STRATIGRAPHY OF ORGANIC-RICH DEPOSITS IN FLOODPLAIN ENVIRONMENTS: EXAMPLES FROM THE UPPER ODRA RIVER BASIN

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Manuscript Received: December 31, 2009
Revised Version: April 28, 2012

Wójcicki K.J., 2012. Stratigraphy of organic-rich deposits in floodplain environments: examples from the upper Odra River basin. *Quaestiones Geographicae* 31(3), Bogucki Wydawnictwo Naukowe, Poznań 2012, pp. 107–117. 12 Figs. DOI 10.2478/v10117-012-0024-6, ISSN 0137-477X.

Abstract. Macrofossil analysis and radiocarbon dating were used to determine the age, composition and succession pattern of organic-rich deposits infilling oxbows and flood basins in the Rivers Kłodnica, Odra and Osobłoga valleys (southern Poland). Both detrital sediments representing the aquatic or terrestrial environments as well as five types of peat accumulated in amphibious or peatland conditions have been identified in cores analyzed. Studies have shown that an accumulation of organic-rich deposits was commonly initiated by terrestrialisation and was typically occurred under eutrophic conditions. In such circumstances, deposit sequences usually begin with aquatic detrital sediment (gyttja), or possibly brown-moss or reed peat. These deposits normally pass into sedge-reed peat and then alder peat. If the accumulation of organic-rich deposits was initiated by paludification, alder peat appears in the lowest sections of the fens. In the upper parts of the sequences, apart from wood peat, organic deposits dominated by sedge remains are also present. The latter were accumulated, probably, as an indirect effect of human activities in the floodplains.

Key words: macrofossils, organic matter, detritus deposits, peat, Holocene

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1. Introduction

Organic-rich deposits are commonly present in valleys formed by low-energy highly sinuous rivers. In southern Poland, they appear mainly in oxbows and flood basins. In these floodplain subenvironments, organic-rich deposits may be important landscape-forming factors determining local hydrological conditions as well as soil and vegetation development.

Organic-rich deposits infilling floodplain topographic depressions are often used to dating fluvial forms and episodes of valley alluviation (e.g. Rotnicki & Młynarczyk 1989; Starkel 2001). They are the subject of numerous palynological reconstructions of the vegetation history on a regional scale (e.g. Kalicki & Zernickaya 1995; Nita & Wójcicki 2005). Relatively little is known, however, about the origin and depositional environment of the considered deposits. Only a few studies have reported data on the composition and succession of organic-rich sediments in oxbows and flood basins on the territory of Poland (*e.g.* Marek 1965; Żurek 1975; Tobolski 1981; Dobrowolski *et al.* 2010; Pawłowski *et al.* 2012). There is a lack of such studies in the upper Odra River basin. The paper presents preliminary results of studies aimed at: (1) identifying the age and composition of organic-rich deposits occurring in the river valleys of Racibórz Basin; (2) reconstructing the succession pattern and accumulation conditions of these deposits throughout the Holocene.

2. Study area and methods

The study was conducted in three major valleys draining Racibórz Basin, southern Poland. In the lower Kłodnica valley (Fig. 1), active and fossil mires are numerous but relatively small (<10 ha, on average 2–4 ha). Organic-rich deposits are common in Late-Glacial and Early-Holocene palaeochannel fills (*e.g.* at the Ujazd/Zandrzyny, Sławięcice and Sławięcice 2 sites). Contribution of organic-rich deposits in Late-Holocene palaeochannel fills is low (e.g. at the Las Turbina site). In addition, few valleyside mires occur at the foot of the slopes (e.g. at the Łany Małe site). They functioned as flood basins in the Late Holocene. The biggest peatland in the Odra valley between Koźle and Krapkowice is the valleyside fen in Większyce (Fig. 2), occupying an area of 63 ha. Fens developed in palaeochannels (*e.g.* at the Chałupki, Żużela, Buchtów and Ligota sites) are much smaller (normally 6–10 ha in extent). Organic-rich deposits infilling oxbow depressions are usually strongly silted up. Also in the lower Osobłoga valley (Fig. 3), few and small (<5 ha, on average 1–2 ha) mires are connected with former river channels mainly (e.g. at the Głogówek, Rzepcze, Żywocice, Stebłów 1 and Stebłów 2 sites). Contribution of organic-rich deposits is rather low both in the Early-Holocene and Late-Holocene palaeochannel fills.

During field-work, a geological cross-sections through selected sedimentary basins were made and deposits were collected with a Russian sampler. The geochronology is based on radiocarbon dating made at the Kiev, Gliwice and Poznań Radiocarbon Laboratories. Normally, the age of bulk peat (gyttja) samples was determined by conventional beta-counting methods. AMS radiocarbon measurements were applied in the cases of the samples at the depth of 77–79 cm from the Sławięcice 1 core and at the depth of 70–72 cm from the Sławięcice 2 core (seeds of *Filipendula ulmaria*, *Sambucus nigra* and *Rubus idaeus* were dated). Within the framework of studies concerning the origin of organic-rich deposits, macrofossils were analysed for 46 samples whose age had been determined by radiocarbon dating. This number included 3 samples containing organic remains but definitely dominated by mineralogical components (loss on ignition below 20%). During sample pre-treatment, organic-rich deposits were warmed with 10% sodium hydroxide solution to dissolve humic and fulvic acids and then washed on a 0.2 mm sieve. Macrofossils were determined by optical microscope and were identified with the use of available guides (*e.g.* Kac *et al.*, 1977; Tobolski 2000). Loss on ignition was calculated as the mass lost after ashing (Tobolski 2000).

3. Results

In reference to the existing classification systems (Tołpa *et al.* 1967; Tobolski 2000), biogenic deposits have been classified as detrital sediments (dominated by exogenous components) or peats (dominated by endogenous remains). The following components were classified as detrital in origin: (1) leaf remains (excluding moss leaves); (2) carpological finds (e.g. fruits, seeds, sporangia and spores); (3) animal remains (*e.g. Cladocera carapaces*); and (4) wood, periderm or epidermis – if it could be demonstrated that these come from above-ground plant parts. An example of above-ground shoot epidermis identified in the samples analysed is the cuticle with rows of stomata covering *Schoenoplectus lacustris* stems. More problematic was the identification of remains of above-ground wood and periderm. For example, wood and periderm of *Pinus sylvestris* found in sequences consisting of aquatic sediments and low-moor peat were considered autochthonous. In contrast, the following components were considered as accumulated by accretion in the place where they formed: (1) roots; (2) moss remains and (3) rhizome and leaf sheath epidermis with-

