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HOLOCENE VEGETATIONAL DEVELOPMENT BASED ON THE KLUKI REFERENCE SITE IN THE GARDNO—ŁEBA PLAIN

Holoceński rozwój roślinności Niziny Gardnieńsko-Łebskiej na podstawie stanowiska wzorcowego Kluki

ABSTRACT. The organogenic sediment from a mire near the Baltic shore were studied by means of different methods, including pollen analyses, plant macrofossils, identification of subfossil beetles and radiocarbon datings.

On the basis of local pollen and macrofossil assemblage zones the vegetational history of the Gardno-Łeba Plain is described since the Preboreal. The changes of water-level in the mire and fluctuations in the level of the Baltic are discussed.

INTRODUCTION

This publication is the first part of an extensive study on the palaeoecology of the Garno—Łeba Plain. It provides most of the results of research into the Kluki/74 site which has been incorporated in a network of primary reference sites within the framework of IGCP Project No 158 subproject B concerning lake and mire environments (Starkel 1981, Berglund 1986). The Kluki primary reference site is representative of a definite area, a palaeoecological subregion of the Baltic Shore (Berglund 1979). The studies have been carried out as part of the International Geological Correlation Programme (IGCP), Project No 158 "Palaeohydrological changes in the temperate zone in the last 15000 years".

The joint study of the Kluki site was begun by the present author and Profesor W. Dzięciołowski in 1974. Its intention was to deal with the Holocene stratotype in the nearshore zone. In addition to a number of borings, the first stage of research involved routine palynological analysis and peat expertise. During the following years Assistant Professor A. Sapek joined the two workers in conducting research, making chemical analyses of 136 biogenic sediment samples. Professor Dzięciołowski's unexpected death interrupted the preparation of the text concerning the chemical study of peat growth, entitled

"Accumulation of mineral compounds in relation to peat mass formation in the biogenic profile Kluki/74". The most important results concerning the chemical studies of peat growth were presented at the national symposium of the IGCP 158 B in Poznań in the spring of 1984. The results of the chemical analyses will be published as another part of the study mentioned above. Unfortunately, it will not be the joint work planned earlier and the space allocated to it will be considerably smaller.

The third part of the study will comprise the results of research into the remaining sites of the Gardno—Łeba Plain and will present a comparison between these results and those of the nearshore zones along the southern Baltic coast. A generalization of these studies in comparison with the data available for other palaeoecological regions will also be attempted.

GENERAL CHARACTERISTICS OF THE GARDNO-ŁEBA PLAIN

Location

The Gardno—Łeba Plain is remarkable along the south Baltic coast for its morphology, origin and geobotany. It forms a longitudinal depression which stretches parallel to the Baltic coastline. Its length is about 40 km, while its greatest, achieved in the middle portion, approaches 12 km. The lowland adjoins the Baltic coastline in the north and cuts into a morainic plateau in the south.

Geological and geomorphological setting

The structure of the Gardno—Łeba Plain is polygenetic (Marsz 1975). The lowland is surrounded in the north by a spit covered with a variety of dunes which, especially in the middle portion of the spit to the north of Lake Łebsko, are in part migrating. The western portion of this spit adjoins the margin of an end-moraine plateau produced by the Garno lobe. According to Liedtke (1969), this end moraine can be correlated with the Kopenhagener Staffel belonging to the Pomeranian Stadial. Large areas lying south of the spit are occupied by lakes and organic accumulation plains (Fig. 1). The surface area of the largest lake, Lake Łebsko, is 7140 ha, while its average depth is 1.6 m. Lake Gardno, the second largest lake, is 2486 ha in surface area, and its depth averages 1.3 m, is 2.6 m at maximum. Both lakes contain diverse bottom deposits up to 6 m thick.

