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THE HOLOCENE DEVELOPMENT OF LAKE WIELKIE GACNO, NW POLAND A PALAEOECOLOGICAL STUDY
Preliminary results

ABSTRACT. The lake Wielkie Gacno is an oligotrophic lake situated within the sandy areas of Tuchola Forest. The stratigraphy of its sediments was studies in detail, on the basis of several longitudinal and transversial series of borings and analyses of 12 profiles in the laboratory. One main profile from the deepest part of the lake and four profiles from the bay were examined by means of pollen and macrofossil analyses, and 23 samples were radiocarbon dated.

The main features of the vegetational development during the last 12 000 years are described and the immigration times of forest trees into the study area are established. The changes of water-level in the lake are traced by means of coarse detritus, seed and fruit analyses.

INTRODUCTION

The palaeoecological investigation of Lake Wielkie Gacno represents one point in the International Geological Correlation Programme (IGCP) — Project No 158, Subproject B. The object of this IGCP-project is to analyse in a high degree of detail palaeoecological reference profiles which have a chronology based on accurate absolute datings from different type regions, in this case one type region in NW — Poland (Fig. 1.).
"The type pollen diagrams will show the regional variation in the development of the vegetation and provide a basis for an interpretation of the relation between vegetation, soil and climate development" (Berglund & Digerfeldt 1976). The interpretation of the limnological and environmental development of the reference area, here represented by Lake Wielkie Gacno and its surroundings, is based on chemical and physical analyses. On the basis of several microfossil and chemical analyses, Holocene settlement and landscape de-

velopment can be reconstructed and valuable palaeoecological, limnological and hydrological correlations can be made between selected type regions in the temperate zone.

The investigation area is situated in SE-Pomerania, in the so-called Bory Tucholskie district. This forest area lies between two tributaries of Vistula River, the Wda and the Brda. The Lake Wielkie Gacno lies between Lake Charzykowskie and the Brda, in a forested lowland and fulfils the requirements of a representative lake, when the present and fossil vegetation representation are considered in having a catchment area radius ca. 15–20 km. This regional representativeness is tested by analyses of surface pollen spectra from 7 different lakes in the same region compared with one lake from an other vegetational area in the same natural geographical area. These spectra are interpreted both by conventional and numerical methods.

This part of NW-Poland, called Bory Tucholskie, has always been a blank area as far as palynological investigations are concerned. However, the lake territory of Kaszuby and Kartuzy to the north of the Tuchola pine forests has been studied to some degree as has the area to the south of this large fo-

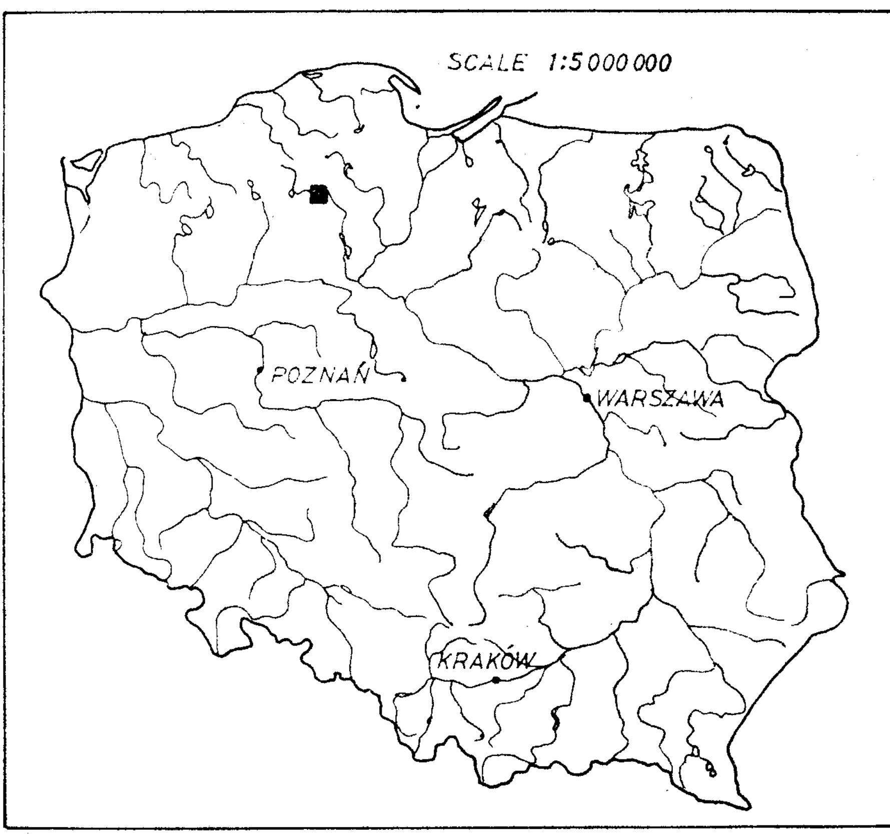

Fig. 1. The investigated type region, (■)

rest area. In the main these studies were undertaken before the second world war and they have been difficult to obtain. All previous investigations are very poor in radio-carbon datings and therefore difficult to compare with this investigation. The most important available modern palynological studies are shown in Fig. 2.

In this paper, the history of the regional vegetation and the water-level changes of Lake Wielkie Gacno-district are presented. The human impact on the natural vegetation has been discussed in an earlier paper (Hjelmroos 1981) and the palaeolimnology of Lake Wielkie Gacno will be published somewhat later. The complete investigation of Lake Wielkie Gacno have been already published (Hjelmroos-Ericsson 1981).

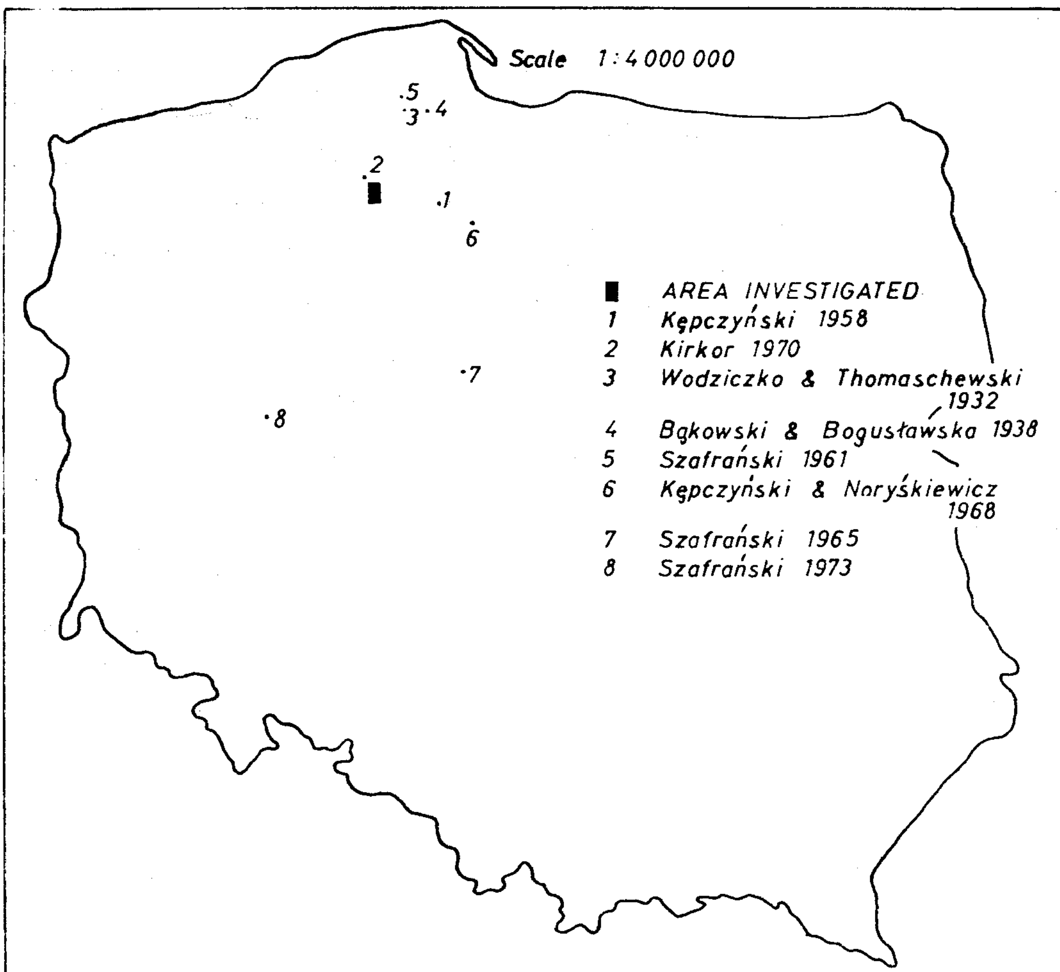

Fig. 2. The most important available modern palynological studies close by the investigated area

THE INVESTIGATION AREA

Geology, geomorphology, topography and soils

The Tuchola pine forest district is situated in the Brzeźna Depression, where Oligocene glauconite sands and Upper Cretaceous marls form the bottom layer. This layer appears in broad erosional cuts in the Miocene sediments. These Miocene sediments, the so-called lignite formation, are ca. 80 m thick bed emerging from beneath Pliocene deposits. The deposites sometimes show a sedimentary character due either to glacial or fluvial erosion.

