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ORIGIN OF LAMINATED SEDIMENTS IN ALLUVIUM OF THE UPPER SAN VALLEY IN THE BIESZCZADY MOUNTAINS, EASTERN CARPATHIANS

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Abstract. Young alluvial sediments in the headwater section of the San river include locally fine-grained, organic-rich, laminated sediments. Characteristics and radiocarbon ages of the laminated sediments indicate that they are fills of old millraces and millponds.

1. INTRODUCTION

The bottom of the San river valley is covered with alluvial terraces locally overlain by slope sediments. The alluvial sediments, especially the older ones, are poorly stratified. Isolated occurrences of finely layered organic-rich fine-grained sediments are present in the studied area in the two lowest terraces (1-3 m and 3-4 m above the channel level). They are manifest by dramatic changes in grain size and depositional structures, and by high content of organic debris. The alluvium was studied in the 35 km long headwater course of the San, from the Uzhok Pass to the Dźwiniacz Depression. This paper presents three selected localities with the laminated alluvium: Beniowa (on the San), Bukowiec (on the Halicz stream) and near Buk (on the Wetlinka stream).

Organic material found at these localities have been dated with radiocarbon method at the Radiocarbon Laboratory in Gliwice.

2. MAIN FEATURES OF THE ENVIRONMENT OF THE UPPER SAN RIVER CATCHMENT

The San and its uppermost tributaries drain high parts of the Bieszczady Mountains. The San valley in its uppermost course runs parallel to the main range and differences in altitude attain 600 m. In contrast to the mountainous relief of the range, the relief of the valley bottom is gentle, similar as in foothill areas. The very gentle (1-4%) vertical gradient of the San river in its headwater course and wide valley bottom favour accumulation of alluvium. The river is meandering with flat-bottomed channel exposing bevelled flysch beds across its width. For the first 15 km the valley is narrow, then it widens (the Dźwiniacz Depression between Sokoliki and Łokieć ca. 650 m altitude) and its bottom is covered with a series of terraces (**Fig. 1**). The major tributaries (Negrylów, Sychłowaty, Halicz, Litmirz, Roztoki) have steep gradients (10-15%) on the slopes of the high mountain ranges, step-like longitudinal profiles and their channels are actively eroding the flysch substrata. In their lower reaches, the gradients are more gentle (1-5%) and alluvium accumulates locally. The area is wooded in more than 80%, mostly by deciduous forest. Only the highest mountain crests, which rise above the timberline (1100-1150 m) and parts the of San valley bottom are not wooded. The woods are expanding now, but their upper and lower limits changed strongly during the centuries in relation to the complex history of human settlement and agriculture in the area. For half of a century now the forest has been expanding over the land that ceased to be used for agriculture. The annual rainfall attains about 1000 mm. The forests and a thick mantle of weathered material – clays and rock debris – slow down the runoff, so that the floods are moderated. The lack of agriculture results in low supply of weathered material to streams. The load of transported debris during floods is markedly lower than in the more deforested and intensively farmed parts of the Carpathians.

3. STRUCTURE OF THE FLOODPLAIN TERRACE

The floodplain terrace is the lowest and youngest of up to six terraces of composite erosional and depositional nature present along the San river valley and in wide sections of the Halicz, Sychłowaty, Roztoki and Litmirz valleys. The alluvium on the higher terraces consists of gravels, while fine-grained sediments are abundant in the deposits of the lowermost terraces (1-3 m, 3-4 m; **Fig. 1**), especially in the floodplain.

The floodplain terrace has a low (up to one metre) flysch basement and a two-storey alluvial cover. The lower part of the cover is a thin (up to 0,5 m) layer of gravels, the upper, thicker (1-2,5 m) is composed mainly of sand, mud and clay. The two parts are separated by organic layer, composed mostly of wood debris (trunks, branches, leaves, seeds) and 0.1-0.4 m thick. The terrace preserves this structure over most of the studied area. Only very locally the typical alluvial mud is replaced by thin alternation of mineral and organic sediments laid down in small artificially dammed reservoirs. The structure of the floodplain in these places is markedly different. The top of the rock basement lowers even beneath the modern channel bottom and the overlying gravel is thinner and lies at a lower elevation. The upper layer of mud is replaced by a thick series of laminated sediments. Lateral boundaries of the laminated sediments clearly reveal outlines of former reservoirs incised into the floodplain.

Fig. 1. Location of study area in the Carpathians (A) and location of the sites with laminated and structureless fine-graned alluvia in the uppermost San river valley (B): 1 – terrace bottom of the San Valley, 2 – the San flood plain, 3 – the studied sediments of the ponds at Bukowiec (1) and Beniowa (Negrylów) – (2).

