Geology, stratigraphy and palaeoenvironmental evolution of the *Stephanorhinus kirchbergensis*-bearing Quaternary palaeolake(s) of Gorzów Wielkopolski (NW Poland, Central Europe)

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Abstract

The sedimentary succession exposed in the Gorzów Wielkopolski area includes Eemian Interglacial (MIS 5e) or Early Weichselian (MIS 5d-e) deposits. The sedimentary sequence has been the object of intense interdisciplinary study, which resulted in the identification of at least two palaeolake horizons. Both yielded fossil remains of large mammals, alongside pollen and plant macrofossils. All these proxies have been used to reconstruct the environmental conditions prevailing at the time of deposition, as well as to define the geological context and the biochronologic position of the fauna. OSL dating of the glaciofluvial layers of the GS3 succession to 141,4±3,0 (below the lower palaeolake) and 79,0±1,5 ka (above the upper palaeolake) indicate that the site formed during the Middle-Late Pleistocene (MIS 6-MIS 5). Radiocarbon dating of the lacustrine organic matter revealed a tight cluster of Middle Pleniglacial Period (MIS 3) ages in the range of ~41-32 ka cal BP (Hengelo – Denekamp Interstadials). Holocene organic layers have also been found, with ¹⁴C ages within a range of

4,330 – 4,280 cal. BP (Neolithic). Pollen and plant macrofossil records, together with sedimentological and geochemical data, confirm the dating to the Eemian Interglacial.

Introduction

A well-preserved, nearly complete skeleton of a tandem-horned rhinoceros *Stephanorhinus kirchbergensis* (Jäger, 1839) has recently been found at an Eemian Interglacial site near Gorzów Wielkopolski, in NW Poland. The remains have been discovered in 2016 during works along S3 Polish national road. They were located at the southern end of an escarpment along the road. The skeleton was preserved in a succession that had accumulated in a small, shallow kettle palaeolake formed during the Scandinavian ice-sheet retreat. The Gorzów deposits belong to at least two limnic cycles, an older one, dating to the Eemian Interglacial (MIS 5e), and an overlying one of Mid-Weichselian (MIS 3) age; the rhinoceros remains were preserved in a gyttja layer of the former unit. Besides the skeletal remains of *Stephanorhinus kirchbergensis*, the site also yielded an isolated left metacarpal bone of fallow deer, *Dama dama* from the basal part of a peat layer that lies over the rhinoceros-bearing gyttja. The rhinoceros skeleton includes the cranium, with full dentition, and almost 120 postcranial bones; the lumbar and caudal part of the spinal column, as well as the left hind limb and a few minor bones were not preserved. All the bones are exceptionally preserved; the skull of the rhinoceros suffered diagenetic crushing, and damages caused by the roadworks.

In the European Lowland area, Eemian Interglacial and Early Weichselian deposits are usually found south of the limit of maximum extension of the Weichselian (Vistulian) glaciation (Marks et al., 2016), whereas within the post-Weichselian areas they are reported only from boreholes and pits (Fig. 1). Up until now, only a few Eemian Interglacial sites were known in NW Poland, and palynological and malacological analysis had been performed in only five of them, i.e. Radówek (Urbański and Winter, 2005), Rzecino (Mirosław-Grabowska, 2008; Winter et al.,

2008; Niska and Mirosław-Grabowska, 2015), Rusinowo (Stark et al., 1932), Słubice (Skompski, 1980; Alexandrowicz and Alexandrowicz, 2010) and Nakło (Noryśkiewicz, 1978). Further to the west, Eemian deposits have been documented around the municipality of Poznań and the southern region of Wielkopolska (Straszewska and Stupnicka, 1979; Kuszell and Malkiewicz, 1999; Bruj and Roman, 2007). From the German Brandenburg and Mecklenburg regions, sediments of Eemian age have been reported by Eissmann (2002), Brose et al. (2006), Hermsdorf and Strahl (2008) and Rother et al. (2017). Middle Pleniglacial deposits of the same age as the upper peats horizon from section GS3 (Fig. 1) of Gorzów Wielkopolski occur in brown-coal open-cast mines in the region of Lausitz (Eastern Germany) (see Mol, 1997; Bos et al., 2001). Kozarski et al. (1980) found Brørup strata in a brickyard nearby Drezdenko (Stary Kurow). Only a few Eemian and Early Weichselian mollusc faunas from these sites were described (Skompski, 1996; Alexandrowicz and Alexandrowicz, 2010), whereas no vertebrate remains had ever been found preserved in situ until now. Other fossil-bearing localities with remains of large mammals are Imbramowice, near Wrocław (Marciszak et al., 2017), Warsaw (Czyżewska, 1962; Borsuk-Białynicka and Jakubowski, 1972), and Konin (Lorek, 1988), and still other similar sites are known in Eastern Germany (Kolfschoten, 2000; Eismann, 2002; Gaudzinski-Windheuser et al., 2014). The nearly complete skeleton of *Stephanorhinus kirchbergensis* (Jäger, 1839) from Gorzów Wielkopolski is therefore key reference for the analysis of the Central European Eemian/Early Weichselian. This study presents the preliminary results of an interdisciplinary research project aimed at performing an in-depth analysis of the rhinoceros from Gorzów Wielkopolski. The paper focuses in particular on the environmental conditions under which the animal lived, as well as on later environmental changes.

Regional setting - study area

The studied area is located in NW Poland (Fig. 2), ca. 6 km to the W of Gorzów Wielkopolski municipality (51°43' N; 15°10' E), along a deep constructional excavation along the S3 national road. The road now cuts through the valley escarpment separating Gorzów Plain, to the north, from the ice-marginal valley of Toruń-Eberswalde to the south. Gorzów Plain is a vast ground morainic plateau intercalated with outwash plain deposits, formed during the maximum extension of the Weichselian glaciation in Western Poland (Germany – Brandenburg phase; Poland – Leszno phase) when, during its climax, the glacial sheets reached the Leszno area, ca. 90 km south of the studied area (Fig. 2A). The ground moraine area is drained to the south by a system of syn- to post-glacial channels, which form a dense network of small erosional, mostly dry, deeply-incised valleys that cut through the morphological crevasse. Gorzów Plain is between 70 to 90 m high a.s.l., whereas the base of the Toruń-Eberswalde valley reaches 18-20 m a.s.l. The fossil bones were found at site GS3 (Fig. 2C); they were preserved in a narrow melt-out depression filled with Eemian lacustrine calcareous gyttja (Fig. 3). Two limnic horizons occur in the central GS3 section (Fig. 4A): the lower one is a lacustrine unit of Eemian age, the upper one is of Weichselian (Vistulian) age. The lacustrine succession is capped by a peat bog deposit (Fig. 4-6), whereas the upper horizon by glaciofluvial and glacial beds. Section GS1 includes about 11 m of lacustrine deposits that end with fine and medium sands interbedded with silty sands. Section GS2 includes 13.5 m of uniform, unsorted, glaciofluvial sands and gravels. The entire GS2 profile is perhaps an older, presumably Saalian glaciofluvial sequence, possibly correlated with the basal parts of the GS1 and GS3 successions (Fig. 3, 4).

Methods

Fieldwork and sampling strategy

Geological and geomorphological maps of the Quaternary strata exposed along a road cut nearby Gorzów Wielkopolski were developed based on a geodetic survey that served to establish a series of cross-sections through which the spatial extent of the extinct lake deposits

was defined (Fig. 6). A Leica SR530 dual-frequency GPS RTK receiver supplied with a VRS net correction device was used for the geodetic survey. Geochemical, sedimentological and environmental reconstructions were based on evidence collected from sections of ca. 11 m of the GS1 (Tab. 1, 2) and GS3 (Tab. 3, 4) successions (Fig. 2C, 3). Moreover, radiocarbon and optically stimulated luminescence dating were performed to define the chronological extent of the exposed sediments (Tab. 5, 6). The GS1, GS2 and GS3 sequences were located on the west side of the S3 road, and section GS4 on the east (Fig. 5, 6). After angle correction, the four sections GS1-GS4 reached the total thicknesses of 21.5, 13.5, 22 and 23 metres, respectively (Fig. 3, 6). A comparative Raław profile (Fig. 3) was built based on a sketchy description of the section drilled by the cartographic borehole no. 62 (Piotrowski et al., 2010). Detailed sedimentological, geochemical, palynological and plant macrofossil analyses have been performed of the GS1, and GS3 sections (Figs. 7-10) aimed to define the characters of the palaeolake deposits and the environmental context in which they accumulated.

