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Characterisation and OSL dating of modern fluvial sediments in the lower Vistula River: testing the zeroing assumption

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Abstract. In this study modern sediments of the lower Vistula River were investigated to determine the relationship between the structure and texture (grain size, rounding and frosting) of the deposits and the possibility of their zeroing. The samples of modern fluvial deposits were collected from the lower Vistula River at two sites in Toruń and Ciechocinek. Sand bars newly emerged from the river were selected for testing. The coarse quartz grains were separated for OSL measurements. The single-aliquot regenerative (SAR) technique was applied for measuring equivalent doses from multigrain aliquots. The obtained dose estimates were found to be very low, proving the reliability of the OSL zeroing assumption. The dose rates were estimated by gamma-ray spectrometry, demonstrating homogeneity of the radiation field. Analysis did not show significant relationships between the examined sediments' capacity to zeroing and their structural and textural characteristics, or the sampling site. The obtained OSL ages of the studied sediments date back hundreds of years and are probably overestimated. The results related to fossil sediments of bars of the age of thousands of years confirm their suitability for the OSL dating method.

Key words:
OSL dating,
fluvial sediments,
zeroing of OSL signal,
bars,
Vistula River

Introduction

Previous studies on luminescence (OSL) of young (recent, Holocene) river sediments aimed, apart from other goals, to define the sedimentation conditions and grain-size features that support the zeroing of OSL signal. This is crucial in the study of the age of fossil river deposits (e.g. Weckwerth et al. 2011, 2013) where partial bleaching can be suspected.

Studies on this issue have been conducted for various types of rivers and alluvial depositional forms. Research on fossil deposits of a holm of the Rhine-Meuse river delta in the Netherlands was done by Truelsen and Wallinga (2003). Based on historical maps, the age of the formation of the holm was estimated to be approximately 300 years. A study by Alexanderson (2007) concerned modern glaciofluvial sediments (ripple-laminated sands) collected from four shallow braided rivers of eastern Greenland (Jameson Land). Samples were taken from the river bed, as well as from the surface and excavations in the sidebars. They represented varied conditions during sediment deposition and exposure to sunlight. Research on flood sediments of the Chavanne River in southern Belgium was undertaken by Vandenberghe et al. (2007). The Chavanne is a small river, meandering within a narrow floodplain. The examined samples were collected from the very recent sandy sediments deposited in the exit of a cut-off meander of the river. Three years prior to the sampling, a special marker was installed at the place of the presumed flood sediments' deposition. The mark allowed the separation of the youngest, i.e. not older than three years, sediments. Two samples of flood sediment were collected, i.e. above and below the mark. Jaiswal et al. (2009) conducted research on the impact of light intensity and water depth on the residual luminescence of quartz grains in recent river deposits. Their research was based on the sediments of low-energy flows within the floodplain of the Kaveri River in southern India. Four sediment samples were collected from two pits for luminescence tests, correlated later with historical flood events.

In this study, recent sediments of the lower Vistula River were investigated to determine the relationship between the structure and texture on the one hand, and the possibility of their zeroing on the other.

The bed of the lower Vistula River, despite its partial regulation, represents both anastomosing and braided river types (Babiński 1992). Its characteristic feature is the presence of numerous bars, which usually occur in the form of large, single embankments of gravel and sand, built up during high waters and floods, and transformed at times of lowering water levels (Babiński 1987). These forms are usually classified as channel mesoforms. Their size is proportional to the width of the riverbed and the height is approximately equal to the annual average water level of the river. At the analysed section of the lower Vistula River, between Ciechocinek and Toruń, their fronts move at an average speed ranging from tens of centimetres to about 1.5 m per day (Babiński 1992).

Study area

The study was conducted within two sidebars of the lower Vistula River between Ciechocinek and Toruń. At the analysed section the Vistula River flows in the eastern part of the Toruń Basin. In the basin, the system is one of an ice-marginal valley and river terraces with dune complexes. At the study section, the width of the Vistula River is from about 300 to 600 m, and the bars herein are from about 100 to several hundred metres long. The deposits building them come mainly from deep erosion, i.e. washing and re-depositing of previously-accumulated sediments, and insignificant side erosion. The existence of bars is the most common seasonal phenomenon, although many of them can survive in a given place for many seasons under a varying hydrological regime. Long-term (although not systematic) observation of bars at the studied section of the Vistula River prove they appear seasonally in the same places, and their sizes and shapes are different.

The studied sidebars emerged in the Ciechocinek region (33 km downstream of the Włocławek dam) and Toruń (27 km downstream of Ciechocinek) during the low water level in late spring 2006 (Figs 1 and 2).

Methods

The OSL test samples were collected under the conditions of changing flows and water levels between

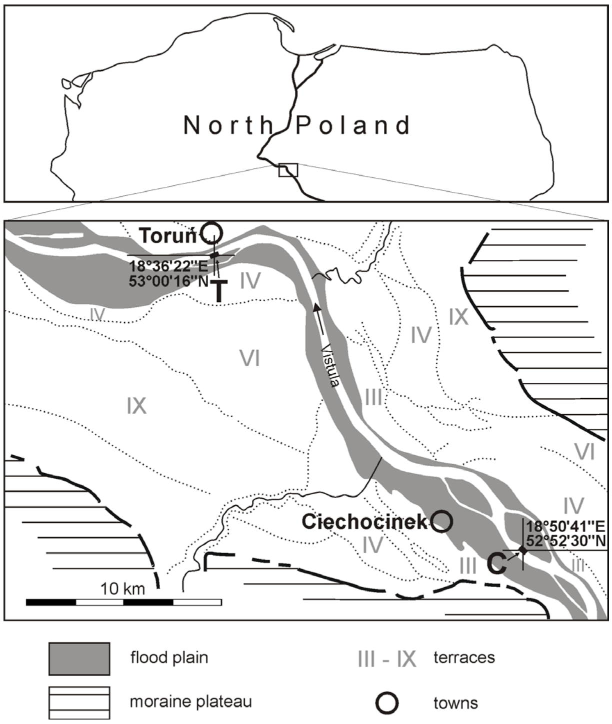


Fig. 1. Location of the investigated bars (black boxes): C – Ciechocinek bar, T – Toruń bar

