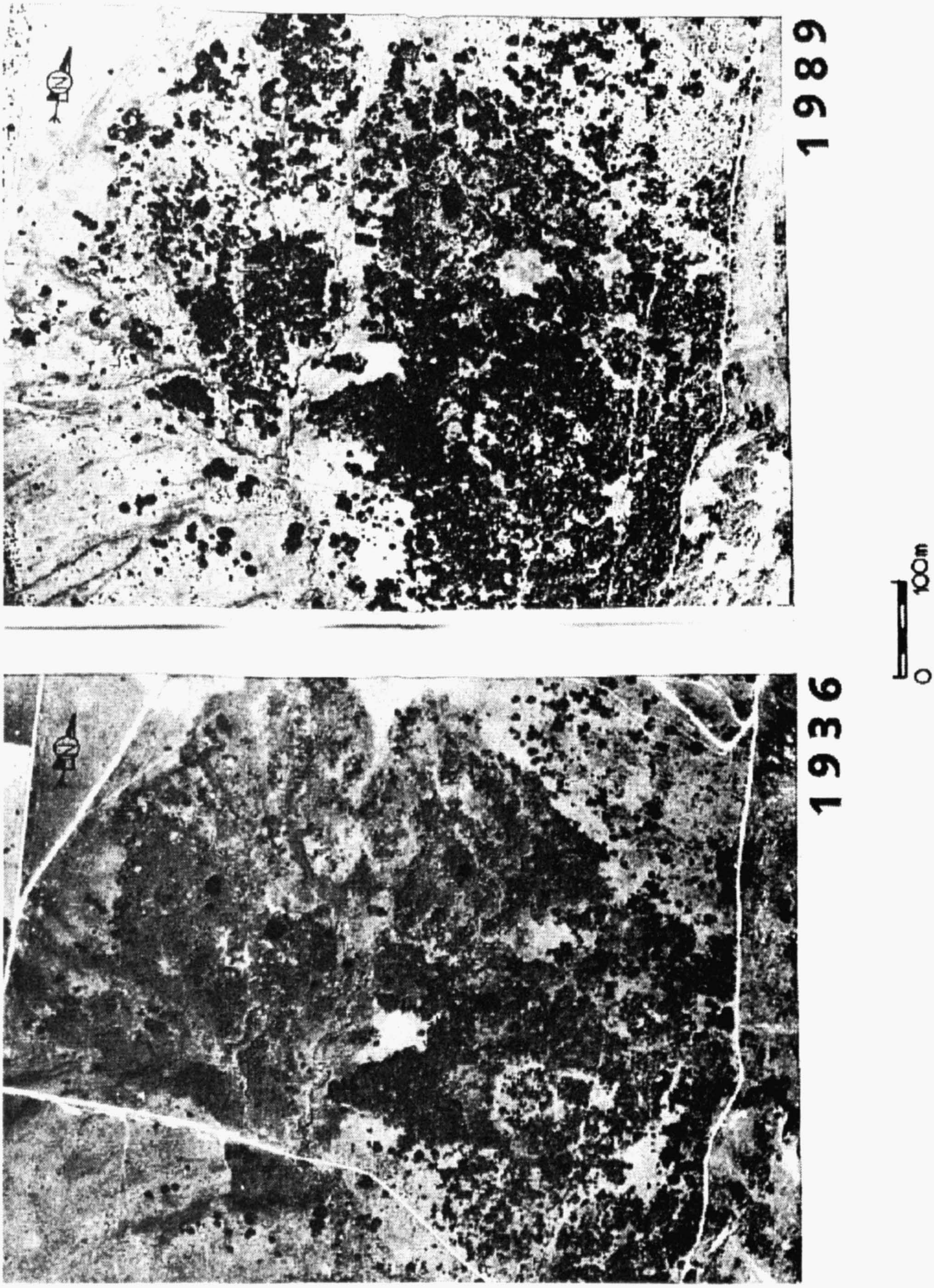

Fig. 3. Comparison of aerial photographs of Pančava Mire in the Krkonoše, taken in 1936 and on July 6, 1989.

