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OPTICAL DATING AND SEDIMENTARY RECORD FROM THE TERRACE DEPOSITIONAL PROFILE OF THE WARTA RIVER (CENTRAL POLAND)

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Abstract: Results of OSL dating and sedimentary studies from the profile of the low alluvial terrace of the middle Warta River are presented. The samples were dated using the single-aliquot regenerative method. Dating was used to establish a timing of the Weichselian Late Glacial events in the river valley environment. Stable conditions on the floodplain are expressed by the deposition of organic-rich series radiocarbon dated at 12 900–12 600 cal BP and 11 600–10 770 cal BP. Samples for OSL dating were collected from the mineral material deposited during the intensification of flood events during the Weichselian decline. The results obtained for the alluvia range from 12.78 ± 0.62 ka b2k to 14.33 ± 0.74 ka b2k. Sedimentological criteria allowed to distinguish between particular flood events. Overestimation of OSL ages is probably a result of rapidity of environmental changes in that time.

Keywords: palaeofloods, Younger Dryas, OSL, sedimentological studies.

1. INTRODUCTION

Timing of past events is one of the most crucial problems of palaeogeographical studies. The existence of sets of both radiocarbon and luminescence dates enables to reconstruct various environmental parameters, however the precision and accuracy depend among others on the investigated time period, type of dated material and depositional event. In defining the rate of processes with a relatively high resolution, basic distinction between particular sedimentary systems (e.g. fluvial, aeolian, glacial) may be insufficient and the recognition of a sedimentary subenvironment is required to understand the development of sedimentary processes. Satisfactory results of age determination using radiometric dating methods are attained by a thorough recognition of the palaeogeography of the area from which depositional events are reported.

The present study focuses on the environmental processes which took place during the quite well recognized time of the Last Glacial Termination in the Warta River valley, Poland. The aim of the study was to establish the time relation between the formation of the organic series, whose age is determined by radiocarbon dating, and the accompanying deposits formed in a fluvial environment. Of particular importance is the determination of the formation time of the series overlying the organic material. This mineral sequence is the result of increased fluvial activity reflected in the flood intensification and overbank deposition. The age determination of the flood deposits may enable to locate this increased activity in the Young-

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er Dryas, in the time of efficient morphological processes induced by global dynamic climatic changes.

2. SITE LOCATION

The study area is located in Central Poland Lowland, in the middle section of the Warta River valley (**Fig. 1a**). The last ice cover was present there during the Wartanian Stage (Czubla *et al.*, 2013). In the Eemian Interglacial the river bottom was situated about 15 m lower than today. During the whole Weichselian, a tendency to aggradation prevailed, mainly due to the subsidence (Widera, 2007). The thick sand series deposited in the wide valley were a source material to fluvial processes of the very end of the Weichselian and the Holocene.

The valley is incised there into a morainic plain and a fluvioglacial plain of Saalian age (**Fig. 1b**). The morphological elements of the valley are weakly expressed, mainly due to its wide extension, attaining there even up to 10 km in width. These include remains of erosional terraces of the Warsaw-Berlin ice marginal streamway and alluvial terraces: a higher one of the Middle Weichselian and a lower one, which stratigraphical position points to the late Younger Dryas.

The site under investigations, Koźmin Las, is located in Koźmin village (N 50°04'51", E 18°40'03") at an altitude of 97.5 m above sea level, on the low terrace of the western side of the Warta River (**Fig. 1b**).

Studies at the Koźmin Las site were carried out in an open test pit. In the walls of this pit the sequence of deposits exposed to a depth of 2.6 m was registered. The depositional sequence consists of three lithological units: lower sandy unit, middle organic-rich unit and upper sandy and sandy-silty unit and makes up the general stratigraphy (Dzieduszyńska and Petera-Zganiacz, 2012). The same profile was reported from the coring sites distributed over the area of at least 20 km^2.