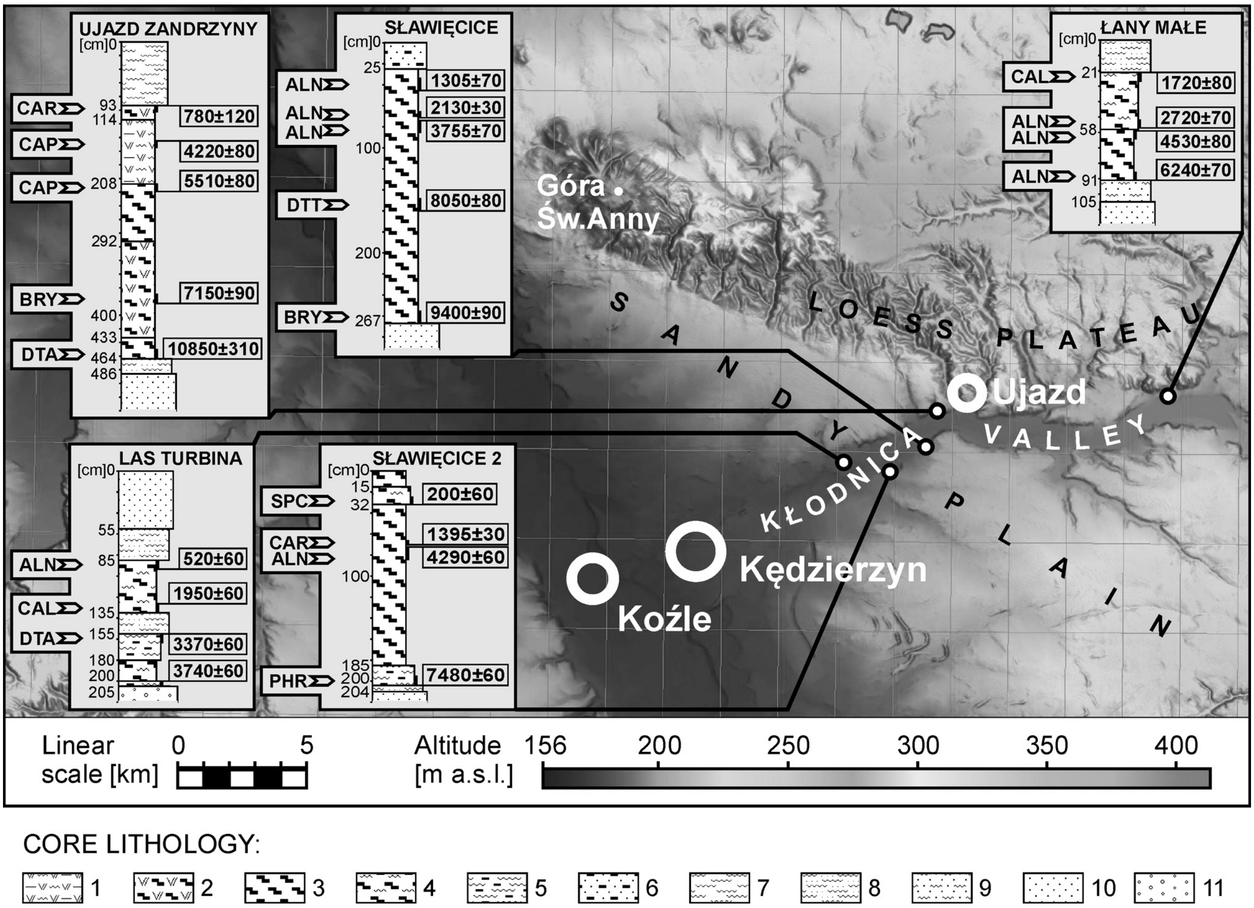

Fig. 1. Lithology and stratigraphy of organic-rich deposits from selected cores taken in the Kłodnica River valley.
Organic-rich deposits: DTA – detrital sediment of aquatic environment, DTT – detrital sediment of terrestrial environment, BRY – brown moss (*Bryaleti*) peat, PHR – reed (*Phragmiteti*) peat and mineralogenic sediment with reed remains, CAP – sedge-reed (*Cariceto-Phragmiteti*) peat, CAR – sedge (*Cariceti*) peat, CAL – alder-sedge (*Alno-Cariceti*) peat, ALN – alder (*Alneti*) peat, SPC – sphagnum moss-sedge (*Sphagno-Cariceti*) peat
Core lithology: 1 – carbonate deposit, 2 – organic deposit containing carbonates, 3 – organic deposit, 4 – organic deposit mixed with mud, 5 – mud with organic matter, 6 – sand with organic matter, 7 – mud, 8 – sandy mud, 9 – muddy sand, 10 – sand, 11 – sandy gravel

out stomata. Finally, detrital sediments accumulated both in aquatic or terrestrial environments as well as five types of peat were identified in the valleys of the upper Odra River basin.

3.1. Detrital sediment of aquatic environment

These deposits exhibit considerable variation in their botanical composition and organic remains are typically highly fragmented. They are usually a mixture of tree remains (*e.g.* leaves, wood and periderm of *Pinus*, *Salix* or *Alnus*), stems and branch leaves of *Bryales* as well as epidermis and roots of *Phragmites australis*, *Carex* and, less commonly, *Schoenoplectus lacustris* (Fig. 4). However, the primary characteristic of these samples is the presence of aquatic bioindicators. *Nymphaeaceae* idioblasts and epidermis were the most common finds; *Potamogeton* epidermis and *Ceratophyllum* spiny teeth were found less frequently. Numerous *Cladocera carapaces* and *Chironomidae* head capsules were found. Finally, 11 sediment samples were classified as detrital sediments of aquatic environment. In the Kłodnica River valley (Fig. 1), sediments of this origin were identified at the sites: Ujazd/Zandrzyny (a sample from a depth of 4.54–4.64 m dated to 10 850±310 ^{14}C yr BP) and Las Turbina (a sample from a depth of 1.55–1.58 m dated to 3 370±60 ^{14}C yr BP). In the Odra River valley (Fig. 2), aquatic detrital sediments were identified at the sites: Większyce (a sample from a depth of 3.64–3.69 m dated to 9 370±150 ^{14}C yr BP), Żużela (samples from a depth of 2.33–2.37 m dated to 6 340±80 ^{14}C yr BP and from a depth of

