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# CHRONOSTRATIGRAPHY OF THE VISTULIAN GLACIATION (WEICHSELIAN) ON THE KUJAWY MORAINE PLATEAU (CENTRAL POLAND) BASED ON LITHOSTRATIGRAPHIC RESEARCH AND OSL DATING

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**Abstract**: The subject of the investigations presented here is fixing dilemmatic character (transgressive or recessive) of the Poznań phase of the Vistulian (Weichselian) glaciation and answering question about possibility of the lithostratigraphic separation of this phase from the Leszno phase in the region of so called Vistula lob. Here we present the outcomes of the research project carried out on a few tills exposures, which constitute the sedimentological record of the last ice sheet advance on the Kujawy Moraine Plateau. The absolute ages of 17 samples (collected from fluvial deposits uncovered in the geological logs) have been determined by means of the OSL method applying the single aliquots regenerative (SAR) dose protocol. The OSL data are analysed with regard to supposed bleaching conditions enduring at the moment of the last transport and deposition of the material. In conclusion some remarks on suitability of fluvial sands for OSL dating are drawn out. In most of the investigated sites, there appears only the single till level associated with the main stage of the Vistulian glaciation. This fact and the results of OSL dating support the thesis, that the Poznań phase in Kujawy Moraine Plateau is not any distinct lithostratigraphic unit, but it is a recessive phase of the last glaciation.

## 1. INTRODUCTION

The paper deals with the issue discussed earlier in literature (among the others: Galon, 1956; Mojski, 1968; Kozarski, 1988, 1995; Marks, 1988; Stankowska and Stankowski, 1991; Wysota, 2002; Wysota *et al.*, 2006) and it refers to the character (transgressive or recessive) of the Poznań phase of the Vistulian Glaciation (Weichselian) and, as a consequence, the lithostratigraphic separation of this phase from the Leszno phase of the last glaciation within the so-called Vistula lobe (**Fig. 1a**).

In the region of the Lower Vistula there is evidence on separateness of the above phases (Wysota, 2002). This thesis is supported by the luminescence dating of the deposits from the Lower Vistula region (Wysota *et al.*, 2002; Wysota *et al.*, 2006). The cited author (Wysota, 2002) tries to extend his conclusions on the site of the Eem Interglacial in Mikorzyn near Ślesin in the Konin region (**Fig. 1b**), where the duality of the deposits of the last glaciation is visible (Kozydra and Skompski, 1996; Stankowski *et al.*, 1999). Wysota (2002) also correlates his results obtained for Lower Vistula region with the two separate till beds in the east part of the Płock Basin documented by Skompski (1969) and other researchers. According to Mojski (1984) those till beds correspond with the Poznań and Leszno phases. After Wysota (2002) the correspondence of deposits in the south of the region of the Lower Vistula with the above-mentioned sites proves the Poznań phase is represented by a separate lithostratigraphic unit which is connected with the separate pan-regional ice sheet advance of the main stage of the Vistulian Glaciation.

## 2. STRATIGRAPHY OF THE VISTULIAN

Stratigraphy of the last glaciation in the Kujawy Moraine Plateau, which is located between the Lower Vistula region and the Konin region (**Fig. 1a**), is based on poorly documented morpho- and lithostratigraphic criteria. This mainly stems from scarcity of the forms and their unclear genesis. According to the various authors, these forms mark the different rank periods of the ice sheet stagnation. Moreover, the tills, which are a sedimentological record of the ice sheet advance, have been inadequately studied. There is very little chronostratigraphic data based on the C-14 or TL methods available on the area.

According to Molewski (2007) there is no evidence the ice sheet advanced onto the Kujawy Moraine Plateau during the Early and Middle Vistulian. The very issue of the existence and extent of the above advances is still being discussed (Wysota, 2002; Makowska, 2004). Thus, the problem of the last glaciation in the studied area is limited to the main stage of the Vistulian Glaciation.

The presently accepted course of the events of the main stage of the Vistulian Glaciation in the Kujawy Moraine Plateau has been based on the Wielkopolska example (Kozarski, 1991a; 1995). It assumes that the Poznań phase is not a separate lithostratigraphic unit, but it is just a stage of the recession of the ice sheet of the Leszno phase. According to Kozarski (1991b) the maximum spread of the Leszno phase was followed by the regression of the ice sheet snout to the new stagnation line in the central part of the Wielkopolska Lowland. To the east of Konin and towards the Vistula, i.e. in the research area, "the snout of the ice sheet of the Poznań phase stretched further due to positive mass balance" (Kozarski, 1991b). The Poznań phase in the southern part of the Kujawy Plateau, though, might have a character of a local transgression.

Following the opinion of Kozarski (1991b), the sites located within the maximum extent of both phases of the main stage of the Vistula Glaciation cannot be correlated undoubtedly with the results of the research carried out in the Lower Vistula region and interpreted as the evidence of the pan-regional ice sheet advance. Lithostratigraphic separateness of both phases should be sought to the south of the area studied by Wysota (2002), i.e. beyond the zone of the maximum extent of the last glaciation, in northern and central part of the Kujawy Moraine Plateau. The authors of the article have undertaken such research in the area defined above.

## 3. METHODS

### 3.1. Study area

Stratigraphic research of the deposits from the Vistulian Glaciation in the Kujawy Moraine Plateau was carried out in 2004-2005 at seven research sites (Molewski, 2007). A limited number of the sites stems from the fact that the Kujawy Moraine Plateau generally lacks natural or artificial exposures where full profiles of the deposits of the last glaciation, especially the tills, would be visible. The studied sites are located along the eastern edge of the Kujawy Moraine Plateau (sites at Boża Wola, Baruchowo, Nieszawa, Raciążek), in the slopes of subglacial channels (tunnel valleys), i.e. the subglacial channel of Lake Gopło (the site at Mielnica) and the subglacial channel of Lake Pakoskie (the site at Kołuda Mała), as well as within the area of ground moraine to the east of Lake Gopło (the site at Gocanówko) (**Fig. 1b**). The detailed lithostratigraphic and sedimentological analyses were carried out. They included the lithofacial analysis followed by the differentiation of the sedimentary units, the analysis of the directional elements (till fabric, palaeocurrents and kinematical indicators), lithological and pethrographic analysis (grain size composition, carbonate content, quartz grain roundness and pethrographic composition of gravels in tills), as well as the OSL dating of the deposits. The detailed results of both sedimentological and lithostratigraphic research carried out at the Nieszawa site have already been published (Wysota *et al.*, 2004; Molewski and Wysota, 2006).