The thickness of Quaternary deposits in the area is 50—80 m. The area around Lake Charzykowskie belongs to the widespread outwash plain in the foreland of the Pomeranian endmoraine zone. The endmoraines surrounding the terminal depression of Lake Charzykowskie were probably formed by

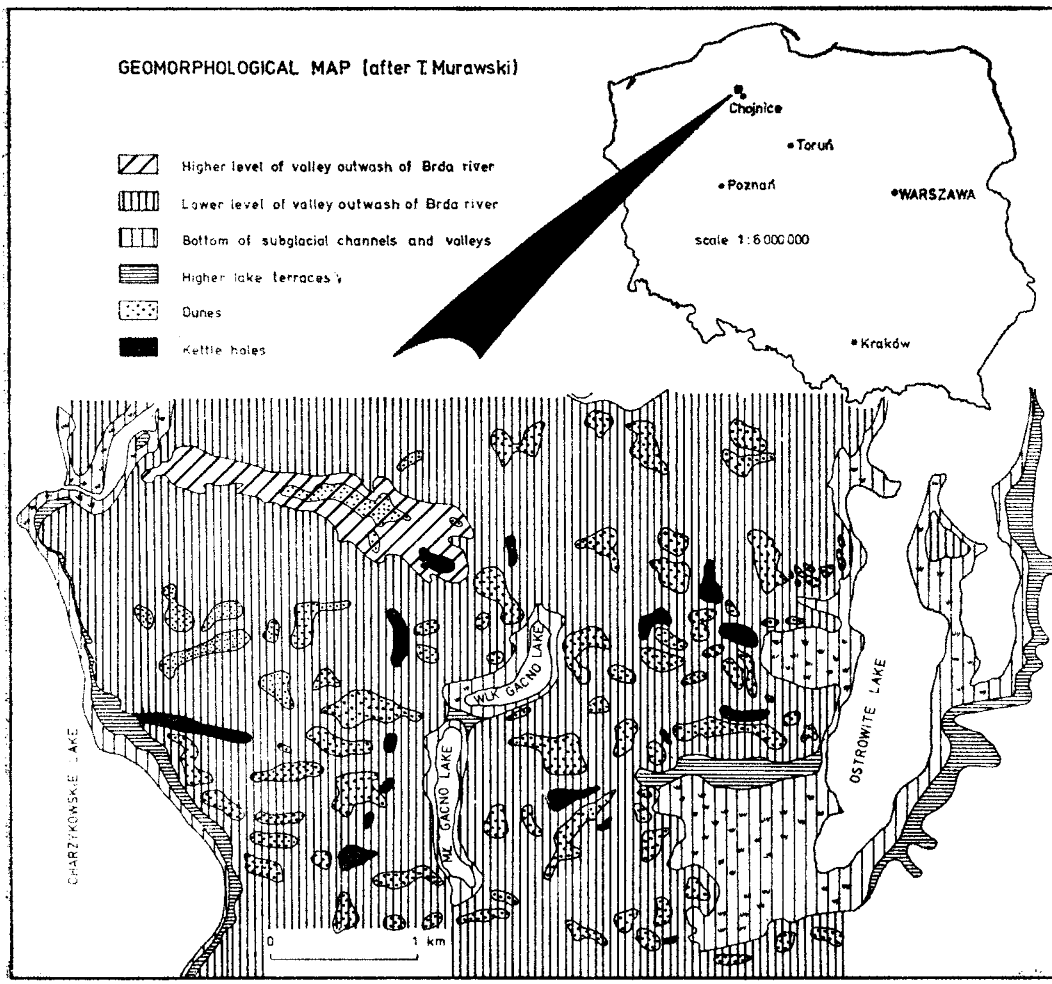

Fig. 3. The geomorphology of the investigation area (after T. Murawski)

minor glacial lobes which extended beyond the ice-sheet front. Sometimes they are called Charzykowo-Gwieździn moraines (Pasierbski 1973). The Pomeranian ice-marginal zone is characterized by the close spacing of morainal forms within the main marginal zone and the development of outwash plains (Galon 1961). Numerous extensive depressions have been formed either by meltwater action and melting dead-ice blocks or by the activity of Late-Glacial and Holocene rivers. The geomorphology of the investigation area is illustrated in Fig. 3.

The landscape is characterized by dunes, which are thought to have been formed partly during the cold periods of the Late-Glacial and partly during the Holocene (e. g. Tobolski 1966). The sites of the dunes are mostly 140—145 m a.s.l. Otherwise the largest part of the area N and NE of Lake Charzykowskie is situated between 135 m and 145 m a.s.l.

The soils originate predominantly in deposits of glacial origin. At the present day they are mainly podsols or podsolized rendzinas formed in sands. Because of the leaching of nutrients a rapid acidification and impoverishment is going on. The raw humus layer is thin and the illuvial horizon which is of a rusty colour is very compact.

Climate

The area surrounding Lake Wielkie Gacno belongs to the lakeland climate region. The summers are quite cool and the arrival of spring is delayed due to the great number of lakes. The lakeland climate region lies within an annual isotherm of +6·5°C, the mean January temperature is — 3°C and that of July +17.5 — +17.0 °C.

The annual rainfall is c. 600–650 mm and the length of the growing season about 190–200 days (Atlas Klimatyczny Polski IMiGW in Atlas Geograficzny Polski 1978).

Recent vegetation

The investigation area belongs to the West Pomeranian Transition Belt in the Belt of the Maritime Plains and Pomeranian Uplands which is a part of the Baltic division of the Central European Lowland-Highland Subprovince (Szafer & Pawłowski 1966). According to the physiographical division of Galon (1947) the area investigated is a part of the Tuchola forests in the uplands and basins division. The West Pomeranian Transition Belt is divided into 4 main districts: a. Marginal zone of Noteć Valley, b. Złotów Upland, c. Tuchola Forests and d. Dobrzyń Upland on the eastern side of the Vistula.

The dominant forest element is *Pinus* with an admixture of *Fagus* growing mostly on sandy soils. *Pinus*-forests are divided into several type-associations depending upon the soil moisture: *Vaccinium myrtillus*-, *Vaccinium vitis-idea*-, *Vaccinium uliginosum-*, *Calluna* — and *Cetraria*-types. On fertile soils *Tilio-Carpinetum* (eastern) — and *Galio (silvatici)-Carpinetum* (western) — associations are found.

The pine forests seen in the investigation area mostly have an anthropogenic origin. The most common forest associations are *Vaccinio myrtilli—Pinetum* (Sokołowski 1965), on wet places *Leucobryo-Pinetum* and *Peucedano-Pinetum* (Matuszkiewicz & Matuszkiewicz 1973). Besides these the more infrequent *Vaccinio uliginosi-Pinetum*, *Luzulo-Fagetum* (Matuszkiewicz & Matuszkiewicz 1973) and *Galio (silvatici)-Carpinetum* (Sokołowski 1970) are found and sometimes also *Carici elongatae-Alnetum* (Sokołowski 1970). The distribution of the several forest associations in the close vicinity of Lake Wielkie Gacno is shown in Fig. 4.

Lake Wielkie Gacno

The lake is part of a glacial channel complex on the lower level of the proto-valley of the Brda river. Its area is 13 ha. The greatest water depth which is encountered in the north-eastern part of the lake exceeds 6 m (Fig. 4).

An organic fine detritus gyttja forms the bottom sediment in all parts of the lake. The maximum thickness of the Holocene sediments found in the north-eastern part of the lake, is 8 m, but mostly the thickness ranges from 3 m to 6 m (Fig. 5). In the deeper parts the gyttja is underlain by sand and silty sand. At the south-western and north-eastern shores, under the Holocene gyttja, a layer of Late-Glacial age is encountered which reaches a thickness of ca. 0·7 m.