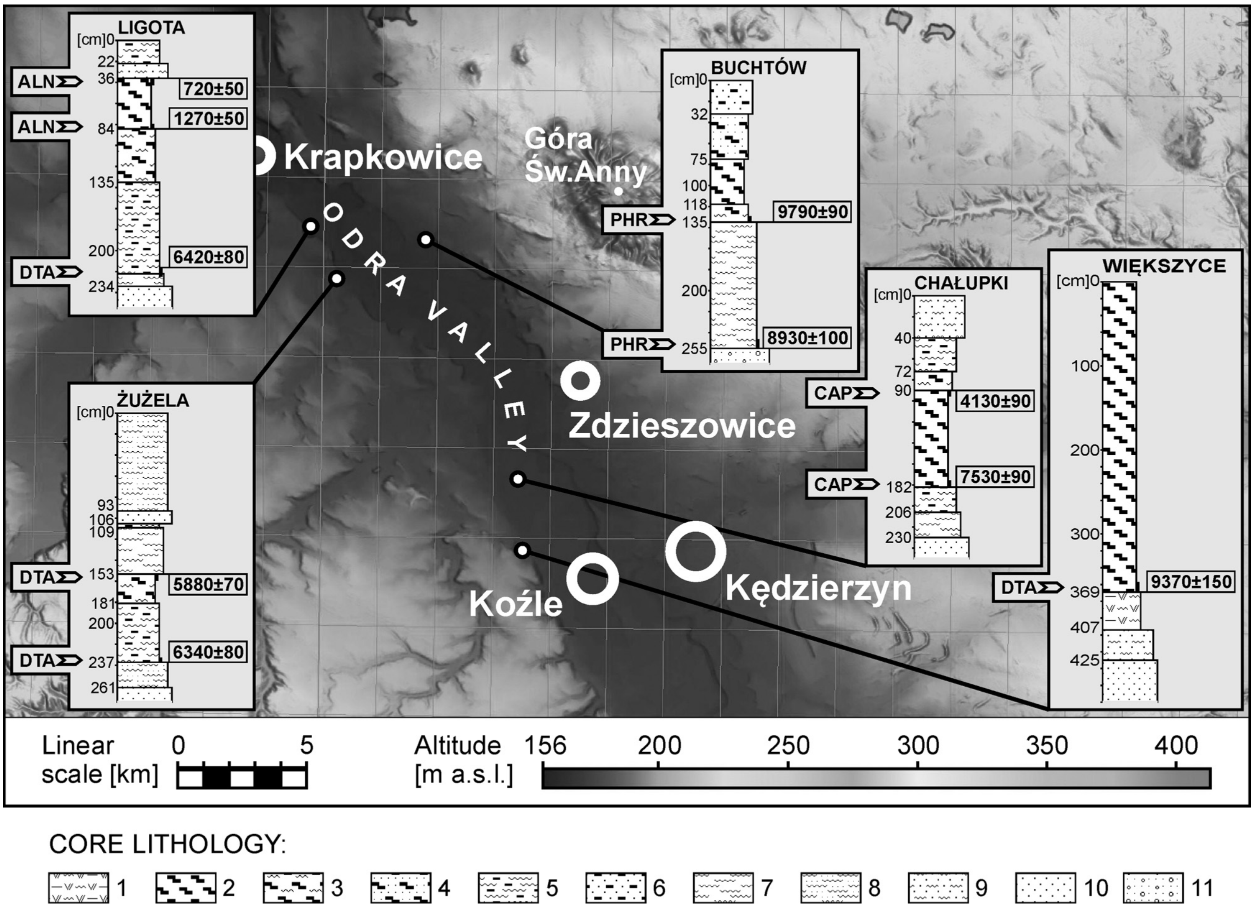

Fig. 2. Lithology and stratigraphy of organic-rich deposits from selected cores taken in the Odra River valley.
Organic-rich deposits: DTA – detrital sediment of aquatic environment, PHR – reed (*Phragmiteti*) peat and mineralogenic sediment with reed remains, CAP – sedge-reed (*Cariceto-Phragmiteti*) peat, ALN – alder (*Alneti*) peat
Core lithology: 1 – carbonate deposit, 2 – organic deposit, 3-organic deposit mixed with mud, 4 – organic deposit mixed with sand, 5 – mud with organic matter, 6 – sand with organic matter, 7 – mud, 8 – sandy mud, 9 – muddy sand, 10 – sand, 11 – gravelly sand

1.53–1.59 m dated to 5 880±70 ^{14}C yr BP) and Ligota (a sample from a depth of 2.16–2.24 m dated to 6 420±80^{14}C yr BP). In the Osobłoga River valley (Fig. 3), sediments of this origin were identified at the sites: Stebłów 1 (samples from a depth of 2.30–2.35 m dated to 3 540±60 ^{14}C yr BP and from a depth of 1.72–1.77 m dated to 3 370±70 ^{14}C yr BP), Stebłów 2 (samples from a depth of 1.38–1.42 m dated to 2 040±90 ^{14}C yr BP and from a depth of 1.01–1.05 m dated to 1 020±70 ^{14}C yr BP) and Żywocice in a sample from a depth of 1.95–2.0 m dated to 10 200±75 ^{14}C yr BP and to the Pre-Boreal according to pollen analysis (Nita pers. comm.).

3.2. Detrital sediment of terrestrial environment

These deposits are dominated by detritus, but do not contain bioindicators of aquatic environment (Fig. 4). Deposits of this type were identified at a depth of 1.5–1.55 m in the Sławięcice core (the Kłodnica River valley) and dated to 8050±80 ^{14}C yr BP. According to pollen analysis, they originate from the Boreal period (Nita, Wójcicki 2005). Detrital sediments are present there as a 17 cm thick layer consisting almost exclusively of *Pinus* wood fragments. This detritus composition indicates that the described layer should not be linked to the low-moor succession recorded at this site.

3.3. Reed peat and mineralogenic sediment with reed remains

Deposits whose organic components are dominated by rootlets and epidermis of *Phragmites australis* were noticed in 3 samples (Fig. 5). In the Kłodnica River valley, these were organic-