The mires occuring in the Gardno—Łeba Plain vary with respect to their origin, deposit thickness and anthropogenic modification. Nearly all mires, with the exception of some telmatic rush communities inhabiting the lake shores have been affected by drainage operations. A large majority of the mires are intensively drained and a number of them have been replaced by mown

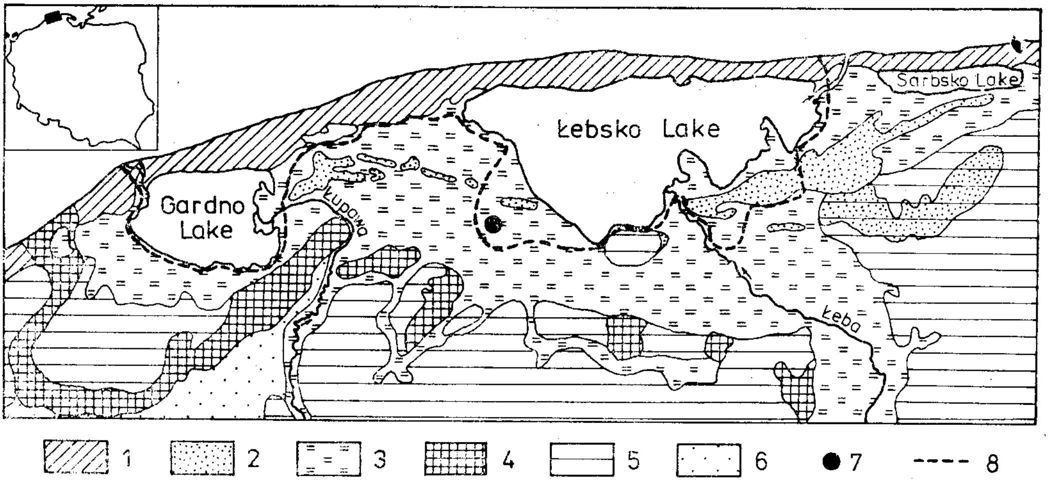

Fig. 1. Schematic map of the Gardno-Łeba Plain geomorphology (according to Marsz, simplified). 1 — coastal dunes, 2 — inland dunes, 3 — organic and mineral accumulations forms, 4 — push moraines, 5 — moraine plateau, 6 — outwash plains, 7 — Kluki/74 reference site, 8 — boundary of the Słowiński National Park

meadows and pastures or even arable fields. In addition to the biogenic accumulation plains the lowland also has considerable areas of diverse mineral sediments. Mention should first be made of aeolian sands on which dunes have been built up. In the east they form close to the southern shore of Lake Sarbsko and continue along the south-eastern shore of Lake Łebsko. They reappear in an area between the western shore of Lake Łebsko and the eastern shore of Lake Gardno. The late-glacial age of some dunes, those for example which lie on the south-eastern shore of Lake Łebsko, has been documented by means of palynology (Tobolski 1972). An extensive alluvial fan, deposited by the Łupawa river, has developed at the plateau margin in the vicinity of Smołdzino. The subfossil flora present in the fan deposits contains *Alnus glutinosa* fruits in addition to other remains. Their presence suggests that this fan formed during the Holocene (Tobolski MS). Attention should also be given to sand-gravel deposits on the southern shore of Lake Dołgie Duże and on the southern shore of Lake Sarbsko. According to Rosa (1963), these can be identified with the limits of the Littorina Sea *.

Mineral deposits are also found to the north-west of the Kluki village.

The earlier literature provides a lot of information about the importance and influence of the Littorina transgression in the Gardno—Łeba Plain. The maximum extent of the transgressing sea is presented in various ways. Not infre-

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* During discussions held at the meeting of the Committee for Sea Research of the Polish Academy of Sciences in November 1983 and during the field session of 1984, Dr. Rosa reported that the so called Nowęcin shore ridge which was classified by him as a coastal form of the Littorina Sea (Rosa 1963) had been formed during the Late-Glacial which thus precluded the possibility of its having been formed by sea action.

quently do the extent lines stretch as far as the till plateau margins (Różycki 1965, Galon 1961). A field of Late-Glacial inland dunes was frequently identified with the Littorina Sea coast. Those dunes were classified as earlier coastal eolian forms (Miszalski 1973). A synopsis of studies on the Holocene marine transgressions occurring in the Gardno—Łeba Plain has been given by Tobolski (1986 MS). The present author will deal with this problem again in one of the next sections.