Lake Wielkie Gacno is a so-called *Lobelia* lake. In Poland this kind of lakes with *Lobelia dortmanna* and *Isoëtes* communities occurs almost exclusively in Pomerania to the west of Vistula river (Pawłowski 1966). Due to the oligotrophic nature of the lake the macrophytic vegetation is poorly developed. In the littoral zone *Lobelia dortmanna*, *Isoëtes echinospora*, *Carex lasiocarpa*, *Littorella uniflora*, *Nitella flexilis* and *Chara delicatula* are found. In the profundal zone the bottom is covered by *Drepanocladus fluitans*. Along the north-eastern shore there is a reed formed by *Phragmites communis*, *Equisetum* and *Carex*.

HISTORY OF THE REGIONAL VEGETATION

Field work and methods

The preliminary stratigraphical investigations of Lake Wielkie Gacno were carried out using a Russian peat sampler. The lake basin has been investigated by means of one longitudinal and 5 transverse sections with particular

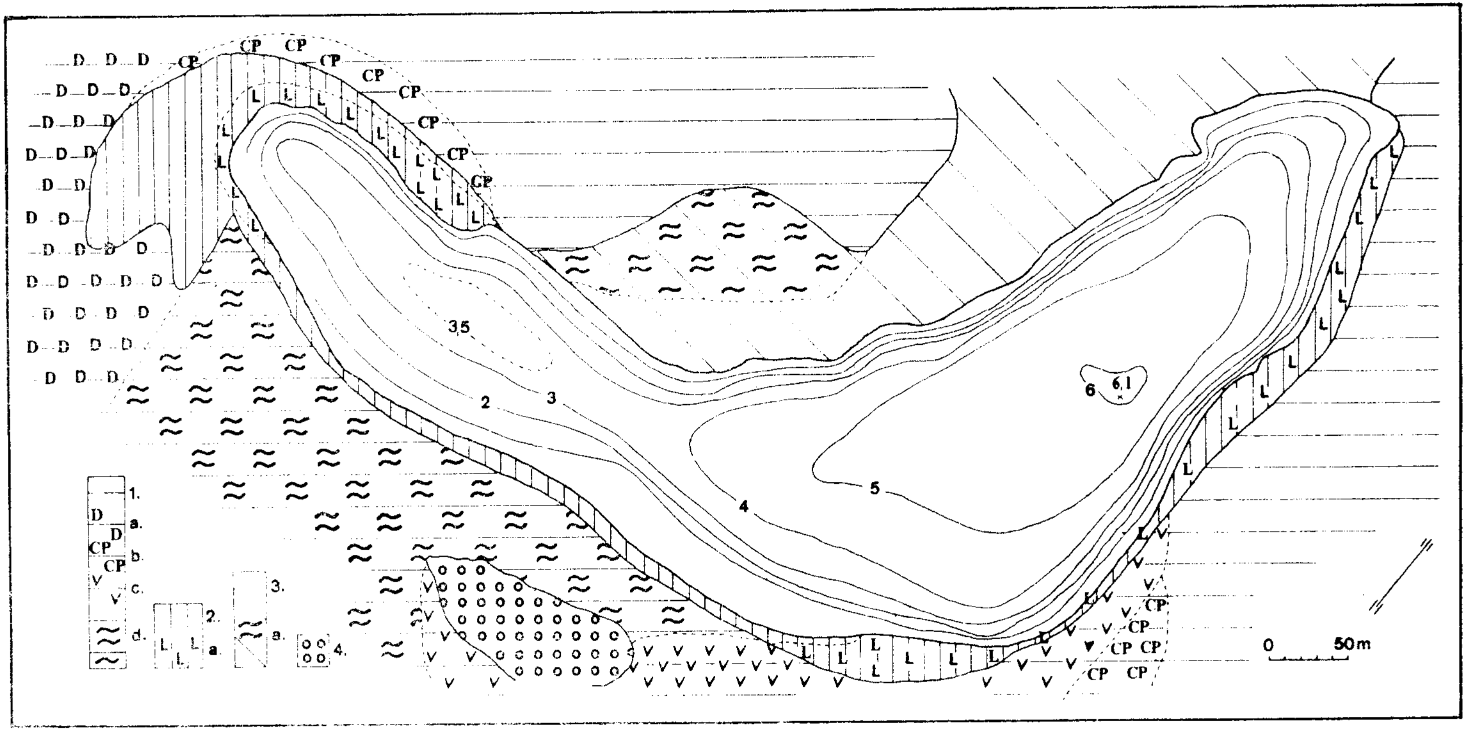

Fig. 4. Lake Wielkie Gacno. Map of the vegetation and the water depth (m). Symbols of the forest associations: 1. *Leucobryo-Pinetum*, 1a. variant with *Deschampsia caespitosa*, 1b. variant with *Calamagrostis arundinaceae* and *Pteridium aquilinum*, 1c. variant with *Vaccinium myrtillus*, 1d. variant mossy. 2. *Molinio-Pinetum*, 2a. variant with *Ledum palustre*. 3. *Cladonio-Pinetum*, 3a. variant mossy. 4. *Vaccinio uliginosi-Pinetum*