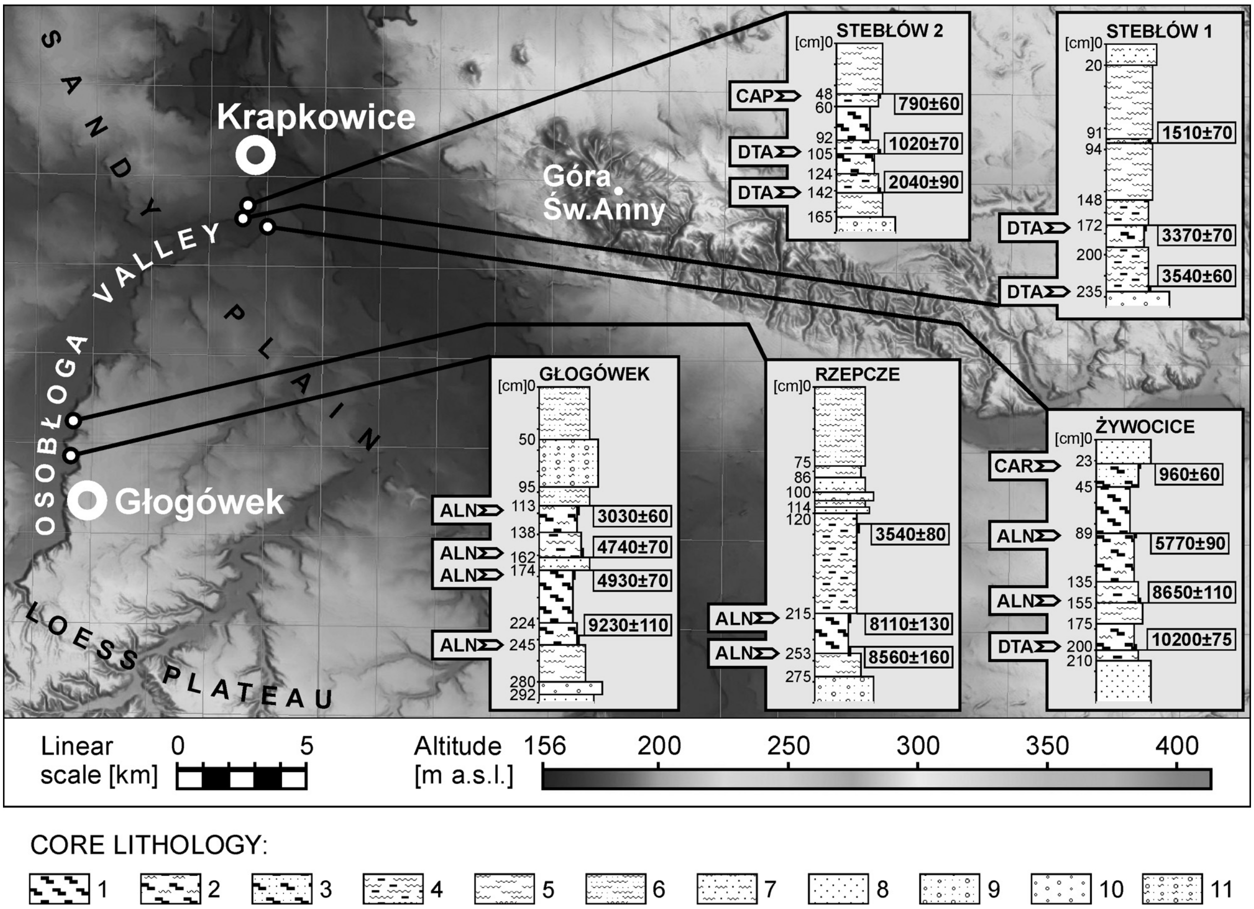

Fig. 3. Lithology and stratigraphy of organic-rich deposits from selected cores taken in the Osobłoga River valley.
Organic-rich deposits: DTA – detrital sediment of aquatic environment, CAP – sedge-reed (*Cariceto-Phragmiteti*) peat, CAR – sedge (*Cariceti*) peat, ALN – alder (*Alneti*) peat
Core lithology: 1 – organic deposit, 2 – organic deposit mixed with mud, 3 – organic deposit mixed with sand, 4 – mud with organic matter, 5 – mud, 6 – sandy mud, 7 – muddy sand, 8 – sand, 9 – gravelly sand, 10 – sandy gravel, 11 – diamicton

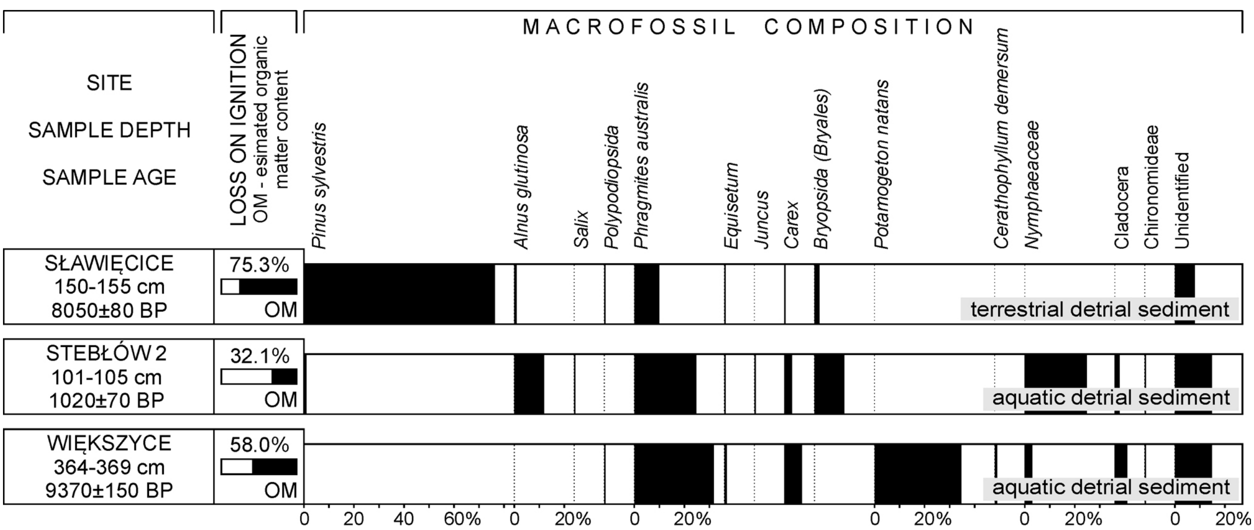

Fig. 4. Simplified macrofossil diagram for selected samples of detrital sediments.

rich muds from the Sławięcice 2 site (a sample from a depth of 1.98–2.04 m dated to 7 480±60 ^{14}C yr BP). In the Odra River valley, reed peat was identified in the Buchtów core in the sample from a depth of 1.30–1.35 m (9 790±90 ^{14}C yr BP). Besides remains of *Phragmites australis*, *Carex* and

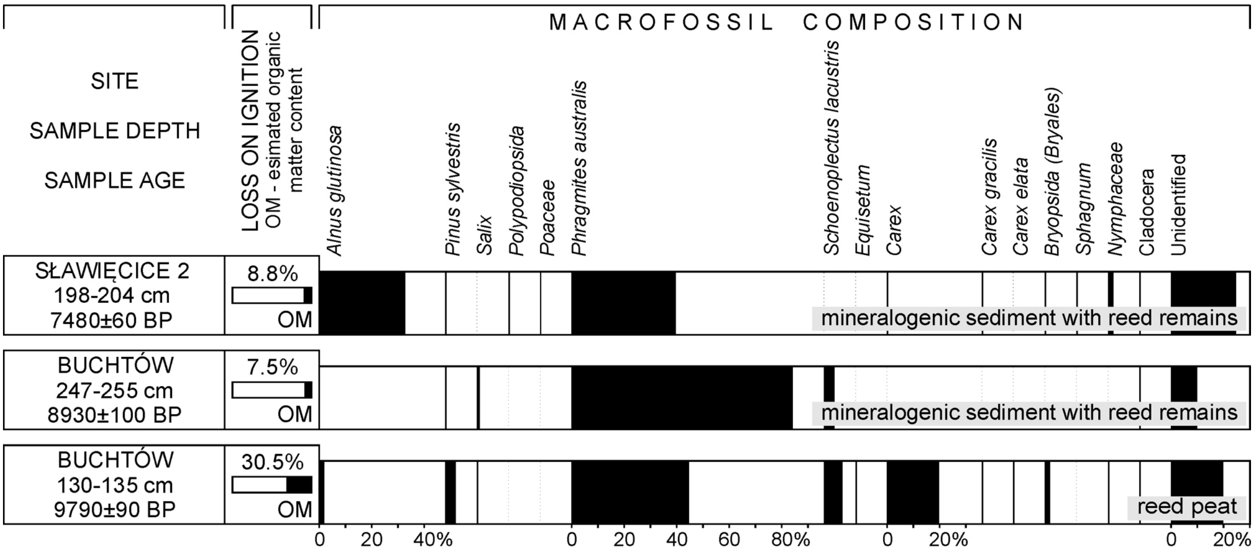

Fig. 5. Simplified macrofossil diagram for samples of reed peat and mineralogenic sediment with reed remains.