3. PREVIOUS STUDIES

Properties of the deposits constituting the lower unit are known largely from earlier surveys performed along the walls of the Adamów lignite opencast mine. This unit is of a fluvial origin. Previous studies indicated its formation in a sand-bed braided river environment during the LGM and subsequent cold periods (Petera, 2002; Forysiak, 2005). For the purpose of the present work only topmost part of the lower fluvial unit was investigated, as

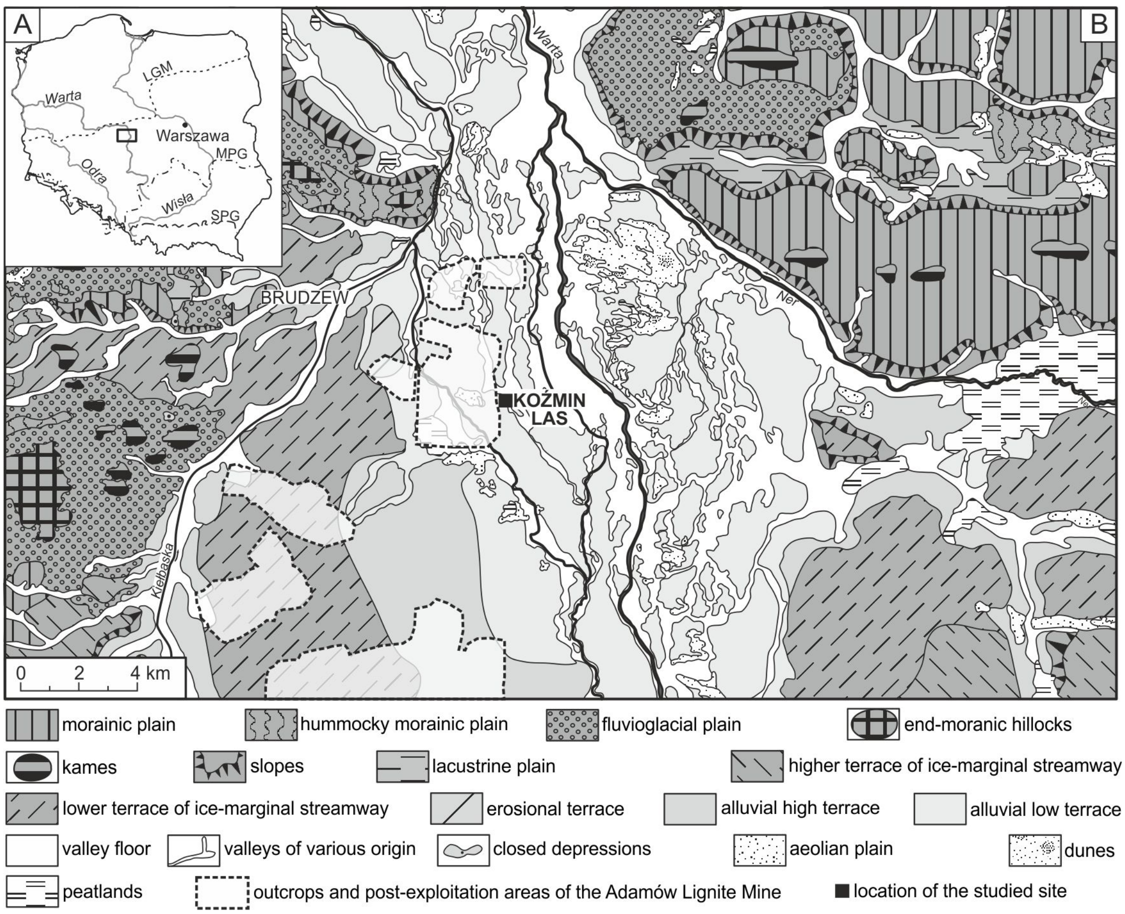

Fig. 1. *Location of the Koźmin Las site against extents of the ice-sheets (after Marks, 2005); on the geomorphological map of the Warta valley and surroundings (after Forysiak, 2005).*

the palaeogeographical background of the overlying organic-rich series.