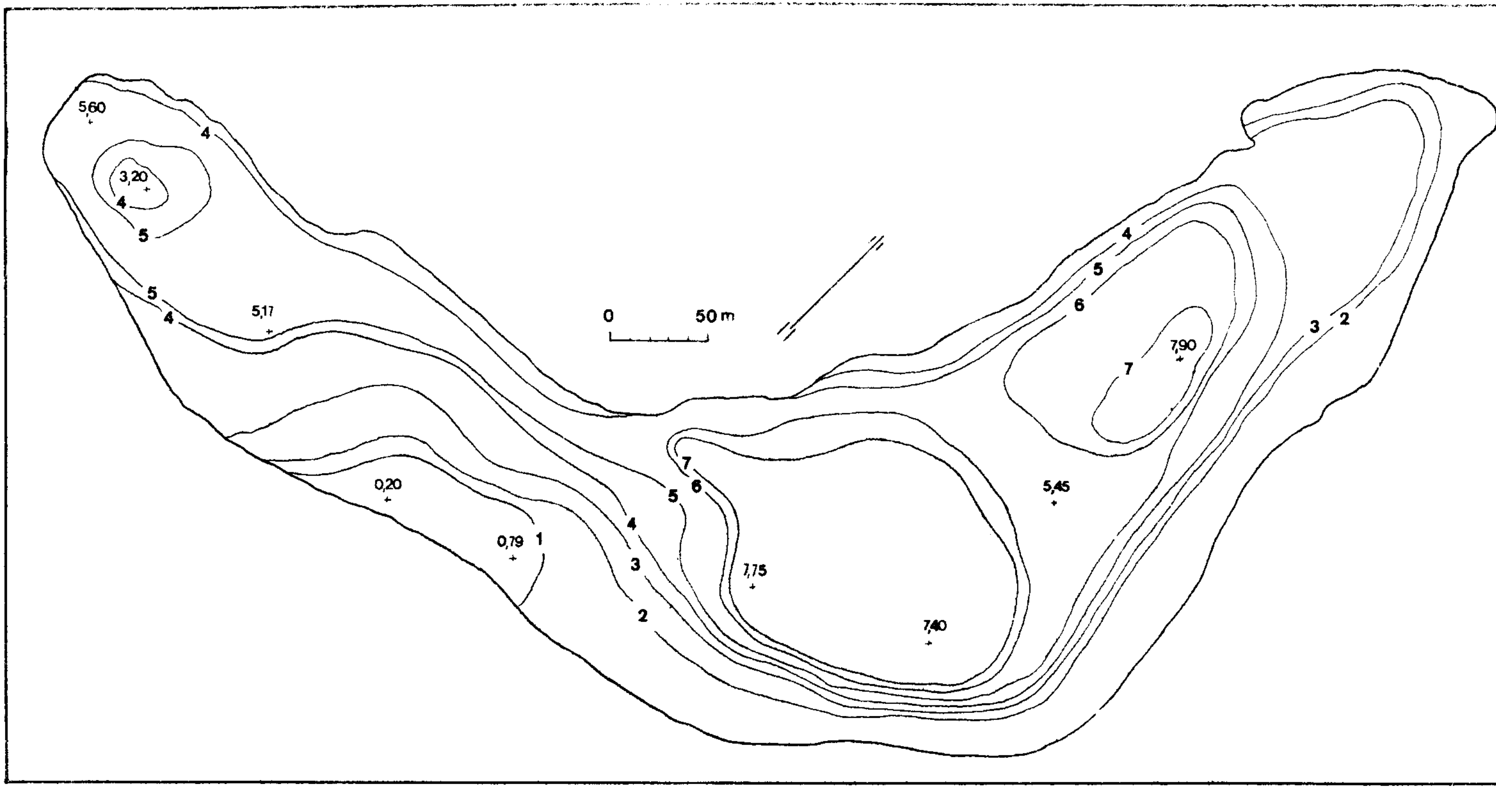

Fig. 5. The thickness of the Holocene sediments in Lake Wielkie Gacno

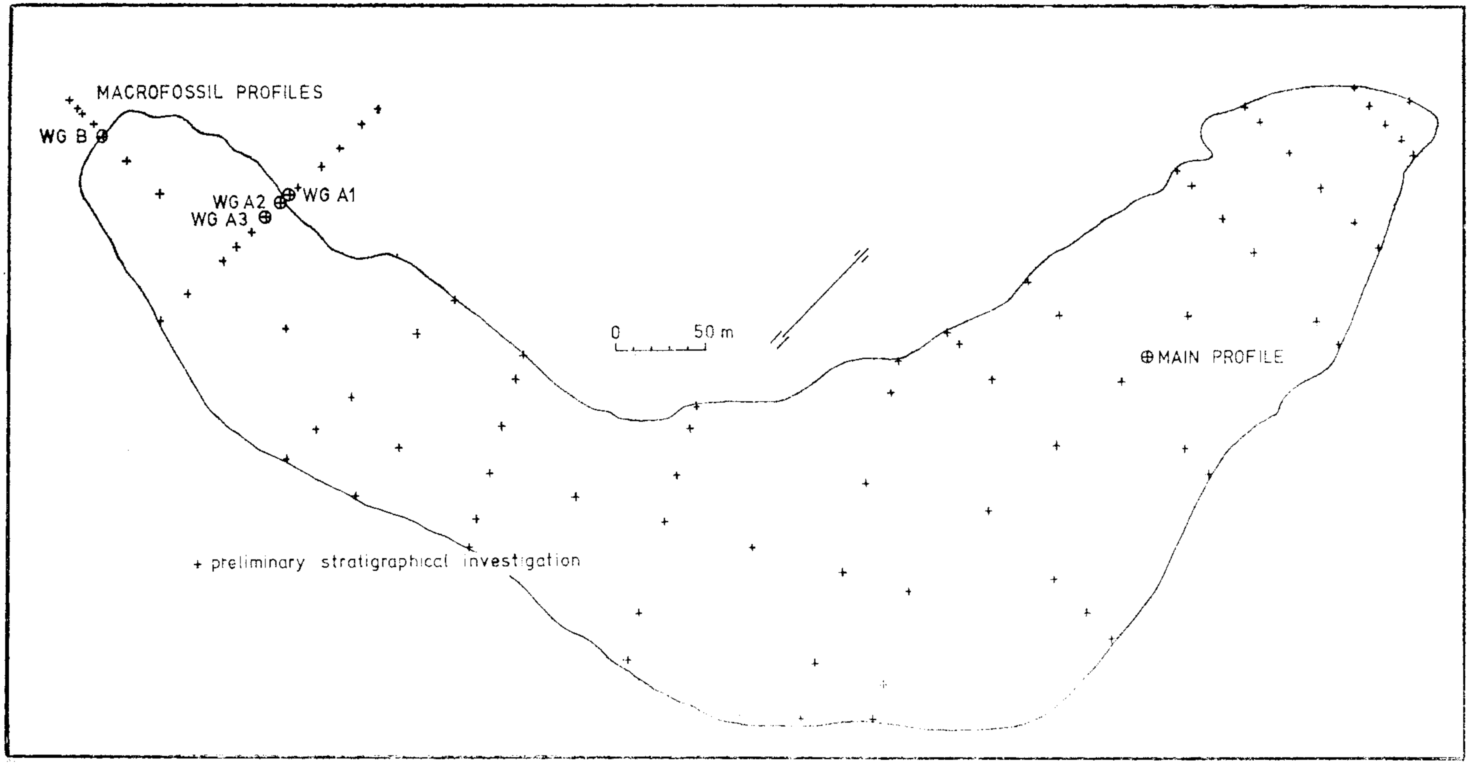

Fig. 6. Map showing the situation of the investigated profiles

attention being paid to the shore areas. 12 sediment profiles were taken to the laboratory for more detail stratigraphical investigations.

The palaeoecological investigations are based on the pollen analysis of one main profile, taken with a Livingstone sampler with a tube length of 1.7 m and diameter of 100 mm, from the deepest part of the lake. The same method was used in taking the four sediment cores for investigating water-level changes. The position of the profiles within the lake is shown in Fig. 6.

Sampling techniques are in accordance with those recommended in the project guide for IGCP 158 B (ed. by **Berglund** 1979), and are presented in Table 1.

Table 1.

Working methods used in the investigation of Wielkie Gacno

Core	Subsample (Volume/density)	Analysis
Main profile	1 cm^3/5 cm	Pollen percent Pollen influx
	1 cm^3/20 cm	Diatoms
	2–5 mm^3/50 cm (at critical points 5–10 cm)	Element analysis
	1 cm^3/5 cm	*Cladocera* analysis
	1 cm^3/5 cm	Physical sediment analysis
	1 cm^3/20–25 cm	Sediment chemical analysis
	continuous	X-radiography
	1 cm^3/20–25 cm	Pigment analysis
	c. 350 cm^3/50 cm (mainly)	^{14}C-dating
Additional profiles	1 cm^3/5 cm	Pollen percent Pollen influx (only in one of the additional profiles)
	c. 350 cm^3/continuous	Plant macrofossil analysis
	1 cm^3/5 cm	Physical sediment analysis (only in the Late-Glacial part of the WG A1-profile)
Additional profiles (cont.)	c. 350 cm^3/at critical points	^{14}C-dating (in the Late-Glacial part of the WG A1-profile)
	2–5 mm^3/at critical points	Element analysis

Stratigraphy of investigated profiles

The sediments are described according to the soil characterization system proposed by **Troels-Smith** (1955). The description of the sediments in the additional profiles WG A1, WG A2, WG A3 and WG B1 is included in the complete investigation of Lake Wielkie Gacno.

Limus detrituosus (Algae) is used to describe the occurrence of algae in the sediment and is comparable to *Limus siliceus organogenes (Lso)* (**Aaby** 1979).

Main profile: Depth below water surface (cm)	Layer no.	Description
505–890	1	Fine detritus gyttja, brown which downwards successively changes to dark-brown Composition: Ld°4, Dg+ Lower boundary diffuse
890–1055	2	Algal gyttja, dark brown Composition: Ld°2, Ld (*Algae*) 2 Lower boundary diffuse
1055–1305	3	Algal gyttja, dark greenish-brown Composition: Ld°1, Ld (*Algae*) 3 Lower boundary sharp
1305–1315	4	Silty sand, light bluish-grey Composition: Ag 2, (Ga+Gs) 2

Pollen analysis and pollen diagrams

Samples for pollen analysis have been prepared using acetolysis and the general treatment follows the method described by Faegri & Iversen (1964). Those samples rich in minerogenic material have been prepared using the $ZnCl_2$-flotation method (Björck et al. 1978). Absolute pollen determinations were made according to the method described by Stockmarr (1971). Ca. 3000 AP were usually counted at each level in the main profile, while in the additional profiles the corresponding number was ca. 1000.

The construction of the pollen diagrams follows the recommendations in the project quide for IGCP 158 B (op. cit.).

Zoning of the pollen diagrams and description of the pollen assemblage zones

The pollen diagrams have been divided into pollen assemblage zones and pollen assemblage subzones in order to facilitate the description of the vegetation history. By means of a series of radiocarbon datings made on the lake sediment it has been possible to obtain an absolute chronology for the zone boundaries which thus provides better possibilities for comparing this profile with other investigations for which an absolute chronology is available.

The assemblage zones and their names have been delimited with the intention of demonstrating the immigration and succession of the trees as reflected in the pollen flora.

The zones do not carry any ecological or climatic implications, although the sequence of immigration may be a reflection of a climatic change which had started somewhat earlier (see e. g. Birks 1973).

The pollen assemblage zones have been defined in the conventional way on the basis of observations of the pollen and spore content of the sediments, without any reference to climate, sediment or chronology. The zones are named as terrestrial spermatophyte pollen zones.

Later on in this study all the pollen assemblage zones have been related to the absolute chronology, put in a table and compared with established chronozones (Mangerud et al. 1974). In the same table a comparison between the different zone systems used in Poland and Southern Scandinavia is presented (Fig. 8).

For a more detailed description of the pollen assemblage zones the reader is referred to the comprehensive paper on Lake Wielkie Gacno.