Schoenoplectus lacustris fossils were identified as an important admixture. Below organic-rich layers, a sandy mud series with plant material dated to 8 930±100 ^{14}C yr BP was present. At this depth (2.47–2.55 m), organic remains consist almost exclusively of *Phragmites australis* rootlets, which were probably responsible for the radiocarbon age inversion.

3.4. Brown moss peat

Deposits dominated by the remains of *Bryales* were identified in two samples from the Kłodnica River valley (Fig. 6). Moss remains, including leafy stems of *Scorpidium scorpioides* among others, clearly dominate at the Ujazd/Zandrzyny site (the sample from a depth of 3.73–3.81 m dated to 7 150±90 ^{14}C yr BP). The domination of *Bryales* as well as *Sphagnum* remains including *Calliergon giganteum, Tomenthypnum nitens,* and *Sphagnum teres* is characteristic for the lowest part of the Sławięcice core (the sample from a depth of 2.63–2.67 m dated to 9 400±90 ^{14}C yr BP and to the Pre-Boreal according to pollen analysis). *Carex* rootlets, *Pinus* periderm and *Menyanthes trifoliata* epidermis are of secondary importance.

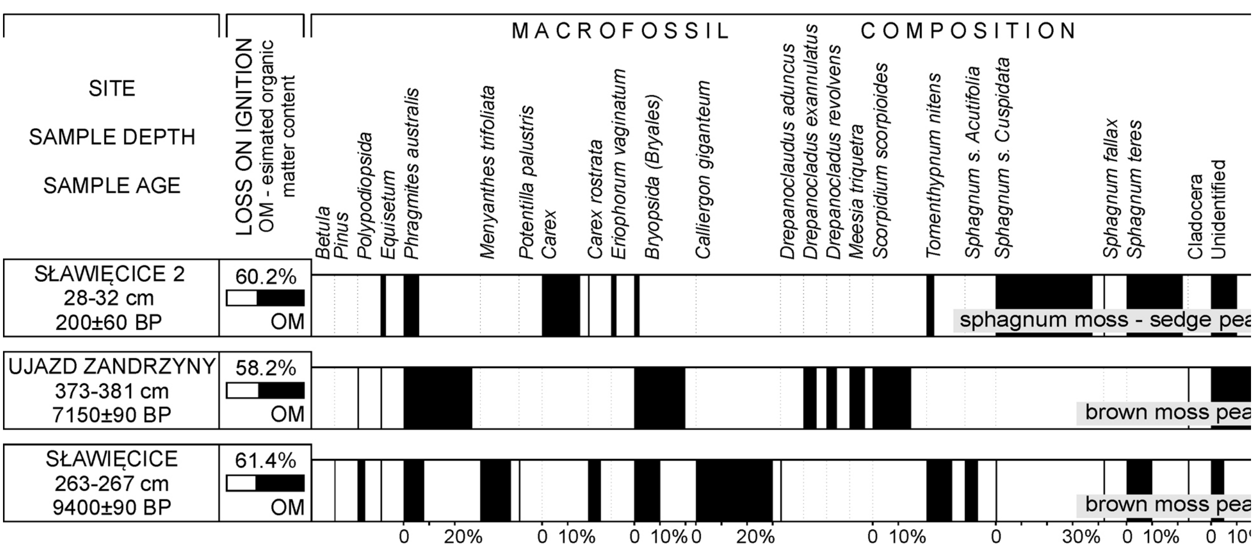

Fig. 6. Simplified macrofossil diagram for samples of brown moss peat and sphagnum moss – sedge peat.

3.5. Sphagnum moss-sedge peat

Sphagnum moss-sedge peat was only identified at the Sławięcice 2 site in the Kłodnica River valley. During the most recent stage of peatland development (a sample from a depth of 0.28–0.32 m dated to 200±60 ^{14}C yr BP), deposits dominated by *Sphagnum* remains and *Carex* rootlets were accumulated (Fig. 6).

3.6. Sedge peat

Sedge peat show significant variation in botanical composition (Fig. 7) and therefore three types of such peat have been distinguished. The most common type is sedge-reed peat dominated by epidermis and rootlets of *Phragmites australis* and *Cyperaceae*. As an admixture, *Equisetum and Bryales* remains were frequently found. In the Ujazd/Zandrzyny core, sedge-reed peat has been described as the sediment dominated by both remains of *Phragmites australis* (the sample from a depth of 2.08–2.15 m dated to 5 510±80 ^{14}C yr BP) as well as *Cyperaceae* roots (the sample from a depth of 1.45–1.55 m dated to 4 220±80 ^{14}C yr BP). In sedge-reed peat dated to 7 530±90 ^{14}C yr BP and found at a depth of 1.76–1.82 m at the Chałupki site in the Odra River valley, wood and periderm of trees (*e.g. Salix*) as well as *Polypodiopsida* sporangia are present. The content of tree remains at this site increases in the sample collected at a depth of 0.90–0.95 m and dated to 4 130±90 ^{14}C yr BP. In the Osobłoga River valley, sedge-reed peat was identified in the Stebłów 2 core at a depth of 0.48–0.52 m (the sample dated to 790±60 ^{14}C yr BP).

Sedge peat, absolutely dominated by *Carex* rootlets, is another type of peat connected with communities of tall sedges. In the Kłodnica River valley, deposits of this origin were identified in the Sławięcice 2 core at a depth of 0.70–0.72 m (the sample dated to 1 395±30 ^{14}C yr BP). In the Ujazd/Zandrzyny core, sedge peat occurs at a depth of 0.93–1.01 m. In the sample dated to 780±120 ^{14}C yr BP, *Carex gracilis* remains were found, among others. The sample found at a depth of 0.23–0.27 m in the Żywocice core, dated to 960±60 ^{14}C BP and to the Sub-Atlantic according to pollen analysis (Nita pers. comm.), shows more floristic variation. Apart from *Cyperaceae* rootlets, *Phragmites australis* and *Equisetum* remains are present there, among others. *Alnus* periderm, deciduous wood fragments and branch leaves of brown mosses are also present in smaller amounts.