### 3.2. Sample preparation and equipment

The absolute ages of 17 samples (**Table 1**, **2** and **Fig. 1**, **2**) have been determined by means of the OSL method applying the single aliquots regenerative (SAR) dose protocol

(Murray and Wintle, 2000). Although in some cases only 2 samples were dated per one site, anyway the presented results are the first absolute ages from Kujawy Moraine Plateau. Moreover the results obtained for all the sites seem coherent enabling for drawing general conclusions for the whole region.

The sand grains of the diameters from the range (0.100 – 0.200) mm were extracted from fluvial sands with the help of wet sieves. Then samples were cleaned with perhydrol (38% $H_2O_2$ for at least 1 hour or until the reaction was finished) and hydrochloric acid (10 % HCl for at least 1 hour or until reaction became quiet) to remove organics and calcite, subsequently rinsed with distilled water and ethanol and dried. After that the quartz grains lighter than 2.70 g/cm$^3$ but heavier than 2.62 g/cm$^3$ were extracted using floating method (heavy liquids prepared with solutions of sodium polytungstate). Then quartz grains were etched in hydrofluoric acid (40% HF for 40 minutes), which removed the outer layer of grains and etched out any remains of feldspar in the samples. The etching process was stopped with help of hydrochloric acid (10 minutes in 10 % HCl), then samples were rinsed with distilled water, ethanol and dried. The purity of samples was checked by routine IR OSL tests. After applying laboratory dose no IR OSL signal was observed that confirms the absence of feldspar contaminations in the samples.

The Riso reader, model Tl/OSL-DA-12 equipped with xenon lamp and excitation filter pack GG-420 (410-580 nm) for stimulation and PM with U-340 filter (290-370 nm) for detection was used for OSL measurements (Bøtter-Jensen and Duller, 1992). The beta source ($^{90}$Sr/$^{90}$Y) with dose rate of 44.5 mGy/s was applied for irradiations.

The annual dose rates (DR), comprised of beta and gamma radiation, were calculated on the base of gamma spectra measured in laboratory (sample amount of 600 ml) with help of Canberra System 100 spectrometer equipped with HPGe detector.

### 3.3. OSL-SAR method and *ED* and *DR* evaluation

The OSL method of dating applied to geological deposits determines the particular moment when an event, which could erase previously accumulated luminescence in mineral grains, has taken place. If transport and/or deposition of the material make the grains to be exposed to the daylight, these can reset luminescence clock. Such process is called the optical bleaching. Its efficiency depends on the conditions of the light exposure (durability, intensity of light and its spectrum). Poor and heterogeneous bleaching may result in large spread of natural luminescence OSL data and as consequence cause high uncertainty of the *ED* value and imprecise OSL age. What is even worse incomplete bleaching is a source of the overestimation of the age of a deposit. Unfortunately, the real extent of bleaching in nature is usually uncertain. Hence, in case of geological samples, it is important to carefully consider the validity of the assumption about bleaching, when the OSL age is interpreted. The OSL data are analysed with regard to bleaching conditions expected from the environment at the moment of last transport and deposition of the material (**Table 1** and **Fig. 3**).

For every sample 24 aliquots (each one containing 5 mg of quartz grains) were used for OSL-SAR measurements (100s of stimulation at 125$^{o}$C). The tests of preheat temperature were carried out at: 180$^{o}$C, 200$^{o}$C, 220$^{o}$C, 240$^{o}$C, 260$^{o}$C and 280$^{o}$C, using four aliquots for every specific temperature. On this base the annealing for 10s at 240$^{o}$C was chosen as the best preheat procedure. The test doses, applied for monitoring sensitivity changes were fixed on the level of 10% of expected *ED* values. For calculations only the beginning part of OSL decay curve (0-1.2 s) was used. The OSL was stimulated by Green Light for 100 s, and it was checked out, that it is enough to totally bleach OSL signal to the PM background level. After bleaching the recovery tests were carried out. The results were in good accordance (in the range of 4%) with values of given laboratory dose. Beside recovery tests, the reliability of obtained ED results was monitored with help of recycling ratio. The recycling ratio was obtained during routine SAR measurements for repeated regenerative dose value and aliquots exhibiting incorrect recycling ratio values (usually less than 4 aliquots) were not taken into account for averaging *ED* values. The regeneration doses were fixed to cover the range around *ED* value, and the growth curve was constructed using four points.

Calculations of *DR* were based on the activities of usually 15 isotopes (anyway more than 12). The correction for water content and the component of cosmic radiation were taken into account (Oczkowski and Przegietka, 1998; Oczkowski et al., 2000). The final uncertainty in OSL age estimation (**Table 2**) is mainly influenced by the standard error of the mean *ED* value, calculated by averaging the results obtained for individual aliquots.

## 4. RESULTS AND DISCUSSION

Most of the analysed geological logs contain the series of fluvial deposits accumulated in the environments of the sand-bed braided rivers (channel and overbank sub-environments) (**Fig. 2**). The Mielnica site is the only one which contains lacustrine and deltaic deposits, while the Kołuda Mała site contains the deposits of a sand-bed meandering river. At six sites the upper deposits contain a moraine till cover. At the Baruchowo site the till has been denuded and is presently fund at the background of the investigated exposure. This till, which is about 1 metre thick, makes one bed, both in terms of its age and facies. At the site of Boża Wola the deposits which underlie the till show partly glacitectonic disturbances, which have been already investigated by Roman (2003).

The deposits described above, predominantly the fluvial sands, were the source of 17 samples for the OSL dating. The results prove that the deposits were accumulated during the Saale and the Vistulian Glaciations (**Table 2**).

The deposits exposed at the Baruchowo site have been researched by Roman (2003) and dated using the TL method. The TL results for the sandy silt series of the deposits, found above a layer of fluvial-residual deposits (**Fig. 2**), showed a vast range of the TL dates: (659±188 ka and 669±169 ka for the lower section of the series; 529±185 ka, 915±229 ka and 853±185 ka for the upper section of the series). Roman (2003) assumes these deposits were accumulated during the Saale Glaciation. However, presented results of the OSL dating prove that this series is younger and it was probably accumulated during the Early Vistulian. The big discrepancy between older TL dates (Roman, 2003) and much younger OSL dates received by the authors (**Table 2**) results probably from the worse effectiveness of the bleaching of the TL signal than the OSL signal (Huntley *et al.*, 1985). Highly imprecise TL dates, which are characteristic for the saturation area of TL signal, also suggest insufficient bleaching during the deposit transportation and accumulation.