A segment of Pančava Mire, illustrated in Fig. 2, comprises 13 bog pools (Table 1) whose size, circumference and shape changed only in insignificant details. Surrounded by steep banks with *Pinus mugo* and ericaceous shrublets, the deep pools (see Nos. 7, 8, 10 and 11) did not change their shape since 1936, the date of the first aerial photography (Fig. 3). In spite of the considerable amount of litter (leaves, rhizomes), annually produced along the shores by sedges and mosses of the *Sphagno dusenii-Caricetum limosae,* no progressive infilling has been recorded. Remarkably, even the shallow bays encountered at the pools Nos. 1 (Fig. 4/6), 3 (Fig. 4/1), 6 (Fig. 5/4) and No. 9, all of them broadly colonized by the *Carici rostratae-Drepanocladetum fluitantis* and the *Sphagno dusenii-Caricetum limosae*, changed neither in their size nor in their outline (cf. Fig. 3). Only locally, features of the shoreline suggested enhanced decomposition of fossil peat; this was obvious along the undermined banks whose consistent upper layer eventually broke from the outer vegetation cover and sank below the average level of neighbouring banks (Fig. 4/4). Judging from the orientation of these banks, mechanical water erosion or wave action could not play major role; biotic decomposition of the peat seems to be the decisive factor. In Fig. 6 four mire pools have been selected in order to show different shapes and composition of marginal communities.

Small pools and their elongated, contour-oriented forms (flarks) show numerous features of progressive disintegration of their banks and bottoms (prevailingly biotic decomposition). In these hollows, occasional small islands of single tussocks of *Eriophorum vaginatum* (Fig. 5/3) result from progressive decomposition of the surrounding peat. On the bottom of numerous depressions, exposed roots of coniferous woody plants from the past mire communities also appear (Fig. 5/5). The bottom and water of the flarks is occupied by species-rich communities of algae, and by associated populations of invertebrates. On the bottom of these flarks, *Zygogonium ericetorum* creates an algal coat - a major source of oxygen required by the decomposing microorganisms (Fig. 5/5); larvae of the *Chironomidae* create a brush of vertical tubes which may contribute to the disintegration of peat, too (Fig. 4/5).

In the majority of hollows, the liverwort *Gymnocolea inflata* plays an important role. During radiation weather, this dark green to black liverwort absorbs heat and warms up the banks, desiccating bottom or shallow layer of water by 2 to 5 °C above the temperature of the surrounding vegetation (Fig. 4/2). Few, if any, invasive vascular plants can establish themselves on the black muddy bottom of these hollows.

As pointed out already by Mejstřík et Straka (1964) Pančava Mire comprises small areas showing the string-and-flark arrangement which is typical for the aapa mires of Scandinavia and Canada (Fig. 4/3, 5/1). In 1992 we have selected in Pančava Mire a smaller segment of sloping surface which was richly dotted by strings and flarks (Fig. 7). Its microtopographic pattern is well visible on the aerial photograph from 1958 (Fig. 2); even the oldest picture from 1936 shows little changes in the microtopography of the string-and-flark section, but major alteration with regard to the *Pinus mugo* and *Picea abies* stands.

In the area of Pančava Mire we have observed, in agreement with the earlier descriptions, numerous relief forms which result from surface and subsurface water erosion. Deep furrows, such as those illustrated in Fig. 5/6, and funnel-shaped or crater-like hollows clearly show the active role of streaming water in the period of melting snow. In these erosional forms, exposed surface of peat is rough and frequently inhabited by mosses and lichens, thus differing clearly from the smooth and fine-grained surface created by fungous and bacterial decomposers.