4. SEDIMENTS OF THE DAM RESERVOIRS

Beniowa. Laminated sediments two metres thick are exposed for 200 metres in both banks of the San near the upper end of the former village of Beniowa, downstream of the outlet of the Negrylów stream (**Fig. 2**).

The floodplain sediments start with a layer, 6-10 cm thick, of wood branches and leaves with pebbles, lying at the top of the flysch basement. This organic-rich layer in turn is covered with a layer of dark clay and mud, impermeable for shallow groundwater whose abundant seeps along the top of impermeable sediments are marked by rusty deposits of iron hydroxides. There are still eight couplets of organic and mineral layers upsection. The organic material consists mainly of needles, leaves, bark and tree seeds. Mineral material consists of mud and clay in the lower part of the section, of sandy muds and clays in the middle part and of sand in the upper part. Three thinning upwards sequences (sand-clayey mud-organic material) are present above the first sand layer. The thickness of the individual layers varies from 2 to 15 cm and increases upsection, so the that the uppermost layer of sandy mud (deltaic sediment) is the thickest (45 cm). The layers change upsection from horizontal and thin at bottom to wavy, often lenticular at top.

Leaf debris from the lower part of the section (1.5-1.6 m, the layer above the ground water seeps, **Fig. 2**) was sampled for radiocarbon dating. The age appeared very young (150±120 BP), and it seems to represent deposition between the end of 17th century and the World War II. The time span in which the whole series of organic-mineral sediments was laid down can not be precisely determined as the sedimentary cycles preserved may represent one flood each, one vegetation season or even longer periods.

Historical documents on the ancient settlement in this section of the San valley provide clues on the timing and causes of the local deposition of the laminated sediments. A cadastral map from 1852 and a topographic map from 1901 show a saw-mill and a grist mill immediately downstream of the section with laminated sediments.

Both mills were situated on the right bank of the San. Both establishments still existed in 1914 (Kryciński, 1995). A small millpond, serving both establishments, existed then at the place where the laminated sediments now occur. The water level in the main channel of the San was raised by a dam to the floodplain level, and backwater extended for about 200 metres upstream. Debris began to accumulate at the head of the reservoir and prograded downstream. The progradation manifests in sediment by the upward-coarsening of grain size. The basin had been completely filled with sediment and then it was dissected by stream erosion after the dam was broken. No dams are now present at this locality; they were destroyed after the local people had been exiled in the 1940ties. The radiocarbon dates obtained for the sediments fit well the historical data.

Bukowiec. A thicker series of similar sediments occurs in the Halicz stream valley at Bukowiec. About 2150 metres upstream from the bridge a 2.5 m-thick section of laminated sediments is exposed in the right bank (**Fig. 2**). A long exposure at the stream bend shows a lengthways and transverse sections through the sediments filling an ancient dam reservoir. The transverse section shows a trough-like arrangement of the sediments. The sequence starts with sandy gravels in which tree trunks up to 60 cm thick are buried. The gravels with trunks are exposed on the margins of the trough only.

The vertical sequences of laminated sediments include 18-28 organic horizons thicker than 1 cm. The thickest, 0.65 m layer of leaves, seeds and twigs lies at the base in the central part of the trough and wedges out towards the margins. Organic material makes up 80-90 percent of the sediment in the lower half of the section, and its mineral fraction consists of mud with admixture of sand. Sand, mud and fine gravel are the main components in the upper part in which the organic interlayers are thinner, often discontinuous, rich in mud. Proportion of sand increases upsection so that it dominates at the top. Lenticular bodies of sand are characteristic of this part of the section (**Fig. 2**). The coarsest clasts occur in the topmost deltaic sediment.

