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CHRONOSTRATIGRAPHY OF THE OKUNIN AND CZEREPACHA LAKE-MIRE GEOSYSTEMS (VOLHYNIA POLESIYE, NW UKRAINE) DURING THE LATE GLACIAL AND HOLOCENE

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Abstract: Cores of lacustrine and lacustrine-peat deposits from the Okunin and Czerepacha sites were examined using the following methods: sedimentological analysis, radiocarbon dating, pollen, ostracod and geochemical analyses. ^{137}Cs distribution was determined in the top parts of these deposits. The obtained results allow us to reconstruct the main stages of evolution of the lake-mire geosystems in relation to regional changes of environmental conditions during the Late Glacial and Holocene.

1. INTRODUCTION

The studies of lakes and mires in the Polesiye have a long tradition, reaching back to the end of the 19th century. They have focused mostly on hydrological and hydrogeological (Tutkovskij, 1899 and 1911 – *vide* Lomaev, 1979; Lencewicz, 1931; Rühle, 1935) or phytogeographical problems (Tymrakiewicz, 1935; Kulczyński, 1939). A possibility of palaeoenvironmental discussion based on the investigations of lacustrine deposits and peat was noticed at that time, but this problem aroused a greater interest during the last quarter of the 20th century (Zernickaja *et al.*, 1988; Zernickaja, 1996). Most of papers dealing with palaeogeography and chronostratigraphy of the Polesiye concern its northern, Belarusian part; the southern part, i.e. the Volhynia Polesiye macroregion, has been considerably less studied till now (Artiushenko *et al.*, 1982).

The presented research works in selected lake-mire geosystems of the Volhynia Polesiye were initiated in 1998. Their aim was to obtain new data concerning climatic and paleohydrological changes in this area during the Late Glacial and Holocene using different methods: sedimentological, pollen, geochemical, ostracod and ^{137}Cs isotope analyses and radiocarbon dating.

2. INVESTIGATED SITES

Geological and palaeomorphological situation was recognised on the basis of several dozen of geological borings (29 from Czerepacha and 67 borings from Okunin sites). For chronostratigraphic and palaeogeographic considerations three cores of undisturbed structure from bottom deposits in the Okunin lake (Ok-54, Ok-55 and Ok-56; **Fig. 2**), and one core from peat-lacustrine deposits of the central part of the largest valley (0.2 ha, maximal depth 2.5 m) in the Czerepacha site (Cz-15 , **Fig. 3**) were taken.

Okunin site (51°12'N, 24°18'E) is situated in a large karst depression, in the upper Vyzhevka river catchment (SW part of the Volhynia Polesiye). This depression is filled with a series of organic deposits (mainly sedge peat) 0.5-9.5 m thick. The small Okunin lake (184.1 m a.s.l., 17.3 ha, maximal depth = 6.5 m), occurring at the head of a karst form, is surrounded by a zone of lakeside mire (**Fig. 1**). The Okunin lake basin was formed in Upper Cretaceous carbonate rocks; soft chalk is exposed both at the northern shore of the lake and at its littoral zone.