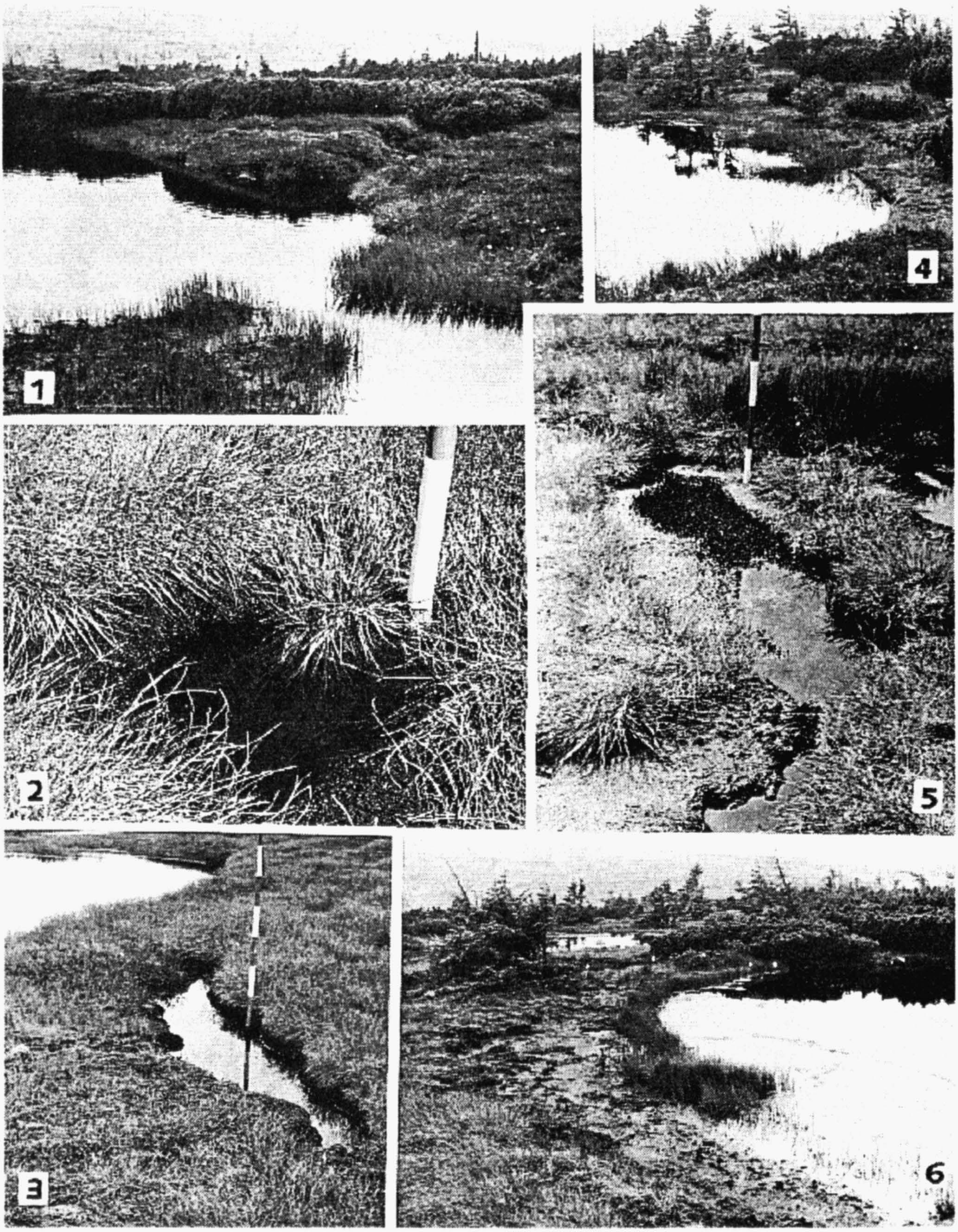

Fig. 4. Elements of microtopography and vegetation on Pančava Mire; 1 - bog pool No. 3 surrounded by the *Chamaemoro-Pinetum mughi*, 2 - embryonic pool between the tussocks of *Eriophorum vaginatum*, occupied by *Gymnocolea inflata*, 3 - pool elongated along the contour line, 4 - bog pool No. 2 fringed by a sunken bank, 5 - desiccating pool whose floor is partly disintegrated by larvae of *Chironomidae*, 6 - bog pool No. 1 fringed by a belt of *Carex limosa* (lake No. 2 in background); for situation and general characteristics of bog pools see Fig. 2 and Table 1.