In the Kłodnica River valley, alder-sedge peat was additionally distinguished, which was dominated by *Cyperaceae* fossils with an admixture of tree remains, mainly fragments of wood and periderm of *Alnus*. Such deposits were noticed at the sites Łany Małe in the sample at a depth of 0.21-0.26 m dated to 1 720±80 ^{14}C yr BP (Wójcicki & Kloss 2008) and Las Turbina in the sample at a depth of 1.31–1.35 m dated to 1 950±60 ^{14}C yr BP.

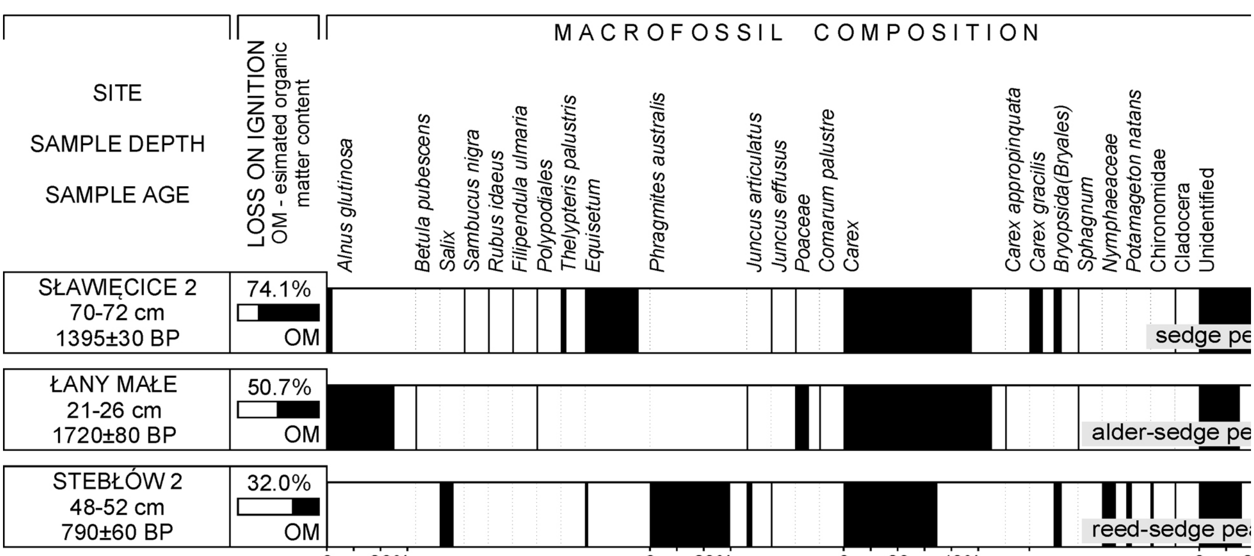

Fig. 7. Simplified macrofossil diagram for selected samples of sedge peat.

3.7. Alder peat

Alder peat was the most commonly found at the sites examined (18 samples). It is dominated by *Alnus* wood and periderm (Fig. 8). *Alnus* remains are often accompanied by seeds (e.g. *Rubus idaeus* and *Sambucus nigra*) as well as *Polypodiopsida* sporangia and spores. As admixtures, *Cyperaceae* rootlets, *Poaceae* remains and *Betula* periderm were also found. In the Kłodnica River valley, deposits of this origin were identified at the sites Sławięcice, Sławięcice 2, Łany Małe and Las Turbina. In the Sławięcice core, alder peat was identified in samples at depths of 0.79–0.84 m dated to 3 755±70 ^{14}C yr BP and to the Early Sub-Boreal according to pollen analysis (Nita & Wójcicki 2005), 0.77-0.79 m dated to 2 130±30 ^{14}C yr BP and 0.33–0.38 m dated to 1 305±70 ^{14}C yr BP. In the latter sample, the dominance of *Alnus* periderm and an increase in content of *Carex* rootlets and *Poaceae* remains were recorded. At the Łany Małe site, alder peat was found at depths of 0.86–0.91 m (the sample dated to 6 240±70 ^{14}C yr BP and to the Pre-Boreal according to pollen analysis), 0.58-0.63 m (the sample dated to 4 530±80 ^{14}C yr BP and to the Boreal, alternatively to the Boreal-Atlantic transition according to pollen analysis), and 0.53–0.58 m (the sample dated to 2 720±70 ^{14}C yr BP and to the Early Sub-Boreal according to pollen analysis). In the Sławięcice 2 core, the presence of alder peat was noticed in the sample collected at a depth of 0.72–0.84 m (4 290±60 ^{14}C yr BP). In the Las Turbina core, deposits dominated by periderm and wood remains were identified at a depth of 0.85–0.88 m in the sample dated to 520±60 ^{14}C yr BP. In the Odra River valley, alder peat was identified at the Ligota site in samples at depths of 0.8–0.84 m (1 270±50 ^{14}C yr BP) and 0.36–0.42 m (720±50 ^{14}C yr BP). In the Osobłoga River valley, alder peat was identified in the Głogówek, Rzepcze and Żywocice cores. At the Głogówek site, peat dominated by *Alnus* wood was found at depths of 2.41–2.45 m (92 30±110 ^{14}C yr BP) and 1.74–1.78 m (4 930±70 ^{14}C yr BP). On the other hand, at depths of 1.58–1.62 m (4 740±70 ^{14}C yr BP) and 1.13–1.16 m (3 030±60 ^{14}C yr BP), deposits are dominated by *Alnus* periderm. In the Rzepcze core, alder peat was identified at depths of 2.51–2.55 m (8 560±160 ^{14}C yr BP) and 2.15–2.19 m (8 110±130 ^{14}C yr BP). At the Żywocice site, deposits of this origin were found in samples at depths of 1.51–1.55 m dated to 8 650±110 ^{14}C yr BP and to the Boreal/Atlantic transition according to pollen data and 0.89–0.93 m dated to 5 770±90 ^{14}C yr BP and to the Atlantic/Sub-Boreal transition according to pollen data (Nita pers. comm.). In these samples, an admixture of *Equisetum* epidermis was found among others.