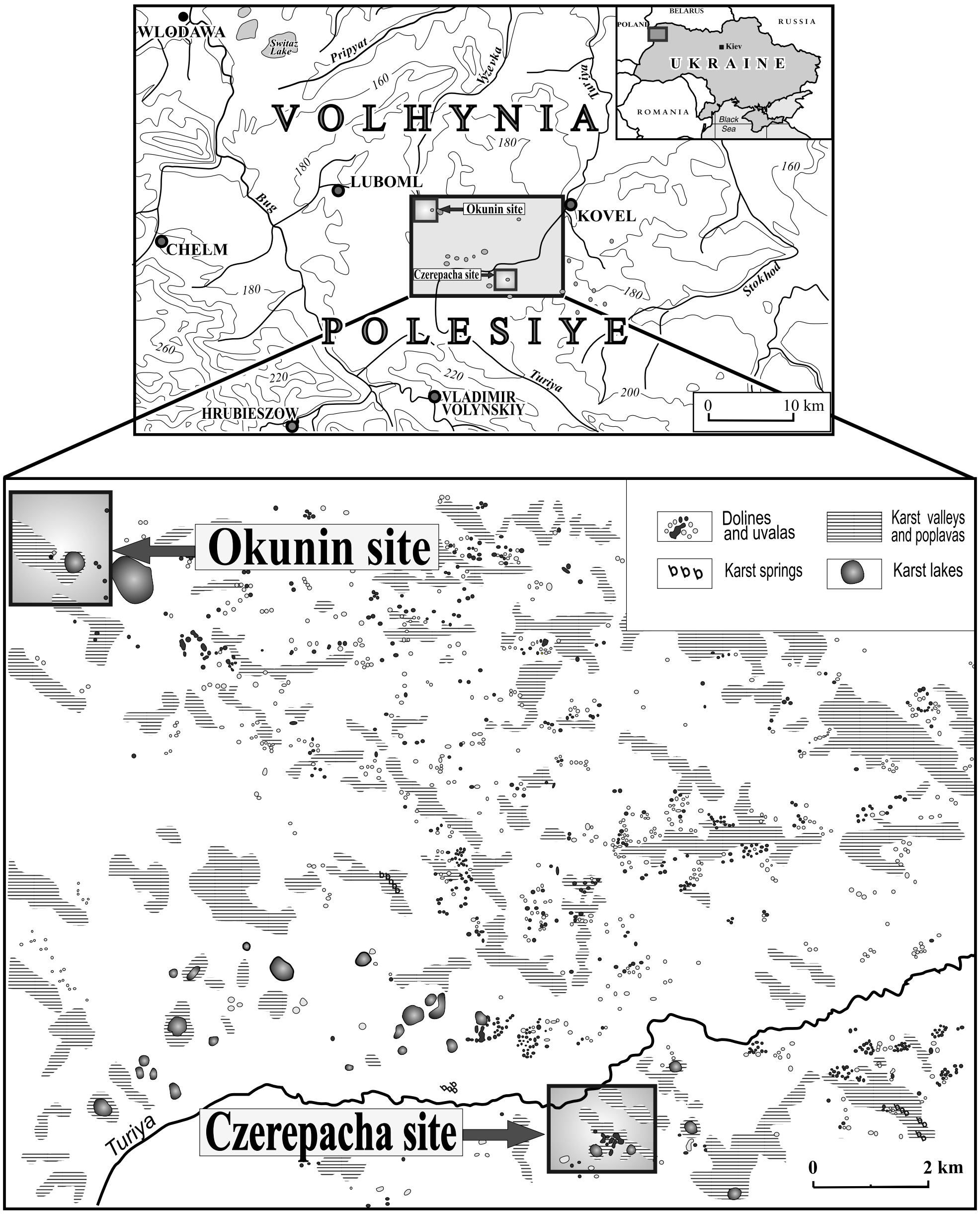

Fig. 1. Location of the studied sites.

Czerepacha site (51°04'N, 24°30'E) is situated in the upper Turia river catchment (southern part of the Volhynia Polesiye). It is a typical example of a karst valley composed of several primary forms (dolines), linearly arranged and included in one surface-drainage system (**Fig. 1**). The valley is 2.2 km long; its NW-SE orientation follows the direction of joint fractures. Upper Cretaceous carbonate rocks (chalk) are commonly exposed in the vicinity of this form. Every doline forming the valley is filled with a series of organic deposits of 1.0-3.2 m thickness. The small Czerepacha lake (177 m a.s.l., 2.8 ha, maximal depth = 9.1 m) occurs at the head of the karst valley.

3. TYPE OF SEDIMENTS

Lithofacial analysis of deposits filling the lake and peat basins allows us to determine the cycles of biogenic sedimentation in each of the studied sites. Facial variability of the deposits in closely examined cores (Ok-55, Cz-15) gives readable record of palaeohydrological evolution of the basins, and indirectly also evidences changes of moisture-thermic conditions.

Maximum thickness of the bored biogenic deposits in the central part of the Okunin lake is 6.5 m (Ok-55 core). They are underlain by a thin layer of sands with gravels of Cretaceous rocks, which lies directly over chalk. A layer of weekly decomposed moss peat, 0.2-0.5 m thick, occurs on these sands in the whole lake basin. It was dated by ^{14}C method at 10370±170 BP (**Fig. 2**), and it contains mosses of the *Calliergon giganteum, Scorpidium scorpioides* and *Drepanocladus revolvens*[1] species which may evidence a shallow, strongly flooded swamp developing probably when permafrost occurred. A change of sedimentation from the swampy to lacustrine conditions is marked by a sharp lithological boundary between moss peat and overlying gyttja. It indirectly suggests a radical change of water supply conditions as a result of permafrost degradation. Rise of the groundwater table and/or subsidence of the basement initiated a long-lasting cycle of lacustrine sedimentation, corresponding to the whole Holocene

[1] *Analysis of macroremnants was made by mgr Marek Bloch in the Department of Plant Systematics, Maria Curie-Skłodowska University, Lublin.*