The sites of Boża Wola and Kołuda Mała show a distinct sedimentation hiatus or erosion of the bed deposits (erosive discordance). The till in these sites is underlain by river deposits of Saale Glaciation. The Nieszawa site contains the deposits which probably come from Early Vistulian and which overlie the series of the Saale Glaciation. At the other investigated sites the studied deposits underlying till were accumulated during the Early and Middle Vistulian (the Mielnica and Gocanówko sites) as well as Late Vistulian (the Raciążek site).

The youngest dating results, of the highest precision (uncertainty of about 3%), were acquired for the deposits underlying till at the Raciążek site: 20.2±0.6 ka and 20.9±0.6 ka (**Table 2**). They unambiguously mean the main stage of the Vistulian Glaciation.

Lithofacial, structural and pethrographic research of the tills as well as the OSL dating proved that besides the Nieszawa site tills, they consist of one bed of till connected with the main stage of the last glaciation. The till is of the same age, but it sometimes differs facially.

At the Nieszawa site four beds of till were distinguished (Wysota *et al.*, 2004; Molewski and Wysota, 2006). The fact that the three lower beds of till differ from the highest bed in terms of the pethrographic composition of their gravels and a clearly diverse directions of the long axis of the clasts proves there exist two, or even three, ice sheet advances. The OSL dating of the deposits underlying this till shows they are closely connected either with the Warthe Glaciation and the main stage of the Vistulian Glaciation or, as it was suggested previously, with the Leszno and Poznań phases of the main stage of the last glaciation (Wysota *et al.*, 2004). As far as the three lower till beds are concerned, the pethrographic analysis indicates the Warthe Glaciation. Thus, it may be concluded this site also belongs to the ones where the Vistulian Glaciation is represented by one bed of till.

Analysing histograms presenting distributions of natural OSL signals (**Fig. 3**) with respect to lithology of dated samples (**Fig. 2**) some remarks on suitability of geological material for OSL dating can be drawn out (**Table 1**). All the samples were collected from rather homogenous and thick enough sediments (may be except BW-1 sample) so one can assume that for particular sample the only source of diversity of natural OSL signal in series of aliquots comes from variety of bleaching conditions experienced by grains during last transport and sedimentation. Hence for poorly bleached samples one can expect wide and asymmetrical shapes of the histograms. The high value of percentage standard deviation *SD* characterising the distribution of natural OSL signal (**Fig. 3**) can be used as a merit of poorly bleached samples. As a matter of fact one can distinguish two sets of samples:

- Badly bleached samples with *SD* value above 40%. These are samples from trough cross-bedded sands (M-9 and G-11) and planar cross-bedded sands (G-12 and KM-14). Such lithology is characteristic for sediments which material was rather rapidly transported and deposited in deep water in a channel of a river. Such environment seems to prevent many grains from sufficient bleaching.
- Well bleached samples with *SD* ranging from 13% to 31 %. These are mainly samples from ripple cross-laminated sands (BW-4, BW-3, BW-2, N-1, N-2 and R-8), and climbing ripple cross-laminated sands (M-10 and R-7), but at last also horizontally bedded sands (B-1, B-3, B-4 and KM-13). It concludes that shallow water and slow transport enables better and more homogenous bleaching.

## 5. CONCLUSIONS

As far as the age is concerned, all the studied sites, excluding the one in Nieszawa, contain only one till bed. It is correlated with the main stage of the Vistulian Glaciation. Such a situation, together with the results of the OSL dating, support the thesis that the Poznań phase in the Kujawy Moraine Plateau is not a separate lithostratigraphic unit and shows a recessive character. Accepting the contradictory thesis, i.e. the one on the transgressive character of the Poznań phase, would mean assuming that either this transgression was accompanied by intense exaration of ice sheet as well as removal of the proglacial deposits or that the margin of the Leszno phase was much smaller in this area than that of the Poznań phase. In such a case the existing till bed would be a sedimentological record of the Poznań phase of the last glaciation.

The assumption that the maximum extent of the main stage in this area took place not earlier than about 21 ka ago (Stankowska and Stankowski, 1988; 1991; Stankowski, 2000) is based on the TL dating of the deposits in the Konin region. The OSL dates from the Raciążek site show that about 21 ka ago the northern part of the Kujawy Moraine Plateau was free from ice sheet. The above data prove the rate of the ice sheet advance in the main stage of the Vistulian Glaciation in the Kujawy Moraine Plateau was fast.

As a conclusion, general rule for collecting samples from fluvial sediments for OSL dating can be expressed: to choose ripple-marked sands, preferably fine sands with wavy-laminated silts and to avoid trough and planar cross-bedded sands, especially coarse-sized sands with gravel.

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**Table 1.** Geological characteristics of the samples and analysis of OSL results.

| Site | Sample name | Lithological features of sampled material | Relative *SD** [%] | Conclusions from OSL results & remarks on environmental conditions of bleaching |
|---|---|---|---|---|
| Boża Wola | BW1 | Sample taken from glaciofluvial (or fluvial) sands and gravel. Structure of this deposit shows glacitectonic disturbances. | 29 | Relatively wide spread of natural OSL signal causes high uncertainty of ED value. The reason could be both: poor bleaching due to glaciofluvial origin (limited day-light exposure) and/or the sampled material consists of grains of various ages ranging from (96 ± 30) ka to ~160 ka and mixed together by glacitectonic disturbances. |
| | BW2<br>BW3<br>BW4 | These samples represent one thick series of fluvial sediments, built of ripple cross-laminated fine sands and wavy laminated silty sands. | 15<br>26<br>22 | The relatively compact histograms of natural OSL signal suggest good bleaching conditions during transport and sedimentation. Well bleached material was deposited in rather shallow and relatively slow-flowing river (flood plain of braided river). The self-consistent OSL age sequence was achieved. |
| Baruchowo | B1<br>B3<br>B4 | Three samples of three series of fluvial sediments. They are mainly built of parallel laminated fine sands and silts (B4), while B1 and especially B3 has admixture of coarse sands. | 31<br>27<br>18 | The material was deposited in rather shallow river (flood plain of braided river) with relatively slow transport (B4) or experiencing periodical variations in flow regime (B1 and B3). What more, quartz grains from sample B4 exhibits features of aeolian transport, which must had occurred prior to the fluvial sedimentation, improving optical bleaching. Relatively broad and symmetric shape of natural OSL signal distribution is responsible for rather high uncertainty of ED assigned for sample B1. This could be connected with periodical variations in flow regime and relatively short transport. It is also reflected by the inversion of OSL ages for samples B1 and B3. |