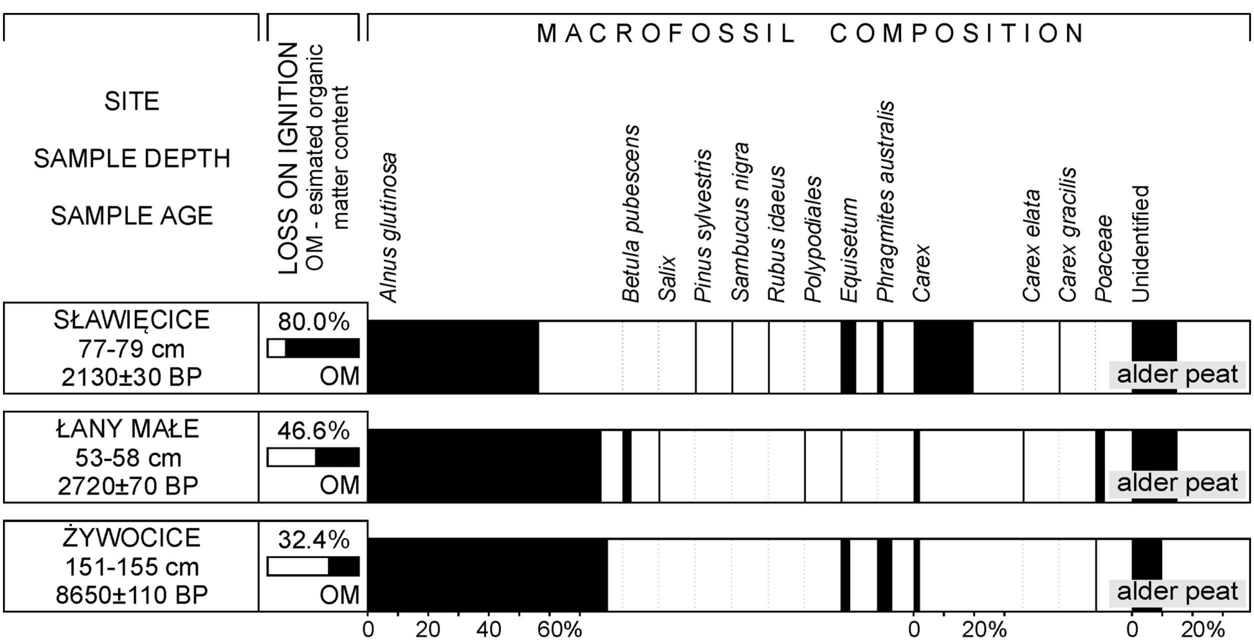

Fig. 8. Simplified macrofossil diagram for selected samples of alder peat.

4. Discussion

In the light of the research conducted, the accumulation of organic-rich deposits in the valleys of the upper Odra River basin was in most cases initiated by the terrestrialisation of water bodies. It is understandable, because most sedimentary basins examined are oxbow lakes. In the lowest sections of the analysed sequences, aquatic detrital sediments are usually present. It is consistent with the observations indicating that peat commonly overlies gyttja in floodplain depressions (*e.g.* Tobolski 1981; Żurek 1993; Pawłowski *et al.* 2012). Deposition of detrital sediments in the upper Odra River basin was most often accompanied by an intensive supply of mineralogenic components. As a result, loss on ignition is usually less than 30% (Fig. 9). The timing of detritus deposition varies corresponding to the occurrence of meander cut-offs.

According to the scheme of sediment succession in a floodplain environment by Żurek (1993), sand and gyttja are usually overlain by alder (optionally sedge) peat. In the upper Odra River basin, however, brown moss peat, reed peat and organic-rich mineralogenic sediments dominated by reed remains often appear as deposits of the early succession stage. They usually occur in the lowest sections of the analysed sequences or directly above detrital sediments of the aquatic environment. Radiocarbon dating indicates that considered deposits were accumulated from the Early Holocene to the Older Atlantic (Fig. 10). Deposits dominated by reed remains are characterized by low loss on ignition (below 35%). They were probably accumulated in an amphibious environment; commonly within valleyside mires, more rarely within depression of oxbows (Żurek 1975). Organic-rich mineralogenic sediments were probably formed because of the penetration of *Phragmites australis* root systems into older alluvium layers. Brown moss peat exhibits high organic matter content (loss on ignition around 60%). It probably accumulated in a shallow aquatic environment or a waterlogged fen. This is evidenced by the high content of aquatic malacofauna (ca. 70%) in the layer of brown moss peat at the Ujazd/Zandrzyny site (Fajer pers. comm.).

Peat dominated by *Cyperaceae* remains were probably deposited in more humid variant of peatland habitats. Such deposits were accumulated under conditions of variable allochthonic component delivery (loss on ignition 32–74%). Ac-

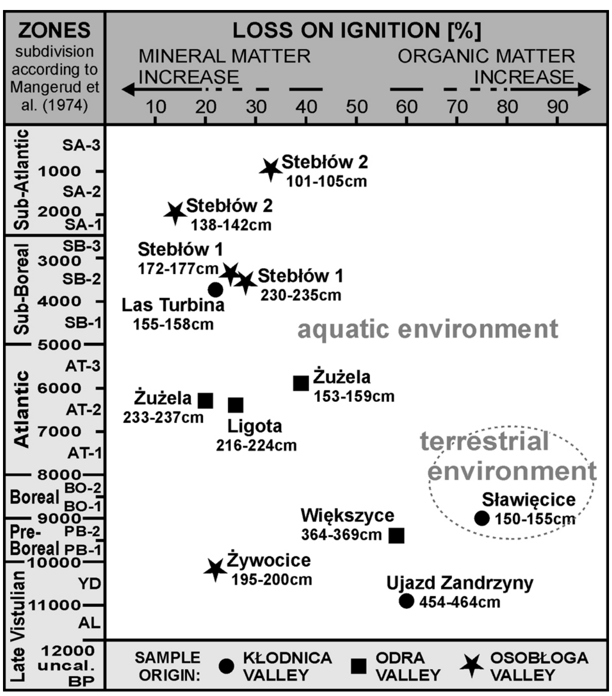

Fig. 9. Organic matter content and deposition chronology of detrital sediments.

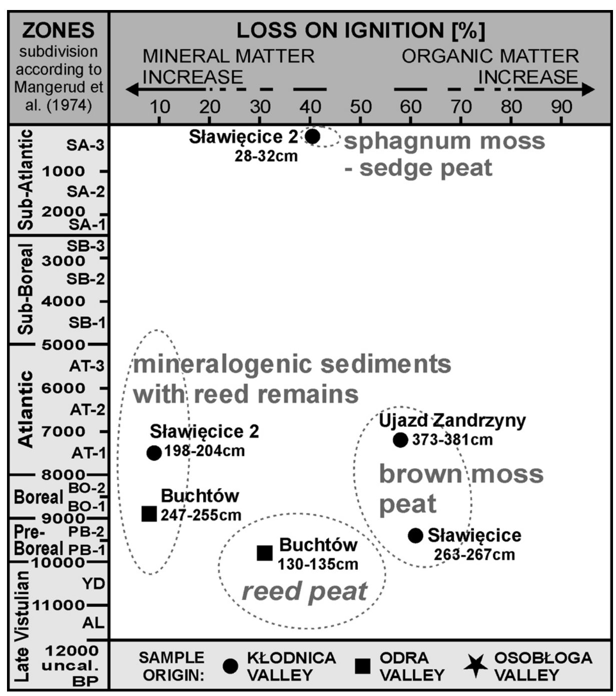

Fig. 10. Organic matter content and deposition chronology of brown moss peat, reed peat and mineralogenic sediment with reed remains.