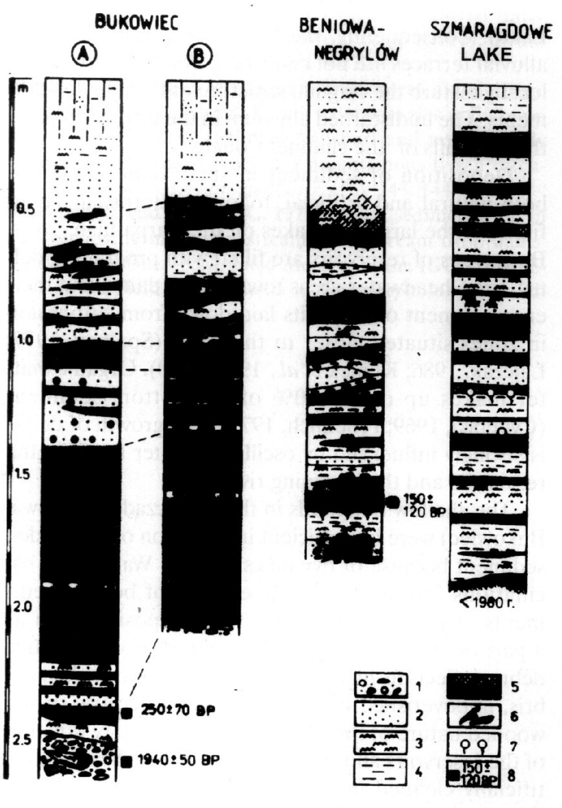

Fig. 2. Lithological columns and radiocarbon ages of ponded stream sediments at Bukowiec, Beniowa (Negrylów) and Szmaragdowe Lake: 1 – gravels, 2 – sands, 3 – muds, 4 – clays, 5 – organic material, 6 – coarse wood fragments, 7 – groundwater seepage, 8 – horizons with dated organic debris.

Radiocarbon dating was made on a fragment of tree trunk from the basal gravel layer (depth 2.60-2.70 m) and of leaf debris from the lowermost organic layer (2.40-2.50 m). The trunk sample was dated as 1940 ± 50 BP and the leaf debris as 250±70 BP. Though both samples come from close positions in the section (**Fig. 2**), the large difference in their age is well justified.

The alluvial sediments in the youngest terraces of the San and Halicz are bipartite, with a distinct erosional surface between the basal gravels and upper mud. The lower part, in which the trunks are buried, could be laid down about two thousand years ago; the upper is much younger. The difference in the time of deposition between the two parts seems to correspond to time of important environmental change, consequence of which was the change in the grain size of sediments denuded in the watershed, from gravel to sand and mud. The age of the San floodplain alluvium downstream of Ustrzyki Dolne has been determined at about 2000 BP (Starkel, 1960).

The sediments at Bukowiec are very young; their deposition was related to damming of the stream and raising its level in order to divert a part of its water for the estate's grist mill and sawmill. The grist mill is mentioned in a document from 1589 and it existed until the World War II. The sawmill is present on the cadastral map of 1852 and its later history is not known. The dam was 32 m long and it was built of logs 10 m upstream of the sawmill (Kryciński, 1995). Relics of the dam are still visible near the downstream end of the exposure. A part of water from this millpond flew through a millrace to the mill downstream.

The millpond intercepted sediment delivered from densely wooded upper course of the Halicz stream. Coarse sediment accumulated in a delta at the head of the reservoir while the finer fraction was laid down as the bottom sediment closer to the dam. In response to progradation, the coarser sediment encroached on the earlier deposited bottom sediment (**Fig. 3**). After filling the reservoir, the Halicz diverted its main course to the millrace leaving the dam not disrupted. When the mill became destroyed, the millrace deepened and the sediment fill was dissected by stream erosion almost to its bottom. The deepest sediments, not hitherto dissected by erosion are being buried by a young gravel delta.

Buk. The rate of filling dam reservoirs on streams in the Bieszczady range has been studied on the modern example of the Lake Szmaragdowe (Emerald Pond) near Buk (Malarz, 1993). The pond was created in July 1980 on the Wetlinka stream near its junction with the Solinka, as a result of a landslide which dammed the stream (Dziuban, 1983; Margielewski, 1991). It was initially 280 m long, 20-45 m wide and up to 5 m deep. The Wetlinka gradually filled it up during floods by depositing gravel at the head, and sand and mud closer to the dam. The gravel delta prograded fast; in 1992 the reservoir was only 70 m long, in 1997 its head was less than twenty metres before from dam. Detailed