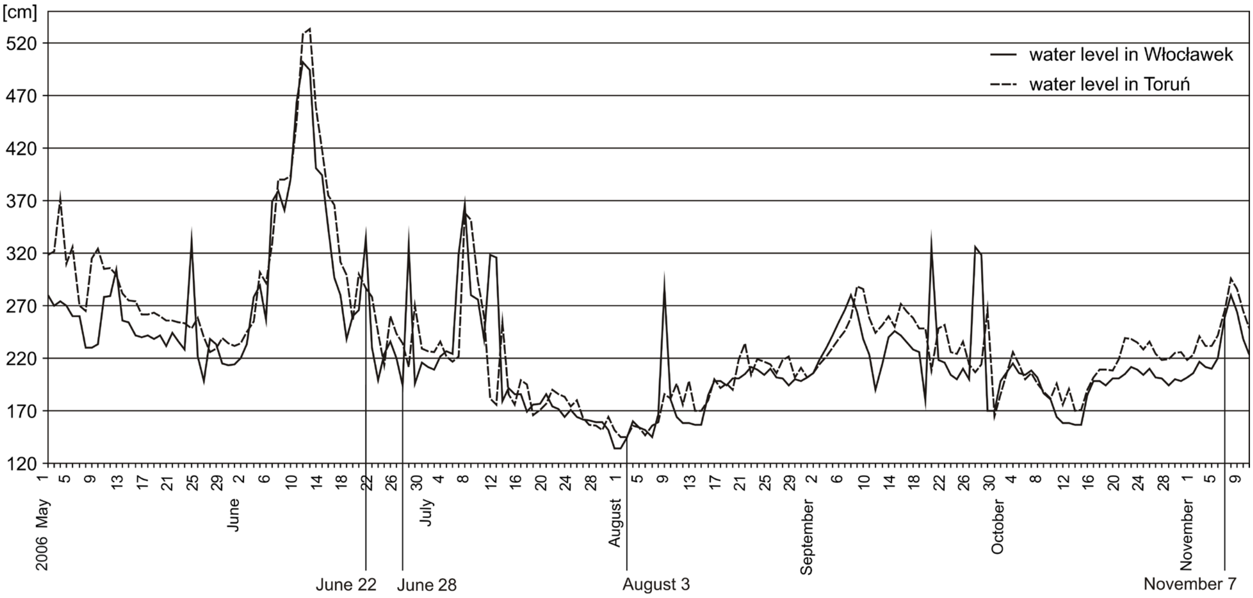


Fig. 2. Water level of the Vistula River during the study period (in Poland, a network of water gauges is referenced to sea level in Kronstadt in Russia); marked sampling days

June and November 2006 (Fig. 2). Changes in the Vistula River water levels during this period were generated mainly by periodic water discharges at the Włocławek dam. In the analysed period, the maximum elevation of the analysed bars' surface above the water was approximately 1.0 m, and the maximum water level above their surface reached about 3.5 m.

In total, 80 samples were collected, from which 18 were dated using OSL (Table 1, Fig. 3). The dated samples came from deposits showing a whole range of structural and textural changes. The samples were taken in various ways, i.e. from a dry or wet bar surface, from pits up to 70 cm deep, and from bar surface under the water (*in statu nascendi*). The samples from the surface layers were collected by scooping them up, with the help of a brush and spatula, directly to black plastic bags and protected against any further accidental exposure to daylight.

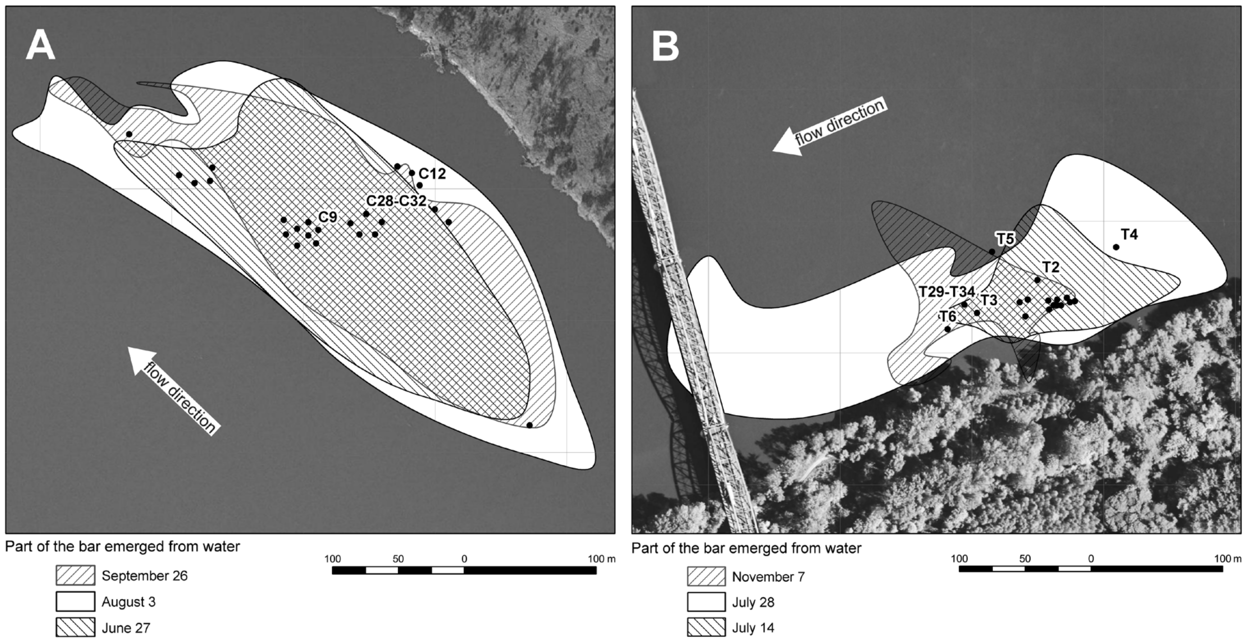


Fig. 3. The Ciechocinek (A) and Toruń (B) bars in 2006; location of sampling sites (black dots)