Climate

With regard to climate, the Gardno—Łeba Plain belongs to the Baltic Climatic Region, as recognized by Romer (1949), more precisely to the Łeba Coastal Plains (A.4). The climate experienced in this region is characterized by the lowest annual temperature amplitude in Poland, high air humidity, a moderate amount of precipitation and the shortest period of snowlie. A climatic diagram from the Łeba station illustrates the most important climatic characteristics (Fig. 2). Attention should be paid to the fact that the plain under consideration contains a lot of localities experiencing an unusually variable local climate, for example a spit covered with migrating or forested dunes, forest-covered peatbogs, meadows, large lake surfaces. These distinctive climatic patterns, which the present author has encountered during his investigations have not yet been studied in detail.

Vegetation

A specific and unique vegetation cover which still displays many natural characteristic occupies the Gardno—Łeba Plain, especially its northern portion. Diverse coastal crowberry forests *(Empetro nigri-Pinetum)* grow on the spit. Small areas on and outside the spit are occupied by deciduous forests, including acidophilous beech forests, alder swamps and swampy birch forests. The rich and specific flora comprising relict species (Tobolski 1981) should also receive attention. A vast area of northern portion of the lowland is protected as the Słowiński National Park which is included in a group of world nature reserves. This national Park is 18247 ha in surface area. Its boundaries are shown in Fig. 1.

With respect to successional vegetation growth in the Gardno—Łeba Plain, two primary successions may be recognized. One of them begins with plants growing on the winter beach. Its successive stages include plants inhabiting a white dune and a grey dune, with the final stage consisting of a coastal forest terminating in dune sand where the groundwater is at considerable depth. Where more variable hydrological conditions exist, communities containing hygrobionts or even hydrobionts begin to appear. The influence of hydrological conditions is particularly visible in deflation hollows.

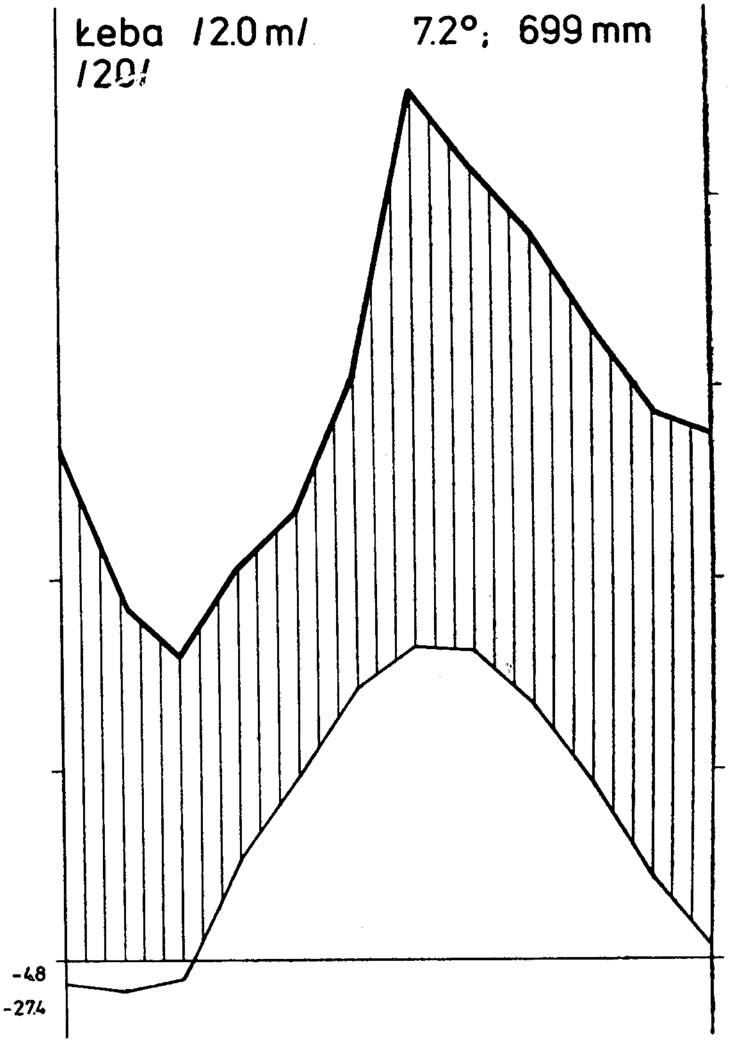


Fig. 2. Climatic diagram (according to Rabski, MS)