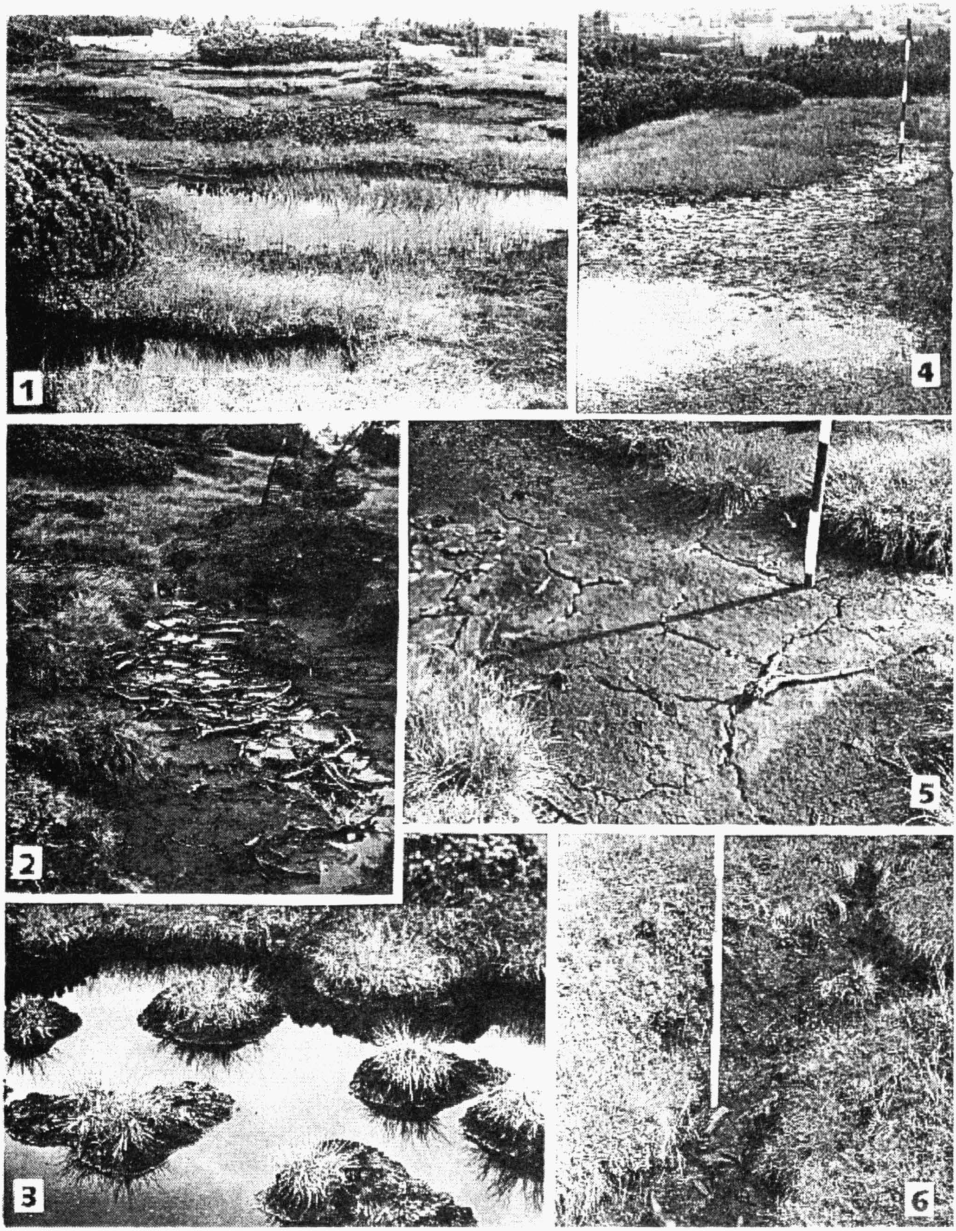

Fig. 5. Features of biotic decomposition and erosion on Pančava Mire: 1 - string-and-flark pattern, partly destroyed by erosion, 2 - exposed roots of *Pinus mugo* along a flark deepened by biotic decomposition, 3 - persisting tussocks of *Eriophorum vaginatum* inside a flark deepened by biotic decomposition, 4 - shallow bay of the mire pool No. 6 inhabited by floating *Drepanocladus fluitans*, *Sphagnum dusenii* and *Carex limosa*, 5 - dry and splitted bottom of a flark covered by an algal coat of *Zygogonium ericetorum*, 6 - erosive furrow on the marginal steep slope, with uncovered old layer of wood remains.