Table 1. List of the characteristics of samples

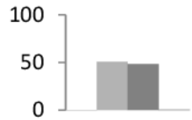
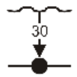
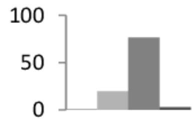
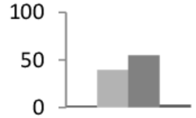
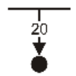
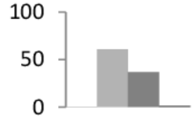
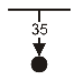
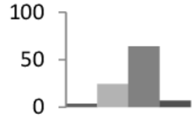
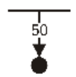
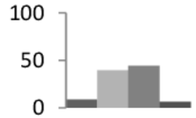
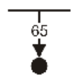
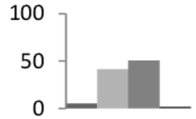
Samples	Sampling method	Percentage of major fraction of the sediment on the Udden-Wentworth scale	Indicators of grain-size distribution according to Folk and Ward				Characteristic of grain-size distribution and name of sediment according to Udden-Wentworth	River bed morphology or sedimentary structure	D_e [mGy]*	OSL age [years]*
			GSS	GSO	GSK	GSP				
C9			1.04	0.577	0.088	0.803	unimodal, moderately well sorted, slightly gravelly sand	association of plane bed and small ripple marks	140+/-170	150+/-180
C12			1.350	0.487	-0.180	0.983	unimodal, well sorted, slightly gravelly sand	small ripple marks	150+/-95	160+/-100
C28			1.086	0.742	-0.244	1.020	unimodal, moderately sorted, slightly gravelly sand	plane bed	130+/-110	140+/-120
C29			0.954	0.580	0.207	0.885	unimodal, moderately well sorted, slightly gravelly sand	trough cross-stratification	470+/-290	500+/-300
C30			1.238	0.820	-0.270	1.518	unimodal, moderately sorted, slightly gravelly sand	trough cross-stratification	600+/-390	640+/-400
C31			0.843	1.151	-0.327	1.386	unimodal, poorly sorted, gravelly sand	trough cross-stratification	450+/-300	480+/-320
C32			1.002	0.855	-0.274	1.228	unimodal, moderately sorted, gravelly sand	trough cross-stratification	570+/-400	600+/-420

Table 1. cont.

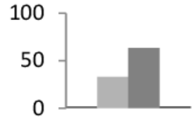
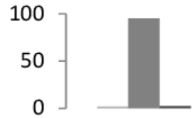
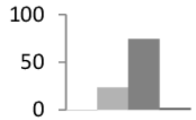
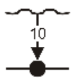
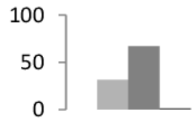
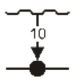
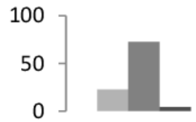
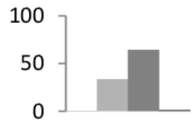
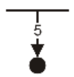
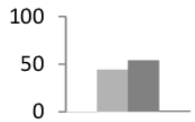
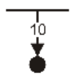
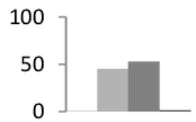
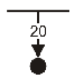
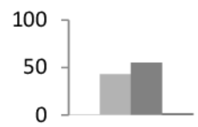
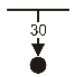
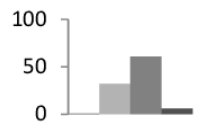
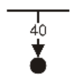
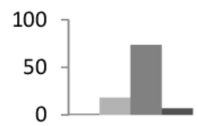
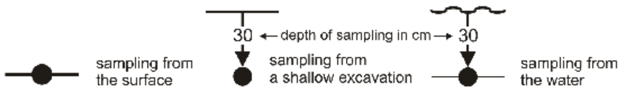
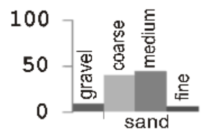
T2			1.195	0.561	-0.140	0.810	unimodal, moderately well sorted, slightly gravelly sand	ripple cross-lamination	90+/-100	120+/-130
T3			1.503	0.322	0.000	0.738	unimodal, very well sorted, sand	bar lee face	90+/-100	120+/-130
T4			1.306	0.499	-0.178	0.948	unimodal, well sorted, slightly gravelly sand	small ripple marks	95+/-90	120+/-110
T5			1.228	0.526	-0.131	0.801	unimodal, moderately well sorted, sand	small ripple marks	100+/-90	130+/-120
T6			1.327	0.514	-0.185	0.966	unimodal, moderately well sorted, sand	small ripple marks	100+/-95	130+/-120
T29			1.212	0.530	-0.105	0.777	unimodal, moderately well sorted, slightly gravelly sand	small ripple marks	90+/-100	120+/-130
T30			1.108	0.565	-0.002	0.771	unimodal, moderately well sorted, slightly gravelly sand	trough cross-stratification	90+/-95	120+/-120
T31			1.106	0.546	0.060	0.734	unimodal, moderately well sorted, slightly gravelly sand	trough cross-stratification	100+/-90	130+/-120

Table 1. cont.

T32			1.128	0.544	0.021	0.736	unimodal, moderately well sorted, slightly gravelly sand	trough cross-stratification	110+/-100	140+/-130
T33			1.222	0.651	-0.122	0.986	unimodal, moderately well sorted, slightly gravelly sand	trough cross-stratification	90+/-95	120+/-120
T34			1.375	0.572	-0.091	1.237	unimodal, moderately well sorted, slightly gravelly sand	trough cross-stratification	120+/-100	150+/-130

Explanations:





GSS – mean particle size
GSO – sorting
GSK – skewness
GSP – curtosis

Deeper sediments were sampled under light-tight cover and packed directly into plastic tubes (Fig. 4).

The samples were obtained from the deposits of various sedimentation structures. These structures can be viewed both from the viewpoint of their relief (river bed morphology) and their internal structure. The samples were taken mainly from megaripples, forming trough cross-stratification (Fig. 5A), and from small ripples imposed on the larger bedforms, forming a ripple cross-lamination (Fig. 5B). A small number of samples were collected from the sediments of horizontal stratification which build the plane bed.

