The role of biogenic accumulation and peat exploitation in
geomorphological development of the Orawa–Podhale basin,
the west Carpathian Mountains

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Introduction: The Orawa-Podhale Basin in the West Carpathians is the area of the largest range of peat bogs in southern Poland. The largest concentration of raised peat bogs in the whole area of the Carpathian Mountains and the Sudety Mountains occurs there (Żurek 1983, 1987, Tobolski 2000). Currently, 30 peat bogs of the area from 5.5 to 660 ha and the mean thickness from 0.2 to 4 m (maximum thickness up to 11 m) are located in that area. The peat bogs are located at the altitude of 592-769 m a.s.l. They are fragments of vast peat bogs, which have been shrunk or fragmented in result of over a hundred years long exploitation of the deposit and land drainage (Łajczak 2001, 2002). The raised peat bogs are transformed in different degrees and cover the area of slightly more than 28 km², in the Polish part of the Orawa-Podhale Basin. They neighbour vast valley bogs, which total area is at least 30 km², with pine or pine–spruce forest, called “pine wood on peat bog”. The thickness of the deposit in certain objects reaches up to 3 m. Density of occurrence of raised peat bogs in the area reaches 12 objects/100 km², percentage of land covered by such peat bogs is equal to 11% and together with valley bogs it is equal to over 24%. Significant part of the basin is also covered by turf peat, which thickness is equal to 0.1-0.3 m. They are used as pastures and meadows.

Peat bogs in the Orawa-Podhale Basin have developed on various age quaternary glaciofluvial cones of the Czarny Dunajec river and in less degree on cones of the Biały Dunajec and the Białka rivers, and also on older Holocene terraces of the Dunajec and the Czarna Orawa rivers (Halicki 1930, Baumgart-Kotarba 1991-1992). The area covered by peat bogs was much larger before introduction of agricultural activity. Their development depended on the local relief, depth of the groundwater level, the net of water courses and local climate (Łajczak 2001, 2002). The bed of peat bogs is an impermeable layer of loam 2 m thick with clay fraction contents > 50%, occurring in gravel. The areas underlain by mud, which slope inclination does not exceed 10 ‰ become bogs easily, which is also supported by surplus of precipitation over evaporation, even in summer season.

Evolution of peat bogs during the Holocene: Large area covered by peat bogs influences relief of the Orawa-Podhale Basin. In many places, the relief of the areas covered with peat bogs does not reflect the relief of the sub-peat surface and becomes an important landscape formation factor influencing environmental attractiveness of the region. The relief of the area covered with peat is very dynamic, especially in the last century. There are four stages of different length in the morphological development of peat bogs:
1) initiation of the peat formation process in local depressions of the land leading to levelling of the land surface,
2) development of peat domes started non-synchronically in conducive places, leading to increased de-levelling in the field equal to maximum thickness of the deposit in the dome.
3) degradation of peat bogs in result of different forms of their usage (from the XIII to the XVI century), especially exploitation of the deposit and drainage processes (from the second half of the XIX century), local disinterring of the sub-peat surface,
4) currently beginning environmental reclamation of several fragments of degraded peat bogs leads to recovering of proper relief and watering remnants of old domes and formation of secondary peat peripheries in post peat areas.

Evolution of peat bogs - first valley bogs started from growth of domes in conducive areas, which covered previously relief of the ground and changed local watersheds. Outflow of ground water and water courses flowing around peat domes have permanently irrigated peat peripheries. The process lasted through the whole Holocene till the beginning of the drainage works started in the XIX century. Analysis of geomorphological location of peat bogs does not confirm the common concept that they are mostly located on the local watersheds in the Orawa–Podhale Basin. Only six of the objects are situated on the local watersheds which suggests they are charged only by precipitation water. Development of the objects has led to increased de-levelling in the field equal to maximum thickness of the deposit in the dome. Further six peat bogs have developed in the lower located parts of the fluvioglacial cones and in spring niches of shallow valleys. Development of bog domes surrounded by less efficient springs results in filling neighbouring valleys by peat and flattening of the local relief. Lower topographic location is occupied by the third group of peat bogs (eight objects) developed on the Riss terrace of the Czarny Dunajec river, along the palaeochannels of the Dunajec river toward the Orawa river (after Baumgart-Kotarba 1991-1992). The observed water losses in the Czarny Dunajec river channel within the area of the cone is reflected by increased discharge of the neighbouring stream.
called the Pickielnik Orawski (Lajczak 2002). It may imply, that subsurface runoff of part of the Czarny Dunajec water to left-side tributaries of the Czarna Orawa river still occurs along palaeochannels covered by peat domes. Development of that group of peat bogs first led to increased levelling in the field (filling of some parts of the palaeochannels by biogenic sediments) and later after growth of the domes again to decrease of levelling with maximum thickness of the deposit in the dome over the palaeochannels. Three further objects, belonging to the fourth group of peat bogs have developed at the foot of the higher terrace on the cones of the Czarny Dunajec and the Bialy Dunajec rivers where shallow erosion dissections caused by small water courses are located. Development of the domes, which peripheries are more intensively charged by percolating ground water, resulted in covering larger area by biogenic sediments, including the foot of the higher terrace, and smoothing morphological contrasts in the field. Four peat bogs belonging to the fifth group of objects have developed on the side of the small fluvial cones superimposing high Holocene terraces of the Czarna Orawa and the Czarny Dunajec rivers. The last three peat bogs, belonging to the sixth group are located in the lowest part of the Czarny Dunajec cone, where neotectonic conditions favour numerous groundwater runoffs (Baumgart-Kotarba 1991-1992). Development of peat bogs has led to decrease of local morphological contrast also in that area and later again to their increase.