The middle unit, of a thickness up to 50 cm, consists of peat and organic silt with an assemblage of tree remains, including stumps *in situ*. It is a well-dated profile whose age has been determined using the radiocarbon method (Dzieduszyńska *et al.*, 2012; 2014). Radiocarbon conventional ages were determined using the scintillation technique in the Laboratory of Absolute Dating in Skała and in the Laboratory of the Museum of Archaeology and Etnography in Łódź (17 dates of tree trunks and 4 dates of organic silt) while the AMS technique was applied in the Poznań Radiocarbon Laboratory (5 dates of pine and birch remains). The conventional age determination was calibrated using the calibration data set IntCal09 (Reimer *et al.*, 2009) and OxCal calibration program ver. 4.1.7 (Bronk Ramsey, 2001, 2009).

On the basis of obtained ages the formation of this part of the profile took place in the period not shorter than between 12 900–12 600 (95.4%) cal BP (Poz-50356) and 11 600–10 770 (95.4%) cal BP (MKL-1077). The data for the trees cover the period since 13 050–12 640 (95.4%) cal BP (MKL-1656) until 12 520–11 770 (95.4%) cal BP (LOD-1402) (Dzieduszyńska *et al*., 2014).

The ^{14}C ages indicate that the unit was formed during the late Alleröd and the Younger Dryas period. The material from the middle unit was also a subject of a multi-proxy paleoecological study, including dendrological approach and analysis of pollen, plant macrofossil, Cladocera and Chironomidae. It showed short terrestrial events interrupted by flood episodes. Among the terrestrial events was the existence of pine forest which grew in the floodplain of the Warta River for about 140–150 years and died in response to a climatic cooling at the beginning of the Younger Dryas and further deteriorating conditions (Dzieduszyńska *et al*., 2014). A record of palaeoenvironmental changes registered at the Koźmin Las site from the middle unit deposits is suited to the abrupt environmental changes of the last Late Glacial (Lowe *et al.*, 2001, 2008; Broecker, 2006).

The upper unit is interpreted as river alluvium. It is composed of 2–3 m thick sandy and sandy silty deposits. The unit was classified as an overbank facies of an anabraching river type 2 (Turkowska *et al.*, 2004).

4. METHODOLOGY

The nature of sedimentary environments and processes dynamics was inferred from analyses of structural and textural properties of the mineral sediments of the upper unit. Sedimentological analyses were carried out according to the Miall (1978) code modified by Zieliński and Pisarska-Jamroży (2012).

For the present study five samples from the upper mineral unit, one sample from the sandy lens within the organic unit and one sample from the topmost part of the lower unit were collected in order to date them using optically stimulated luminescence (OSL). The sampling was done manually from a cleaned vertical section and the samples were taken by inserting tubes into the profile. The sample form the sandy lens was taken as a monolith dissected from the profile (**Fig. 2**). The samples were taken from a depth range of 2.58 to 1.25 m. The measurements were performed at the Gliwice Luminescence Laboratory (Silesian University of Technology).

All samples were dried in the laboratory. High-resolution gamma spectrometry using a HPGe detector manufactured by Canberra was carried out in order to determine the content of U, Th and K in the samples. Before the measurement, the samples were stored for ca. 3 weeks to ensure equilibrium between gaseous ^{222}Rn and ^{226}Ra in the ^{238}U decay chain. Each measurement lasted for at least 24 hours. Annual doses were calculated using the conversion factors of Adamiec and Aitken (1998).

The cosmic ray dose-rate to the site was determined as described by Prescott and Hutton (1994). We assumed that the average water content was no higher than 15% and consequently used a value of (18 ± 4)% for further calculations. Based on these data, the average dose rates were calculated (see **Table 1**).

For OSL measurements, coarse grains of quartz (90–125 μm) were extracted from the sediment samples by routine treatment with 20% hydrochloric acid (HCl) and 20% hydrogen peroxide (H_2O_2). The quartz grains were separated using density separation with the application of sodium polytungstate solutions leaving grains of densities between 2.62 g/cm^3 and 2.75 g/cm^3. The grains were sieved twice, before and after the 60 min etching with concentrated hydrofluoric acid (HF).