^{14}C-chronology and chronozones

Radio-carbon dates from the Holocene material were obtained in order to determine the rate of sediment accumulation. In the Late-Glacial material only the most important pollen zone boundaries and pollen floristic levels were dated. The datings are listed in Table 2.

Radio-carbon dates

Table 2.

Sample	Depth below water surf. cm	Age $T^1/_2$:5568 B. P.	Lab. no.	Corrected age B. P.
Main profile:				
Detritus gyttja, brown. Just below the boundary WG 8/WC 7	530–535	780±50	Lu-1541	275
Detritus gyttja, brown. Above the boundary WG 7:3/WG 7:2	580–585	1220±50	Lu-1540	875
Detritus gyttja, brown. Above the boundary WG 7:2/WG 7:1	630–635	1790±50	Lu-1613	1450
Detritus gyttja, brown. Above the boundary WG 7/WG 6	680–685	2250±50	Lu-1612	2075
Detritus gyttja, brown. Middle part of WG 6:2	730–735	2650±55	Lu-1611	2600
Detritus gyttja, dark brown. Middle part of WG 6:1	780–785	3320±55	Lu-1610	3150
Detritus gyttja, dark brown. At the boundary WG 6/WG 5	830–835	3740±55	Lu-1609	3750
Detritus gyttja, dark brown. The earlier part of WG 5:2	880–885	4230±60	Lu-1608	4300
Algal gyttja, dark brown. The upper part of WG 5:1	930–935	4810±60	Lu-1470	4900
Algal gyttja, dark brown. Middle part of WG 5:1	950–955	5130±60	Lu-1539	5130
Algal gyttja, dark brown. Above the boundary WG 5/WG 4	980–985	5430±65	Lu-1538	5430
Algal gyttja, dark brown. Upper part of WG 4:2.	1030–1035	5950±65	Lu-1537	5950
Algal gyttja, dark greenish-brown. Middle part of WG 4:2	1080–1085	6590±70	Lu-1469	6590
Algal gyttja, dark greenish-brown. Middle part of WG 4:1	1130–1135	7160±75	Lu-1536	7160
Algal gyttja, dark greenish-brown. Upper part of WG 3:2	1180–1185	8120±80	Lu-1535	7800

Algal gyttja, dark greenish-brown. At the boundary WG 3:2/ WG 3:1	1230–1235	8350±80	Lu-1534	8550
Algal gyttja, dark greenish-brown. At the boundary WG 3/WG 2	1255–1260	8830±85	Lu-1533	8975
Algal gyttja, dark greenish-brown. Middle part of WG 2:1	1280–1285	9280±90	Lu-1532	9350
Algal gyttja, dark greenish-brown. At the boundary WG 2/WG 1	1304–1308	9870±90	Lu-1531	9775

Wielkie Gacno A1:

Clay gyttja, dark green-grey. At the boundary WG c:2/WG c:1	335–340	11.000±100	Lu-1470
Sandy clay gyttja, light greenish-grey. Middle part of WG c:1	348–352	11.100±105	Lu-1680
Clayey algal gyttja, dark brown. At the boundary WG c/WG b	356–360	11.380±100	Lu-1679
Algal gyttja, dark brown. At the boundary WG c/WG b	367–371	11.840±110	Lu-1678

When the radio-carbon dates are plotted against time and depth (Fig. 7) one comes to the conclusion that the age of the upper samples deviates from their true age. This may have been caused by prehistoric and historic agri-

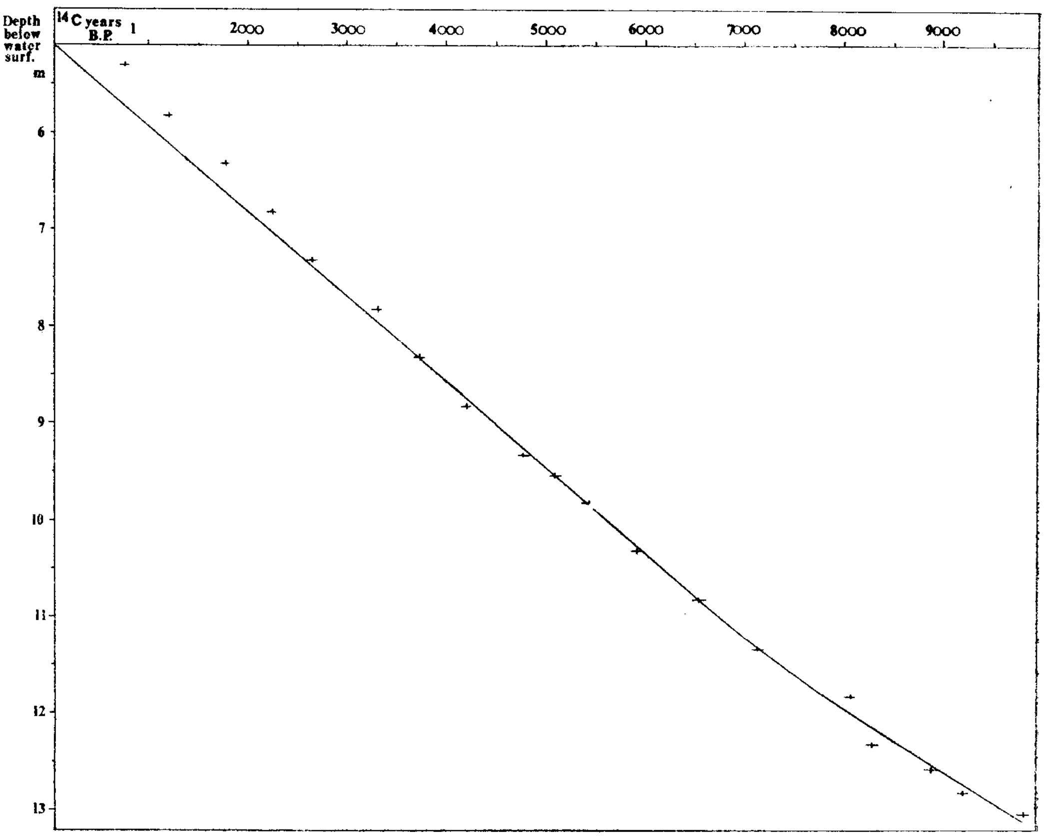

Fig. 7. ^{14}C-dates plotted against depth and the graphically fitted time-depth curve

cultural activity and thus the erosion of older organic material transported into the lake (see e. g. M. Tolonen 1978; Huttunen & Tolonen 1977; Jóhansen 1975). Due to the relatively slight human impact in the immediate neighbourhood of Lake Wielkie Gacno the differences between the radio-carbon dates and their assumed true ages are quite small and increase regularly towards the sediment surface. The correction applied due to possible field erosion is based on the assumption that the accumulation rate has been constant after 7000 B.P.

In the Fig. 7 the radio-carbon dates are plotted against the depth below the sediment surface and indicate the rate of sediment accumulation. Dating of the pollen assemblage zones and sub-zones has been established by interpolation based on a graphically fitted time-depth curve. The chronozone and