Geochemical and sedimentological analyses

A total of 171 and 181 sediment samples were analysed from the sections GS1 and GS3, respectively (Fig. 7, 8); a constant sampling pace of 6 cm per ca. 11 metres was maintained for the lacustrine sediments of the GS1 sequence as well as for the bottom part of the GS3 section. All samples were freeze-dried in a Beta 1-8 LD plus Lyophiliser (Christ). Following homogenisation, some samples were analysed for grain size distribution, using a Mastersizer 3000 laser grain size analyser (Malvern Instruments Ltd.). This permitted to determine the relative percentages of the different grain size fractions, as well as to calculate graphically, according to Folk and Ward (1957), their major properties: mean grain diameter (MD), standard deviation (SD), skewness (Sk), and kurtosis (KG). In addition, loss on ignition at 550°C was calculated on about 2 g sediment samples dried at 105°C to estimate the percentages of organic

and mineral matter content. The organic matter-deprived ash remaining after sediment combustion was treated with 2 ml 10% hydrochloric acid and 2 ml hydrogen peroxide in a Speedwave microwave mineraliser (Berghof). Atomic absorption spectrometry assays of the solutions obtained, aimed at revealing their content of Na, K, Ca, Mg, Fe, Mn, Cu, and Zn, were conducted using an AAS SOLAAR 969 spectrometer (Unicam). The air-dry sediment samples were also used to determine per cent contributions of total carbon, total nitrogen, and total sulphur, using a VARIOMAX CNS analyser (Elementar). All the lithological and geochemical analyses were carried out at the laboratory of the Geology and Palaeography Unit of the University of Szczecin. The data were subjected to statistical treatment, primarily with Microsoft Office Excel software as well as with PAST Palaeontological Statistics (Hammer et al., 2001) to identify geochemical horizons. The grain size data were stored and processed using GRADISTAT software (Blott and Pye, 2001), and C2 programme (Juggins, 2007) was used to visualise the results of laboratory analyses.

Bone remains

The teeth of the rhinoceros were measured according to Van der Made (2010) and Shpansky (2016), and the postcranial bones following Gromova (1935, 1960), Guérin (1980) and Van der Made (2010); Von den Driesch (1976), Di Stefano (1996), Lister (1996) were used for the measurement and identification of the metacarpal bone of fallow deer.

Pollen and plant macroremains

Thirty-five samples for pollen analysis were collected from a depth of 10.26 to 1.38 m (from bottom to top) of section GS3 (Fig. 9). The samples were acetolyzed according to Erdtman's method (1960). Before acetolysis, a tablet containing Lycopodium spores per 1 cm³ was added to each sample as a quantitative indicator (Stockmar, 1971; Berglund and Ralska-Jasiewiczowa, 1986). Pollen spectra were counted on two slides from a surface area of 20x20 mm routinely up to a total of ca. 500 grains. Thirty-eight samples, each of 150 ml of sediment, were collected

for plant macroremains analysis from a depth of 10.26-2.10 m of section GS3, at an average pace of 10-40 cm (the same adopted for the pollen sampling). The samples were macerated with 10% KOH, boiled to a pulp, and wet-sieved using a ϕ 0.2 mm mesh sieve. The concentrated sieved residue was then sorted under a stereoscopic microscope. Plant remains that could be identified were selected and placed in a mixture of glycerine, water and ethyl alcohol (1:1:1) with the addition of thymol. Macrofossils were identified with the use of keys, atlases (e.g. Cappers et al., 2006; Velichkevich and Zastawniak, 2006, 2008), literature data, as well as using a reference collection of present-day seeds and fruits, as well as collections of fossil floras housed in the Palaeobotanical Museum of the W. Szafer Institute of Botany of the Polish Academy of Sciences, Kraków. Qualitative and quantitative results of the plant macrofossil analysis are presented in a diagram (Fig. 10) plotted with POLPAL software for Windows (Nalepka and Walanus, 2003). Local Macrofossil Assemblage Zones (L MAZ) were distinguished in the diagram of macroscopic plant remains from section GS3; they were numbered and labelled, from base to top, GS3-M1 to GS3-M8.

Geochronological data

Three optically stimulated luminescence datings (OSL; Fig. 11, Tab. 6) and five radiocarbon ^{14}C datings (Tab. 5) were performed for representative stratigraphic horizons of sections GS3 and GS4 (Fig. 3-5). All OSL measurements were made on individual quartz grains by the Department of Radioisotopes of the Silesian University of Technology, according to standard procedures (for details see Aitken, 1998; Galbraith et al., 1999; Murray and Wintle, 2000; Guérin et al., 2011). OSL datings were obtained from samples of glaciofluvial sands collected from three different levels of section GS3. The samples were collected with steel tubes (1) 21.8 m b.s.l. at the bottom of the lower palaeolake section; (2) 16.5 m b.s.l., from a ca. 2 m-thick interlayer between the two lacustrine successions and (3) 10.5 m b.s.l., ca. 0.5 m at the top of the upper (second) palaeolake section. Dose rates were calculated using the conversion factors

of Guerin et al. (2011). For beta dose rate the cosmic ray dose-rate to the site was determined as described by Prescott and Stephan (1982). Sand-sized grains of quartz (90–200 μm in diameter) were extracted from the sample using standard purification procedures (e.g., Aitken, 1998). All OSL measurements were made using an automated Risø TL/OSL DA-20 reader for multi-grain aliquots, each of ca. 1 mg. The stimulation light source was a blue ($470 \pm 30 \text{ nm}$) light emitting diode array (LED) delivering 50 mW/cm² at the sample (Bøtter-Jensen et al. 2000). Detection was through 7.5 mm of Hoya U-340 filter. Equivalent doses have been determined using the single-aliquot regenerative-dose (SAR) protocol (Murray and Wintle, 2000). Final OSL ages have been calculated using the Central Age Model (Galbraith et al. 1999) and presented on radial plots. Plant macrofossils and peat of the upper palaeolake succession of GS3 and two peat layers of section GS4 have been radiocarbon dated: the upper layer of GS4 is located in a hollow on the top of glacial till and a lower one just below the base of glacial succession (Fig. 3-5, Tab. 5).

Results

Lithology and geochemistry

Section GS1

Lithological and geochemical analyses of ca. 11.5 m of limnic deposits at the bottom of section GS1 (Fig. 4B, 7; Tab. 1, 2) revealed the clear dominance of silt fractions in the range from about 60 to 90%. The highest admixture of sand fractions was found in the upper part of the succession, from 0.0 to about 3.5 m (Fig. 7A). In the middle of the stratified sequence, at 3.5–9.5 m, features a minor share of fine sand. It is only below 9.5 m that the relative amounts of both medium and fine sand markedly increase. The mean grain size (M_z) of the limnic deposits ranges between 5 and 7 ϕ units. Sorting (SD) varies but gradually increases moving downward along the sequence. Most grain size distributions are negatively skewed (Sk); symmetric and

positively skewed distributions occur only at 2-3 m of the GS1 section. Kurtosis (KG) ranges from values higher than 1.1, in the bottom part of the succession, to 0.7-0.8, in the upper part. Organic matter (Fig. 7B) is distributed almost homogenously throughout the section, and varies from about 4 to 6%; only between 10.5-11.1 m it reaches values of 8-11%. The organic matter content correlates significantly with the concentrations of total sulphur and iron (Tab. 2). Total carbon content in the limnic deposits tends to decrease gradually moving downwards along the section and is most strongly and positively correlated with calcium, magnesium, and total nitrogen. On the other hand, negative correlations were obtained with zinc, potassium, and sodium. The highest total nitrogen concentrations were recorded between about 0.75-4.0 m and 7.0-7.3 m. The total sulphur concentration remains virtually stable at about 0.015% in the upper and middle part of the sequence, while in the lower half it rises from 0.015 to 0.045 %. Total sulphur concentrations increase steadily, peaking in the organic-matter-rich layer at 8-11 m. Noteworthy is also a strong, positive correlation between total C, total N and Ca concentrations. Na/K and Fe/Mn concentrations remain stable in all but the lower part of the section, where higher values are reached. No significant variations were observed in the concentrations of other chemical elements.