Fig. 4. The Toruń bar – sampling in the shallow excavation

The grain-size distribution of part (18 samples) of the collected sediment samples was analysed using sieves with mesh size of 10.0, 5.0, 2.0, 1.0, 0.80, 0.50, 0.25, 0.10, 0.05 mm. The statistical parameters of the grain-size distribution were calculated using the formulas shown in Folk and Ward (1957). The Udden-Wentworth classification and terminology (Wentworth 1922) was applied to characterise the sediment (Table 1). Studies on rounding and frosting of the 0.8- to 1.0-mm quartz grain fraction were performed using the Cailleux method (1942) modified by Mycielska-Dowgiałło and Woronko (1998). The modified method combines grain-surface analysis with identification of grain-shape class using Krumbein (1941) scale for sedimentary particles. Each quartz grain is classified into one of seven groups: fresh angular surface (NU), round matt surface (RM), round shiny surface (EL), intermediate matt surface (EM-RM), intermediate shiny surface (EM-EL), broken (C) and others.

From the samples for testing OSL, the coarse grains (i.e. in the range from 100 to 200 microns) were extracted by wet sieving in the dark room of our laboratory. The samples were cleaned with 10% HCl and 30% H_2O_2 solutions, and then heavy liquids with densities 2.63 and 2.70 g/cm^3 were applied for quartz separation. In order to remove the outer quartz grain layer (accessible for exterior alpha radiation) and etch out any remains of feldspar, the samples were etched for 40 minutes in 40% HF solution. The large aliquots, each one containing c.a. 100 quartz grains, were prepared for OSL measurements, according to the standard procedure used in our laboratory for dating measurements. The grains were arranged in a single layer with the help of a mask (6 mm in size) and silicon oil, which was used to enhance the adhesion.

Fig. 5. The Ciechocinek bar: A – trough cross-stratification sand and gravel in the shallow excavation (length of the spade 55 cm); B – transversal chain megaripples (after Allen 1968) with superimposed small ripples (length of the spatula – 25 cm)

All the OSL measurements were carried out using an automated Risø TL/OSL-DA-20 reader (Bøtter-Jensen et al. 2010) equipped with a blue, LED light source for stimulation (wave length of 470 nm and delivering 80 mW/cm² at the sample), and a photo multiplier tube (PMT) with a Hoya U 340 filter (7.5 mm) for detection in the wave length range from 290 to 370 nm. The $^{90}Sr/^{90}Y$ beta source was attenuated and applied for irradiation with a dose rate of 18.1±0.3 mGy/s (Przegiętka and Chruścińska 2014).

The equivalent dose (D_e) values were determined using the Single Aliquot Regenerative SAR-protocol (Murray and Wintle 2000). For each sample, 48 aliquots were measured by 40 s with blue light stimulation at 125°C after a preheat at 200°C for 10 s. The preheat temperature was chosen on the basis of test measurements. Six preheat temperatures ranging from 160°C to 260°C in steps of 20°C were applied, using 8 aliquots for each preheat temperature. Low regenerative dose values were applied in the SAR procedure, typically of the order of 100 mGy. Special calibration of the beta source dose rate was carried out for short irradiation times (Przegiętka and Chruścińska 2014).

The D_e was estimated by linear regression applied to OSL signal integrals: from 0 to 0.8 s, after late background (taken from the end of the OSL decay curve) subtraction and correction for sensitivity changes. The reliability of obtained results was monitored with the help of a recycling ratio monitored during routine SAR measurements for repeated regenerative dose value. Absence of feldspar contamination was checked for each aliquot by routine IR OSL tests at the end of the OSL measurements. For some aliquots the natural OSL signal appeared even lower than OSL response to zero dose, resulting in negative D_e value in those cases. This could possibly have been caused by thermal transfer, although the preheat temperature was kept as low as 200°C in an attempt to minimise this effect. For such aliquots, the ratio of natural OSL to single value of regenerated OSL signal was simply applied to calculate equivalent dose D_e, instead of constructing the complete growth curve. The recovery tests performed with higher doses revealed a bright OSL response and confirmed the appropriateness of the SAR protocol used.

The annual dose rates (Dr), comprised of beta and gamma radiation, were calculated on the basis of gamma-ray spectra measured in the laboratory using a Canberra System 100 spectrometer equipped with a HPGe detector. The samples (usually of c.a. 450 ml) were dried out, put into standard Marinelli beakers and kept tightly closed for 30 days prior to the start of the measurement (in order to reach the radon secular equilibrium). The spectra were usually recorded for 4–5 days and then specific activities [Bq/kg] of several gamma-emitters were derived and sorted in the following groups (Oczkowski and Przegiętka 1998a):

1. Thorium series (full) : ^{228}Ac, ^{212}Pb, ^{212}Bi, ^{208}Tl,
2. Pre-thoron: ^{228}Ac,
3. Pre-Rn ^{238}U series : ^{234}Th, ^{234m} Pa, ^{226}Ra,
4. ^{222}Rn and after series : ^{214}Pb, ^{214}Bi, ^{210}Pb,
5. Uranium ^{235}U series (full) : ^{235}U, ^{223}Ra,
6. ^{40}K (and ^{87}Rb activity is calculated assuming $^{40}K/^{87}Rb$ activity ratio of 0.142),
7. Others: ^{137}Cs.

Assuming the subset secular equilibrium, the weighted average activities for the groups were calculated. Based on these, partial annual dose rates from beta and gamma contributions were evaluated.

For samples collected from the surface layers, the gamma doses used for the age calculation should be reduced since these samples are not completely surrounded by the sediment. However, if we intend to estimate the completeness of zeroing, instead of just dating modern sediments, then assuming the dose rate value representative for fully-covered deposit is justified for all the samples. From the radiological point of view, the material in both bars appeared to be uniform, especially regarding concentrations of main contributions to the dose rate – i.e. radioisotopes from ^{235}U and ^{232}Th series. Due to the above, the average dose rates were assumed to be representative for fully-covered deposit, and were used for the OSL age calculations: (0.943±0.048) mGy/a and (0.777±0.019) mGy/a for the Ciechocinek and Toruń sites, respectively. The effect of moisture was taken into account for beta and gamma doses separately, following Aitken (1985) recommendations. The cosmic gamma dose rate component of 0.280 mGy/a was included for all samples alike.