An automated Daybreak 2200 TL/OSL reader (Bortolot, 2000) was used for the OSL measurements of multi-grain aliquots. The aliquots were prepared by

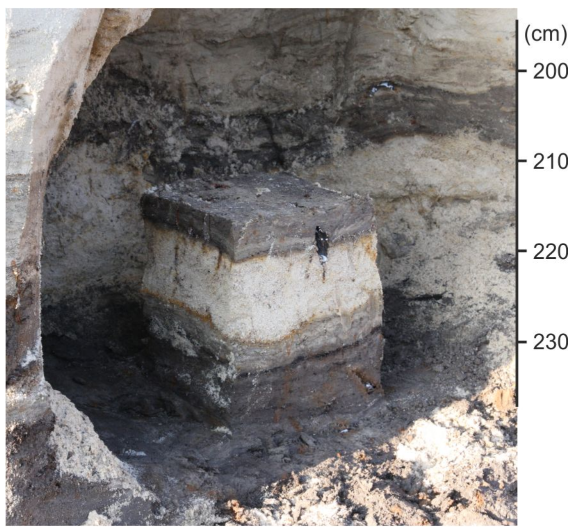

Fig. 2. *Monolith prepared to collecting to OSL dating of the sandy lens within organic deposits (Photo J. Petera-Zganiacz).*

Table 1. *Basic information about investigated samples with dose rates and ages calculated using CAM.*

Sample No	Depth (cm)	Sample description	Dose rate (Gy/ka)	OSL age (b2k)	Laboratory No	Sampling method
1	125	fine sand and silt	1.111 ± 0.043	14 310 ± 660	GdTL-1515	tube
2	135	fine sand and silt	1.344 ± 0.049	13 690 ± 680	GdTL-1516	tube
3	140	fine sand and silt	1.258 ± 0.044	12 780 ± 620	GdTL-1410	tube
4	170	fine sand and silt	0.938 ± 0.034	5 750 ± 350	GdTL-1411	tube
5	175	fine sand and silt	0.938 ± 0.037	14 330 ± 740	GdTL-1517	tube
6	224	sand	0.684 ± 0.026	13 140 ± 920	GdTL-1413	monolith
7	258	sand	0.645 ± 0.024	13 130 ± 730	GdTL-1412	tube

spraying silicone oil onto 10-mm-diameter stainless steel discs through a mask with holes of a diameter of ca. 6 mm and attaching the grains to the oil-covered areas. For blue light stimulation an array of blue LEDs (470 ± 4 nm) delivering about 60 mW/cm^2 at sample position was used. Laboratory irradiations were made using a calibrated ^{90}Sr/^{90}Y beta source integrated to the reader delivering a dose rate of 4.91 Gy/min.

For the samples, equivalent doses were determined using the single-aliquot regenerative-dose (SAR) protocol (Murray and Wintle, 2000). The OSL SAR protocol which was used in our measurements contained the following steps:

1) Irradiation with the regenerative beta dose D_i
2) Preheat at the temperature 260°C for 10 s
3) Blue light stimulation at the temperature 125°C for 100 s
4) Irradiation with the test dose D_t (10% of the natural dose, but not less than 5 Gy)
5) Cut-heat at the temperature 220°C
6) Blue light stimulation at the temperature 125°C for 100 s.

The SAR dose response curves were best represented by a single saturating exponential. The obtained dating results for this site were calculated using the Central Age Model (CAM), Galbraith *et al.* (1999) and are presented in **Table 1**.

5. RESULTS

The topmost part of the lower unit consists of sand deposited in a sand-bed braided river environment. Properties of the deposit at the Koźmin Las site allowed to distinguish between channel an overbank subenvironments. Ripple and horizontal lamination of medium- and fine-grained sands (Sr, Sh) constituting the topmost part of the series points to the deposition on a floodplain (**Fig. 3**).

In the middle unit the massive structure of silt and organic mud dominates (C, FCm, Fm). In the upper part, appears sandy silty layer with horizontal lamination (SFh) (**Fig. 3**). The deformation of the internal structure of the series is caused by the presence of numerous tree remnants. Flat-bottomed structures, slight undulations and drop structures registered at the base of the unit result from a load casting (Anketell *et al.*, 1970). The middle unit was deposited in a distal floodplain environment of a single channel or anabranching river system.