A different succession is associated with organic substrata. It begins as stages in the infilling of coastal lakes and terminates in forest communities of alder swamps (*Carici elongatae-Alnetum*). Basically, the above successions are associated with the spit region. However, some of the plant communities spread onto the mineral surface of the lowland (Wojterski 1975, Dzięciołowski & Tobolski 1975).

Forested areas occur on spits, inland dunes and the adjacent plateau lying to the south-east of Lake Łebsko, as well as in the vicinity of Kluki and the area lying to the south of Lake Dołgie Wielkie. Pine stands prevail on spits but swamp birch, alder or an oak-beech forest also occur on the coastal dunes in the vicinity of Czołpino. The inland dune sands on the south-east shore of Lake Łebsko are chiefly covered by pine forest. However, there are small clusters of alder trees (*Circaeo-Alnetum* and *Fraxino-Ulmetum*) in the Łeba river valley. The peat substrate supports alders. In the vicinity of Kluki there is a small area in which fertile beech wood (*Melico-Fagetum*) grows and large areas of oak-beech forests colonizing the rich soil. Extensive pine stands occur on both peat and mineral substrates. Pine remains absolutely dominant in the forest to the south of Lake Dołgie Wielkie. High land-use capability characterizes some of them, especially those adjoining the so called coastal ridge.

THE KLUKI MIRE

Characteristics of the Kluki mire

The Kluki reference site is situated in the centre of an extensive mire complex occupying large areas to the west of the south-western shore of Lake Łebsko. This complex is separated by a narrow, belt of nearly parallel low dunes which seems to constitute the western extension of the Late-Glacial inland dunes lying close to the south-eastern shore of Lake Łebsko. A genetic relationship to this dune-field may be justified on the basis of location, i.e. part of the dunes lie beneath Preboreal and Boreal biogenic deposits, archaeological artefacts (Mesolithic finds, Tobolski 1975 p. 61) and specific floristic constituents (Tobolski 1987 MS). The inland origin of these dunes and thus, their early age, compared with the adjacent coastal dunes of younger age also affected biogenic sedimentation. A belt of those dunes under consideration forms a distinct boundary which divides the mire complex into two separate basins of biogenic sedimentation, differing from each other with respect to thickness, sediment type and the inception of deposition (Tobolski 1981, 1984).

To the south of the dune belt, especially between Łokciowo and Kluki there is an extensive deep basin infilled largely with peat. The maximum depth that has been measured until now is 6.7 m at the Kluki reference site but it exceeds 5 m at many places. A separate basin of biogenic sedimentation also occurs to the north of the dune belt. This is considerably shallower as the peat thickness rarely exceeds 2.5 m except at the dome of a raised bog in the 74th sector of the Kluki Conservation District. Biogenic sedimentation began in the southern basin during the Preboreal. The age of these sediments has been calculated on the basis of palynology in the case of profiles Kluki/74 and Wi/VIII and by means of radiocarbon dates in the case of profile Kluki/74. Two 5 cm thick basal samples lying immediately one above the other gave dates of 9865±105 yr B. P. (Gd-548) and 9855±315 yr B. P. (Hv 9104). It should also be mentioned that calcareous gyttja occurring at the base of a mire lying south of the buildings at the state farm of Łokciowe was deposited in the closing phase of Younger Dryas (Marsz & Tobolski 1971). To the north of the dune belt deposition began as late as the later stage of the Atlantic period. The oldest ^{14}C date is

5950±130 yr B. P. (Gd—830). The most important characteristics of this peatbog complex can be seen in the geo-morphological section through the Gardno—Łeba Plain. This section reveals the location of the pollen profiles which have been dated by radiocarbon and the beginning of the continuous curve for hornbeam (*Carpinus*), to which an approximate date of 3800 yr B. P. has been assigned.