* Relative standard deviation *SD* [%] representing wideness of natural OSL signal distribution

*The table continues on the next page*

**Table 1.** Geological characteristics of the samples and analysis of OSL results - *continued*

| Site | Sample name | Lithological features of sampled material | Relative *SD** [%] | Conclusions from OSL results & remarks on environmental conditions of bleaching |
|---|---|---|---|---|
| Mielnica | M10 | The sediment is built of fine and medium-grained sands showing climbing-ripple cross-laminated and low-angle inclined-bedded structure. | 30 | The distribution of natural OSL signal has rather broad shape suggesting, that probably the upper part of delta of a river with relatively shallow water but rather massive transport didn't assure appropriate conditions for efficient bleaching. The low uncertainty of ED value was achieved only by careful selection of OSL results. |
| | M9 | The sample taken from coarse sands and gravel forming fluvial sediments showing trough cross-bedded structure. | 66 | The histogram of natural OSL signal exhibits extremely vide and asymmetric distribution of results, indicating serious problems with bleaching efficiency. The day-light exposure was probably limited due to quite deep water and fast transport in channel of a river. ED value is accompanied by rather high uncertainty. |
| Gocanówko | G11<br>G12 | Both samples represents one fluvial series built of medium-grained sands, but G11 has admixture of gravel, while G12 contains some finer sand. Sample G11 shows the trough cross-bedded and G12 planar cross-bedded structure. | 40<br>82 | For both samples there are very wide spreads of natural OSL signal. It causes so high uncertainty of ED values that only their rough estimations are given. Basing on such data OSL ages were calculated, which however can't be treated as absolute ages but rather as very rough approximations. Apparently, the bleaching conditions were very poor in channel of a river, relatively deep underwater. Furthermore, on the base of lithological analysis, one can expect quite fast transport in case of G11 sample. |
| Kołuda Mała | KM13<br>KM14 | Both samples taken from medium-grained and fine fluvial sands. For sample KM14 the planar cross-bedded structure of sediment layers was detected. | 26<br>39 | Sample KM13 shows not very wide spread of natural OSL. Unfortunately, the regeneration doses applied in OSL measurements were not big enough enabling only estimation of lower level of ED value and OSL age. For sample KM14 rather high uncertainty of ED comes from diversity of natural OSL results. Both samples represents channel sediments of meandering river. Especially in case of KM14 one can expect that deep water and fast transport could cause some problems with bleaching of the material. |
| Nieszawa | N1<br>N2 | Both samples represent one thick series of fluvial sediments, built of ripple cross-laminated fine sands. | 22<br>22 | The OSL results exhibit rather compact distribution, suggesting quite efficient bleaching occurring in relatively shallow and slow waters on flood plains of braided river. |

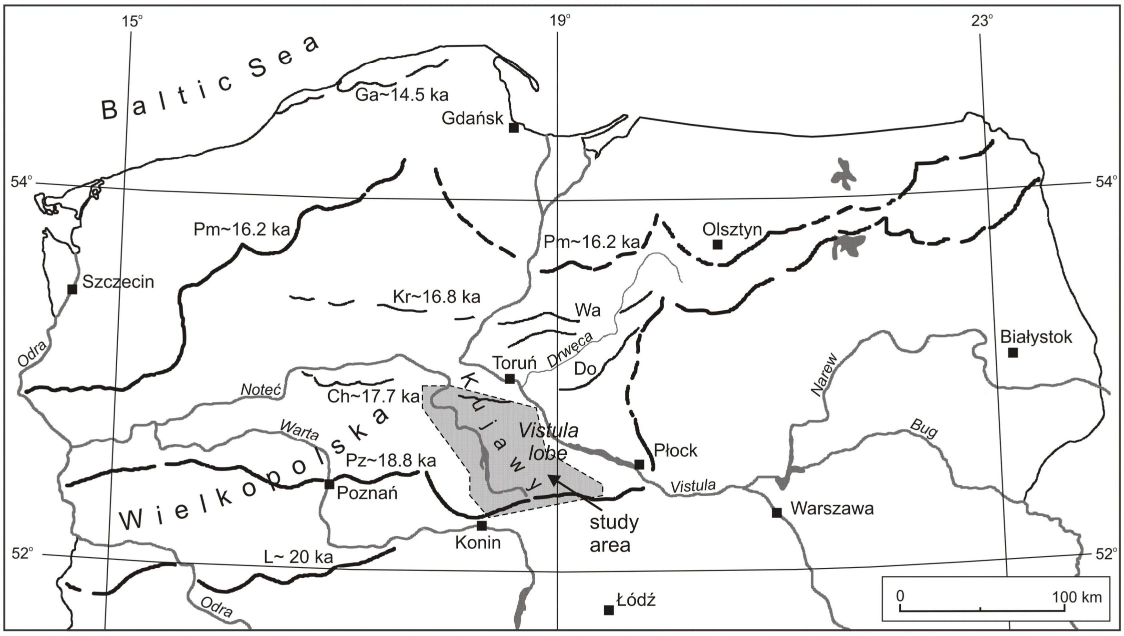
* Relative standard deviation *SD* [%] representing wideness of natural OSL signal distribution