Section GS3

The ca. 11 m of section GS3 analysed for this study includes gyttja, limnic chalk, silty sand and peat layers (Fig. 4A, 8; Tab. 3). There is a dominance of silts, mixed with minor amounts of fine and very fine sand. Sands characterise in particular the middle part of the section, at around 4.5–6.0 m; they lay over 60 cm of black peat (Fig. 4A). Mean grain sizes (Mz) range around 5–6 ϕ units; sorting (SD) constantly reaches 1.5 ϕ (Fig. 8A). Skewness (Sk) changes remarkably only at the bottom and in the central part of the section, ranging from -0.2 to 0.5 ϕ . Kurtosis (KG) is persistently one ϕ all but at the very bottom (10.5 m) of the sequence. Geochemical analyses revealed significantly high Ca content (200–320 mg/g) in the limnic facies and

elevated levels of organic matter at 0–2 m and 6.5–7.0 m (Tab. 4). The highest values of the total carbon, nitrogen and sulphur indexes occur at a transition from the organic mud to peats. Ca/Mg and Na/K indexes reach the highest values in the gyttja/limnic chalk horizons, whereas Fe/Mn increase significantly for the peat horizon. Na+K+Mg/Ca ratio reaches maximum values at 0–2 m and 4.5–6.5 m, and is negligible elsewhere. Six geochemical zones have been identified in section GS3.

Palaeobotanical analysis

The frequency of pollen was from high to very high. The results of the pollen analysis of section GS3 are presented graphically in a percentage pollen diagram (Fig. 9) plotted using POLPAL software for Windows (Nalepka and Walanus, 2003); 12 Local Pollen Assemblage Zones (LPAZ) could be distinguished, based on the samples GS3-1 to GS3-12.

Cool climatic conditions, typical of final glacial phases, prevailed when organic sediments started accumulating in the lake (GS3-1 *Betula*-NAP L PAZ, Fig. 9). The Late Saalian (Wartanian) glaciation was characterised by very deforested landscapes, rarely overgrown with *Betula*, *Juniperus* and with a very few trees of *Pinus*. On the other hand, there were numerous steppe communities with Poaceae and *Artemisia* as well as tundras with *Betula nana* and *Cyperaceae* (Fig. 9). During this period, at the level of GS3-M1 L MAZ (Fig. 10) the local vegetation was initially dominated by Characeae, which appeared in the lake. At the bottom of the reservoir, they occurred in communities that preferred clear water rich in calcium carbonate, which encrusted their thalli. As a result, the sediment was supplemented with calcium carbonate.

The beginning of the Eemian Interglacial was marked by the development of bright and open birch-pine forests (GS3-2 *Betula*-*Pinus*), with an admixture of *Ulmus* in more humid places (GS3-3 *Pinus*-*Betula*-*Ulmus*; Fig. 9). Herbaceous vegetation was becoming increasingly rare at the time, which indicates a significant increase of tree crowns density and that climatic

conditions had improved. Then forests evolved into the *Quercetum mixtum* communities (GS3-4 *Quercus-Fraxinus-Ulmus*), in which *Quercus* became dominant, and *Pinus* was abundant. There was a characteristic small increase in the participation of herbaceous plants, which indicate that these communities have become brighter again. The first four L PAZs are included in a thin layer of sediment (36 cm), which indicate a slow rate of sedimentation or compaction of sediment. In the level of GS3-M2 L MAZ (Fig. 10), the local presence of several tree species growing close to the shore of the lake is confirmed by the fruits and fruit scales of *Betula* sect. *Albae*, fruits *Alnus glutinosa* as well as by the remains of *Pinus sylvestris*. At that time there were already communities similar to contemporary reed bed with *Typha* sp. in the lake. *Najas marina* and *Nuphar lutea* appeared at this time, which indicates that the water in the reservoir had grown progressively warmer.

The appearance of *Corylus* in association with *Quercus* (GS3-5 *Corylus-Quercus-Alnus*) and, successively, also with *Tilia cordata* (GS3-6 *Corylus-Tilia-Alnus*) indicates a further improvement of climatic conditions. *Alnus* was also important at this time; it was accompanied by *Ulmus* and *Fraxinus*, which indicates the development of riparian communities. In addition to the macroremains of birch, pine and alder, the level of GS3-M3 L MAZ provided also remains of *Tilia platyphyllos*, which indicates the local presence of this other species of lime in the vicinity of the reservoir. The communities of largely rooted macrohydrophytes were dominated by floating species, among which *Najas marina*, *Nuphar lutea*, *Brasenia* sp., and *Trapa natans*.

The climatic optimum of the Eemian Interglacial was characterised by the development of oak-hornbeam forests, including *Carpinus*, *Corylus*, *Quercus* and *Tilia cordata*, as well as of riparian forests, mainly represented by *Alnus* (GS3-7 *Carpinus-Corylus-Alnus*; Fig. 9). The upper part of the level of GS3-M3 L MAZ (Fig. 10) provided fruits of *Carpinus betulus* and nuts of *Corylus avellana*, while in the lake, alongside other species characteristic of the climate

optimum, such as *Brasenia* sp., and *Trapa natans*, *Najas marina* was ever more present. The level of GS3-M4 L MAZ, which is also included in time period of the climatic optimum, was characterised by an increased presence of rush vegetation, including *Cladium mariscus*, *Typha* sp. and *Schoenoplectus lacustris*. The very significant increase in the proportion of peat vegetation such as *Eleocharis palustris* and *Carax pseudocyperus*, versus the preceding zones most likely results from gradual shallowing of the basin and intensive overgrowth of its shores. The disappearance of *Carpinus*, which was gradually replaced by pinewoods including *Picea*, *Abies* and *Pinus sylvestris*, indicates a climatic and soil deterioration (GS3-8 *Picea-Abies-Carpinus*). As a consequence, *Pinus* completely dominated the surrounding landscape (GS3-9 *Pinus*; Fig. 9), which is tantamount to the approaching end of the Eemian Interglacial. The results of the analysis of macroremains from level GS3-M5 L MAZ (Fig. 10) indicates that the reservoir was progressively infilling with sediments. The diaspores of aquatic plants have disappeared, and peat vegetation, with numerous mosses and sedges, begins to dominate. A dwarf birch appeared again in the environment, and this indicates the deterioration of climatic conditions.

The cooling of the climate at the beginning of Weichselian Glaciation is confirmed by the dwindling and significant withdrawal of woody communities. A characteristic element of this time was *Calluna vulgaris*, together with numerous herbaceous plants (GS3-10 *Calluna vulgaris*-NAP-*Pinus*); *Juniperus* and *Pinus* also appeared in this period (Fig. 9). The reservoir became shallow and was dominated by *Sphagnum*, which created peat bog. Humid areas were inhabited by tundra communities, typified by the presence of *Betula nana*. The depletion of species, the drop in frequency of plant macroremains in all the ecological groups present in the GS3-M6 L MAZ level and the highest amounts of sclerotia of *Cenococcum geophilum* in the entire sequence indicate that strong processes of resedimentation were underway along the

banks of the reservoir, which explains the numerous occurrence of thermophilic trees pollen (Fig. 10).

Further cooling led to the withdrawal of *Pinus*, as well as to the spread of a pioneering and heliotropic birch-tree in a landscape dominated by herbaceous communities (GS3-11 *Betula*-NAP). Relatively stable, but cool climate, led to the development of rare pine and birch forests mixed with herbaceous vegetation (lower part of GS3-12 *Pinus*-*Betula*, Fig. 9). The numerous macroremains of dwarf birch (*Betula nana*) at the level GS3-M7 L MAZ indicate an increase in the amount of shrub-tundra-type vegetation surrounded by a lake. The aquatic vegetation of *Potamogeton filiformis* is also indicative of cold climatic conditions. The results of the plant macroremains analysis in the last determined level GS3-M8 L MAZ correlate with those of the palynological analysis performed in the upper part of the level GS3-12 L PAZ, where variable values of *Pinus* and *Betula* indicate fluctuations in unstable climatic conditions, but with a slight warming trend. The transition of from *Najas marina* and *Najas flexilis* aquatic plant assemblages at this level may indicate a slight short-term improvement of climatic conditions, while *Characeae* oospores denote a new deepening of the palaeolake (Fig. 10). Palaeobotanical analyzes of other samples from section GS3 are in progress.

Bone remains

Some bones of *S. kirchbergensis* were found still preserved in anatomical connection; others were disarticulated and displaced (Fig. 4F). The bones surfaces are virtually unabraded and unaffected by weathering. They show no evidence of hunting or butchering by humans, nor of carnivore ravaging. The teeth are heavily worn, which indicates that the individual reached a relatively old age. Based on the size of its long bones, the individual stood about 182 cm at the withers, which makes it one of the largest known representatives of the species. Its size probably discouraged predators from attacking it.