Results and discussion

The depositional structures featured within the two analysed bars were formed under varying flow and water-level conditions. Structures of trough cross-stratification emerged as a result of migration, growth and burial of megaripples (3-dimensional dunes) building up the mid-channel bars. They were formed in the conditions of the upper part of the lower flow regime. Deposition from rhythmic bedload transport, mainly rolling, as well as local erosion, were then dominant (Fig. 6A). These processes occurred in the environment of substantial flow dynamics and the inability of suspended particles to be deposited. Ripple cross-lamination developed as a result of the migration of small ripples imposed on other bedforms, mainly 3-dimensional dunes. They were formed in low-energy flow conditions, i.e. in the lower part of the lower flow regime. Deposition resulted from rhythmic bedload transport. Horizontal stratification originated as a result of the upper plane bed development (Fig. 6B) under relatively high-energy flow conditions, whereas deposition was from near-bed suspension.

The sediment samples collected from the two sidebars predominantly consist of slightly gravelly sand (about 70% of the samples), as well as sand and gravelly sand (Table 1). The samples from the Ciechocinek bars have a slightly higher content of gravel. These sediments are in most part moderately well sorted (about 60% of the samples), and well and moderately well sorted in the unimodal distribution.

Based on the mean grain diameter in individual sediment samples in the Sundborg diagram (1956, 1967), the ranked flow speed was read, i.e. depositional speed and river transport environment competence, which is the lowest current speed needed to move the largest sediment grains (Fig. 6C). The depositional speed value was found to be about 0.3 m/s, as read from the cessation of movement. Riv-

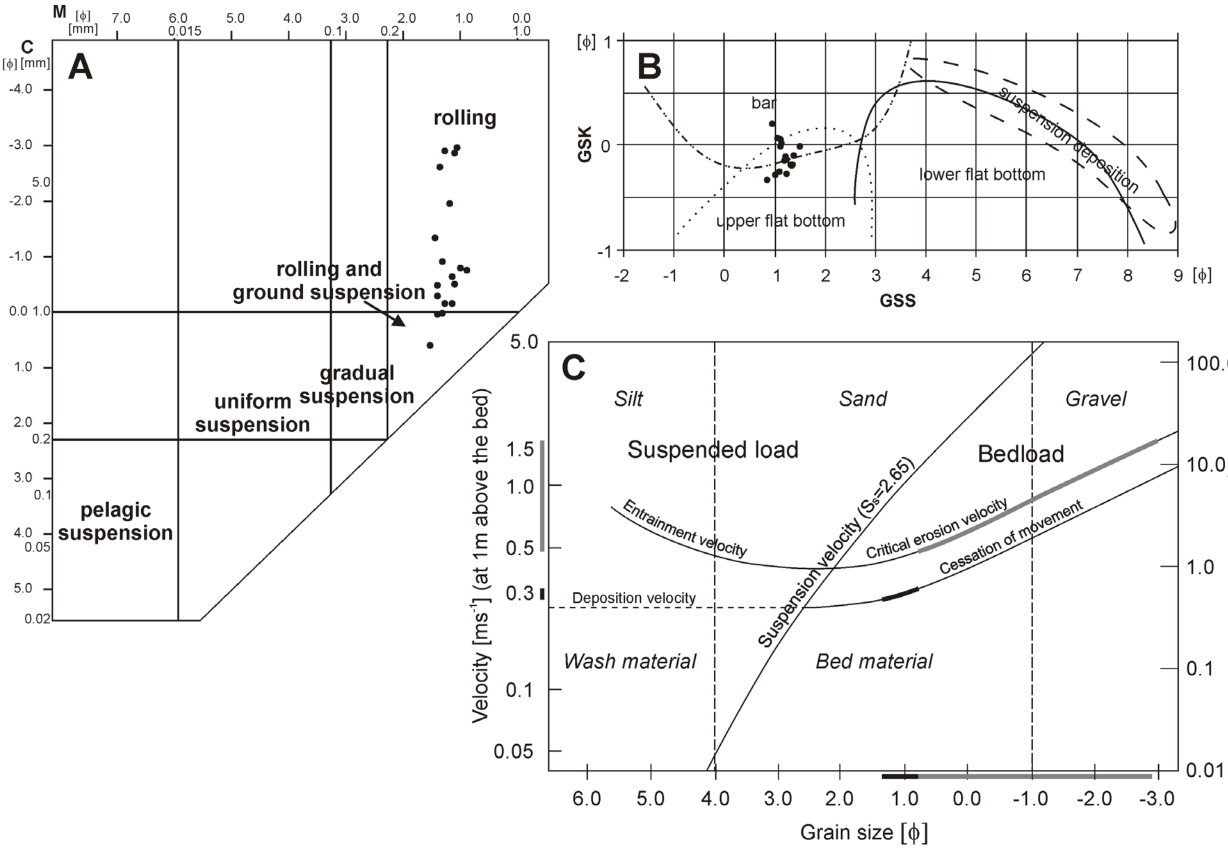


Fig. 6. Particle size analysis indicators: A – CM diagram (relation between the C = first percentile and M = median) after Passega (1964) and Passega, Byramjee (1969); B – diagram of relation between the indicators of skewness (GSK) and mean particle size (GSS), after Juśkiewicz (Chutkowski, Juśkiewicz 2007); C – diagram of relation between flow velocity, grain size and state of sediment movement for uniform material of density 2.65 g/cm^3, after Sundborg (1956, 1967)

er transport environment competence (entrainment velocity) was read from the line of critical erosion velocity, and ranged from 0.5 to 1.5 m/s.

The performed study on rounding and frosting characteristics of quartz grains (Fig. 7) shows a strong dominance of intermediate, shiny surface grains (EM-EL) in all samples, and uniformity of the studied material. Such results are specific to a flowing water environment. Together with rounded, shiny surface grains (EL), which are associated with long water transport, they constitute from 91 to 99% of the analysed grains for each sample. Characteristically, the EM-EL grains distinguish themselves by shining across almost their entire surface, although their rounding varies from poor to very good. Incomplete shining of the grains' surface layer allows their structure to be observed below the top layer of shine. This allows identification of a former grain type and early sedimentary environment. About half of the EM-EL grains, in which it was possible to identify the primary type of the grain, are matt intermediate (EM-RM) and matt rounded (RM). This indicates a delivery of the material from aeolian active regions, either now or in the past. Angular grains of fresh surface (NU) have a small share. Their corners and the surface parts are shined, but their shape remains unchanged. This suggests that transportation of these grains happened in suspension and/or by traction. Apart from the EM-EL and EL grains, EM-RM and RM were also distinguished. Their combined share does not exceed 7%. Other grains, such as those of fresh surface (NU), broken (C) and others, are represented by single specimens. The content of quartz in the samples varies and ranges from 64 to 94%. It is 77% on average for sediment samples from the Ciechocinek bar, and 85% for samples from the Toruń bar.