**Table 2.** OSL dates of deposits from Kujawy Moraine Plateau.

| Site | Sample name | Material | Depth [m] | Lab. No. | Equivalent dose *ED* [Gy] | Dose rate *DR* [Gy/ka] | Age [ka] | Stratigraphy |
|---|---|---|---|---|---|---|---|---|
| Boża Wola | BW-1 | Glaciofluvial sands | 3.50 | TPN1 | 104 ± 32 | 1.079 ± 0.005 | >96 ± 30 | ? |
| | BW-2 | Fluvial sands | 4.00 | TPN2 | 229 ± 15 | 1.272 ± 0.005 | 180 ± 12 | SAALIAN |
| | BW-3 | Fluvial sands | 4.55 | TPN3 | 350 ± 23 | 1.272 ± 0.005 | 275 ± 20 | SAALIAN |
| | BW-4 | Fluvial sands | 4.87 | TPN4 | 365 ±24 | 1.272 ± 0.005 | 287 ± 19 | SAALIAN |
| Baruchowo | B-1 | Fluvial sands | 1.30 | T046 | 148 ±19 | 0.979 ± 0.014 | <151 ± 22 | ? |
| | B-3 | Fluvial sands | 4.30 | T048 | 83 ± 5 | 0.781 ± 0.004 | 106 ± 6 | EARLY VISTULIAN |
| | B-4 | Fluvial silts | 11.50 | T049 | 168 ± 10 | 0.516 ± 0.003 | 326 ± 21 | SAALIAN |
| Mielnica | M-10 | Deltaic sands | 3.10 | T007 | 83±6 | 1.693 ± 0.007 | 49 ± 4 | MIDDLE VISTULIAN |
| | M-9 | Fluvial sands | 5.75 | T006 | 81±11 | 0.945 ± 0.004 | 85 ± 12 | EARLY VISTULIAN |
| Gocanówko | G-11 | Fluvial sands | 3.20 | T001 | ~28 | 0.763 ± 0.003 | ~37 * | VISTULIAN? |
| | G-12 | Fluvial sands | 3.60 | T002 | ~37 | 0.612 ± 0.003 | ~60 * | VISTULIAN? |
| Kołuda Mała | KM-13 | Fluvial sands | 2.95 | T003 | >125 | 0.634 ± 0.003 | >197 | SAALIAN |
| | KM-14 | Fluvial sands | 3.70 | T004 | 157±18 | 0.565 ± 0.003 | 278 ± 33 | SAALIAN |
| Nieszawa | N-1 | Fluvial sands | 5.75 | T043 | 200+/-9 | 1.810 ± 0.010 | 110 ± 5 | EARLY VISTULIAN? |
| | N-2 | Fluvial sands | 6.60 | T044 | 115+/-9 | 0.796 ± 0.003 | 144 ± 11 | SAALIAN |
| Raciążek | R-7 | Fluvial sands | 5.45 | TPN5 | 39.2±1.2 | 1.874 ± 0.009 | 20.9 ± 0.6 | LATE VISTULIAN |
| | R-8 | Fluvial sands | 6.70 | T005 | 37.1±1.1 | 1.840 ± 0.009 | 20.2 ± 0.6 | LATE VISTULIAN |

* mean value from numerous aliquots with a large *ED* scatter

**a**




**b**

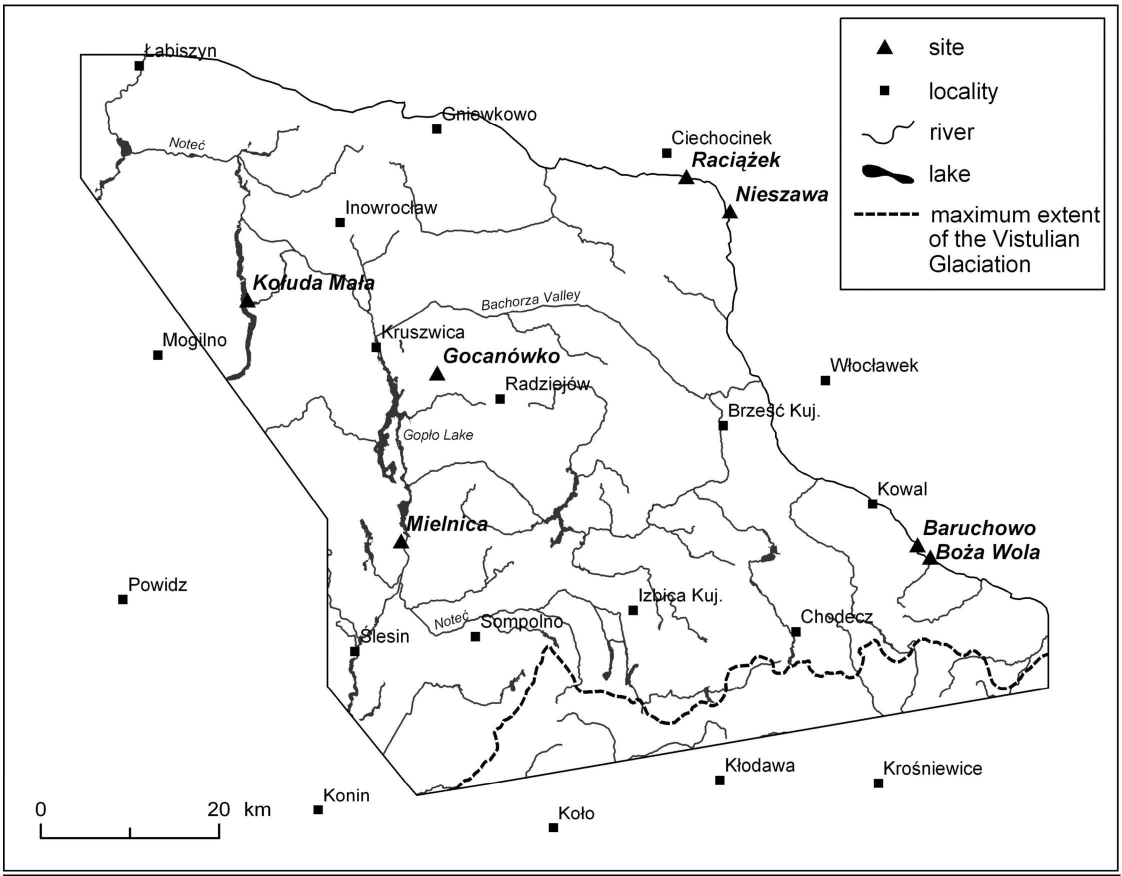



***Fig. 1.** Study area: a – location against the last ice sheet margines in Poland (after Kozarski, 1995); L – the Leszno phase, Pz – the Poznań phase, Ch, Do – the Chocież and Dobrzyń subphases, Kr, Wa – the Krajna and Wąbrzeźno subphases, Pm – the Pomeranian phase, Ga – the Gardno phase; b – location of the research sites.*