The fallow deer from Gorzów Wielkopolski is the earliest known representative of *D. dama* in the Polish fossil record. Up to this moment, the only known fossil remains of fallow deer were known from the Lower Pleistocene (MIS 58-40) deposits of Żabia Cave, which are assigned to *Dama* cf. *farnetensis* (Stefaniak, 2015). Other finds of fallow deer, mentioned in earlier literature (Kowalski, 1959; Czyżewska, 1989) are reported from historical sites and are now lost to record. The extant *D. dama* was introduced in Poland in the early Middle Ages as a park animal (Kowalski, 1959; Czyżewska, 1989). This discovery adds to the list of Polish Interglacial faunas.

Geochronological data

Combined optically stimulated luminescence and radiocarbon dating of the GS3 sequence (Fig. 3) revealed a time period ranging from the Late Saalian (ca. 140 ka) to the Mid-Holocene (ca. 5 ka). OSL results were obtained on quartz grains collected from basal, central and upper inorganic horizons under, between and over, respectively, the lower and upper palaeolake deposits. All OSL dated samples failed statistical $P(\chi^2)$ homogeneity test, therefore they could be interpreted in the context of mixture model as representing different age populations with age dispersion for individual sample bracketing between 6.4 to 16% (Fig. 11). However, in our interpretation we do refer more likely to the central age model when discussing the OSL results, as the statistical approximation of each dataset, bearing in mind the OSL method limitations. The OSL central ages are in the range between $141,4 \pm 3,0$ and $79,0 \pm 1,5$ ka (Tab. 6, Fig. 11) and regularly grow younger toward the top of the sequence. The upper palaeolake, macrofossil-bearing, organic-rich, black peat horizon laying just above the OSL-dated GdTL-2831 sample ($79,0 \pm 1,5$ ka) was radiocarbon dated. This sample gave an age of 40,661 cal median years BP (Tab. 5). Radiocarbon datings of four samples collected from middle and upper peat horizons (Fig. 5B) of section GS4 yielded two groups of ages: the oldest (36,172 – 33,236 cal med yr BP) were recorded in the middle peat and can be referred to the Mid-Pleniglacial (MIS3) phase;

the youngest Mid-Holocene ages (4,940 – 4,852 cal med yr BP) were recorded in the peat located on top of the glacial till. The OSL datings defined the minimum age of glaciofluvial sequence that deposited before formation of first, Eemian palaeolake, whereas the radiocarbon ages place clearer chronological limits to the history of the evolution of the younger palaeolake.

Discussion

The results of lithological and geochemical studies of the sediments filling the analysed sedimentary basin, as well as the radiocarbon and OSL ages and the results of the palaeobotanical analysis, delineate distinct stages of evolution of the palaeolakes (see Table 7 for summary). The local stratigraphic succession starts to deposit at ca. 170-180 ka during the Late Saalian (Wartanian) glaciation in a glacial/glaciofluvial environment, as indicated by the oldest OSL dated quartz grains, some time before the formation of the lower palaeolake (Fig. 12). The lake began to develop in the Early Eemian coinciding with climate warming; carbonate gyttja accumulated, together with a fairly significant amount of allochthonous minerals. In the coastal zone, sandy material reached the basin; a quite significant proportion of it was found in the lower part of section GS1 (Fig. 4B). During this phase, the lake was supplied not only by calcium carbonate-rich groundwater but also, to a large extent, by surface waters, which brought in allochthonous materials (Fig.8). The high proportion of manganese and iron oxides and hydroxides in the sediments of this phase indicates that oxidising conditions prevailed both in the coastal zone and off the lake shore. High concentrations of manganese have repeatedly been reported in the sediments deposited during the early stages of development of some lakes of the temperate climatic zone (see Łacka et al., 1998; Borówka and Tomkowiak, 2010). According to Crerara et al. (1971/72), this is a characteristic phenomenon observed in shallow, well-oxygenated, oligotrophic reservoirs where conditions favoured the precipitation of manganese hydroxides in the form of $Mn(OH)_4$. The quite high content of Ca in the form of $CaCO_3$ may be associated with the inflow of ground waters very rich in HCO_3^- and ^{++}Ca ions, derived from

the decalcification of glaciofluvial sediments at the bottom of the sedimentation basin. In the initial phase of the reservoir, during the Late Saalian glaciation (MIS 6, GS3-1 L PAZ; Fig. 9), these sediments deposited under cold, dry climatic conditions, when the landscapes were dominated by steppe communities of Poaceae and *Artemisia* and tundras of *Betula nana* and Cyperaceae. They continued accumulating for almost all the Eemian Interglacial (MIS 5e) from E1 (GS3-2 L PAZ) to E5 (GS3-7 L PAZ; Fig. 89), under improving climatic conditions that peaked in the climatic optimum, when forests were dominated by varied oak-hornbeam communities. The communities of macrophytes spread in the palaeo-reservoir (GS3-M1 to GS3-M4 L MAZs) when the early lake was still relatively deep, reaching up to approximately 10 m or more, and had transparent waters rich in calcium carbonate. Over time, the lake turned shallow and eutrophied (Fig.10); five cycles of limnic chalk deposited along its margins, and two in its central part. At the current stage of research, it can only be assumed that this cyclicity is driven by climate. The Ca/Mg, and Na/K curves (Fig. 7, 8) show a clear predominance of chemical over mechanical denudation during the accumulation of the lower limnic chalk, although the upper part of both sequences shows a marked decrease in the Na/K ratio. Curves illustrating the variability of the so-called erosion index ($(Na+K+Mg)/Ca$) for both exposures show that only during the initial phase these were important processes of sedimentation, and became negligible later on. This advanced stage of sedimentation correlates with the palaeobotanical samples GS3-8 and GS3-9 L PAZs (E6 and E7, Fig. 9), which correspond to the declining Eemian Interglacial when climatic conditions gradually deteriorated, and boreal pine forests became dominant. The latter is the time that corresponds to level GS3-M5 L MAZ (Fig. 10), which in fact documents a progressive progradation of the lake margins and shallowing and shrinking of the palaeo-reservoir. The remains of *Stephanorhinus* lay in this lowermost part of the section (Fig. 4F). The last phase of the Eemian lake ended up with the accumulation of the ca 0.6 m of *D. dama*-bearing peat. In this phase in section GS 1, there was

the accumulation of ~ 5 cm of sandy-silts containing a significant amount of organic matter. It is worth noting that in both sections GS1 and GS3 the transitional portion between the lower chalk level and the layer of organic sediments is not visible (Fig. 4A), which indicates a fairly rapid change in the water level, as well as in the conditions of sedimentation in the basin. The pollen spectra (GS3-10 L PAZ; Fig. 9) tells us that significant climatic cooling and drying, and thus deforestation, occurred at this time. The area surrounding the lake was then overgrown mainly by heathland, steppe and tundra communities. The absence of a dense plant cover led to an increase in surface flow and redeposition of sediment. The lake shrank, became shallow, and transformed into a peat bog, consistently with the results of the macroremains analysis (GS3-M6 L MAZ, Fig. 10). The lower palaeolake deposits were overlain by silt-sand sediments; at the same time sands deposited in the upper part of section GS1. Based on lithology and structural analysis, this over 10 m thick part of the sequence GS1 is interpreted as a delta deposit, or an inflow cone accumulated from the southern side of the sedimentation basin. OSL dating sandy inlayer sample of section GS3 gave a central age of $109,9 \pm 2,5$ ka (MIS5d), which could be correlated with the onset of the Weichselian glaciation (Fig. 12). This result agrees with the palaeobotanical observations which attest to a cold climate and a landscape dominated by specific herbaceous vegetation communities and with the variable spread of woody *Pinus* and *Betula* communities. This horizon, therefore, documents shifting climatic conditions towards colder contexts. This observation correlates with GS3-11 L PAZ, the lower part of GS3-12 L PAZ (Fig. 9), and with GS3-M7 L MAZ (Fig. 10), which also confirms cold climate with tundra vegetation. The upper part of GS3-12 L PAZ (Fig. 9) and level GS3-8m L MAZ (Fig. 10) indicate improved climatic conditions and an increased level of the lake water. The upper deposits undoubtedly indicate a return of lake sedimentation, as shown by the increase in Ca content (Fig. 8A) to 250-300 mg / g (60-75% CaCO₃ calculated). In contrast to the lower limnic chalk, Ca in this layer of carbonate sediments is positively correlated with