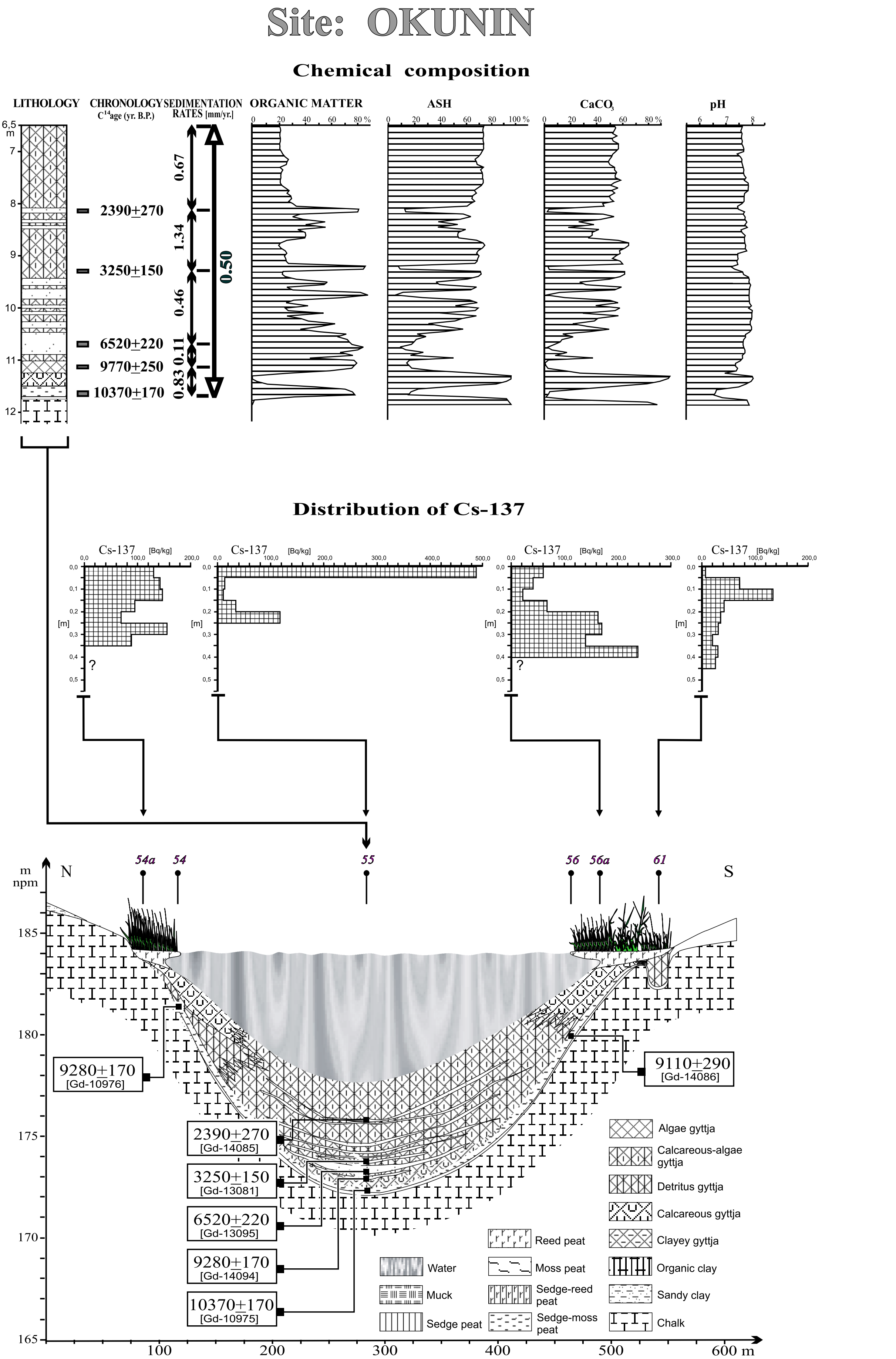

Fig. 2. *Geological cross-section of the Okunin lake together with the chronostratigraphical and chemical characteristics of the selected cores of bottom deposits.*