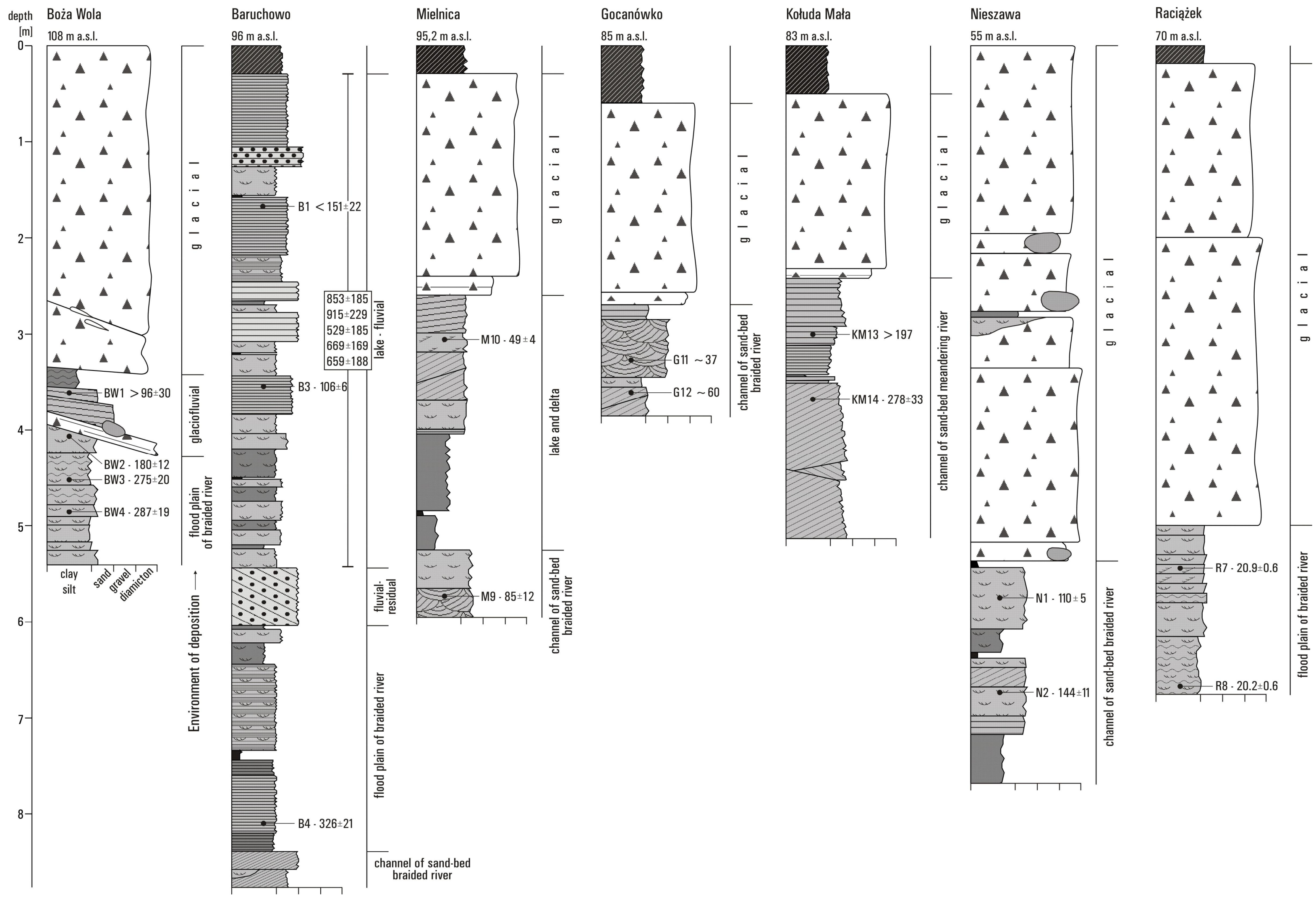



***Fig. 2.*** *The studied geological logs from the Kujawy Moraine Plateau with OSL dates obtained for investigated fluvial deposits. For Baruchowo log the TL dates of Roman (2003) are printed in a frame located on the border. (Both OSL and TL ages are given in ka).*