general sulphur, and negatively with the content of organic matter (LOI), TOC, K, Fe, Cu and Zn (Tab. 4). This proves that there was a pure chemical precipitation of carbonates, and no contribution by aquatic vegetation. This was most probably associated with the shallowness of the lake, where well-oxygenated waters favoured the precipitation of manganese hydroxides, which was particularly marked at the boundary between the subzones GZ3-4a and 4b. The presence of oxidising conditions is also confirmed by the low Fe/Mn ratio, which persists throughout the period of accumulation of the upper limnic chalk layer (Fig. 8). Moving upwards in sequence GS3 we meet a new set of bog sediments, which are radiocarbon-dated to 40,661 cal med yr BP. A thin layer of peat lies directly on the upper limnic chalk, and is covered by a series of glacial sediments; this peat was also dated in section GS4 to about 37,7 - 32,4 ka cal BP (Tab. 5). On this basis, it can be assumed that the peat and organic-mineral sediments that rest on the upper limnic chalk accumulated in rather dry and cold climatic conditions short before the last ice sheet covered the area of the Polish Lowlands (see Marks et al., 2016). The chemical composition of mineral-organic sediments indicates a significant amount of erosion processes and mechanical denudation during the filling of the basin. However, chemical denudation processes were not negligible, as evidenced by the reduced, but notable amount of Ca, as well as by the pattern of the curve of the Ca/Mg ratio (Fig. 8). The sedimentary basin had become a periodically flooded swamp. There is a chronological anomaly between the radiocarbon age (41,385-39,928 ka cal BP) of the upper lake sediments and the OSL-dating to 79,0±3,4 ka of the overlying glaciofluvial unit. This apparent age inversion between the ¹⁴C and OSL datings might be explained supposing the reworking and re-deposition of the quartz grains used for the OSL analysis. In fact, Piotrowski and Sochan (2008, 2009) and Piotrowski et al. (2010) reported a radiocarbon age of 34,360 ±1,500 ka cal BP (site RAC62 in fig. 2B) for the peat horizon lying over the gyttja layer that were drilled by the cartographic borehole no. 62 (Raclaw), ca. 5 km NW of Gorzów area (fig. 2B), (Fig. 3).

East of the RAC site (Fig. 2B) peats yielded a radiocarbon age $> 35,0$ ka BP (uncalibrated, open). Finally, glaciofluvial sediments from Łupowo (LUP in fig.2B) have TL ages ranging from $84,0 \pm 12,7$ to $79,2 \pm 11,9$ ka BP (Piotrowski et al., 2010). In the light of the radiometric ages obtained for this study, it can be speculated that a substantial amount of pre-Weichselian quartz grains in the glaciofluvial deposit of section GS3 was reworked during the middle Pleniglacial.

During the last stage of evolution of the study area there was the transgression and withdrawal of the Weichselian ice cover towards the area of Pomerania, in the course of a time period of ranging from about 24,500 to 17,500 years (Rotnicki and Borówka 1990, 1995a, b; Marks 2002, 2012; Stroeve et al., 2015). Despite the lithology of the sediments that fill the analysed sedimentary basin could suggest that the rock elements were highly susceptible to shear under the stresses imposed by the vertical pressure of ice and by the transgression of an ice sheet that moved relatively fast in this area, no glaciotectionic disturbances were noted. This occurs when the edge of the ice sheet pauses for a long time in a place. After some time, the pressure squeezes the underlying deposits out in front of the margin of the ice sheet (Rotnicki 1976, Jaroszewski 1991). Similarly, glacier recession from the Poznań (to the south from the research area) to the Pomeranian (to the north from the research area) phase occurred fairly rapidly in this area. This is consistent with the recent reconstructions of the speed of deglaciation of the European Lowland (Stroeve et al., 2015). The process of glaciation in the study area caused the accumulation of a relatively thick glacial series, which in the GS3 and Raław successions (Fig. 3) exceed the overall thickness of 10 metres. These observations suggest that Gorzów palaeolakes have to survive Scandinavian ice sheet advance during the Last Glacial Maximum, at the same time preserving Eemian large mammal remains. Following this observation, if we would assume a normal *post-mortem* position of rhinoceros skeleton preceding burial

processes, ice-sheet overriding fossilised lacustrine sequence could be at least partly responsible for on-site observed *Stephanorhinus kirchbergensis* skeleton disarticulation.

Conclusions

Remains of rhinoceroses of the genus *Stephanorhinus* are known from many European sites, but they generally consist of only a few bones or teeth (Billa and Zervanová, 2015). For this reason, the specimen from Gorzów Wielkopolski is a significant find. Preliminary analyses of this rhinoceros-bearing site indicate that the local sedimentary succession extends throughout a period running from the Eemian interglacial and Vistulian glaciation up to the middle Plenivistulian (MIS 5-3). The Gorzów Wielkopolski stratigraphic sequence was the result of a virtually uninterrupted accumulation of siliciclastic and organic sediments from the decline of the Saalian glaciation (MIS 6), through the Eemian interglacial (MIS 5e) to the Hengelo and Denekamp interstadials (MIS 3). Sites with similar periods are Hengelo and Moershoofd, in the eastern Netherlands, and Oerel, in Germany (Behre and Lade, 1986, Vandenberghe and Plicht, 2016). Remains of *S. kirchbergensis* had been found in other 10 Polish sites, but most are of unknown age. Polish large mammal fauna is fairly imperfectly known. Most mammal-bearing sites are caves in the Kraków-Częstochowa Upland: Nietoperzowa Cave, Ciemna Cave, Biśnik Cave, Cave in Dziadowa Skała, Deszczowa Cave. The faunal assemblages from these sites are largely dominated by cervids, but lists include the brown bear, the cave bear, the cave lion, the grey wolf, the horse *Equus ferus*, the woolly rhinoceros, the woolly mammoth, the aurochs, and the steppe bison. Polish mammal-bearing open-air sites include Imbramowice, Józwin near Konin and Warsaw-Szczęśliwice, which yielded remains of four large mammal taxa, i.e., the straight-tusked elephant *Palaeoloxodon antiquus*, the horse *E. ferus*, the woolly rhinoceros, and *S. kirchbergensis*. In total there are 17 large mammal species (Kowalski, 1959; Czyżewska, 1962, 1989; Jakubowski et al., 1968; Borsuk-Białynicka and Jakubowski, 1972; Jakubowski,

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3 534 1988, 1996; Kubiak, 1989a, b; Wojtal, 2007; Stefaniak et al. 2009; Made et al., 2014; Valde-
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5 535 Nowak and Nadachowski, 2014; Stefaniak, 2015; Marciszak et al., 2017). Several species,
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7 536 whose remains were found in western European interglacial sites (Koenigswald, 1991; Kahlke,
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9 537 1999; Kolfschoten, 2000; Eissmann 2002; Pushkina, 2007; Musil, 2010), are missing from the
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11 538 Polish fossil record (e.g., *Equus hydruntinus*, *Stephanorhinus hemitoechus*, *Hippopotamus*
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13 539 *amphibius*, *Bubalus murrensis*). The new site of Gorzów Wielkopolski contributes new
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15 540 knowledge about the interglacial fauna of Poland and Central Europe.
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TABLES

Table 1. Lithology of the GS1 profile (lower part).

Depth (m)	Height (m a.s.l.)	Lithology
0.00 - 0.45	51.20 - 50.75	Light grey-beige silty sand
0.45 - 2.30	50.75 - 48.90	Light grey limnic chalk
2.30 - 3.50	48.90 - 47.70	Light brown limnic chalk with admixture of sand
3.50 - 9.50	47.70 - 41.70	Brown limnic chalk
9.50 - 11.40	41.70 - 39.80	Brown calcareous gyttja with admixture of sand
11.40 - 11.60	39.80 - 39.60	Light brown fine and medium sand

Table 2. Matrix of correlation (r) between the contents of organic matter and selected geochemical elements in the limnic deposits of the Gorzów GS2 profile.