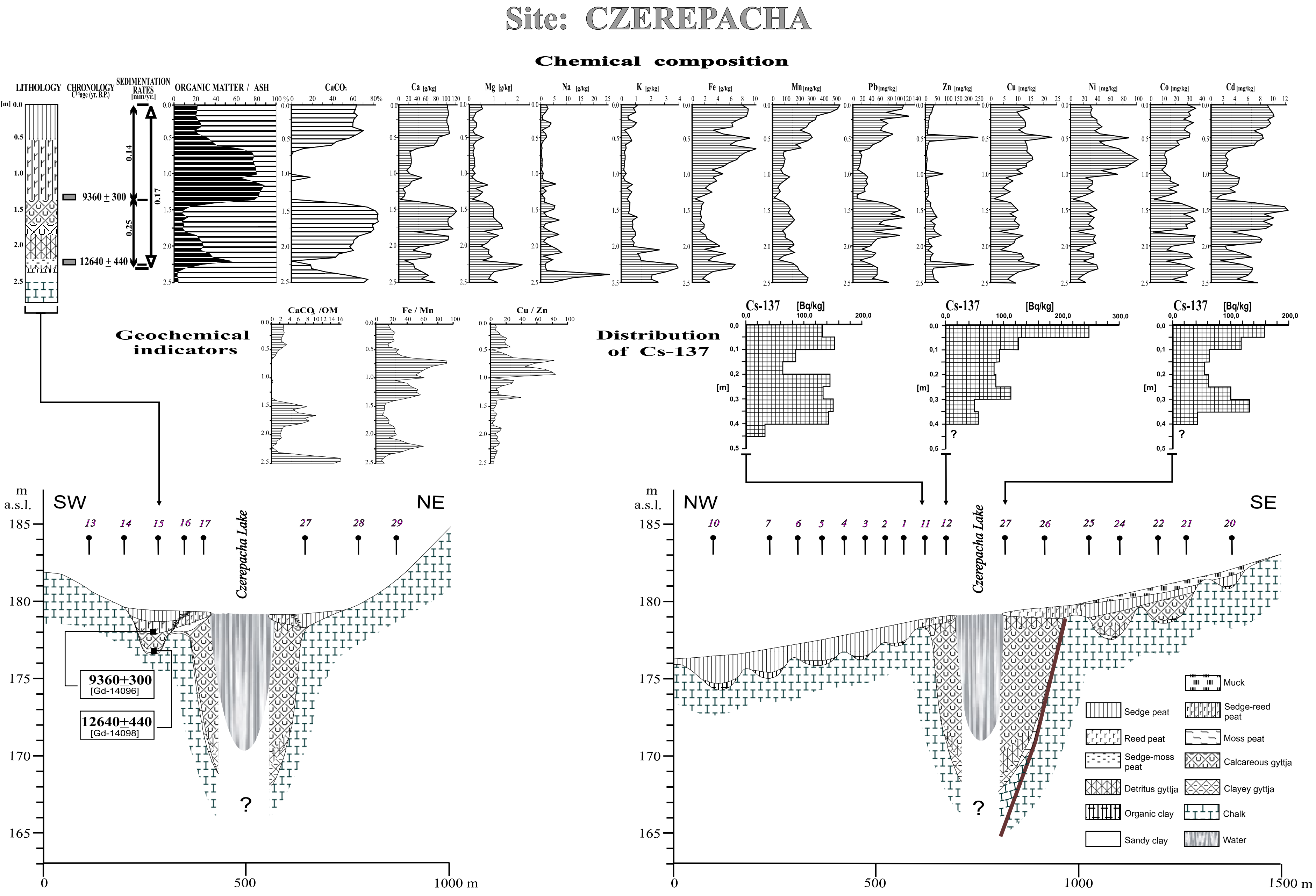

Fig. 3. *Geological cross-section of the Czerepacha lake and mire together with the chronostratigraphical and chemical characteristics of the selected cores of bottom deposits.*

period. Fluctuations of the lake water-level during the last 10 ka are evidenced by a distinct lithofacial variability of the gyttja deposits, stressed by a changing content of organic matter (OM) and $CaCO_3$ (**Fig. 2**). Increase of OM suggests a relative shallowing of the lake, and higher content of calcium carbonate evidences a rise of moisture and groundwater table. The lacustrine series in the Ok-55 core consists of algae, algae-calcareous, calcareous and detritus-calcareous gyttjas (**Fig. 2**).

The longest (2.5 m) of the analysed cores from the Czerepacha site (Cz-15) was taken from the central part of the karst doline. Lithology of biogenic deposits is here very differentiated, evidencing considerable changes of environmental conditions during sedimentation of these deposits. Sharp lithological boundaries in the profile (**Fig. 3**) suggest radical changes of water supply conditions or occurrence of stratigraphic hiatuses. Bottom part of the Cz-15 core consists of clayey weathered chalk changing upwards into dark-grey organic clay. It is overlain by a thin (0.05 m) layer of detritus gyttja which is gradually replaced by weakly decomposed sedge-moss peat. Radiocarbon dating of peats indicates that they were accumulated during the Oldest Dryas or Bölling (**Fig. 3**). Bottom moss peats are separated from the overlying gyttja by a sharp boundary. Lacustrine series is 0.75 m thick and bipartite; its bottom part is built of detritus-calcareous gyttja, and upper part – of calcareous gyttja (**Fig. 3**). A sharp boundary occurs between the lacustrine series and the overlaying sedge-reed peats (0.9 m thick), and also between the latter ones and the overlying sedge peats strongly enriched with calcium carbonate (**Fig. 3**).

4. RADIOCARBON DATING

Chronology of events is based on the radiocarbon dating of bottom deposit series with the highest content of OM which evidence main cycles of organic sedimentation in both examined basins. Nine samples from four profiles was dated using the ^{14}C method: 7 samples of lacustrine deposits collected from 3 cores taken in the Okunin site, i.e. Ok-55, bored in the central part of the lake and Ok-54, Ok-56, bored in its littoral zone; 2 samples of peat-lacustrine deposits collected from one core Cz-15 taken in the Czerepacha site.

^{14}C dating was carried out in the Gliwice Radiocarbon Laboratory using small gas proportional counters L4 and L5, with 0.3 l volumes and CO_2 filling gas pressure 1 atm, destined to dating of samples with low quantity of organic matter (Pazdur *et al.*, 2000). The small amount of organic matter for investigations is the source of relatively high laboratory errors of radiocarbon ages. ^{14}C conventional ages and lithology of the analysed samples are presented in **Table 1**.

5. RESULTS OF POLLEN ANALYSIS

Six samples were taken for pollen analysis from the bottom part of the Ok-55 core which contains mineralogenic substratum (clayey weathered chalk and organic clays) of the organic series, bottom moss peats, overlying algae and algae-calcareous gyttjas (**Fig. 4**). For a possible correction of the radiocarbon ages, pollen analysis was additionally carried out in 4 samples from the Cz-15 core.

The bottom sample of the Ok-55 core, taken from a depth of 11.8 m (mineral matter), is characterised by high pollen values of *Pinus* (79%) and *Artemisia* (13 %), and low frequencies of *Betula* (3 %). Birch pollen rises to 19 %, and that of *Artemisia* falls to 1.9 % in the overlying sample from a depth of 11.6 m (moss peat). Single pollen grains of *Ulmus* appear. Values of Cyperaceae increase to 12 %, and those of Poaceae undiff. to 9 %. Such pollen spectra may indicate that organic accumulation in the Okunin lake started in the early part of the Holocene (**Fig. 4**). A change of sedimentation type from peat to lacustrine took place during the Preboreal period (PB-2?). In the pollen diagram it is recorded by the decrease of *Artemisia* curve down to 1.9 % and the occurrence of the continuous curve of elm. Sudden appearance of the continuous and high curves of thermophilous trees (*Quercus* 6 %, *Ulmus* 4.6 %, *Corylus* 5.2 % and *Tilia* 0.5 %) at a depth of 11.2 m suggests a stratigraphic hiatus or very low rates of biogenic accumulation. It may also be confirmed by the occurrence of single pollen grains of *Fagus* and *Carpinus* in the overlying samples from the depths of 10.9 and 10.6 m. The results of pollen analysis correspond well to the radiocarbon dating obtained for this profile (**Fig. 4**).