The upper unit is composed of sand and silt lithofacies. Four main sand lithofacies with ripple lamination (Sr) are separated by finer material: silty sand and sandy silt with horizontal or flaser laminated (SFh, FSh, SFf) (**Fig. 3**). The contact between one of the sand lithofacies and the underlying lithofacies is of erosional character which suggests a higher dynamics of fluvial processes during the deposition. Towards the top sand lithofacies are thinner, with low-angle cross-stratification (Sl) or massive structure (Sm). The iron compounds indicate fluctuations of the former groundwater level. From 80 cm upwards the deposit is strongly transformed by soil processes while the topmost part of the profile is destroyed by coal mining activities (the investigated site is located very close to the recultivated outcrop). The deposition of the upper unit is attributed to a proximal floodplain of an anabranching river type 2.

The upper unit is almost completely of the minerogenic origin. Only the lower part of the unit is relatively rich in organic matter, in the form of fine detritus dispersed in sandy silt, which comes from the washing out the underlying organic deposits. Besides, sandy lithofacies with ripple cross-stratification contain few small coal fragments. The characteristic feature of the base of the unit is the occurrence of tree trunks. The most probably these tree remnants were incorporated from the middle unit during floods.

The OSL analysis of the topmost part of the lower unit gave the result 13 130 ± 730 b2k. The resulting date of the sample taken from sandy lens within the organic unit was 13 140 ± 920 b2k. The results yielded for 4 samples of the upper fluvial unit, overlying the organic material, range from 12 780 ± 620 b2k to 14 330 ± 740 b2k, while the dating of the fifth sample indicated 5 750 ± 350 b2k. Location of the samples and OSL dating results are given in **Figs. 3**, **4** and **Table 1**.

6. DISCUSSION

The main scientific problem is the time of formation of sandy-silty material of the upper unit, which OSL age seems overestimated in relation to the timing of events leading to the formation of the organic-rich series, whose age is approximated with radiocarbon dates. Taking into