	LOI	Total C	Total N	Total S	TOC	Na	K	Ca	Mg	Fe	Mn	Cu	Zn
LOI	1												
Total C	-0,36	1											
Total N	-0,15	0,65	1										
Total S	0,75	-0,30	-0,25	1									
TOC	0,02	0,68	0,82	-0,02	1								
Na	0,02	-0,54	-0,60	0,09	-0,49	1							
K	-0,38	0,59	-0,21	-0,36	-0,41	0,41	1						
Ca	-0,13	0,78	0,43	-0,15	0,44	-0,42	-0,65	1					
Mg	-0,20	0,43	-0,01	-0,16	0,28	0,21	-0,32	0,32	1				
Fe	0,73	-0,61	-0,42	0,58	-0,34	0,28	-0,01	-0,39	-0,26	1			
Mn	-0,07	-0,46	-0,39	-0,12	-0,40	0,39	0,57	-0,42	-0,23	0,42	1		
Cu	-0,10	-0,43	-0,36	-0,11	-0,37	0,56	0,51	-0,34	-0,03	0,17	0,56	1	
Zn	-0,06	-0,73	-0,35	-0,07	-0,47	0,50	0,82	-0,72	-0,43	0,31	0,67	0,51	1

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Table 3. Lithology of the GS3 profile (lower part).

Depth (m)	Height (m a.s.l.)	Lithology
0.00 - 1.80	59.61 - 57.81	Dark grey sandy and silty peat with intercalations of organic silts
1.80 - 1.93	57.81 - 57.68	Black peat
1.93 - 4.18	57.68 - 55.43	Light grey limnic chalk
4.18 - 6.30	55.43 - 53.31	Light brown silts and sandy-silts
6.30 - 6.94	53.31 - 52.67	Black peat
6.94 - 10.93	52.67 - 48.68	Grey limnic chalk

Table 4. Matrix of correlation (r) between the contents of organic matter and selected geochemical elements for the limnic chalk from the Gorzów GS3-3 profile (**bold** - lower chalk; regular - upper chalk).

	LOI	Total C	Total N	Total S	TOC	Na	K	Ca	Mg	Fe	Mn	Cu	Zn
LOI	1	0,74	0,81	0,81	0,88	0,06	0,30	-0,74	-0,34	0,63	0,45	0,60	0,68
Total C	0,48	1	0,81	0,42	0,84	0,14	0,07	-0,36	-0,11	0,22	0,09	0,34	0,37
Total N	0,68	0,79	1	0,66	0,80	-0,03	0,20	-0,44	-0,08	0,61	0,56	0,47	0,55
Total S	0,63	0,45	0,80	1	0,76	0,01	0,44	0,83	-0,45	0,90	0,62	0,74	0,85
TOC	0,71	0,82	0,97	0,78	1	0,27	0,46	-0,68	-0,21	0,60	-0,28	0,66	0,74
Na	-0,12	-0,59	-0,65	-0,41	-0,64	1	0,66	-0,18	0,19	0,08	-0,39	0,30	0,27
K	-0,29	-0,62	-0,48	-0,28	-0,52	0,28	1	-0,53	0,22	0,56	0,08	0,63	0,68
Ca	0,24	0,87	0,54	0,22	0,57	-0,52	-0,51	1	0,34	-0,69	-0,27	-0,68	-0,75
Mg	0,05	0,54	0,16	-0,01	0,23	-0,19	-0,61	0,53	1	-0,24	-0,28	-0,31	-0,36
Fe	-0,20	-0,81	-0,50	-0,14	-0,53	0,46	0,64	-0,83	-0,66	1	0,69	0,71	0,80
Mn	-0,29	-0,49	-0,41	-0,24	-0,40	0,33	0,07	-0,39	-0,18	0,19	1	0,36	0,39
Cu	0,07	0,11	0,03	0,05	0,08	-0,19	0,32	0,25	0,02	-0,11	-0,10	1	0,79
Zn	-0,27	-0,85	-0,58	-0,26	-0,60	0,40	0,73	-0,78	-0,66	0,85	0,25	0,04	1

Table 5. Results of radiocarbon dating, ages calibrated using OxCal INTCAL13 approach (Reimer et al., 2013). Explanations for abbreviations: m a.s.l. (metres above sea level); m b.s.l. (metres below surface level).

Sample number	Laboratory code	Sampling altitude (m a.s.l.) / depth (m b.s.l.)	Dated material and geological context	Conventional age years BP	Cal 1 sigma years BP (95%)	Cal median years BP
GS3-1	Beta-93676	58.7 / 12.0	Macrofossils Upper palaeolake peat, just below OSL sample	36,010 ± 330	41,385 – 39,928	40,661
GS4-2	Poz-97161	58.1 / 9.9	Upper palaeolake peat	32,200 ± 500	37,710 – 35,032	36,172
GS4-3	Poz-97162	58.0 / 10.0	Upper palaeolake peat	29,060 ± 310	33,906 – 32,402	33,236
GS4-4	MKL-3527	59.9 / 8.1	Peat on the glacial till top	4,280 ± 110	5,280 – 5,163 (7,1%) 5,135 – 5,105 (1,5%) 5,077 – 4,526 (86,9%)	4,852
GS4-5	MKL-3526	60.0 / 8.0	Peat on the glacial till top	4,330 ± 120	5,303 – 4,780 (79,6%) 4,770 – 4,580 (15,8%)	4,940

Table 6. Laboratory codes of investigated GS3 profile, samples depth (m b.s.l. = meters below surface level), specific activities of natural radionuclides, dose rates, calculated mean ages for all investigated fractions using CAM model.

Lab. Code	Sampling depth (m b.s.l.)	U (Bq/kg)	Th (Bq/kg)	K (Bq/kg)	Dose rate (Gy/ka)	OSL central age (ka)	Number of measured aliquots
GdTL-2831	10.5	4.4±0.1	6.0±0.2	192±6	0.77±0.03	79.0±1.5	19
GdTL-2830	16.5	4.8±0.1	4.7±0.1	206±6	0.74±0.03	109.9±2.5	58
GdTL-2829	21.8	8.4±0.2	6.7±0.2	257±7	0.90±0.04	141.4±3.0	47

951 **Tabel 7.** Distinct phases of the sedimentary basin development at the Gorzów Wielkopolski palaeolakes research area.

Phases of the sedimentary basin development	Lithology		Geochemistry		L PAZ	L MAZ Bone remains	Hydroclimatic conditions
	Section GS1	Section GS3	Section GS1	Section GS3	Section GS3	Section GS3	
Phase I	LLZ-2 (40.0-41.7 m a.s.l.) Calcareous gyttja - increased content of medium- to fine grained sand (ca. 10-20%) - increase of Mz from 5.5 at the bottom to 6.5 phi in top	LLZ-1a (48.6-49.2 m a.s.l.) Calcareous gyttja - sand fraction recognized - Mz value in the range between 2 and 6 phi	GLZ-2 (40.0-40.25 m a.s.l.) - low organic matter content and TOC - increased content of lithophilic elements (Na, K, Mg) as well as Fe and Mg GLZ-3 (40.25-41.0 m a.s.l.) - increased content of organic matter, S and Fe - decrease content of Mn	GLZ-1a (48.6-49.2 m a.s.l.) - increased content of K, Fe, Mn, Zn - upward decrease of Fe/Mn and erosion index	L PAZ-1 Betula-NAP (Betula nana, Juniperus, Artemisia, Poaceae)	M1 Characeae, Typha sp., Ceratophyllum demersum	Climate typical for park tundra; vast free open space resulting in intensification of mineral matter delivery to the lake basin; onset of permafrost degradation and Ca-rich groundwater influx to the lake. Increase of lake water level and growth of redox conditions in southernmost (deeper) part of the lake. Late Saalian Glaciation/Early Eemian (MIS 6 / MIS 5e)
Phase II	LLZ-3 - LLZ-6 (41.0-50.6 m a.s.l.) Calcareous gyttja - in the lower part (LLZ-3 & 4) initially increase of clay and decrease of silt fraction - above (LLZ-5 & 6) increase of sand content	LLZ-1b & 1c (49.2-52,6 m a.s.l.) Calcareous gyttja /limnic chalk - slightly increase of mid- to coarse-grained mud content	GLZ-4 (41.0-50.9 m a.s.l.) - high content of Ca, Mg, Mn and total carbon (TC), - decrease of Fe and S content (GLZ-4a & 4b) - continuous decrease of Mg (GLZ-4c, 4d & 4e)	GLZ-1b & 1c (49.2-52.6 m a.s.l.) - high content of Ca, Mg, Mn, TC and progressive decrease of Fe content - low content of organic matter, TOC and sulphur	L PAZ-2 - LPAZ-7 Betula-Pinus Pinus-Betula-Ulmus Quercus-Fraxinus-Ulmus Corylus-Quercus-Alnus Corylus-Tilia-Alnus	M2 - M4 Najas marina Typha sp. Nuphar lutea, Nyphaea alba, Brasenia sp., Trapa natans, Betula, Pinus, Alnus, Tilia,	Succession of plants typical for the Eemian Interglacial. Intensive Ca-rich groundwater inflow to the lake; stepwise shallowing of the lake coinciding with calcareous sediments deposition, with upward