Pinus, *Betula* and *Artemisia*, and also Poaceae undiff., Cyperaceae and *Juniperus* are the main components of pollen spectra in the bottom samples from the Cz-15 core (2.25 m – detritus gyttja; 2.15 m – sedge-moss peat). They indicate that biogenic sedimentation in the basin started in the Late Glacial (Bölling?). In the samples from the depths of 1.45 m (calcareous gyttja) and 1.35 m (sedge-

Table 1. *Results of radiocarbon dating of samples from Okunin and Czerepacha sites.*

Sample name	Depth [m]	Lithology	Lab. No.	^{14}C Age [BP]
Ok-55	11.60-11.70	Sedge-moss peat	Gd-10975	10370±170
Ok-55	11.10-11.15	algae gyttja	Gd-14094	9770±250
Ok-55	10.75-10.83	algae gyttja	Gd-13095	6520±250
Ok-55	9.24-9.31	algae gyttja	Gd-13081	3250±150
Ok-55	8.10-8.15	algae gyttja	Gd-14085	2390±270
Ok-56	4.05-4.10	moss peat	Gd-14086	9110±290
Ok-54	2.78-2.86	sedge-moss peat	Gd-10976	9280±170
Cz-15	2.15-2.20	sedge-moss peat	Gd-14098	12640±440
Cz-15	1.33-1.38	sedge-reed peat	Gd-14096	9360±300

reed peat) pine and birch pollen, and also not numerous pollen of thermophilous trees (*Ulmus, Quercus, Fraxinus and Tilia*) occur, indicating the Early Holocene (Preboreal?) age of these deposits.

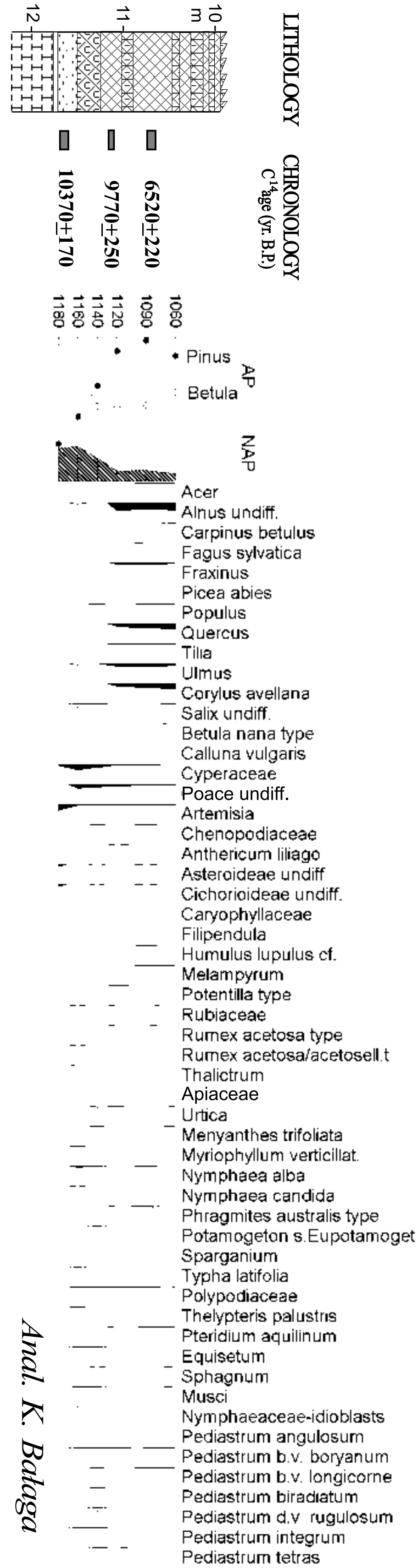

Fig. 4. *Pollen diagram of the lower part of the Ok-55 core.*

6. OSTRACODA COMPOSITION

Ostracods were studied in the Ok-55 lacustrine core. Structures of palaeobiotopes were analysed in small samples ≤ 5 cm long, taken with regard to lithofacial variability of the lacustrine deposits. Fauna belonging to 21 species, 12 genera and 3 families was recognised. Besides determination of the ostracod species composition, there was used a complex palaeolimnological analysis which included facial variability of deposits, their bulk density, occurrence of macroremnants, molluscan fauna and so on (Zubovič, 1983). All these data were used for detailed paleogeographical reconstructions, among others for estimation of climatic and hydrologic (lake water-level) changes in the successive evolution stages of the lake (**Fig. 5**). Stratigraphic interpretation of the ostracod analysis results made by S. Zubovič (1983) differs considerably from the data obtained using other methods; in his opinion the organogenic sedimentation in the Okunin lake could have started about 3 ka earlier (**Fig. 5**).