If applying the classification of mountain peat bogs after Kaule and Göttlich (1976), the first group may be subsumed to the ridge peat bogs, and the others to the raised bogs either symmetric or asymmetric. When applying the classification given Dembek et al. (2000) the first group may be belong to ombrogenic bogs, and the bogs located lower or in watershed zones may belong to topogenic ones. The other groups of peat bogs were of outflow character before development of domes over them. Considering common occurrence of impermeable layer of loam in the Orawa-Podgale Basin it may be assumed that before the XIII – XVI century almost the whole area of the basin (except flood terraces) could have been covered by peat layer of various thickness. Vast domes, which number was probably 16, covered probably the area two times bigger than currently (in the area of the Polish part of the basin) and they were surrounded by vast zones of valley bogs.

Horizontal development of peat domes led to formation of new lines of water runoff at the edge of the domes. Transit water courses, which old run was blocked, cut into both sides of the dome deeper than the layer of loam. Their meandering course should be explained by high retention coefficient of the peat covered catchment areas. On the other hand, increase of the domes which were not accompanied by transit water courses caused shallowing of erosion cuts in the forefield of the domes. According to the XVIII and the XIX century maps, before starting of draining works, peripheries of those peat bogs had no drainage system. In farther forefield of the peat domes numerous lines of water runoffs gathered together in a main stream with a meandering course.

**Anthropogenic degradation of peat bogs:** Agricultural colonisation of Podhale and Orawa regions and placing arable lands in the areas covered with thin layer of the peat resulted in liquidation of peat deposit in the area. Thin layer of peat remained only in meadows and pastures. Thicker peat deposits survived only in places difficult to access, still covered with forest. The oldest forms of anthropogenic degradation of raised bogs, such as burning the deposit were described already in the XVIII century, collecting bedding or picking up fossilised tree trunks from peat (described since the half of the XIX century) did not cause significant changes in the relief of the domes (Lajczak 2001). Bog domes started to shrink quickly in result of exploitation of the deposit, began in the period of 1850-1880 and intensified in 1940-1990 by individual land owners and owners communities. In result of that exploitation some of the domes have become fragmented and four objects disappeared completely. Peat exploitation along edges of domes towards the centre of peat bogs is the oldest and still common form of the deposit exploitation. Such exploitation has led to formation of typical land forms in the Podhale–Orawa Basin. Exploitation in the fields of different size within the area of peat domes was carried on only in few places and it has not caused significant changes of the shape of the domes. Very noticeable changes of vast fragments of peat domes have been caused by peat exploitation by means of industrial methods since 1945 and draining works accompanying the exploitation.

Exploitation started at the edge of the peat bog towards the centre of the dome causes its decrease. A layer of deposit 1 m thick is usually left in post peat areas. In many such places mineral ground is exposed. Old erosion forms, even much distant from active lines of water runoff, are uncoverered in such places. Excavation wall which is formed in result of exploitation follows a zigzag line. In the past it was 6 m high in some of the excavations. Currently it is usually 2-3 meters high. At the foot of the exploitation scarp at the edge of the dome there are many peat holes 1.5 meter deep where water running off the deposit is collected. Fragmentation of domes is the other result of exploitation of the discussed peat bogs. In result of peat bog exploitation, some fragments of peat domes have been changed into „peat remnants” forming a vertical 3 m high scarp rising over wide post peat areas. Post exploitation scarps in many places are accompanied by crevasses in peat at the edge of the dome of the visible depth to 2 m and different degree of opening. Along them, peat packs slide down. They become liquiefy during spring thaw. The process helps to gently the profile of the scarp and it is more advanced in the objects where exploitation was finished earlier, especially on „warm” slopes exposed towards (S-W). For
example, at the dome of the peat bog “Bór na Czerwonem” protected as a natural reserve since 1956, the old vertical scarp has changed into a slope which inclination is equal to 5-20°.