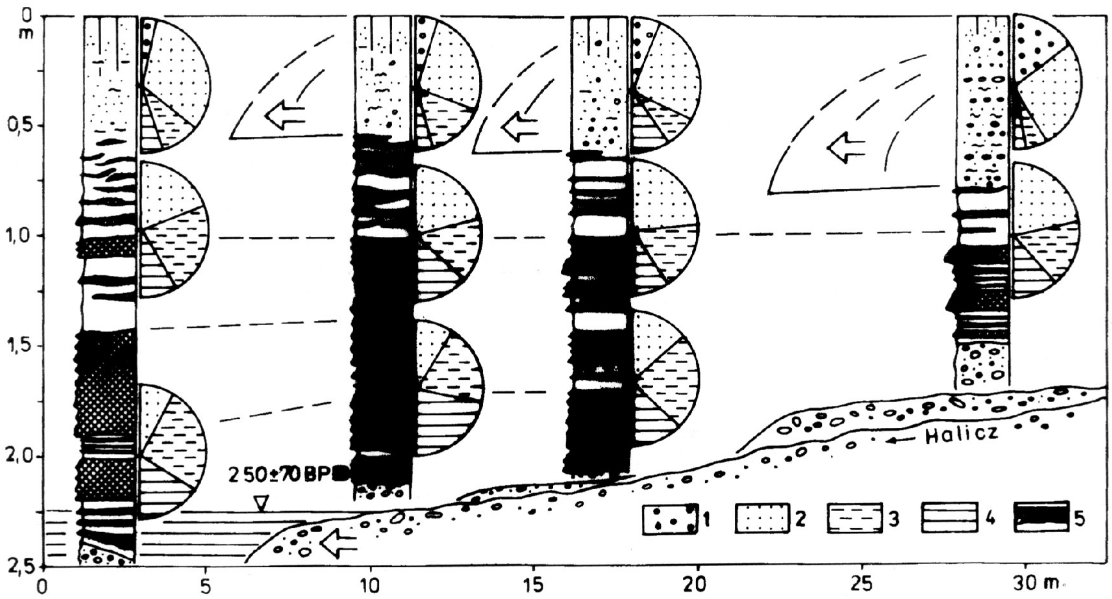

Fig. 3. *Variation in grain-size and stratification of sediments in the alluvial basin at Bukowiec: 1 – gravel, 2 – sand, 3 – mud, 4 – clay, 5 – organic debris.*

measurements of the increasing volume of the sediment fill during the period 1980-1992 have shown an average rate of sediment supply of 487 m³ (Malarz, 1993). At the same time the landslide debris dam was gradually dissected and water level in the reservoir sank, so that it is no more than 1 m deep now. The fine-grained sediments laid down near the dam have been also dissected. At present, a 1.8 m thick section of the fine-grained sediments is exposed on both sides of the pond near the dam. The sequence of sediments is similar to those at Beniowa and Bukowiec (**Fig. 2**). It consists of alternating organic and mineral sediments. The organic sediments in the shallow part of this sequence were studied for their seeds and fruits content (Cabaj and Pelc, 1991) and malacofauna (Alexandrowicz, 1993). Malarz (1993) described textural characteristics of the topmost mineral layer. The base of this series is not exposed and it has been being buried by the prograding gravel delta.

5. DISCUSSION

The number of depositional organic-mineral cycles proves that they are not seasonal but rather flood cycles. Each flood could leave one organic-mineral couplet. During bigger floods a part of earlier deposited layers could be eroded. Accumulation was less intense with the progress in dissection of the dam. As a result, the average rate of accumulation corresponds to several cycles per year. The filling of the millponds at Beniowa and Bukowiec occurred probably in the same way as in the Lake Szmaragdowe Jeziorko.

It is important that the studied reservoirs were filled to the level of the floodplain terrace (Beniowa) or the next higher alluvial terrace (Bukowiec, Szmaragdowe Lake). Consequently, the longitudinal profiles of the alluvial terraces are not disturbed. Young reservoir fills locally disturb the original structure of the alluvial sediments. The undisturbed alluvium in the terraces is older than the fills of the channel troughs.

Deposition of sediment in small dam reservoirs, both natural and artificial, follows patterns similar to filling of the large dam lakes on the Carpathian rivers. Both types of reservoirs are filled with prograding deltas, from headwater areas towards the dams, and their encroachment on deposits laid down from suspension in zones situated closer to the dams (Spaleny, 1977; Łajczak, 1986; Klimek *et al.*, 1989, 1990). Organic matter makes up only 5-10% of the bottom sediment (Cyberski, 1969; Froehlich, 1975). The growth of deltas is strongly influenced by oscillating water levels in the reservoirs and the incoming rivers.

The shallow millponds in the Bieszczady (Beniowa, Bukowiec) were less efficient in retention of suspended sediment because of dynamics of flow. Water level oscillations favoured episodic erosion of bottom sediments. The coarse fractions were deposited also as a part of bottom sediment. The abundance of organic debris reflects its high proportion in the transported debris, impoverished in mineral fraction because of the wooded nature of the watershed. The utilitary function of the reservoirs allows us to suppose that they were artificially cleaned in order to keep them serviceable. The described sediment fills are similar to sediments filling small reservoirs behind debris dams in other parts of the Carpathians, for example in the Beskid Sądecki (Lipski, Gładki, 1979; Froehlich, Klimek, 1979; Froehlich, 1982). The reservoir fills in the Bieszczady are already completely dissected by stream erosion and are incorporated into alluvial terrace sequences and they offer better possibility of studying the process of reservoir filling.

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