In general, all the samples demonstrate a very weak natural OSL signal, which is the result of low equivalent dose D_e, itself being the consequence of the young age of the sediment and a low level of residual luminescence probably remaining in some grains (which is discussed later). The material itself exhibits typical luminescence sensitivity and gives a stronger OSL response for higher doses, as were used in recovery tests.

The obtained distributions of D_e estimates for six selected samples are shown in Figure 8 as illustrative examples. Results of the average D_e values received for all the samples are listed in Table 1.

Fig. 7. Percentage of quartz grains groups of rounding and surface characteristics in the Ciechocinek and Toruń samples

The concentration of uranium, thorium and potassium calculated from gamma spectra are presented in Figure 9 a–d, which show that the results within Toruń as well as Ciechocinek bars are uniform. Activities of ^{137}Cs were also detected in the samples, and the dependence of its concentration on sediment depth is presented in Figures 9 e and f for Ciechocinek and Toruń bars, respectively. Although the influence of caesium concentration on annual dose rate is negligible, its presence inside sediments suggests that the sediment shouldn't be older than 20 years.

As mentioned before, for each bar, a single annual dose rate value, representative for fully-covered deposit, was assumed for all the samples and was used in OSL age calculations. The obtained OSL ages are presented in Table 1. Assuming contemporary origin of the sediments, it enables the evaluation of the age overestimation for series of buried sediments, the same as it would appear in the case of fossil deposits. Otherwise, if we used lower dose rates for shallower samples (reduced due to lack of sediment cover), it would result in older dates for superficial samples. Such results could even produce an age inversion for given series of sediments. Although the effect of age inversion would be masked by wide uncertainty ranges, it could suggest that D_e estimates are related not only to the age of sediments, but include a certain constant part, which could originate from residual luminescence.

An attempt to determine the dependence of the OSL age (zeroing) of the analysed sediment on its structural and textural characteristics (indicators of grain size) and the sampling location is shown in the diagrams (Fig. 10). Based on the 18 dated sediment samples of the bars in Ciechocinek and Toruń, significant correlations between the characteristics of sedimentation and the OSL age cannot be confirmed. Bar deposits in Toruń show similar ages (120–150 years), regardless of the sampling place

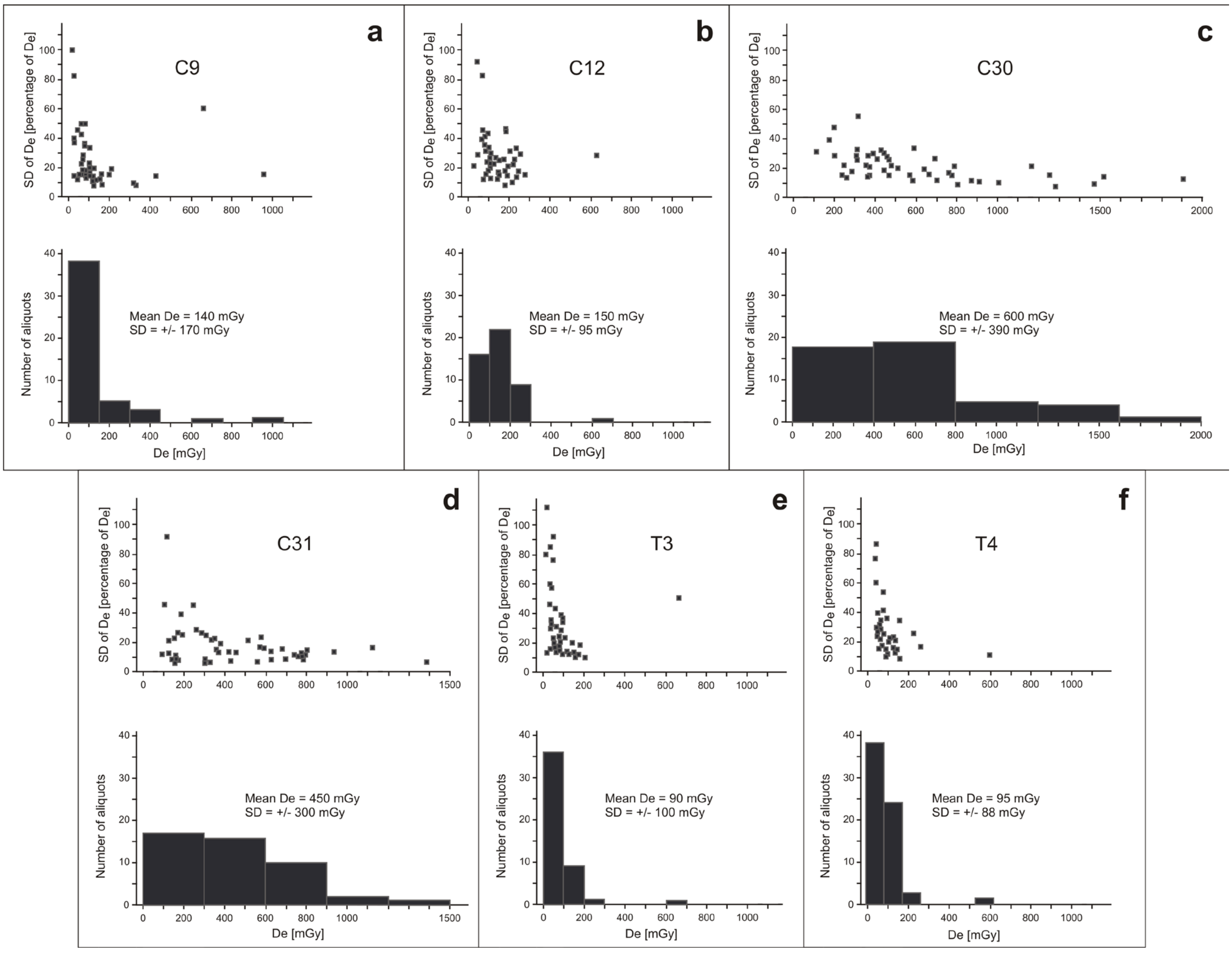


Fig 8. Distribution of equivalent dose D_e values measured by SAR OSL method for bar sediment samples

(bar surface or substrate). The deposits from the bar surface in Ciechocinek show comparable ages (140–160 years), while the age of the deposits from this bar's substrate is several times greater (480–640 years). Regardless of the credibility of the obtained dates, this possibly indicates a greater stability of the bar in Ciechocinek.