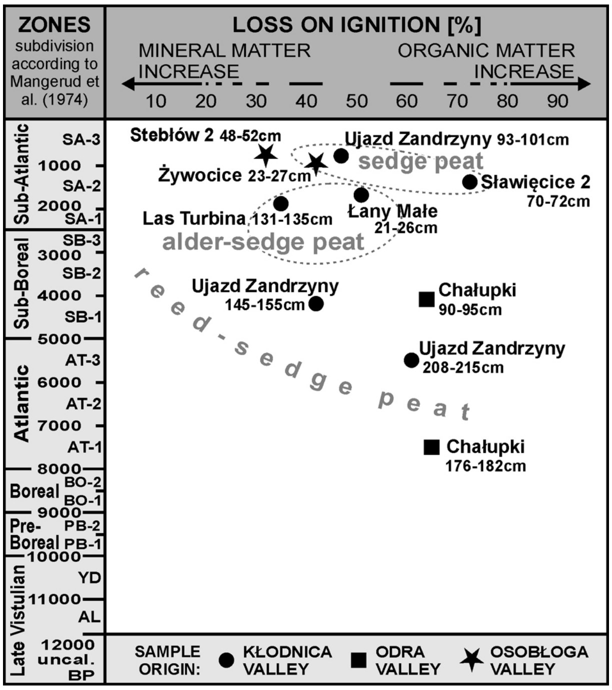

Fig. 11. Organic matter content and deposition chronology of sedge-reed, sedge, alder-sedge and sphagnum moss-sedge peat.

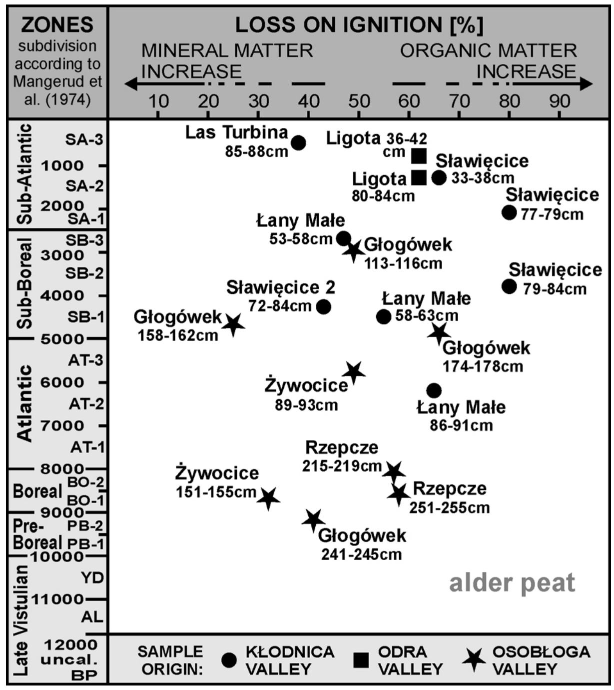

Fig. 12. Organic matter content and deposition chronology of alder peat.

cording to Żurek (1993), sedge peat (Magnocaricioni peat) is connected with the youngest phases of the organic deposit succession in river valleys. In the upper Odra River basin, sedge-reed peat occupies various positions in the sequences of deposits – most frequently as the next succession stage after detrital sediment or moss peat. They are dated to the Middle and Late Holocene (Fig. 11). On the other hand, sedge, alder-sedge and sphagnum moss-sedge peats most frequently appear in upper sections of the sequences analysed, as sediments of the youngest succession stage. All samples of these sediments were dated to the Sub-Atlantic.

Alder peat is one of the most important types of organic-rich sediment in river valleys on the territory of Poland (Marek 1965; Żurek 1975) including the upper Odra basin. The accumulation of alder peat was accompanied by a variable mineralogenic matter delivery (loss on ignition 24–80%). This type of peat usually occurs in the middle and upper sections of the sequences analysed as the deposit of a later succession stage. However, at the Łany Małe, Głogówek and Rzepcze sites, alder peat already occurs in the lowest section of the sequences. It indicates that peat formation was initiated by paludification. On the other hand, it cannot be ruled out that at the Łany Małe site, alder peat developed on a substratum of older sediments accumulated in an aquatic environment. This is indicated by chitinous remains of Cladocera identified at a depth of 0.86–0.8 m (Wójcicki & Kloss 2008). The age of alder peat varies (Fig. 12). Samples from the Osobłoga River valley were dated to the older part of the Holocene – from the Pre-Boreal to the Sub-Boreal period. Samples from the Rivers Kłodnica and Odra valleys (with the exception of the Łany Małe site) were dated to the Late Holocene.

5. Conclusions

Macrofossil investigations have indicated varied origins of organic-rich sediments infilling oxbows and flood basins in the Rivers Kłodnica, Odra and Osobłoga valleys. Both detrital sediments representing the aquatic or terrestrial environments as well as five types of peat accumulated in amphibious or peatland conditions were identified. Nearly all the deposits examined were formed in sedimentary basins supplied by eutrophic waters.

The study allowed to verify the sediment succession model: gyttja (sand) → alder peat → sedge peat → (optionally) sandy mud, proposed by Żurek (1993) for the fluvial-fed mires. In the upper Odra basin, the succession of organic-rich deposit usually occurs according to the general direction: aquatic detrital sediment (gyttja) → brown moss or reed peat → sedge-reed peat → alder peat. Such pattern corresponds to the vegetation changes related to the terrestrialisation of water bodies: open-water species → floating aquatics → attached aquatics → reedbeds → willow or alder scrub (Brown 1996). The lithological transitions deviating from the terrestrialisation pattern were rarely noted. The appearance of alder peat in the lowest part of the sequences analyzed can be related to paludification of valley sides (as at the Łany Małe site) or oxbow banks (as at the Głogówek and Rzepcze sites). At the most recent stage of the peatland development recorded at the Żywocice, Łany Małe, Sławięcice and Sławięcice 2 cores, the transition from alder peat towards organic deposits dominated by *Cyperaceae* remains (including sphagnum moss-sedge peat) is observed (probably as a result of increase in anthropogenic pressure in valley floors).

In the light of the radiocarbon dating, the most complete record of terrestrialization stages preserved in the sequences of deposits representing fens formed during Late Glacial and Early Holocene. The depositional sequences of the Late-Holocene mires are reduced (a lack of brown moss and reed peats) and clearly dominated by alder peat. Accumulation of alder peat in the Osobłoga River valley started as early as the Holocene began. The accretion of alder peat in the Kłodnica River valley was primarily a Late Holocene phenomenon, although according to results of pollen analysis the expansion of forest communities dominated by alder may have already been initiated during the Late Boreal (Nita & Wójcicki 2005).

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