Peat has been exploited since the XIX century in the peat bog “Puścienna Rękowiańska”, one of the two largest peat bogs in the Orawa–Podhale Basin in a different way because of a relatively low dome. The peat is exploited there on large areas within the range of the dome. The exploitation scarp within the range of each exploitation field moves from the centre of the dome towards its periphery, which causes formation of vast shallow working basins. They are boggy areas where many watercourses flow out from the dome, currently drained. They are charged by groundwater infiltrating from the Czarny Dunajec river channel. In the post-exploitation basins many peat holes, often filled with water, occur.

Industrial exploitation of the peat deposit leads to larger transformations of peat bogs. In one of such exploited peat bog covering the area of 35 ha 1.5 layer of peat has been excavated and a layer 2 m thick has been left. The peat layer has been covered with a net of draining ditches, which currently are shallow and overgrown by vegetation. A layer of peat 2 m thick has been excavated from an exploitation field in another peat bog and a part of the deposit 1.3 m thick has been left. The ditches there are also shallow and overgrown. In both peat bogs the old scarps at the edge of exploitation fields have been levelled and the transformed areas being overgrown with bush do not differ from the other parts of the objects. The situation is different in the third object, where the exploitation field covers the area of 60 ha and the pit covering the area of 12 ha is 2–4 m deep. Also that field has been covered by the net of draining ditches, which depth varies, due to continued exploitation works, from 0.7 m to 4.5 m. The ditches walls are vertical and they are overhung in several places. Only few of them have become shallow.

Current total area of the discussed peat bogs is equal to 2836 ha, which is decreased by 34% when compared with the state at the end of the XIX century. The total area of domes has also decreased by 1/3, from 1977 to 1312 ha. At the end of the XIX century they constituted 46% of the area of peat bogs, while currently, despite their significant reduction, they are still close to 50%. Since 1894 each peat bog has reduced its surface form 11 to 100% and their domes from 14 to 90% (Łajczak 2001), which proves large local differences in the tempo of anthropogenic transformations of their morphology. Cartographic analysis of the range of the peat bogs proves the fastest decrease of the surface of their domes in the period 1940-1990.

Intensive exploitation of peat bogs in the area of the Polish part of the Orawa–Podhale Basin has caused that large fragments of domes have preserved only in half of the objects. The traces of domes have remained only in other peat bogs. However, vast post peat areas around the remnants of the domes prove they must have been very large. Their size may be determined basing on maps, beginning from 1855. Applying the criteria given by Myślińska (2001), post peat area over 0.5 ha and the average thickness of the deposit over 0.2 m should be classified as the most contemporary degraded form of peat bogs.

**Current state of peat bogs:** After 1990 r. the amount of individual exploitation of the deposit in the discussed peat bogs has decreased significantly. Draining ditches have not been cleaned either, which resulted in slower outflow of water from the post peat area and locally faster growth of bog vegetation, previously restrained by excessive dryness of the deposit. Wide zones of post peat area have shrunk around the domes, locally turning into peat bog peripheries. That desired process will increase after introduction of suggested activities, which aim to stop runoff of water from the post peat area (Łajczak 2002). For the last 15 years, old exploitation scarps on many partly damaged domes have been turning into slopes with decreasing inclination. Progressing process of environmental reclamation accelerates the process. Various stages of such morphological transformation of the old edge zone of partially damaged domes can be observed in many peat bogs. They transform from areas of very young morphology (a vertical scarp, numerous peat holes filled with water) to gentle, but very wet slopes of domes completely covered with boggy vegetation. If exploitation of peat deposit is stopped and high dampness of the post peat areas is restored the process of environmental recovery will result in formation of domes surrounded by peat bog peripheries. However, the size of the domes will be much smaller than in the period before peat exploitation.

**Bibliography:**
Maps and aerial pictures applied for the paper:
Die Spezialkarte der Österreichisch-Ungarischen Monarchie, 1894, 1:75 000, Wien.
Zdjęcia lotnicze, 1994, około 1:20 000, Warszawa.