Conclusions

The tested sediments were deposited under varying water levels, flow energies and transport processes, providing a highly dynamic river environment. According to Babiński (1992) the dynamics of waters of the lower Vistula River does not allow it to be concluded that there are unidirectional changes of the bars' grain size with the distance covered. The analysis of all the deposit samples from the two bars, i.e. the Ciechocinek bar, and the Toruń bar located 27 km further down the river, shows relatively little variation in grain size. These are variously sorted sands, with a small admixture of gravels, slightly higher in the case of the sediments from the Ciechocinek bar. There was also no significant difference in rounding and frosting of quartz grains in the samples from both bars. Grains typical of a flowing water environment definitely dominate there. It is interesting to conclude that a significant number of grains were originally formed in the aeolian environment. Furthermore, the content of quartz in the samples from the Toruń bar is higher than that of Ciechocinek, suggesting a theoretically longer sediment transport. At the presented stage of research into the dependence of the OSL age (zeroing) of the examined sediment on its sedimentological characteristics and sampling place, no significant correlations are shown (Fig. 10).

The remains of ^{137}Cs found in the samples can be connected to Chernobyl pollution. Former surveys reported ^{137}Cs and ^{134}Cs activities detected in this territory, which originated from the Chernobyl catastrophe (Oczkowski et al. 1996). Hence the peak of maximum ^{137}Cs concentration, which is observed for deeper samples (0.35 m in Toruń, and

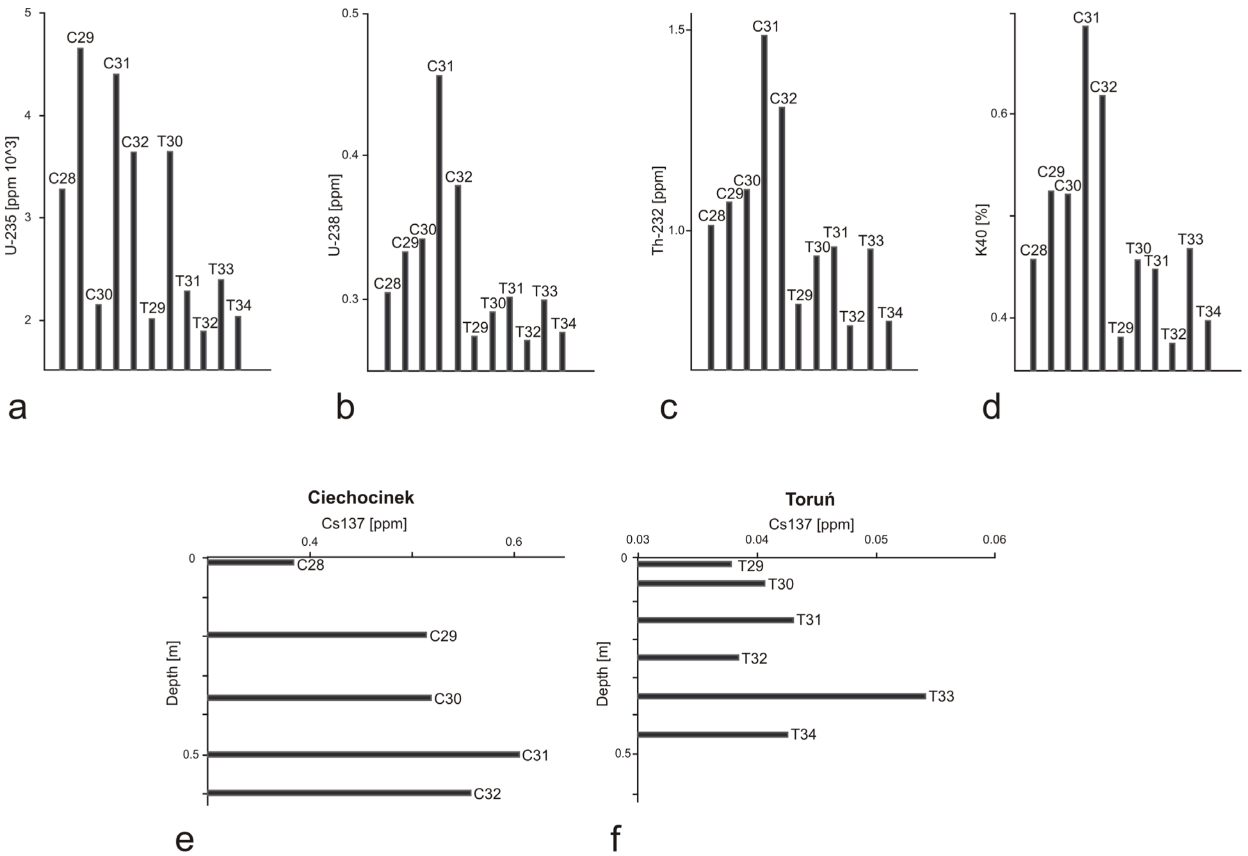


Fig 9. Concentration of radioisotopes measured by gamma spectrometry for bar sediment samples: a – ^{235}U, b – ^{238}U, c – ^{238}Th, d – ^{40}K and dependence of ^{137}Cs concentration on depth of sample for: e – Ciechocinek site and f – Toruń site

0.5 m in Ciechocinek) can be correlated with 1986, i.e. the year of Chernobyl fall-out. It confirms that in 2006, when the samples were collected, the age of these samples couldn't have been more than 20 years. Therefore, the OSL ages (presented in Table 1) seem to be overestimated, even despite wide uncertainty margins.