The existence of the dune belt between the northern and southern basins led to variations in the peatbog complex (Tobolski 1981). The northern basin was directly affected by early transgressive phases of the Baltic, whereas the southern basin within which the Kluki primary reference site is located was not influenced by sea transgressions. This is indicated by continuous biogenic sedimentation during the Holocene.

Vegetation and man's activity in the Kluki peatbog

The vegetation cover of the mire complex under consideration is not homogeneous but in spite of modifications, it still displays many natural characteristics and a great diversity. The latter depends upon a number of factors the most important of which are differences in the duration of the peat-forming process, differing hydrological conditions in the two basins, as well as a variety of economic activity of varying intensity.

A belt of bulrushes (*Scirpo-Phragmitetum* s. l.) with dominant *Phragmites australis* stretches across the northern peat basin of Lake Łebsko, reaching 500 m in width in places. In this portion of the mire this community is the most important telmatic component in the infilling process of the lake. Smaller areas are occupied by sedges of the order *Magnocaricetalia* which include patches of the assemblage *Caricetum gracilis*. Of the remaining eutrophic mire communities, mention should be made of *Dryopteris thelypteris* clusters and alder forest (*Carici elongatae-Alnetum*).

Meso- and oligotrophic plant communities are represented in the northern basin and in the northern part of the southern mire surrounded by swamp forests (*Vaccinio uliginosi-Pinetum*) and a raised bog which, on a phytosociological map (Wojterski 1978) has been classified as *Ericetum tetralicis*. A shallower peat layer is inhabited by various tree stands including *Pinus sylvestris*, *Betula pubescens*, *Picea excelsa* and, not infrequently, *Quercus robur*. A large majority of such forests falls under the classification of *Betuletum pubescentis* on the above phytosociological map.

Rubus chamaemorus habitats are one of the floristic peculiarites of this mire (Piotrowska & Żukowski 1973). The above species grows within patches of *Ericetum tetralicis*, as well as in swamp forests in both parts of the mire complex. The nearest site is about 500 m from the Kluki reference site. Within the Polish flora, *Rubus chamaemorus* is regarded as a glacial relict with Arctic-Boreal connections. In view of the mire history the localities for that plant mentioned here should not be regarded as relict sites. Habitats suitable for the species may have appeared about two thousand yers ago at the earliest within a subfossil community of *Betuletum pubescentis* in the southern mire basin where infilling began as early as the Preboreal. The history of the vegetation cover permits a hypothesis to be put forward (Tobolski 1981) that *Rubus chamaemorus* and other plants of this type colonizing the Gardno—Łeba Plain are late arrivals from the Boreal zone.

Man's activity induced profound changes in the vegetation cover of the mire complex in the vicinity of Kluki. In particular, its southern portion, extending from the plateau margin in the vicinity of the Żelazo village as far as the Łokciowe village in the north, has undergone extreme anthropogenic modification. It is now intensely used as mown meadows. During the growing season it is mown several times and in consequence, dry grass is obtained. Intense meadow use was preceded by drainage of which a dense network of ditches is indicative. Such a meadow-use pattern calls for intensive mineral fertilization which is frequently carried out from the air. Neither is the forested portion of the mire free of man's influence. The regulation of hydrological conditions is detectable at all sites even in the initial bulrush-covered strip where ditches have been dug and dikes have been constructed over the last fifteen years.

Pollen analysis indicates that the history of man's activity within the mire is long. Up until the 17th century is was not so intensive that the numerous peat-forming phytocoenoses were irreversibly deformed or destroyed. Only with the incorporation of the Gardno—Łeba Plain into the area intensely used for agriculture, which took place in the 17th century, and the large-scale regulation of hydrological conditions, which occurred in the second half of the 18th century (Kobendzina 1976) did anthropogenic popressure become intense. A specific characteristic of this mire is the proximity of an early local (Słowincy) settlement which occured in the Kluki village. Inhabitants of this village even used small areas of the mire as ploughed fields for cultivating cereals, root crops and vegetables. Today many such abandoned fields or pastures may be recognized in various stages of forest regeneration.