	and decrease of clay and silt fraction - decrease of Mz and increase of SD values		- increase of potassium content (GLZ-4d & 4e)		Carpinus-Corylus-Alnus	Carpinus, Corylus, Juniperus, Picea Rhinoceros bone remains Deer bone (uppermost part of lacustrine deposits)	increasing allochthonous mineral deposits content. Eemian Interglacial (MIS 5e)
Phase III	LZZ-7 (50.6-51.3 m a.s.l.) Silty sand with organic matter, especially at 50.9 m a.s.l.	LLZ-2 (52.6-53.2 m a.s.l.) Peat with sand at the bottom	GLZ-5 (50.9-51.3 m a.s.l.) - at the bottom (~50.9 m a.s.l.) higher content of organic matter, TOC, N, S and Fe - residual content of Ca and increase of Na, K, Cu and Zn concentration	GLZ-2 (52.6-53.2 m a.s.l.) - high content of organic matter, C, N, S and TOC - initially high content of Fe, afterwards decreasing gradually - low content of Ca, Mg, Mn	LPAZ-8 Picea-Abies-Carpinus Rapid increase of pine pollen percentage, with at the same time decreasing importance of oak, hazel and hornbeam	M5 Betula, Pinus, Alnus, Betula nana, Carex	Development of a valley bog evolved on the lacustrine sediments under cold climatic conditions, completed with species typical for tundra vegetation. Probable rise of permafrost in the ground and interruption of intensive feeding of the basin by a groundwater. End of Eemian/Early Weichselian (MIS 5d-5a)
Phase IV	Upper part of the section (51.3 - 60.0 m a.s.l.) Fine- and medium-grained sands, deltaic	LLZ-3 (53.2 - 55.4 m a.s.l.) Sands with a changing grain-size, intercalated with silts, horizontally laminated	-	GLZ-3 (53.2- 55.4 m a.s.l.) - raised content of lithophyte elements – Na, K, Mg, Cu and Zn; visible correlation between their content	LPAZ-9 i 10 Pinus C.v. - NAP-Pinus - significant content of NAP (30-50%) - Co-occurrence of tundra species	M6 Small amount of plant macrofossils, Betula nana at the upper part	Accumulation of mineral deposits, sandy silts and silts in low flow conditions, formation of delta at the southern margin of the basin. Low groundwater basin recharge and high

				and a percentage of silt-clay fraction in the deposit - insignificant content of Ca	(Betula nana) and plants with higher thermal requirements (i.a. Tilia) reflects that they accumulated as a secondary deposit		surface outwash may indicate existence of permafrost in the ground. Early Weichselian (MIS 4)
Phase V	-	LLZ-4 (55.4-57.6 m a.s.l.) Calcareous gyttja /limnic chalk, small amount of sandy silts	-	GLZ-4 (55.4-57.6 m a.s.l.) - high content of Ca, Mg, Fe and Mn, especially at the initial stage (GLZ-4a)	LPAZ-11 i 12 Betula - NAP Pinus-Betula Gradually decreasing content of NAP	M7 & M8 At the beginning, numerous Betula nana and Typha sp. macrofossils (M7), next replaced with freshwater plants macroremains - Characeae, Najas Marina, Najas flexilis (M8)	Reactivation of lacustrine basin intensively fed with Ca-rich groundwater, climatic conditions shift toward optimum Early MIS 3
Phase VI	-	LLZ-5 & 6 (57.6-59. m a.s.l.) Highly disintegrated peat with 20 to 80% of organic matter content. Radiocarbon age ~40,661 cal. BP for plants macrofossils (60 m a.s.l.)	-	GLZ-5 i 6 (57.6-59.6 m a.s.l.) - high content of organic matter, C, N, S and TOC, especially at GLZ-5 level and between 58,0 and 59,1 m a.s.l. - high and gradually increasing Na, K, Mg, Cu, and Zn content,	-	-	Deterioration of shallow mesotrophic lake and valley-type periodically flooded peat grow Late MIS 3 (Hengelo - Denekamp ?)

				which correlates well with increasing values of erosion index - small but important content of Ca and Mn			

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FIGURE CAPTIONS

Fig.1 Location of the Eemian interglacial deposits in Poland and Eastern Germany with indicated Pleistocene Scandinavian Ice Sheet maximum extents. Map explanations: black dots – Eemian interglacial sites reported in the literature; red dots – sites with fossil bones findings; green dots – sites with palynological and malacological analyses.

Fig.2 A – Location of the research area in Poland at the peak of the Last Glacial Maximum (LGM) during the Late Weichselian (Vistulian) Scandinavian ice-sheet advance; **B** – LiDAR-based digital elevation model showing the morphological escarpment separating the Gorzów Lowland (to the north) from W-E-oriented, Toruń-Eberswalde ice-marginal valley. Please note the network of small post-LGM dendritic basins with valleys roughly oriented to the south. Sites of interest mentioned in the text: RAC62 – Borehole Raclaw 62, which drilled a peat horizon radiocarbon-dated to $34,360 \pm 1,500$ ka cal. BP (Lod-820); RAC – borehole with a peat horizon dated to $> 35,000$ BP (Lod-872), LUP – Łupowo site, TL ages from 84.0 ± 12.7 to 79.2 ± 11.9 ka BP; all sites locations and data after Piotrowski et al. (2010). **C** – Detailed LiDAR representation of the Gorzów Wielkopolski (GS1-GS4) sequences; GS3 is where the bones of rhinoceros, the subject of the present study, were found.

Fig.3 Stratigraphic exposures (in metres) in the Gorzów Wielkopolski area as well as in the Raclaw 62 borehole (the latter is based on data from Piotrowski et al., 2010). Legend: 1 – Weichselian till with mixed sands and gravels; 2 – fine and medium grain sand; 3 – unsorted sand mixed with gravel; 4 – silty sand; 5 – limnic chalk; 6 – gyttja; 7 – sandy silt; 8 – silt; 9 – peat; 10 – OSL age ka BP; 11 – calibrated median radiocarbon age (see table 5 for details); 12 – bones.

Fig.4 Photographs of sections exposed at the Gorzów Wielkopolski research area. **A** – section GS3: 1 – Weichselian till with mixed sands and gravels; 2 – fine and medium grain sand (OSL sample GdTL-2831); 3 – upper Pleni-Weichselian peat; 4 – limnic chalk and gyttja; 5 – sands and silty sands; 6 – lower peat; 7 – limnic chalk and gyttja; 8 – brown gyttja; 9 – Saalian glaciofluvial sands and gravels. **B** – section GS1: 1 – fluvial sands (fan delta); 2 – limnic chalk and gyttja; 3 – Saalian glaciofluvial sands. **C** – section GS4; 1 – organic sands and silt, locally with peat; 2 – mixed glaciofluvial sands and gravelly diamicton; 3 – lacustrine sands, silt and calcareous gyttja; 4 – peats; 5 – lacustrine calcareous gyttja; 6 – fine and medium grain sand; 7 – unsorted glaciofluvial sands and gravels. **D** – basal part of sequence GS3: 1 – grey limnic chalk and gyttja; 2 – brown gyttja; 3 – Saalian glaciofluvial sands and gravels. **E** – rhinoceros and deer bone-bearing section: 1 – Weichselian till with mixed sands and gravels; 2 – limnic chalk and gyttja; 3 – sands and silty sands; 4 – peat; 5 – grey limnic chalk and gyttja, showing the site where the bone remains were retrieved; 6 – brown gyttja; 7 – Saalian glaciofluvial sands. **F** – section GS3; the nearly complete skull of *Stephanorhinus kirchbergensis*; a malacological horizon can be recognised just above the skull.

Fig.5 Eastern (A) and western (B) geological cross-sections of the site, projected on N-S plane. Section GS3 showing where bones were found, as well as section GS4; arrows indicate sampling spots and relative ^{14}C calibrated median radiocarbon ages (see tab.5). Legend: 1 – mixed glaciofluvial sands and gravelly diamicton; 2 – lacustrine lower unit (calcareous gyttja); 3 – lacustrine upper unit (sand, silt and calcareous gyttja); 4 – fine and medium grain sand; 5 – limnic chalk; 6 – peat; 7 – unsorted glaciofluvial sands and gravels; 8 – organic sands and silts; 9 – peats: (a) lower, (b) middle and (c) upper horizon.