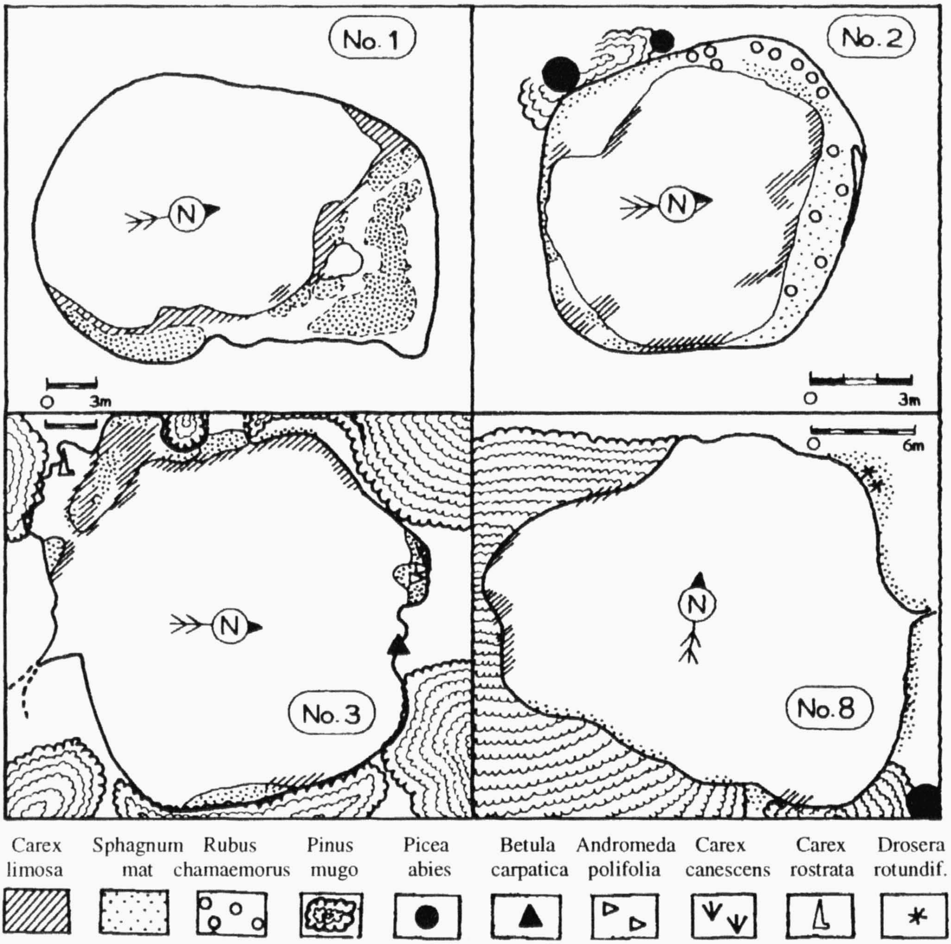

Fig. 6. - Ground plan and vegetation of four mire pools on Pančava Mire; for numbers and situation of the pools see Fig. 2. and Table 1. Vegetation pattern indicates main stands with respective dominants. Recorded on July 3, 1992.

Plateau-at-Sněžka Mire in the Eastern Krkonoše

Plateau-at-Sněžka Mire (in Czech: Rašeliniště na Pláni pod Sněžkou; in Polish: Torfowisko na Równi pod Sniezka) lies at an elevation of about 1400 m, astride the Polish/Czech boundary. This site was repeatedly studied due to its topmost position and remarkable microtopography (Rudolph et Firbas 1927, Rudolph, Firbas et Sigmond 1928, Tolpa 1949, Fabiszewski 1981). A detailed survey by Rudolph, Firbas and Sigmond in 1928, and repeated aerial photographs of this site offer a good opportunity to trace potential changes of larger mire pools, and alterations in the hummock-and-hollow structure.

Comparing the available documents we can conclude that after six decades none of the 10 largest pools on Plateau-at-Sněžka Mire have substantially changed in their size, shape and mutual position. While a certain stability of marginal forms in the outline of deeply cut banks of larger pools would be expectable, the apparent constancy of small and shallow pools (or shallow bays of larger pools) remains a puzzle.

Differences in the microtopography between the aerial photographs 1936 and 1989 are much smaller than those which might be deduced from comparison of the present-day situation with the ground plan published by Rudolph et al. (op. c.). This should be explained by different interpretation of microsites and their vegetation in the course of surveying. No doubt, in the nearest future an attempt should be made to repeat the detailed mapping in the same area.