Location of profile Kluki-74

Borings were made 900 m south of the eastern extremity of Kluki village (17°19′, 54°40′). This area is part of Kluki reserve which is an administrative unit of the Słowiński National Park and of the Kluki Conservation District. On the map of the Słowiński National Park (data of 1 January 1973), the profile is situated in the 77th sector, at the south-eastern corner of subsector k at a height of 2.1 m a.s.l. The mire in this area supports a swamp forest *(Vaccinio uliginosi-Pinetum)* with tall pine stands *(Pinus sylvestris)* of age class V and with 70 percent crown density. The vegetation cover occurring close to the boreholes has been identified with a form of typical mire birch forest *(Betuletum pubescentis)* on a map of plant communities of the Słowiński National Park (Wojterski 1978). Unfortunately, the above author has published neither descriptions nor phytosociological tables of the units recognized. Thus, the criteria by means of which he has classified those forest communities remain unknown.

Sediment typology

Fifteen horizons of biogenic sediments are recognized and within some of them lower-order units may be distinguished. Table 1 gives in detail the horizon number, its depths, degree of humification, estimated using the v. Post method, and a discription of its constituents after Troels-Smith (1955).

Table 1

Description of sediments, based upon Troels-Smith's (1955) system

Horizon no.	Depth range in m	Degree of humification	Description of sediments constituents
I	0.0—0.1	H_6	Sand-rich brown peat with *Ericaceae* roots
II	0.1—0.3	H_6	Brown peat; Sh 2, Th (Erioph) 1, Tb (Sphag) 1, Dg+, Tl+
III	0.3—0,7	H_3	Dark-brown peat; Tb (Sphag) 3, Tl 1, Th (Erioph) (+), Sh+
	(0.4—0.7)	H_2	Brown peat; Tb (Sphag) 4, Th (Erioph) (+)
IV	0.7—0.93	H_3	Dark-brown peat; Tb (Sphag) 3, Th (rad) 1, Tl (+), Sh (+)
V	0.93—1.1	H_2	Brown peat; Th (rad) 3, Th 1, Sh+
VI	1.1—1.6	H_{3-4}	Dark-brown peat; Th (rad) 3, Tb (Bryal) 1, Tl+, Sh+
	(1.45—1.5)	H_5	Brownish-black peat; Th (rad) 2, Sh 2, Tl+
VII	1.5—1,75	H_2	Brown peat; Th (Phr) 4, Tb (+), Tl (+)
VIII	1.75—1.98	H_3	Brown peat; Tl 2, Th (Phr) 1, Sh 1
	(1.9—1.98)	H_3	Brown peat; Tb (Sphag) 3, Th 1, Sh+
IX	1.98—2.6	H_2	Brown peat; Th (rad) 3, Tl 1, Tb (Bryal) (+), Th *(Dryopteris)* (+)
X	2.6—3.0	H_4	Brownish-black peat; Th (rad) 2, Th 1, Tl 1, Tb (Bryal) (+), Sh (+)
XI	3.0—4.05	H_5	Light-brown peat; Th 2, Th (rad) 1, Sh 1, Th (Phr) +, Tl+
XII	4.05—4.5	H_5	Brownish-black peat; Th (rad) 2, Th 1, Sh 1, Tl (+)
XIII	4.5—6.43	H_2	Brown peat; Th 3, Sh 1, Tl (+)
XIV	6.43—6.57	H_4	Dark-brown peat; Th 3, Sh 1, Tl+
XV	6.57—6.7		Detritus gyttja; Ld 2, Dl 1, Sh 1, Ag+
(XVI)	6.7—		Yellowish-brown fine sand; Ga 3, Ag 1, Sh (+)

In order to give the main characteristics of the biogenic sediments a simplified description is given below. Identification is based on the macroscopic characteristics of the sediments and on microscopic examination of the vegetative remains in peat smears.