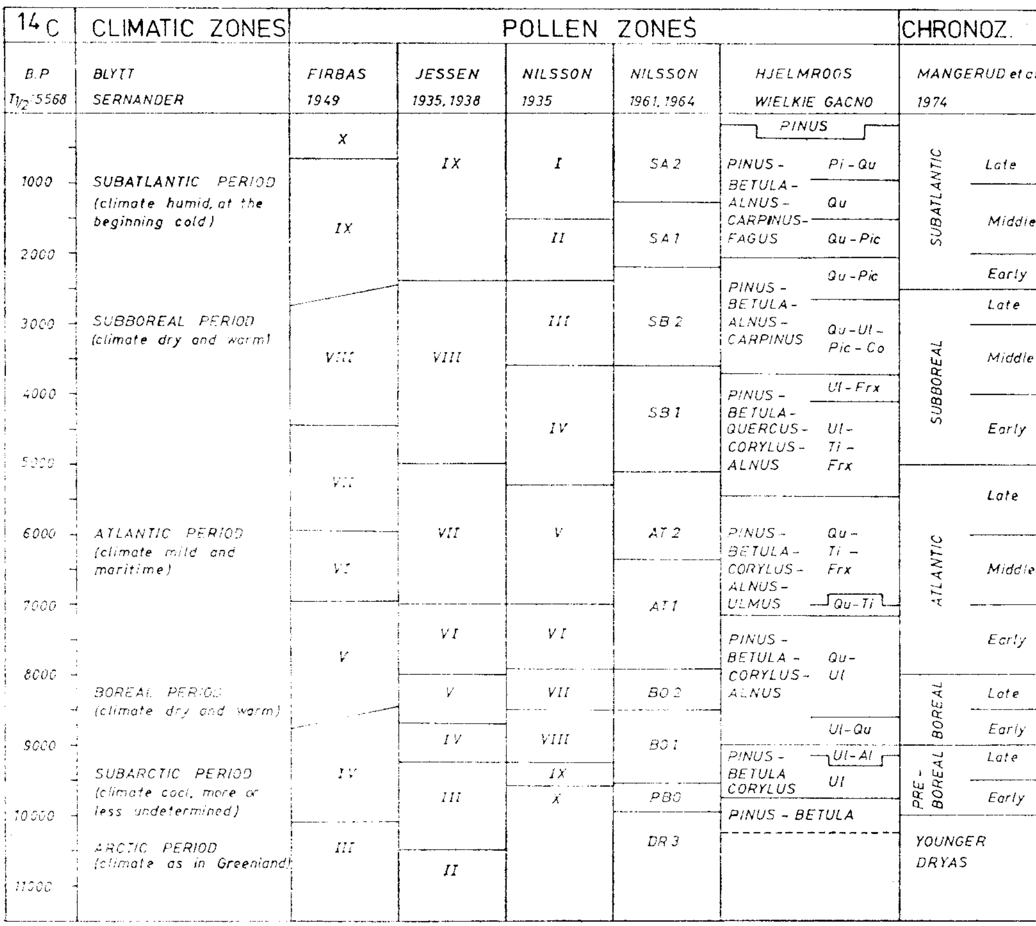

Fig. 8. Comparison between the PAZ's of Lake Wielkie Gacno and the chronozones as well as their relation to the different zone systems used in Poland and Southern Scandinavia

sub-chronozone boundaries in the pollen diagram have been fixed by means of the same curve.

A comparison between the PAZ's, which have been used as biostratigraphical units in the Wielkie Gacno diagrams and the chronozones is given in Fig. 8.

The immigration of the tree species in North Poland

As mentioned above, the boundaries between the PAZ's have been drawn mainly on the basis of the order of immigration of the forest trees. A correlation between the Wielkie Gacno pollen diagram and other pollen diagrams from northern and north-eastern Poland is made difficult because of the paucity of reliable ^{14}C datings in these other diagrams. The chronological development of the forest trees in the Wielkie Gacno area is shown in Table 3.

Table 3

Corrected ^{14}C-ages for the most important events in the development of forest, excluding *Pinus* and *Betula*

Corylus:		*Tilia*:	
— rational limit	9750 BP	— empirical limit	8750 BP
— first maximum	9150 ,,	— rational limit	7150 ,,
— last decrease	2800 ,,	— disappearance	2850 ,,
Alnus:		*Fraxinus*:	
— empirical limit	9600 BP	— empirical limit	9000 BP
— rational limit	9150 ,,	— rational limit	6900 ,,
— last decrease	1250 ,,	— disappearance	3650 ,,
Ulmus:		*Carpinus*:	
— rational limit	9750 BP	— empirical limit	5000 BP
— "elm-decline"	5050 ,,	— rational limit	3900 ,,
— finally decrease	2800 ,,	— decline	300 ,,
Quercus:		*Fagus*:	
— empirical limit	9550 BP	— empirical limit	5150 BP
— rational limit	8950 ,,	— rational limit	2050 ,,
— last decrease	900 ,,	— decline	300 ,,

Remarks on the main features in the vegetation development

Late-Glacial

The development of the Late-Glacial vegetation communities in the Lake Wielkie Gacno area seems to have been fairly typical of that for Central and Northern Poland and Northern Central Europe.

The pollen analytical results prove that the boundary of the subarctic forest during the Allerød chronozone was situated to the north of the modern

Tuchola woods. *Pinus* had already immigrated in the earlier part of the Allerød after which it expanded rapidly. During the cool Younger Dryas chronozone forests also existed in the area. The tree cover was, however, thinner than before. This open forest composed primarily of *Betula* trees, with only occasional *Pinus* was mainly situated in sheltered favourable places. As a whole the vegetation of the Younger Dryas chronozone was strongly dominated by *Juniperus* communities.

Holocene

The forest succession started in the earlier part of the Pre-boreal chronozone at which time the areas of steppe-like communities and Late-Glacial herb and shrub communities were gradually becoming restricted. As soon as the climate amelioration had set in *Pinus* came to occupy the high places and *Betula* spread out onto the low-lying moist land. Along the rivers and lake shores, as well as on wet places between the dunes, there were most probably associations like the modern *Filipendulo-Geranietum palustris* from the order *Molinetalia*. In the later part of the Early Pre-boreal chronozone *Corylus* expanded and occupied those soils with a thicker mull layer where neither *Pinus* nor *Betula* could compete with it. In this part of Pomerania *Ulmus* arrived simultaneously with *Corylus*. Although *Ulmus* has a longer lifespan than *Corylus*, its growth rate is particularly slow during its youth and it was thus easily smothered by *Corylus*, but wherever elm could find unoccupied spaces it hindered the spread of hazel. Elm succeeded in establishing itself on the very best soils and consolidated its position on these until later, during the Atlantic chronozone, when *Tilia* gradually took these soils over. It has been supposed that *Alnus incana* immigrated from the south during the final phase of the Pre-boreal chronozone. It played an important role in flooded areas when it could form forest communities perhaps mixed with *Ulmus*.

It is very difficult to try to reconstruct the forest communities during the older part of the Holocene. There may have been greater differencies between the life amplitude and ecological demands of the tree species at that time and those of today.

However, during the Boreal and the Early Atlantic chronozones it is probable that the drier, sandy soils of less favourable habitats, mostly on higher ground were occupied by *Pinus sylvestris*. The pine forests were probably mixed, containing *Betula* and *Quercus* (cf. *Q. petraea*). It is assumed that *Q. robur* was growing on more moist soils and competing with *Ulmus* in terms of lifespan. As the soils became gradually richer and moister the forest became *Ulmus*-dominated with an admixture of *Alnus* and *Corylus*. A few *Tilia* and *Fraxinus* trees may have occurred in the elm forest on the most fertile soils. Along rivers and lake shores and on flooded habitats *Alnus (A. incana)* and *Betula* perhaps with *Salix* and *Populus* formed thickets with a distinct nitrophilous herb layer *(Cannabaceae, Compositae* and *Urtica)*.

In the middle and upper part of the Late Atlantic chronozone the competition between several species seems to have led to the establishment of climax iorest. *Fraxinus*, *Ulmus* and *Quercus* together played an important role with *Tilia* in the *Quercetum mixtum* forests on the better soils. *Pinus* was restricted to the extremely poor places with a high degree of permeability, where, in richer stands *Ericaceae* (incl. *Calluna*) may have been the dominant species in the herb and shrub layers. Here soils were probably podsolized to some extent. It is quite obvious that in richer areas acidophilous oak-pine forests were common. The shrub layer seems to have been rather poor, formed primarily by young plants of broad-leaved trees *Corylus avellana* included. *Pteridium aquilinum* is thought to have been abundant in these forests. On fertile ground numerous kinds of deciduous forests developed, usually with nemoral broad-leaved trees as the dominating species. The most common of these may have been the associations of elm mixed with *Tilia*, *Fraxinus* and *Quercus*. The old fluvial deposits which were rich in nutrients were probably covered by elm carrs. These changed to alder-ash carrs in places which were periodically flooded. The soils of the alder-ash carrs were rich in nutrients, too, but contained more mineral substratum than those of the elm carrs. *Corylus avellana* stands were restricted to the forest margins and along the lake shores.

In the final phase of the Late Atlantic chronozone oak, lime and even ash seem to have a slight retrogressive development. Probably the climate had become more humid, which led to the increased leaching of soils and their gradual degradation. Elm reacted somewhat later to the probable deterioration of its growing-conditions.

Prehistoric man seems to have begun primarily to exploit those *Quercetum mixtum* forests situated on the richer soils.

During the following temporary pioneer phase *Corylus* expanded and formed pioneer forests in which *Betula* was present. Favourable conditions for the *Fraxinus-Alnus* dominated forests on rich moist places continued into the Sub-boreal chronozone.

In the Middle Sub-boreal chronozone the forest composition changed noticeably. In the first place this may have been due to edaphic factors. The soils in the investigation area are largely poor and sandy and leaching in such soils is very rapid. Through this deterioration the soils became more acid. The changed conditions in the nemoral broad-leaved forests were most beneficial to *Quercus*. Even *Fagus* seems to have formed minor stands at that time. Communities corresponding to the modern *Querco-Carpinetum* developed, when prehistoric man took advantage of the better soils probably primarily destroying the *Ulmus*- and *Tilia*-communities. Simultaneously the climate became a little cooler and drier allowing suitable conditions for *Carpinus* to expand into the area, while elm and lime were gradually suppressed.