Fig.6 (A) Map showing the location of detailed geological cross-sections (B) based on a geodetic survey conducted in the Gorzów Wielkopolski area, along the S3 national road excavation. Location of the GS1-GS4 sections and the calibrated median radiocarbon dated levels. For the legend of the lithostratigraphic units see Figure 5.

Fig.7 Results of the sedimentological and geochemical analyses of section GS1. See text for explanations.

Fig.8 Results of the sedimentological and geochemical analyses of section GS3 profile. See text for explanations.

Fig.9 Simplified pollen diagram of section GS3. Acronyms GS3 L PAZ are explained in the text. Legend: R PAZ – Regional Pollen Assemblage Zone, BZ – Biostratigraphic Zone; L.G. – Late Glacial; L.W. – Late Wartanian; S – Saalian.

Fig.10 Summary diagram of macrofossils from section GS3. Legend of abbreviations: f - fruit, fsc - fruit scales, sc - scales, s - seed, en - endocarp, n - needle, co - cone, sk - sclerocia, l – leaf. The scale below diagram shows the quantitative results of the plant macroremains. Legend: L MAZ – Local Macrofossils Assemblage Zone, L.G. – Late Glacial; L.W. – Late Wartanian (Late-Saalian); S – Saalian.

Fig.11 Radial plots (Galbraith, 1990) of single grain quartz OSL ages for all investigated samples from section GS3 with the estimated representation of peak age for separate grains populations revealed with mixture algorithm. All scatterplots have been prepared with a RadialPlotter software (Vermeesch, 2009).

Fig.12 Middle- to Late Pleistocene climatic changes based on SPECMAP foraminiferal $\delta^{18}\text{O}$ time series (from Winograd et al., 1997) and range of distribution of Gorzów Wielkopolski palaeolakes deposits based on ^{14}C and OSL data, with an indication of Heinrich (H1-H6) glacial-depositional events (from Hemming, 2004).

Fig.1 Location of the Eemian interglacial deposits in Poland and Eastern Germany with indicated Pleistocene Scandinavian Ice Sheet maximum extents. Map explanations: black dots – Eemian interglacial sites reported in the literature; red dots – sites with fossil bones findings; green dots – sites with palynological and malacological analyses.

Fig.2 A – Location of the research area in Poland at the peak of the Last Glacial Maximum (LGM) during the Late Weichselian (Vistulian) Scandinavian ice-sheet advance; B – LiDAR-based digital elevation model showing the morphological escarpment separating the Gorzów Lowland (to the north) from W-E-oriented, Toruń-Eberswalde ice-marginal valley. Please note the network of small post-LGM dendritic basins with valleys roughly oriented to the south. Sites of interest mentioned in the text: RAC62 – Borehole Raclaw 62, which drilled a peat horizon radiocarbon-dated to $34,360 \pm 1,500$ ka cal. BP (Lod-820); RAC – borehole with a peat horizon dated to $> 35,000$ BP (Lod-872), LUP – Łupowo site, TL ages from 84.0 ± 12.7 to 79.2 ± 11.9 ka BP; all sites locations and data after Piotrowski et al. (2010). C – Detailed LiDAR representation of the Gorzów Wielkopolski (GS1-GS4) sequences; GS3 is where the bones of rhinoceros, the subject of the present study, were found.

165x97mm (300 x 300 DPI)

Fig.3 Stratigraphic exposures (in metres) in the Gorzów Wielkopolski area as well as in the Raclaw 62 borehole (the latter is based on data from Piotrowski et al., 2010). Legend: 1 – Weichselian till with mixed sands and gravels; 2 – fine and medium grain sand; 3 – unsorted sand mixed with gravel; 4 – silty sand; 5 – limnic chalk; 6 – gyttja; 7 – sandy silt; 8 – silt; 9 – peat; 10 – OSL age ka BP; 11 – calibrated median radiocarbon age (see table 5 for details); 12 – bones.

106x176mm (300 x 300 DPI)

Fig.4 Photographs of sections exposed at the Gorzów Wielkopolski research area. A – section GS3: 1 – Weichselian till with mixed sands and gravels; 2 – fine and medium grain sand (OSL sample GdTL-2831); 3 – upper Pleni-Weichselian peat; 4 – limnic chalk and gyttja; 5 – sands and silty sands; 6 – lower peat; 7 – limnic chalk and gyttja; 8 – brown gyttja; 9 – Saalian glaciofluvial sands and gravels. B – section GS1: 1 – fluvial sands (fan delta); 2 – limnic chalk and gyttja; 3 – Saalian glaciofluvial sands. C – section GS4: 1 – organic sands and silt, locally with peat; 2 – mixed glaciofluvial sands and gravelly diamict; 3 – lacustrine sands, silt and calcareous gyttja; 4 – peats; 5 – lacustrine calcareous gyttja; 6 – fine and medium grain sand; 7 – unsorted glaciofluvial sands and gravels. D – basal part of sequence GS3: 1 – grey limnic chalk and gyttja; 2 – brown gyttja; 3 – Saalian glaciofluvial sands and gravels. E – rhinoceros and deer bone-bearing section: 1 – Weichselian till with mixed sands and gravels; 2 – limnic chalk and gyttja; 3 – sands and silty sands; 4 – peat; 5 – grey limnic chalk and gyttja, showing the site where the bone remains were retrieved; 6 – brown gyttja; 7 – Saalian glaciofluvial sands. F – section GS3; the nearly complete skull of *Stephanorhinus kirchbergensis*; a malacological horizon can be recognised just above the skull.

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209x296mm (300 x 300 DPI)

Fig.5 Eastern (A) and western (B) geological cross-sections of the site, projected on N-S plane. Section GS3 showing where bones were found, as well as section GS4; arrows indicate sampling spots and relative ^{14}C calibrated median radiocarbon ages (see tab.5). Legend: 1 – mixed glaciofluvial sands and gravelly diamicton; 2 – lacustrine lower unit (calcareous gyttja); 3 – lacustrine upper unit (sand, silt and calcareous gyttja); 4 – fine and medium grain sand; 5 – limnic chalk; 6 – peat; 7 – unsorted glaciofluvial sands and gravels; 8 – organic sands and silts; 9 – peats: (a) lower, (b) middle and (c) upper horizon.

179x129mm (300 x 300 DPI)

Fig.6 (A) Map showing the location of detailed geological cross-sections (B) based on a geodetic survey conducted in the Gorzów Wielkopolski area, along the S3 national road excavation. Location of the GS1-GS4 sections and the calibrated median radiocarbon dated levels. For the legend of the lithostratigraphic units see Figure 5.

209x285mm (300 x 300 DPI)

Fig.7 Results of the sedimentological and geochemical analyses of section GS1. See text for explanations.

198x190mm (300 x 300 DPI)

Fig.8 Results of the sedimentological and geochemical analyses of section GS3 profile. See text for explanations.

199x186mm (300 x 300 DPI)

Fig.9 Simplified pollen diagram of section GS3. Acronyms GS3 L PAZ are explained in the text. Legend: R PAZ – Regional Pollen Assemblage Zone, BZ – Biostratigraphic Zone; L.G. – Late Glacial; L.W. – Late Wartanian; S – Saalian.

168x136mm (300 x 300 DPI)

Fig.10 Summary diagram of macrofossils from section GS3. Legend of abbreviations: f - fruit, fsc - fruit scales, sc - scales, s - seed, en - endocarp, n - needle, co - cone, sk - sclerocia, l - leaf. The scale below diagram shows the quantitative results of the plant macroremains. Legend: L MAZ – Local Macrofossils Assemblage Zone, L.G. – Late Glacial; L.W. – Late Wartanian (Late-Saalian); S – Saalian.

186x139mm (300 x 300 DPI)

Fig.11 Radial plots (Galbraith, 1990) of single grain quartz OSL ages for all investigated samples from section GS3 with the estimated representation of peak age for separate grains populations revealed with mixture algorithm. All scatterplots have been prepared with a RadialPlotter software (Vermeesch, 2009).

Fig.12 Middle- to Late Pleistocene climatic changes based on SPECMAP foraminiferal $\delta^{18}\text{O}$ time series (from Winograd et al., 1997) and range of distribution of Gorzów Wielkopolski palaeolakes deposits based on ^{14}C and OSL data, with an indication of Heinrich (H1-H6) glacial-depositional events (from Hemming, 2004).

115x77mm (300 x 300 DPI)