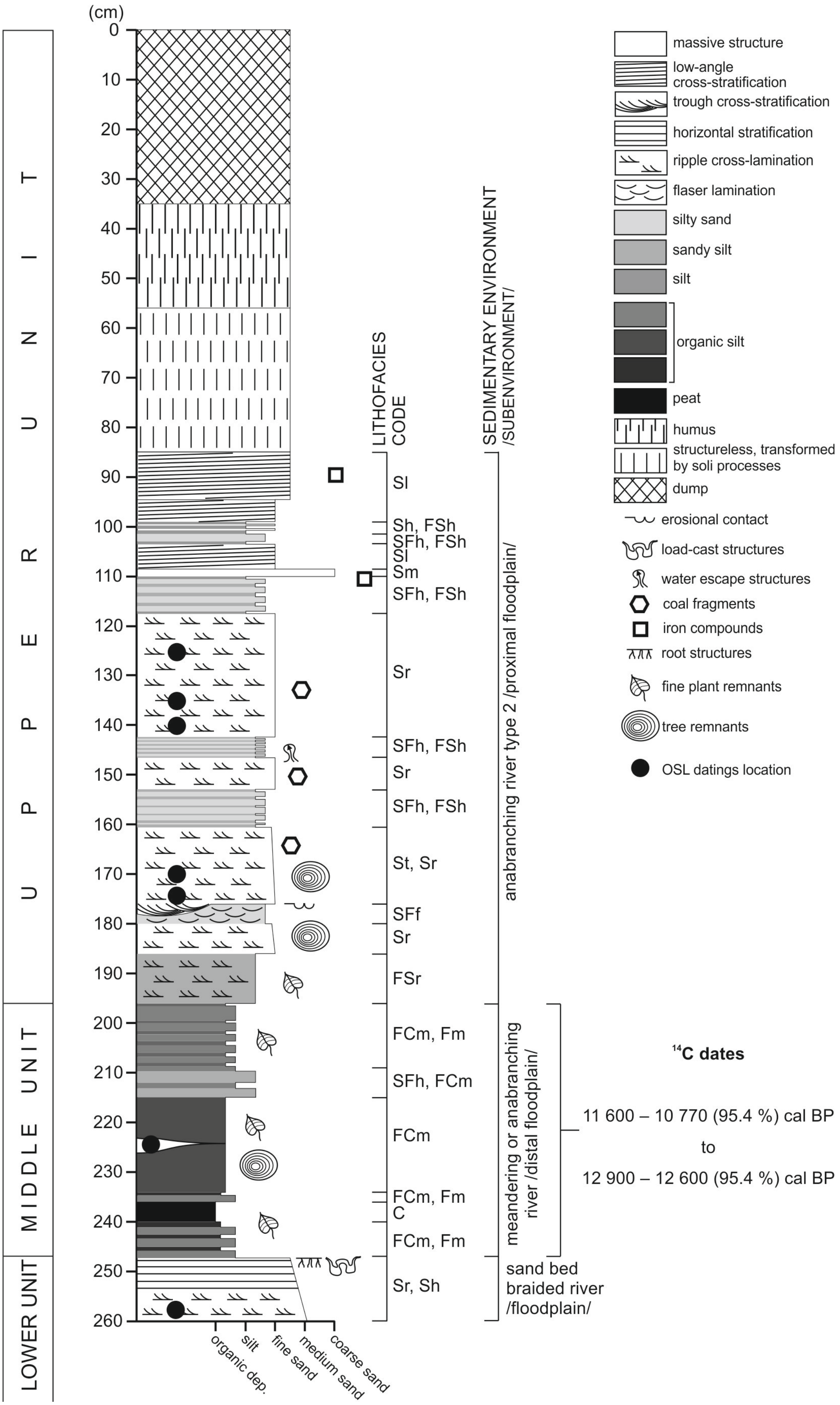

Fig. 3. *Depositional sequence at the Koźmin Las site*

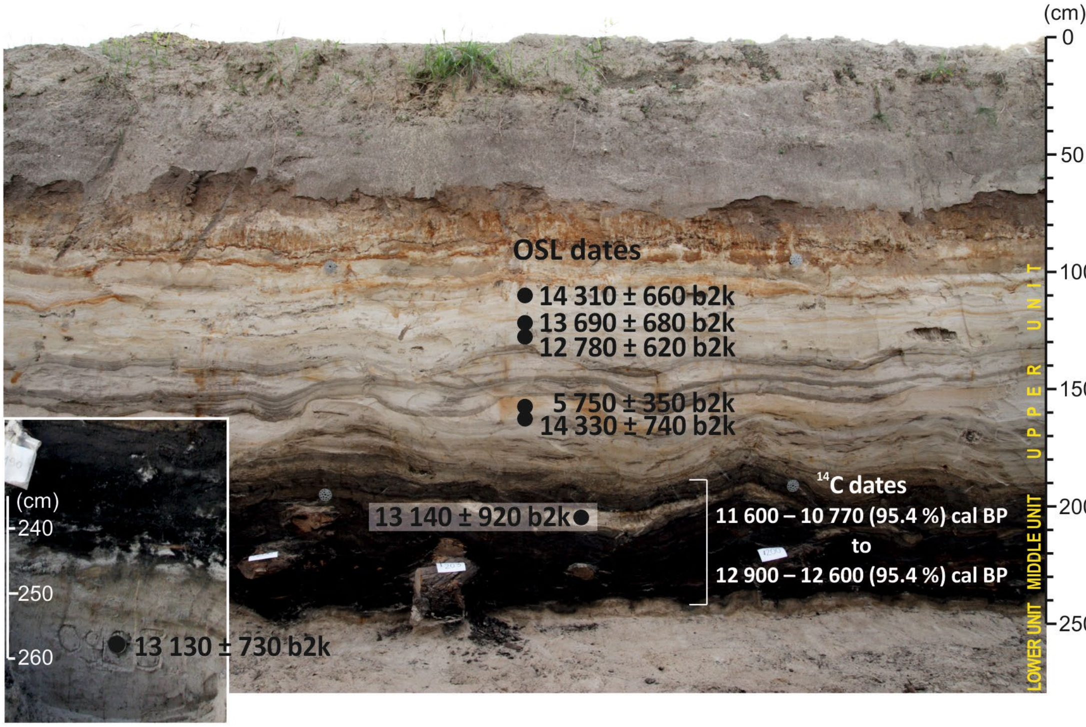

Fig. 4. *^{14}C age determination of the middle unit deposits and location of the OSL sampling (Photo J. Petera-Zganiacz).*

account the Walanus and Goslar (2009) opinion, it may be assumed that compared to 5% analytical error of OSL dates, the deposits both underlying and overlying the organic sequence are of the same age. As there is no reasonable explanation of such a situation with geological/sedimentological circumstances, incomplete bleaching of the previously accumulated dose is likely the most probable cause.