The following main palaeogeographical conclusions were drawn from the ostracod analysis:

1. Development of the modern lake basin started in the Oldest Dryas (DR-1). Bottom part of the lacustrine series is built of deposits formed in a shallow, cold lake; thin layer of organic, slightly sandy clays overlies chalk. The following pre-Eemian ostracod species were found in this layer: *Eucypris sp.l.*, *Cyclocypris sp.*, *Candona ex. gr. stagnalis*, *Candona renaria* Zubowicz, *C. cuneata* Zubowicz, *C. aff. candida* O. Müller and *Cyclocypris aff. ovum* (Jurine). Their occurrence may indirectly suggest that the Mesopleistocene basin of the pra-Okunin lake was reactivated during the Late Glacial (!).
2. Lake became deeper and deeper as a result of gradual subsidence of substratum during the Bölling; thermal conditions of water (three phases of warming were separated by slight coolings) fluctuated synchronously with the changes of the lake depth.
3. In the Older Dryas (DR-2) a small rise of the lake water-level (almost to the modern level) occurred as well as a decrease in water mean temperature in summer half-year by about 2 °C in comparison with the modern temperatures.
4. In the Alleröd (AL) a distinct, long-lasting rise in water mean temperature and a short-lasting lowering of water-level occurred simultaneously; therefore, the climate was rather warm but dry. In the last stage of this period the lake water-level was lower than the modern one by about 1.0 m.
5. Small rise in mean temperature of the lake water occurred at the beginning of the Younger Dryas (DR-3); the later part of this period was characterised by slight cooling and distinctly lower precipitation (rise in the dryness index).
6. Gradual increase in air temperature, and distinct rise of the lake water-level and water temperature started from the beginning of the Holocene (PB-1 and PB-2).
7. Slight climatic cooling occurring in the Boreal period (BO) was connected with a decrease in precipitation; water mean temperature was lower than the modern one by about 1 °C.

8. A considerable rise in precipitation and air temperature took place in the Early Atlantic period (AT-1); the Middle Atlantic period (AT-2) was characterised by distinct fluctuations of the lake water-level (greater than the modern ones), and changes of water temperature from 15.5 to 17.0 °C. In the Late Atlantic period (AT-3) a rise in air temperature (which was probably higher than the modern one by 1.5-2 °C) and a distinct lowering of the lake water-level (to about 1.2 m below the modern one) occurred.

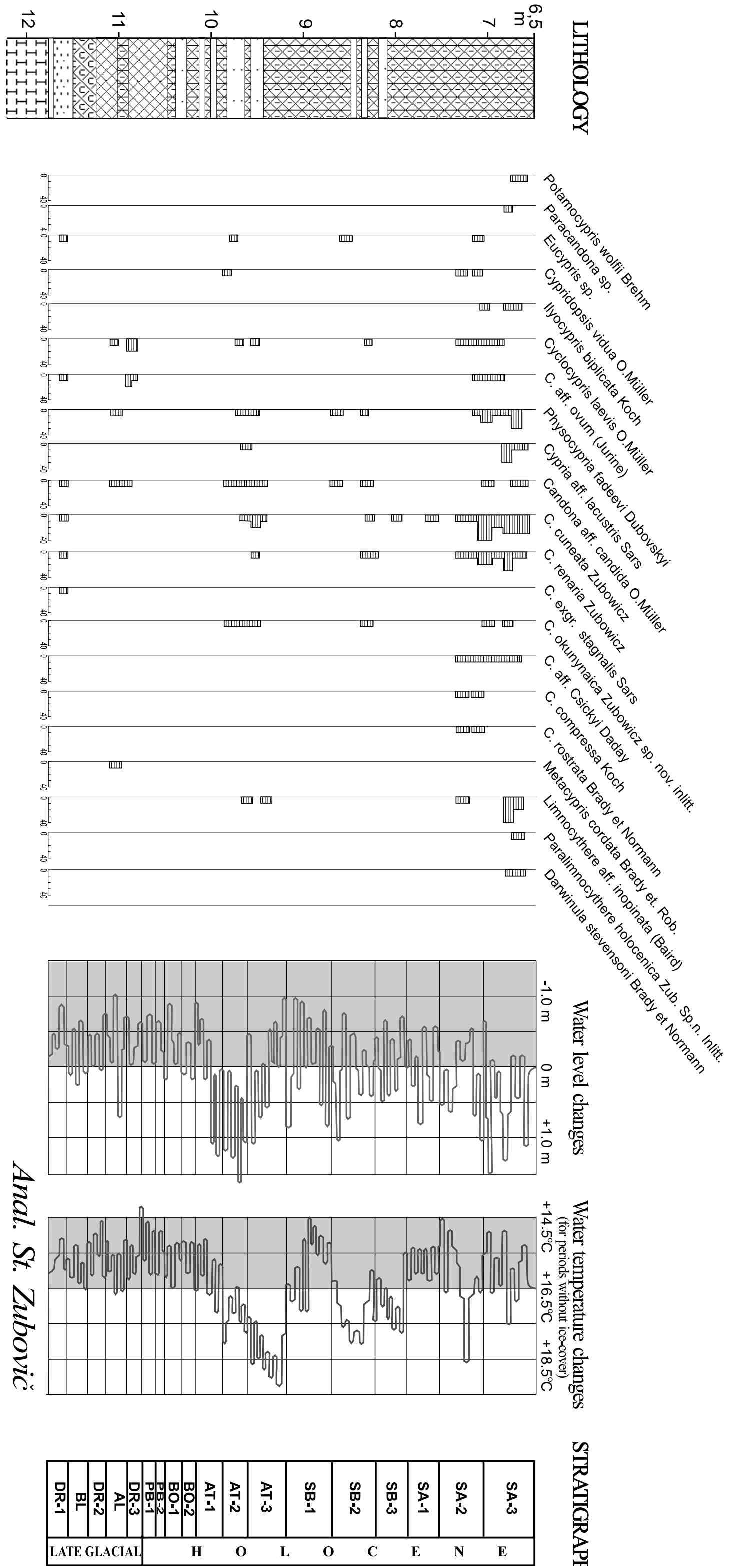

Fig. 5. *Ostracod diagram of the Ok-55 core with palaeolimnological interpretation.*