The obtained OSL results turned out to be very much alike for all the samples studied. The high uncertainties of OSL ages are dominated by uncertainties of D_e estimates (Table 1). This is partially caused by the low level of luminescence signal, which reduces the precision due to limited OSL reader sensitivity, irregularities of the growth curve and restricted resolution in application of low regenerative doses (Przegiętka and Chruścińska 2014). However, the spread of D_e values is also responsible for widening the uncertainty range in D_e estimates, especially for deeper samples (Fig. 8). This spread can be attributed to the skewed distribution of residual luminescence signal, which is characteristic for partially-bleached material (Przegiętka and Chruścińska 2013). However, the distributions of D_e results suggest that only a minority of aliquots exhibits significant level of residual luminescence. Anyway, the partial bleaching of sediment not only increases the scatter of the obtained OSL results, but also makes the calculated age of the deposit older than true age.

Similar age values (Table 1) obtained for modern sediments can be interpreted as the age overestimation caused by residual luminescence connected with the former history of the material. It seems to be as high as 150 years, but associated uncertainty is of the same order. Nevertheless, if we take it into account for deeper samples and subtract this overestimation from as-received OSL dates, then we obtain younger ages, which are more consistent with the expectations and results of ^{137}Cs distributions.

The lack of a clear relationship between the structure and texture of the sediments and the quality of bleaching of OSL signal in quartz grains seems to prove that this material was earlier subjected to many cycles of erosion-transport-deposition. One should keep in mind, that actual structure and

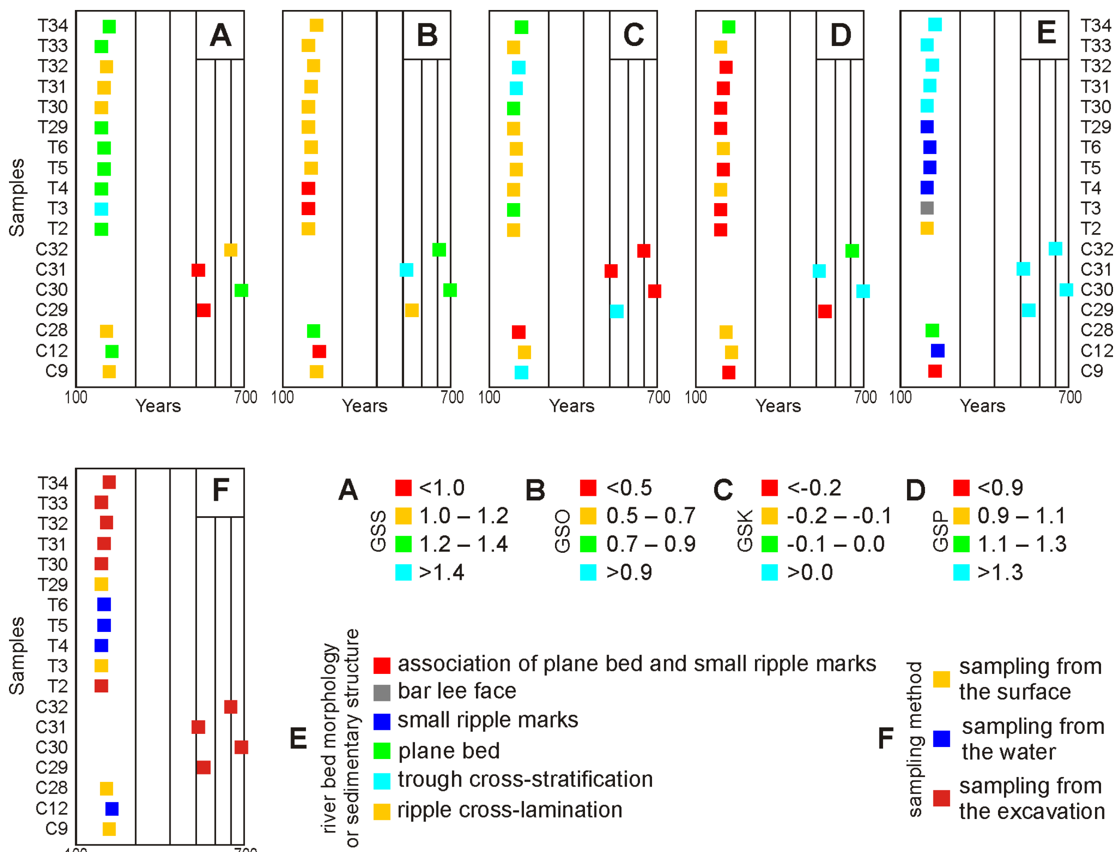


Fig. 10. Diagrams of the dependence of the OSL age on their textural and structural characteristics and sampling place

texture of sediment reflects the conditions of only one – the last – episode of sedimentation. However, the bleaching quality appeared to be similar for all the types of sediments because it could be shaped gradually – not in one, but in a recent succession of episodes. Since, on average, such a slice of history is similar for all quartz grains deposited in the bar, the level of residual luminescence is also averaged between sediments. Hence, in bar sediments neither structure nor texture can indicate the better bleached material and justify differentiation in the credibility of OSL dating results.

The obtained results suggest that our dating procedure applied for regular bar sediments suffers from age overestimation. This is probably connected to residual luminescence remaining in quartz grains, which can result from partial bleaching in a fluvial environment. This result is equivalent to c.a. 150 years of the OSL age overestimation for core sediment (fully covered sample). Such an effect cannot be accepted in the dating of modern sediments, and needs to be corrected for recent sediments. However, in the case of fossil regular bar sediments older than 15,000 years, the effect of age overestimation would be insignificant (less than 1%) and can easily be neglected. Contrary to this, in the TL dating method applied for geological deposits – still as favourable for good bleaching conditions as aeolian sediments – the harmful effect of the residual signal should be taken into account, even for relatively old aeolian deposits (Oczkowski and Przegietka 1998b). This comparison clearly demonstrates the better effectiveness of optical bleaching of OSL than TL signal, which is one of the main advantage of applying OSL over TL for dating in geology.

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