Factors of the microtopography

Various views have been expressed with regard to decisive environmental and biotic factors of the present-day microtopography of the subalpine mires in the Krkonoše. In agreement with earlier Scandinavian authors, Rudolph et al. (1928:215-216) stressed two dominant factors in the formation of strings and flarks: sliding peat (Torfgleiten) and unilateral surface washing (Überrieselung). Hueck (1939:99-100) emphasized frost, solifluction and pressure of the snowpack. Ferda et Mejstřík (1964:122) mentioned ragged peat surface and subsequent erosion. Klementowski (1979:160-161) pointed out erosional and frost processes, and concluded that „there is, on the mire, a state of equilibrium between processes of destruction and the biological ones". Tolpa (1985: 307-311) wrote about the prevalence of erosion over the regeneration processes.

Our observations in the Krkonoše agree with the Scandinavian experience summarized by Sjörs (1965, 1990): The surface of the less vigorously growing or stagnating mires is sculptured primarily by small differences in filling up and desiccation of hummocks and depressions. In the Krkonoše mires, this differentiation is initiated by incidental vegetation factors, particularly by clonal growth of scattered graminoids, such as *Eriophorum vaginatum*, whose dense tussocks leave isolated gaps in the field layer and whose sheaths are particularly resistant to decomposition. On inclined surface, differentiation of microsites in accordance with the hydric regimes affects the rate of (1) production of aboveground and underground biomass, (2) accumulation of necromass, and (3) biotic decomposition of the peat, on variously orientated „banks" of the embryonic pool. Due to frequent showers and rapid evaporation of water over the plateaus of the Krkonoše, saturation of hollows and pools varies even during a single day. Changes of the aquatic, littoral and limosal „ecophase" (sensu Hejný 1960) on the upper bank and particularly on the lower bank of an individual hollow tend to be less dramatic and less pronounced; intermittently dry/wet and, therefore aerobic/anaerobic conditions alter on „lateral" sides of any of these hollows, which phenomenon consequently brings about enhanced activity of decomposing microorganisms and extension of embryonic pools along the contours. Ultimately, this process creates the contour-oriented flarks and the strings, their counterparts (Figs 5/1 and 7).

Algae and *Gymnocolea inflata* are stronger competitors than the peat-forming mosses in the hollows (Fig. 4/2 and 4/5). This liverwort and numerous algae, possibly, support the rate of biotic decomposition of the peat due to release of oxygen during the photosynthesis. Vigorously growing *Zygogonium ericetorum* (Fig. 5/5) can be particularly