9. The Subboreal period (SB) was characterised by considerable fluctuations of the lake water-level and temperature related to oscillations of air moisture and temperature. A considerable but short rise in precipitation at the beginning of this period (when air temperature was similar to the modern one) was followed by its decrease which lasted during the whole SB-1 phase. Continuous decrease in mean annual air temperature, and fluctuations of mean annual precipitation were characteristic features of the Middle Subboreal (SB-2). A slow rise in air temperature and moisture took place from the middle of the SB-2 phase to the end of the Subboreal; it was only broken by a short cooling on the turn of the SB-2 and SB-3.

10. Distinct cooling (a fall in mean annual temperature of lake water by about 2 °C) and a rise in climatic dryness index (a lowering of the lake water-level by about 0.5 m) occurred on the turn of the Subboreal and Subatlantic periods (SB/SA). The Early Subatlantic period was characterised by distinct stabilization of thermic conditions (mean annual temperature was similar to the modern one) and slight fluctuations of moisture. Distinct climatic cooling and higher precipitation occurred in the SA-2 phase. A slow rise in mean annual air temperature and sinusoidal changes of precipitation have occurred since the end of this phase to the modern times.

7. RESULTS OF GEOCHEMICAL ANALYSIS

Complete geochemical analysis of 50 samples (5-cm-long portions) from the Cz-15 core (**Fig. 3**) was carried out. Main physico-chemical parameters (contents of OM, $CaCO_3$ and pH) were determined in 106 samples from the Ok-55 core (**Fig. 2**). Dry mass, organic matter and ash were determined by standard methods used in chemical analysis of organic soils (Sapek and Sapek, 1990 and 1997). Macroelements (Na, K, Ca, Mg, Fe) and microelements (Mn, Cu, Zn, Pb, Ni, Co, Cd) were analysed using the ASA technique after removal of organic matter and digestion of mineral matter with mixture of acids (hydrofluoric, nitric and perchloric acid).

Vertical distribution of micro- and macroelements is very closely connected with lithological types of bottom deposits (a lithological boundary usually corresponds to a distinct geochemical boundary). It concerns especially those elements which are the main chemical components of the deposits and determine the nature of geochemical environment in the studied area, i.e. Ca, Fe, K, Mg and Na (**Fig. 3**).

Carbonate rocks of the Upper Cretaceous predominate around both lake-mire basins, so calcium is the main component of the deposits filling these basins. In the Cz-15 profile its maximum contents (205-245 g/kg) occur in the lacustrine series (calcareous and detritus-calcareous gyttjas), and in the upper sedge peats (**Fig. 3**). The content of Ca in the profile is distinctly positively correlated with the contents of Mg, Mn, Cu, Pb, Co and Cd. High content of $CaCO_3$ is also a typical feature of the almost whole lacustrine part of the Ok-55 profile (calcareous-algae and calcareous gyttjas); however, its content ranges from 0 to 95 %, evidencing distinct fluctuations of the lake water-level. The $CaCO_3$/OM ratio is one of the important features of the calcareous deposits (Wojciechowski, 2000). When considering geological structure of the area (karst processes developing in chalk) one can use this ratio as an indirect index of moisture-thermic changes which have occurred in the environment. Including the radiocarbon ages of these deposits, we can suppose that the regular rise of the groundwater table (and simultaneously of leaching rates) occurred in the following stages: i) Bölling (?); ii) long-lasting period from the Alleröd to the close of the Preboreal; iii) Atlantic period; iv) Subatlantic period (**Fig. 3**).

From the palaeogeographical point of view these geochemical indices are also important (Fe/Mn and Cu/Zn), the changes of which reflect the fluctuations of redox conditions in the environment (Digerfeldt, 1988; Borówka, 1992). When the groundwater table was relatively low, the conditions were more reducing and corresponded to higher OM contents (depths of 0.6-1.0 m, 1.1-1.4 m and 2.1-2.3 m); more oxidizing conditions were related with the rise of the groundwater table (depths of 0.0-0.5 m and 1.4-2.1 m).

8. ^{137}Cs DISTRIBUTION IN VERTICAL PROFILES

^{137}Cs content was determined in the top parts of lacustrine and mire deposits in both studied sites (**Fig. 2**, **3**). Four cores from the Okunin site (Ok-54a, Ok-55, Ok-56a and Ok-61) and three cores from the Czerepacha site (Cz-11, Cz-12 and Cz-27) were sampled for this analysis. These cores were taken along the NE-SSW section in the Okunin and NW-SE section in the Czerepacha sites, traced across the marginal and central parts of the sedimentary basins (**Figs 2** and **3**). Homogenous samples representing the 5-cm-long portions of the cores were analysed. Content of ^{137}Cs was determined by means of a gamma spectrometry method using of the "TUKAN" multi-channel impulse amplitude analyser. The measurement time for each sample lasted 24 hours (345,600 s).