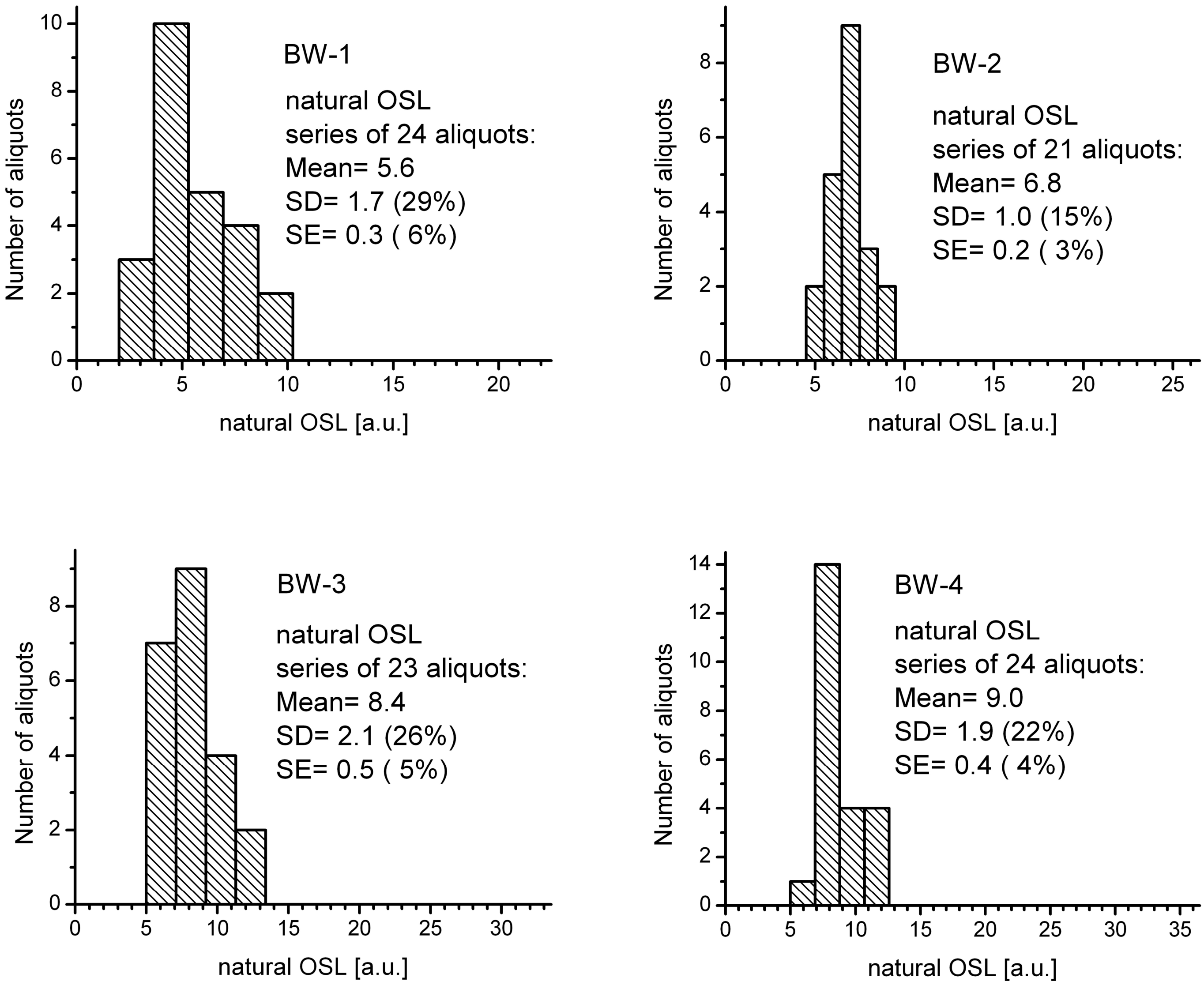



**Fig. 3.** The histograms showing distributions… *continues on the next page*

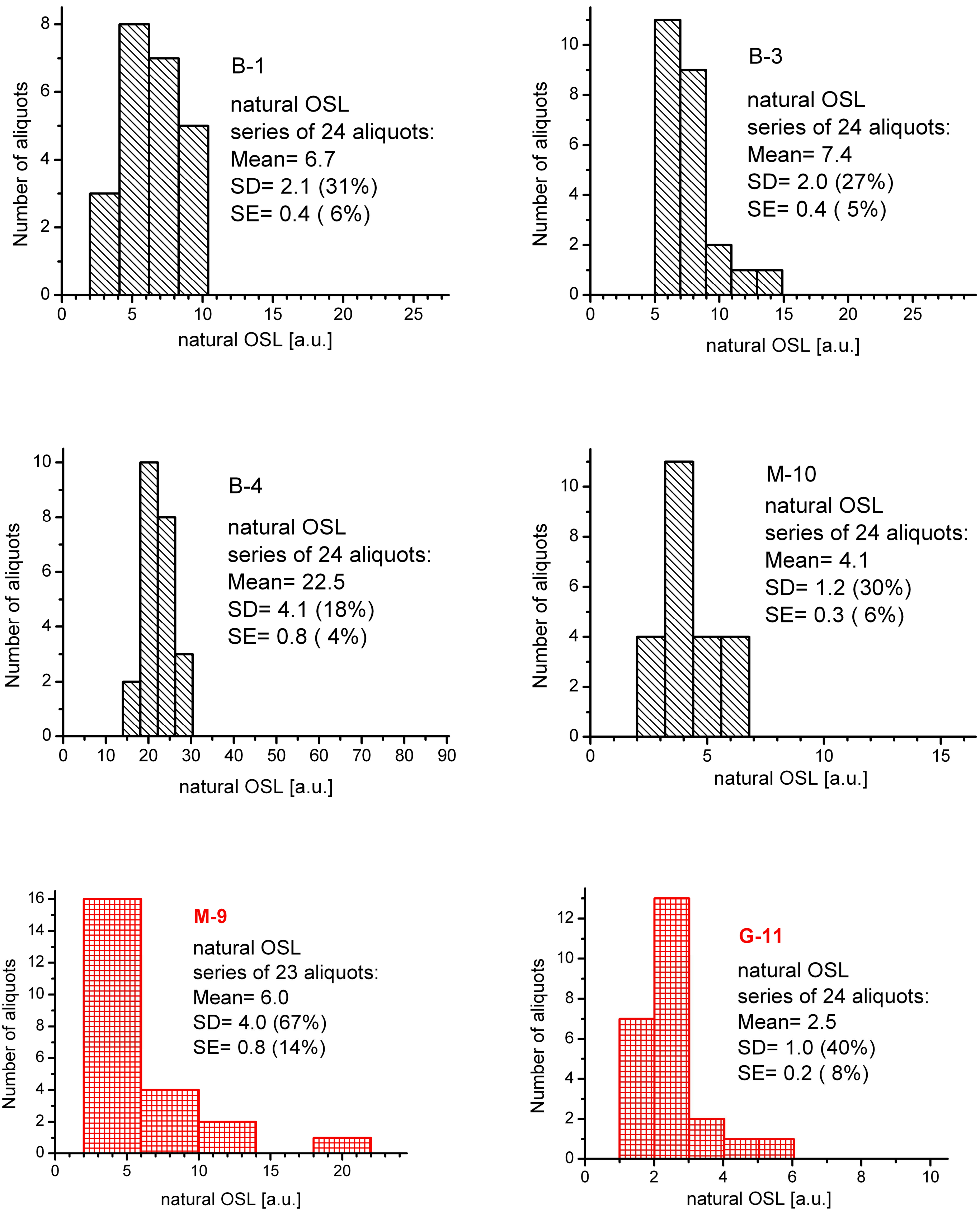



**Fig. 3.** The histograms showing distributions… *continues on the next page*

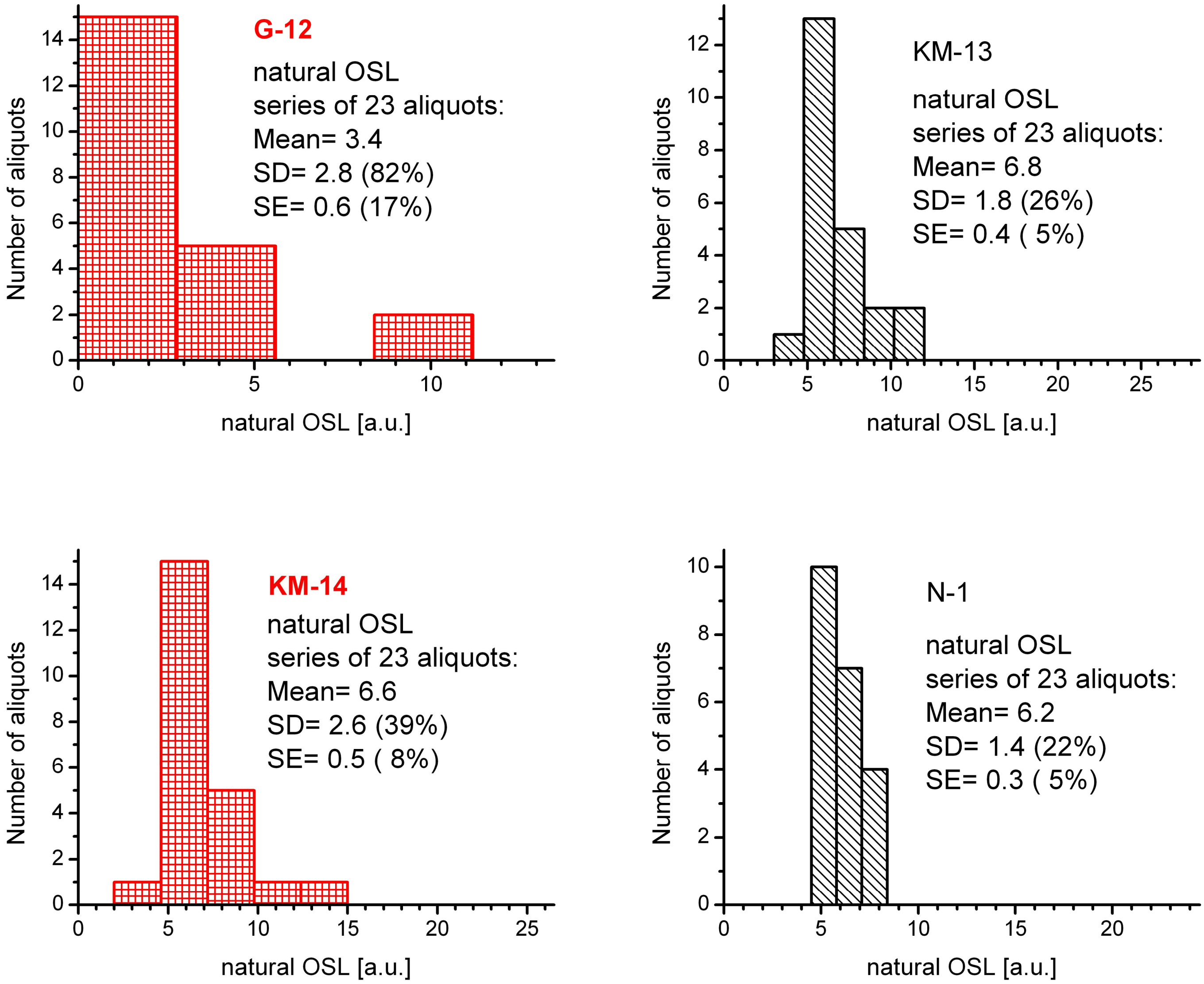



**Fig. 3.** The histograms showing distributions… *continues on the next page*

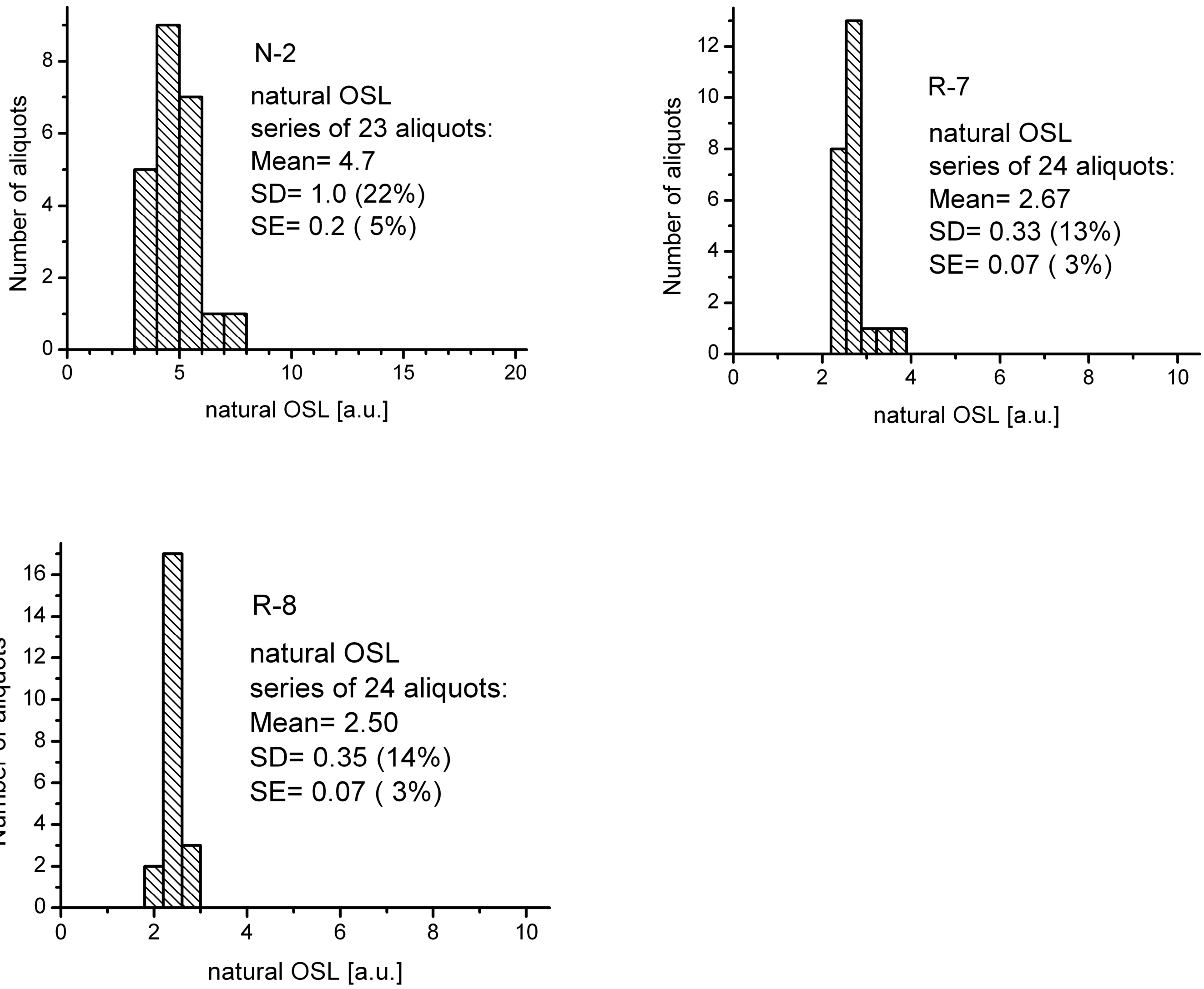



***Fig. 3. - continued***

***Fig. 3.*** *The histograms showing distributions of calibrated natural OSL signal (corrected for* aliquot to aliquot variations of OSL intensity*). For each aliquot the natural OSL signal was obtained by integrating natural OSL decay curve in the range of the first 1.2 seconds. Then, natural OSL signal was calibrated by dividing this value by the sum of light calculated for the first 1.2 seconds from OSL decay curve obtained after applying the test beta dose. Standard preheat (for 10 s at 240$^o$C) was performed prior to read out of both the natural and calibration OSL curves (at 125 $^o$C). SD denotes for standard deviation and SE is standard error. The poorly bleached samples are marked in red colour.*