In the Middle Sub-atlantic chronozone *Corylus* seems to have disappeared and lost its importance on wet places, along river sides and lake shores. This was principally to the benefit of *Fagus*, which mainly occupied fertile soils, being bounded at higher altitudes by *Pino-Quercetum* associations and at lower ones by *Querco-Carpinetum*. Beech attains the eastern limit of its occurrence in Poland and, therefore, is often found mixed in *Querco-Carpinetm* associations today. The important role of *Alnus* prevailed even during the Sub-atlantic chronozone on flooded lake shores and river sides.

In the later part of the Sub-atlantic chronozone humidity increased and initially the exploitation of arable land resulted in an acceleration of erosion and the leaching of soils and thus a reduction in the nutrient capital. In the investigation area soils, which even under natural conditions were poor, could no longer provide agricultural land but were grazed and gradually employed for forestry. The forest communities were formed largely artificially and *Vaccinio myrtilli-Pinetum* was the most common. The composition of the shrub layer was rather poor: most frequently young plants of the deciduous trees occurred, mainly *Quercus* and *Betula.* The herb layer was also sparce, the dominant species being *Vaccinium myrtillus* and *Vaccinium vitis-idea.* Along lake shores, in water-logged places *Alnus* formed smaller stands. *Fagus* most likely thrived on soils comparable to those of the *Alnus* stands.

The pollen influx data

The pollen influx-diagram for the Holocene shows four main phases in the total pollen influx: a. high values during the Pre-boreal, Boreal and Early Atlantic chronozones, b. low values until the beginning of the Early Sub-boreal chronozone, c. high values up to the middle part of the Middle Sub-atlantic chronozone and d. low values during the uppermost part of the profile.

The decrease at the chronozone boundary Early/Middle Atlantic from around 10000 to 5000 grains $cm^{-2}yr^{-1}$ can be explained fairly easily. It is thought that when forest associations have reached their climax stage, the denseness of the forest probably effectively prevents pollen dispersal.

At the beginning of the Early Sub-boreal chronozone the influx rates for NAP increase slightly and about 4700 BP, almost simultaneous with the finds of the first cerealea pollen, influx values for AP increase strongly mostly rising to 10 000 grains $cm^{-2}\cdot yr^{-1}$ and reaching a maximum at the beginning of the Middle Sub-boreal chronozone (25 000 grains $cm^{-2}\cdot yr^{-1}$). *Pinus* is still dominant but *Betula, Corylus* and *Alnus* also seem to increase clearly. Perhaps the forests were more open and the good light conditions favoured the dispersal of the pollen of those pioneer species growing in cleared areas. These species are also considered to be heavy pollen producers.

In the middle part of the Middle Sub-atlantic chronozone simultaneous with the short-term rise in the influx values of *Alnus* and *Carpinus* the rates of all other species decrease dramatically. It could be possible that land use in the investigation area was so intensive that, the tree species as well as the herbs and graminids did not have enough time to produce pollen before they were destroyed by man. However, it seems that this is a real decrease as that time is very poor in terms of historical facts. Perhaps the temporarily changed sedimentation rate, which because of the incomplete ^{14}C-datings is impossible to notice, caused that change in the influx frequencies.

It is also imaginable that the changes in soil conditions (e. g. prolonged leaching) caused a drop in productivity and thus a decrease in the production of pollen grains.

It have to be stressed that each of the changes in the pollen influx rate during the Holocene has probably been a result of many different both climatical, edaphical and anthropological effects which alone and/or together have influenced upon the natural vegetation.

Influx values are low up to A.D. 1400 and after that *Pinus* frequencies increase successively reaching the recent values of 17000 grains in the uppermost samples. The *Pinus* rise is most probably due to the pollen production from the *Pinus* forests planted in the investigation area. The values of other AP and NAP are very low.

History of the regional changes in natural forest vegetation in Lake Wielkie Gacno district during the Holocene

The main features of the Holocene vegetational development are illustrated in Fig. 9 in the simplified AP-pollen diagram based on the corrected pollen values (cf. Andersen 1973) for each tree species [1]. In interpreting such diagrams the glacial and interglacial cyclic scheme of Iversen (1958) has often been applied. Iversen reworked and completed the theory of von Post (1946) concerning the correlation between climatic conditions and vegetation development. Iversen also emphasized the importance of soil development and the competition for light in this connection.

Full glacial time is followed by the protocratic stage of the Late-Glacial and the first part of the Holocene. During this time the low-competitive and light-demanding pioneer plants immigrated to the neutral, unleached mostly minerogenic soils. Iversen advocated that the Pre-boreal period should also be included in the protocratic stage. In the Wielkie Gacno area the protocratic stage is assumed to have finished around the chronozone boundary Early/Late Pre-boreal.

The pioneer stage was followed by a mesocratic stage comprising the greater part of the Holocene. In the beginning the immigrating forest trees were competiting of the growing space only reaching a well-balanced stage gradually and later, when the climate reached its optimum, fertile slightly acid soils developed and soil leaching was only just beginning. The climax forests achieved their maximum shade during the Late Atlantic and Early Sub-boreal periods according to Iversen.

In the investigation area *Corylus* was as common as the *Quercetum mixtum* species during the Late Pre-boreal, Boreal and earlier part of the Early Atlan-

[1] Figs. 9 and 10 under the cover.

tic chronozones. The climax forests developed during the Middle and Late Atlantic chronozones, which also is indicated by the low pollen influx-values.

The beginning of the last stage, the telocratic stage, is often placed at the beginning of the retrogressive development of the forest vegetation. Accelerated leaching and soil degradation caused by increased humidity and climatic deterioration are characteristic of this stage. In the Wielkie Gacno area the boundary between the mesocratic and telocratic stages is not sharp. The nemoral broad-leaved forest culminated and the retrogressive forest development began around the chronozone boundary Atlantic/Sub-boreal. However, the transition phase was rather long. The representation of *Quercus* remained virtually unchanged, during the Sub-boreal chronozone it reached a somewhat higher representation than before, while *Ulmus, Tilia* and *Fraxinus* show a distinct retrogression. At the chronozone boundary Sub-boreal/Sub-atlantic *Fagus* expanded with a simultaneous slight increase in *Betula.*

Because of the characteristic dune topography and the naturally sandy poor soils, the vegetational development of Lake Wielkie Gacno area is somewhat different than that of the forests in South Scandinavia. It is thought that throughout the whole of the Holocene the forest vegetation consisted of a mosaic of several different kinds of associations growing partly on the poor sandy soils of the dunes and partly on the more fertile and favourable places between the dunes and along the rivers and lake shores. The regional vegetational forest development in clearly seen in the pollen diagrams and it should be stressed that the nemoral broad-leaved forests were well developed even on the natural soils of the Lake Wielkie Gacno area. The succession was rather sensitive to changes in the level of the ground water and more or less dominated by *Pinus* during the whole of the Holocene. Among the nemoral broad-leaved trees *Quercus* was the most outstanding.

During the Atlantic chronozone especially, when the ground-water level is thought to have been higher, the nemoral broad-leaved associations were able to expand onto higher ground and *Pinus* was forced onto the poorest places, mainly on the higher dune-tops. During that time the mull layer on the sandy soils was thicker and richer in nutrients. Retrogressive development of the forest vegetation started at the beginning of the Sub-boreal chronozone, which is thought partly to have caused the increased values for the pollen influx. This was probably due to climatic deterioration, more active soil leaching and human interference with the forests. The ground-water level was probably lower than before and the mull layer became thinner. Those broad-leaved forests which were not destroyed by man were forced onto the lower levels along the watercourses. The acidophilous *Pino-Quercetum* association began to develop and, on the more mature places, *Querco-Carpinetum* associations began to appear.

In the Middle and Late Sub-atlantic chronozone humidity increased and the exploitation of arable land resulted in accelerated erosion and soil leaching and thus a reduction in the nutrient capital. Except on the advantagous moister places between the dunes and along the watercourses the mull layer was very thin and such areas could no longer serve as agricultural land. The forests became naturally occupied by associations dominated by *Pinus* and were gradually exploited for forestry purposes. The modern forest communities were largely formed artificially and the *Vaccinio myrtilli-Pinetum* is the most common.

INVESTIGATION OF THE WATER-LEVEL CHANGES

The investigation of Holocene water-level changes in Lake Wielkie Gacno is based on macrofossil and pollen analyses of four sediment cores taken in the south-western bay of the lake. Three of the profiles were taken along a line extending from the northern shore of the bay, while the fourth profile was taken at the shore in the innermost part of the bay.