Spectrometric analysis revealed the occurrence of caesium in all examined cores to a depth of 24-45 cm. However, its content varies in a large range; from 30 to 245 $Bq \cdot kg^{-1}$ in the peat cores, and from 12 to 486 $Bq \cdot kg^{-1}$ in the lacustrine core (Figs 2 and 3). Two or sometimes even three distinct maxima of ^{137}Cs concentration were found, independently of a deposit type; they occur in the top parts (usually at a depth of 5 cm) and in the bottom parts (at a depth of 25-30 cm or/and 30-35 cm) of the analysed cores. Such distribution of caesium in the vertical profile is similar as in other European lake and lake-mire geosystems in which the ^{137}Cs content was determined (He *et al.*, 1996; Smith *et al.*, 1999) and corresponds with the global changes of radioactive fallout during the last 50 years. Therefore, the successive peaks of caesium content should be connected with the first nuclear tests which were conducted on a large scale on the turn of the 50's and 60's of the last century (the bottom samples) and with the Chernobyl nuclear accident (the top samples). The obtained results afford possibilities for a quantitative valuation of radioactive contamination in the studied area (caesium content is here similar as its maximum values in the bottom deposits of the Masurian Lakes, and 4-5 times higher than in the Scandinavian and British lakes – *vide* Zalewski *et al.*, 1995; Smith *et al.*, 1999). These results were also used for estimation of the rate of lacustrine organogenic sedimentation (Ok-55 core). Rate of modern organogenic sedimentation (loose, unconsolidated gyttja deposits) in the Okunin lake was determined on the basis of ^{137}Cs content at 0.64 $cm \cdot yr^{-1}$. Linear sedimentation rate calculated for the small lakes in S England was usually two times higher in the same period and amounted to 1-2 $cm \cdot yr^{-1}$ (He *et al.*, 1996).

9. CONCLUSIONS

Complex data from the analysed cores allow us to reconstruct a palaeoenvironment of the studied lake-mire geosystems. Despite the presented here different dating results of the successive stages of their development, we try to estimate the regional changes of climate and water conditions in the southern part of the Volhynia Polesiye during the last 13 ka.

1. **Late Glacial (12.3-10.25 ka BP).** Biogenic sedimentation in the Volhynia Polesiye started in the Bölling (*ca* 12.3 ka BP). It is confirmed by radiocarbon dating and pollen analysis of the Cz-15 core (and also by ostracod analysis in the Ok-55 core – in the opinion of S. Zubovič). Shallow mires (mainly sedge, sedge-moss and moss ones) developed during short warming but when permafrost still occurred. Biogenic sedimentation rate was slowed down by cooling in the Older Dryas (12.3-11.8 ka BP). Beginning of the Alleröd (11.8-10.9 ka BP) was characterised by long-lasting warming with rather low groundwater table. A considerable increase in moisture and acceleration of carbonate sedimentation occurred in the later part of this period. Small, episodic lakes (Czerepacha site) were formed in places. They underwent considerable shallowing or complete decline during the Younger Dryas (10.9-10.25 ka BP), and reed-sedge peats succeeded again.
2. **Holocene (10.25 ka BP – the present).** Long-lasting warming, developing since the Preboreal (10.25-9.3 ka BP), resulted in a complete decline of permafrost and radical change of water supply conditions. Activation of vertical water drainage caused subsidence of bottoms in some mire basins and development of rather deep lakes (it is indirectly evidenced by ^{14}C dating and pollen analysis of the Ok-55 core). Cooling and moisture decrease in the Boreal (9.3-8.4 ka BP) were recorded by the lowering of groundwater table and the increase in redox indices; biogenic sedimentation rate distinctly fell (*ca* 0.11 $cm \cdot yr^{-1}$ in the Okunin lake). A slow increase in mean air temperature and precipitation occurring in the Atlantic period (8.4-5.0 ka BP) was connected with the rise of groundwater table. These changes were recorded by calcareous gyttja which was deposited over algae and detritus gyttjas in lake basins (Ok-55 core); reed and reed-sedge peats were

accumulated in mires. This long-lasting rise in air temperature and moisture was interrupted only in the middle Atlantic period by one short episode of cooling and lowering of the groundwater table which was radiocarbon dated at 6300-6600 BP. The Subboreal period (5.0-2.8 ka BP) was characterised by considerable fluctuations of temperature and moisture, evidenced by a great facial variability of biogenic deposits. An Early Subboreal stage of abrupt cooling and a simultaneous rise in dryness indices (rapid rise in the OM/$CaCO_3$ proportion) is distinctly visible in the profiles; a slow rise in air temperature and moisture started in the middle part of the Subboreal. The Subatlantic period (<2.8 ka BP) was characterised by rather stable thermic conditions and small fluctuations of moisture. Mean air temperature was gradually increasing after slight cooling at the turn of the Subboreal and Subatlantic periods. The groundwater table also rose; carbonate content in the lake-mire geosystems distinctly increased (calcareous-algae gyttja was accumulated in the Okunin lake, and amorphous $CaCO_3$ was precipitated within sedge peats in the Czerepacha mire).

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