0.0—0.1 m	raised bog forest peat, increasingly decomposed
0.1—0.93 m	raised bog moss peat, cotton-grass-bog-moss in places, poorly decomposed
0.93—1.75 m	sedge peat, poorly decomposed
1.75—2.0 m	transition bog-moss-forest peat, poorly decomposed
2.0—3.0 m	forest-sedge peat, poorly decomposed
3.0—4.0 m	herbaceous peat, decomposed
4.0—4.9 m	sedge peat, poorly decomposed
4.9—6.57 m	*Cladium* peat, poorly decomposed
6.57—6.7 m	clay-rich, moderately detritus gyttja
6.7—	humus-rich, laminated fine sand.

Absolute chronology of profile Kluki-74

In order to establish the absolute chronology of the profile 20 radiocarbon datings have been made. Among them, 19 dates were supplied by Assistant Professor M. **Pazdur** of the Isotopic Chronometry Department of the Institute of Physics, the Silesian Polytechnic of Gliwice, and one date was obtained from the ^{14}C Laboratory of Hannover.

Table 2

^{14}C dated samples from Kluki/74

Depth range in cm	Age in yr B. P.	Reference number
25— 30	230 ± 50	Gd—1305
60— 65	865 ± 60	Gd— 565
80— 85	1355 ± 60	Gd—1306
100—105	1530 ± 50	Gd—1307
120—125	1750 ± 50	Gd— 564
170—175	2120 ± 45	Gd—1308
190—195	3080 ± 50	Gd—1321
240—245	3865 ± 70	Gd— 563
275—280	4675 ± 55	Gd—1330
310—315	4910 ± 90	Gd—1315
340—345	5050 ± 45	Gd—1331
380—385	5305 ± 75	Gd— 562
430—435	6055 ± 120	Gd— 855
460—465	6670 ± 60	Gd—1323
505—510	7400 ± 60	Gd—1587
540—545	8130 ± 85	Gd—1322
575—580	8370 ± 115	Gd— 547
630—635	9110 ± 70	Gd—1329
655—660	9855—315	Hv—9104
660—665	9865 ± 105	Gd— 548

STUDY METHODS

Collection of samples

Samples for analysis were taken with a peat corer (the Russian sampler) of chamber 10 cm wide and 50 cm long. For each profile borings were taken alternately from two holes. Four cores were taken for the following investigations:

core I: pollen analysis and ^{14}C dating,
core II: macrofossils, plant remains, degree of humification,
core III: chemical analysis and complementary investigations, e.g. water content, ash content,
core IV: a reserve core destined to be used as a control and for any new lines of research.

The monoliths collected were wrapped in polythene and stored in a cool room.

Pollen analysis

Samples for pollen analysis were taken from the fresh material in the laboratory using a toot which gives a sample 1 cc. in volume. They were treated in the following way:

1) 10% KOH treatment in a boiling water bath for 30 minuts,
2) sieving through a 0.5 or 0.2 mm mesh sieve and washing through with water,
3) acetic acid anhydride treatment and acetolysis for 2 minutes,
4) treatment with acetic acid anhydride, water, addition of *Lycopodium* tablets,
5) washing with water, glycerine treatment and staining in basic fuchsin.

Macrofossil analysis

Fresh, five centimetre long samples from the core, which were 200 cm^3 in volume, were analysed. The samples were gently split, and some of the constituents were described using the Troels-Smith system (1955). The split parts were then placed in a glass vessel 1.5—2 litres in volume. Extraction was carried out in water with the addition of nitric acid at a ratio of 1 l of water to about 10 ml of acid. The duration of the extraction varied from two-three hours to a 24-hr period depending upon the degree of humification and the degree of compaction. The suspension was then washed with running water and sieved through four sieves of 2 mm, 0.5 mm, 0.3 mm and 0.2 mm mesh. Macrofossils, which were picked out of particular fractions under a binocular microscope at a magnification of ×10 were fixed in a mixture of water, glycerine and ethyl alcohol at ratio of 1 : 1 : 1 with added thymol.

In order to provide a full description of the sediments many samples were examined under the microscope to give qualitative and quantitative analyse of peat smears. For this a lump of peat, about the size of a pea, was spread over the slide using glycerine and examined at a magnification of ×100. The quantity of these constituents, as well as that of the amorphous matter was also estimated.