In addition to the determination of seeds and fruits the analysis also comprises a determination of the amount of coarse organic and minerogenic material in the sediment. The underlying principle in the interpretation of the seed and fruit analyses is that a lowering in water-level will usually result in lakeward spreading, and a rise in water-level in shoreward displacement of the marginal macrophyte vegetation. If such changes in the spreading of the macrophyte vegetation have occurred these can be interpreted and reconstructed on the basis of the seed and fruit analyses.

The principle behind the interpretation of the coarse organic and minerogenic material in the sediment is that sediment deposited in shallow water close to the shore will normally contain a larger amount of both coarse organic material originating from the marginal macrophyta vegetation, and reworked coarse minerogenic material. Changes in the amount of coarse material may accordingly indicate displacement of the shore connec ted with water-level changes. In lake like Wielkie Gacno which are characterizedby a rather sparce and restricted marginal macrophyte vegetation the determination of the coarse organic and minerogenic material will, on the whole, give more reliable and detailed information about water-level changes than the fruit and seed analyses.

The changes in coarse material in the four sediment profiles from Wielkie Gacno can be seen in the diagram in Fig. 10. The profiles are correlated by pollen analysis and the diagram also shows changes in the rate of sediment deposition. On the basis of changes in the coarse organic and minerogenic material five shallow-water periods, probably caused by a lowering of the water-level, are indicated in the analyzed profiles. The oldest lowering was evidently the strongest, and this occurred in the WG 1 and WG 2:1 pollen assemblage zones. The succeeding lowerings occurred during the middle part of the WG 3:2 PAZ, during the WG 4:2 PAZ, during the later part of the WG 5:1 and the earlier-middle part of the WG 5:2 PAZ and during the WG 6:2 and the WG 7:1 PAZ, respectively. As indicated by the interruption of deposition at

A1, the bottom at this site was above the deposition limit for the two oldest water-level lowerings.

The results of the water-level changes from Lake Wielkie Gacno are compared with available investigations from Central and Northern Poland as well as with some investigations from Southern Sweden (Hjelmroos-Ericsson 1981).

THE PALAEOLIMNOLOGY OF LAKE WIELKIE GACNO

A complete palaeolimnological investigation has been carried out from the material originating in the main core from Lake Wielkie Gacno (Hjelmroos-Ericsson 1981).

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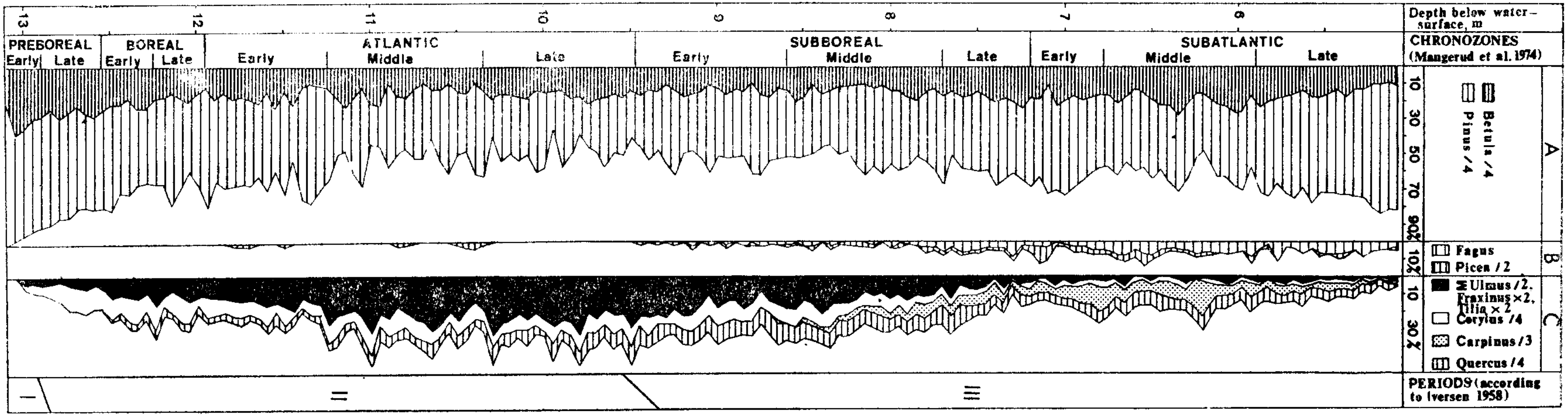

Fig. 9. Lake Wielkie Gacno, the simplified AP-pollen diagram based on the corrected pollen values

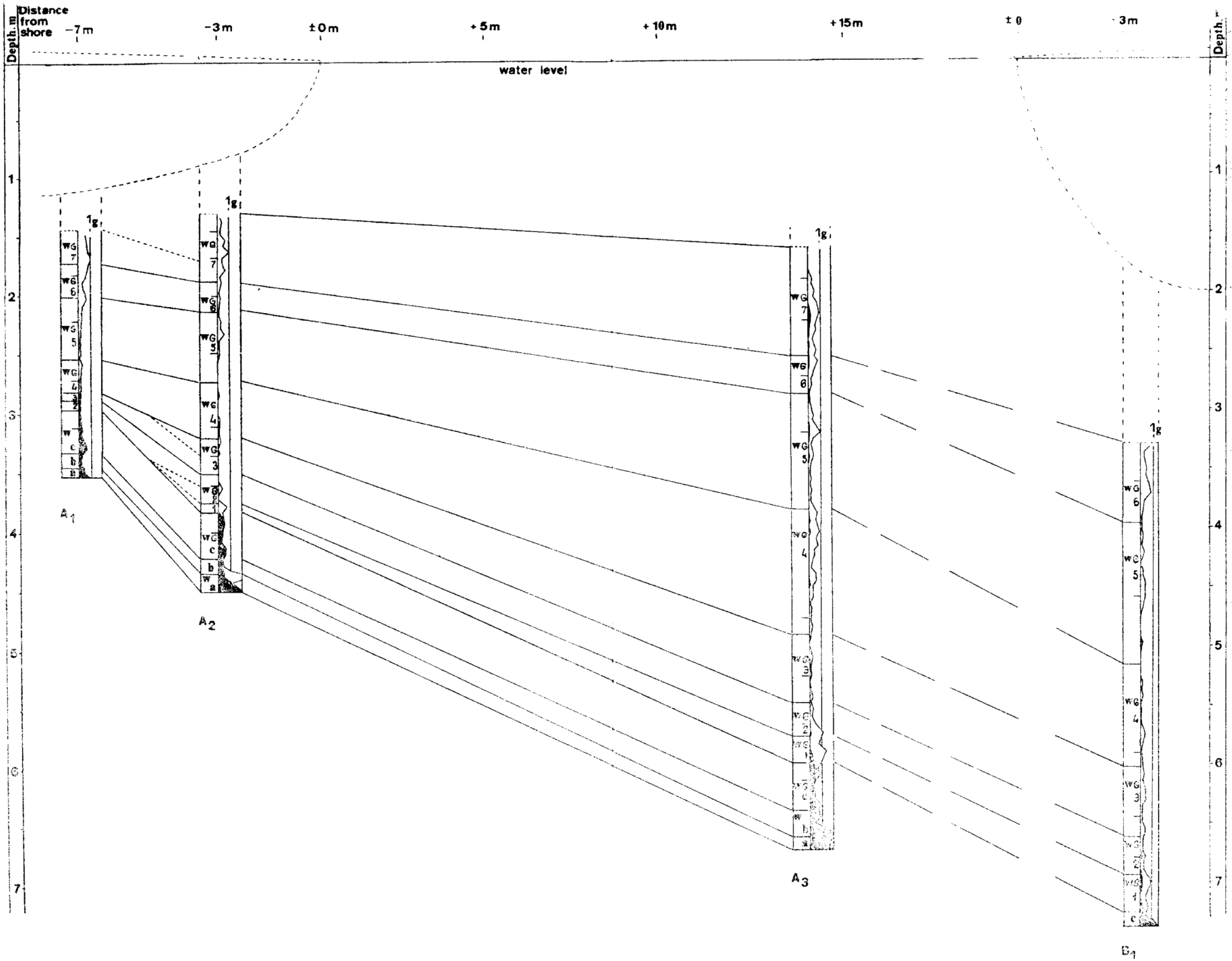

Fig. 10. Lake Wielkie Gacno. Section of the macrofossil profiles A1, A2, A3 and B1. Amounts of the coarse organic material (unfilled curve) and the mineregenic material (filled curve) are illustrated beside each profile