The source material for the overbank upper series was derived from Late Weichselian alluvia. The sample from the topmost part of the lower unit gave an OSL date of 13 130 ± 730 b2k, thus the age of these fluvial deposits has been estimated to be younger than suggested in the earlier studies. A new dating result indicates that their formation may have lasted up to Weichselian late glacial beginnings. These deposits dominate in the fossil bottom of the valley throughout the study area. Only where the extensive (up to a few square kilometers), shallow (1–1.5 m) basin occupied by swamps, initial peatbogs and riparian forest, was formed (Dzieduszyńska *et al.*, 2012; Kittel *et al.*, 2012), they became covered with organic material of the middle unit. Indistinct edges of the basin, to which the organic series comes up, were probably intensively eroded during the subsequent floods.

As the Hjulstrom diagram, modified by Sundborg (1956) shows, the fraction of fine- and medium-grained sands is most susceptible to set in motion in the fluvial environment; their erosion occurs already in the water at a depth of 1 m and current velocity below $0.5\ m \cdot s^{-1}$. A possibility of taking by flood waters a material different than that resting below the organic unit seems very limited, mainly due to significant extension of the Warta River valley in the studied section. On the one hand, it is a factor contributing to determining the age of redeposited material. At the same time, there is also an unfavorable factor — the overbank deposits of an anabranching river type 2 were accumulated under conditions in which achieving the zero value of the luminescence level was difficult. Transport of these deposits took place in the near-bottom waters by traction, saltation and intermittent suspension (Gradziński *et al.*, 1986). Waters which periodically flooded the basin with remnants of tree trunks were loaded with suspension which caused cutting off from light to the bottom, while the transport intensity as well as the sedimentation ratio were probably significant.

Because OSL samples within the upper unit were taken from the layers with ripple cross-lamination containing coarser grains and of largest thickness (Sr), these deposits might have been not exposed to light at all after falling of a flood wave. It can be assumed that more reliable OSL ages could be obtained from the thin layers of silty sands and silts (SFh, FSh) alternating the dated sands. Lithofacies SFh, FSh represent a waning stage of river flood and were deposited due to slackening water current or even no movement of grains and a considerably shallower flow (Zieliński, 1995, 1998). The topmost portions of horizontally stratified silts in postflood conditions could at least temporarily make the topographic surface of the floodplain and be exposed to light. Nevertheless, as the OSL sampling procedure requires collecting a large volume of deposit to a tube with a diameter which in the studied profile exceeded the thickness of the layer, it was impossible to use the silts for the age determination.

As mentioned earlier, radiocarbon dating from the organic material places the middle unit in the time of extreme and rapid environmental changes of the very end of the Weichselian. The chronostratigraphical division of the Last Termination based on data from both continental deposits (e.g. Mangerud *et al.*, 1974; Litt *et al.*, 2001; Starkel *et al.*, 2013) and Greenland ice cores (Björck *et al.*, 2008) points to the short stratigraphic phases defining palaeogeographical events. Also the duration of the individual events in the study area, including the forest existence and deposition of the whole organic series, was relatively short. An attempt to establish timing of events in the valley, taking place before and after the well-recognized episode of the forest existence, has been not fully successful. It should be emphasized that a few percent error limits of the OSL dates, ranging from ± 620 to ± 740 years, exceed the forest duration or possibly a period of the formation of the whole organic-rich unit. Therefore, in the presented case, the limitations of the OSL method to precise dating of short events, in terms of a geological time scale, and to dating of deposits attributed to a quick sedimentation are superimposed.

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