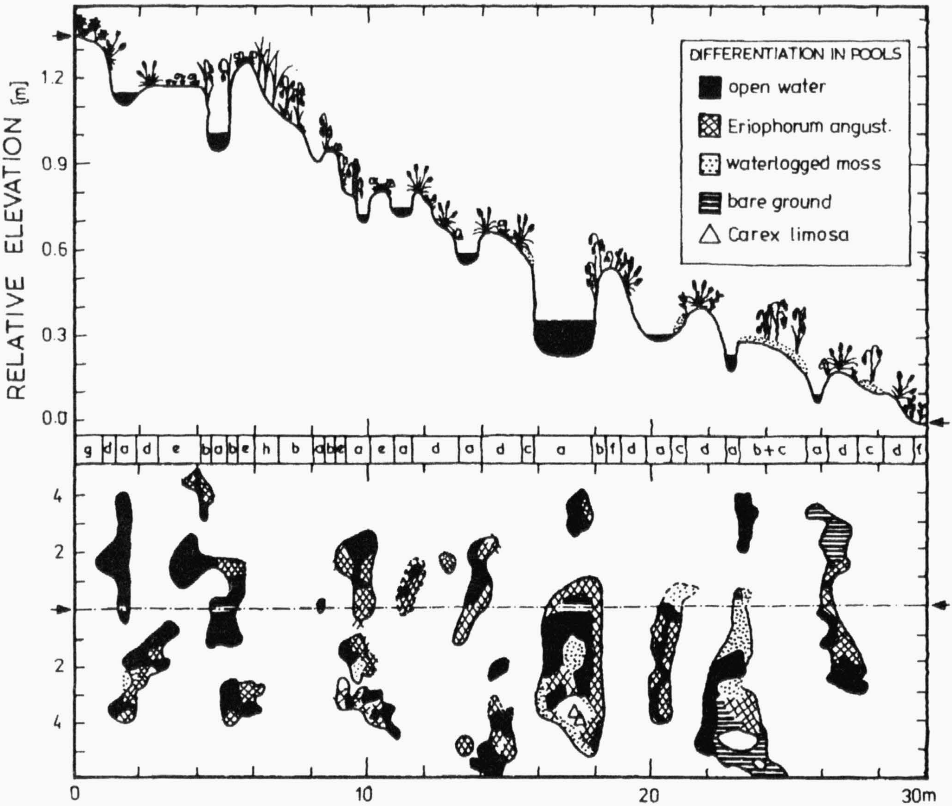

Fig. 7. - Ground plan (bottom) and cross-section (top) of a string-and-flark mire in the SW part of Pančava Mire; its situation see in Fig. 2. Phytosociological composition along the transect is indicated as follows - a: microalgal communities, b: *Calliergo sarmentosi-Eriophoretum vaginati*, c: *Sphagno dusenii-Caricetum limosae*, d: *Eriophoro vaginati-Polytrichetum stricti*, e: *Chamaemoro-Empetretum hermaphroditi*, f: *Sphagno robusti-Empetretum hermaphroditi*, g: *Chamaemoro-Pinetum mughi*, h: *Polytricho communis-Molinietum caeruleae*.

effective. [The richness of algal flora in the alpine mires of the Krkonoše is widely known (Hueck 1939: 92) and its ecological peculiarities have been confirmed by collections of numerous species, including some taxa new for science (Kalina 1970).]

Teeming life of benthic animals reinforces the disintegration process on the bottom of small depressions and pools (Fig. 4/5). [The subalpine mires of the Krkonoše are well known for their diversified fauna of *Chironomidae, Simuliidae and Tipulidae.*]

On flat surface, the embryonic depressions may gradually increase and deepen into circular or irregularly outlined hollows. Resistant tussocks of *Eriophorum vaginatum* may withstand the pressure of decomposition and remain as isolated islands in the hollow (Fig. 5/3). We have to assume that larger bog pools on the plateaus of the Krkonoše developed by similar past processes of biotic decomposition which were continually active, particularly with regard to destruction of the necromass of fen plants, such as *Carex limosa* and *C. rostrata*. In the view of our 60-years-long evidence, terrestrialization and infilling of pools did not take place in the subalpine mires of the Krkonoše.

Studying the stratigraphy of Plateau-at-Sněžka Mire, Rudolph et al. (1928:213-214) found evidence that both the bog pools and the string-and-flark systems existed in the past, i.e., even during more favourable conditions for peat accumulation. The distribution of bog pools did not changed. As mentioned above, few if any signs of infilling and terrestrialization can be recorded around the bog pools. It is difficult to assume that these hollows in the peat deposit are a product of physical (erosive) disintegration and frost action only - a common explanation of the microtopography in the Krkonoše mires (see above). A long history of similar mire pools and even larger peatland lakes is described by Scandinavian and Canadian authors (Svensson 1988, Foster et al. 1988).

Souhrn

Dlouhodobé pozorování subalpinských blatišť (sensu Jeník et Soukupová 1989) v Krkonoších nasvědčuje tomu, že v protikladu procesům kumulace organické hmoty působí efektivní biotická dekompozice rašeliny. Opakované letecké snímkování z let 1936, 1958 a 1989 i starší podrobné mapování ukázaly, že za období šedesáti let se na Pančavské louce a na Pláni pod Sněžkou významně neměnila mikrotopografie tvořená kolky a šlenky či stringy a flarky, ani velikost a tvar blatištních jezírek (kolků). Literaturou předpokládané zazemňování jezírek buď vůbec neprobíhá, nebo postupuje mimořádně pomalu. Na svažitém blatišti je kolísající hladina v zárodečných prohlubních mezi trsy *Eriophorum vaginatum* pravděpodobně primární příčinou vzniku odlišných mikrobiotopů na „březích" přivrácených nebo odvrácených od svahu; střídavé zamokření, vysychání a provzdušnění (okysličení) pak ovlivňuje (1) primární produkci biomasy, (2) ukládání nekromasy a (3) biotickou dekompozici; dekompozice je rychlejší ve směru vrstevnice, kde se výrazněji uplatňuje intermitentní zavlhčování a zavlažování. Je pravděpodobné, že biologická aktivita houbových a bakteriálních destruentů nekromasy v obvodu flarků je podpořena kyslíkem uvolňovaným při fotosyntéze dominantní játrovky *Gymnocolea inflata*, jež nachází ekologické optimum právě v limózní ekofázi břehů a depresí mikroreliéfu.

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