Radiocarbon dating

Five centimetre long samples were taken from the first core for dating. The material was dried in an electric oven for a hours and then sealed in polythene bags before being sent to the ^{14}C laboratory.

Results

Pollen analysis

The results are presented in three pollen diagrams. Figure 3 shows the total percentage diagram (AP+NAP = 100%). Pollen of aquatic plants, *Cyperaceae, Cladium mariscus, Polypodiaceae, Dryopteris thelypteris* and sporomorphs of other telmatophytes are not included in the NAP sum. This diagram gives a listing and location of all radiocarbon dates and a column of numbers designating local pollen assemblage zones. The next two diagrams also illustrate this site. For technical reasons these are simplified diagrams with particular reference to significant tree and shrub pollen types. Figures 4 and 5 present a diagram of sporomorph concentration in 1 cm^3 of deposit and an influx diagram, respectively.

Macroscopic plant remains

The results are presented in Fig. 6 in the form of histograms which show absolute numbers of macroscopic fossils in a sample 200 cm^3 in volume. In the case of uncountable remains an estimation scale has been applied. Such histograms have sinuous top edges. The macroscopic remains are also presented in table 3 in which they are grouped, to a certain extent, after phytosociological tables. For technical reasons absolute numbers of remains are given for 10 cm thick samples in this table, i.e. two adjacent samples have been combined in order to make the table more compact.

Local pollen assemblage zones from Kluki/74

The following local pollen assemblage zones (LPAZ) have been recognized:

K_1 = *Betula-Pinus* PAZ at a depth of 650—665 cm.
A decreasing amount of *Betula*, an increase in *Pinus*, maximum amounts of *Salix*, continuous curves for *Juniperus* and *Populus*, the beginning of the curves of *Corylus*, *Ulmus* and *Cladium mariscus*,

K_2 = *Pinus-Corylus* PAZ at a depth of 570—650 cm.
Maximum amounts of *Pinus*, regular occurrence of *Corylus* with a maximum 11.5% and of *Ulmus* with a maximum of 1.6%, fairly regular occurrence of *Populus*, sporadic presence of *Alnus*, *Quercus* and *Picea*,

K_3 = *Pinus-Ulmus* PAZ at a depth of 495—570 cm.
High proportions of *Pinus*, regular occurrence of *Ulmus* with a maximum of 6.5% and of *Corylus* with a maximum of 11.1%; continuous, though low curves for *Alnus* and *Quercus*, regular occurrence of *Tilia* from the depth of 555 cm up,

K_4 = *Alnus-Cladium* PAZ at a depth of 415—495 cm.
Pinus declines an increase in *Alnus*, *Quercus*, *Ulmus*, and the beginning of the continuous curve for *Fraxinus* at the lower boundary of this zone; on the average, 12% *Quercetum mixtum* with a high contribution from *Ulmus* (4.5%, on average); occurrence of the first maximum of *Alnus* 21.3%, and presence of maximum quantities of *Cladium mariscus*,

K_5 = *Thelypteris* PAZ at a depth of 332.5—415 cm.
Polypodiaceae beginning to occur in maximum amounts, a rise in the curve *Pinus* and an *Ulmus* decline at the boundary; the distinctive characteristic is an increased proportion of *Pinus*, an increase in NAP and a smaller quantity of *Alnus*,

K_6 = *Quercus-Corylus* PAZ at a depth of 245—332.5 cm.
Ulmus decline and an increase in NAP at the boundary; regular occurrence of *Picea*, though in small amounts (0.4—1.3%) a considerable proportion of *Quercus* and *Corylus*, a decline in *Pinus* and *Polypodiaceae*,

K_7 = *Carpinus* PAZ at a depth of 125—245 cm.
The beginning of the continuous curve for *Carpinus* and maximum amounts of *Quercus* at the boundary; a decline in *Corylus*, *Ulmus*, *Tilia* and *Fraxinus*, scarce *Fagus* and *Picea*; a continuous curve for plants indicating human activity,

K_8 = *Fagus* PAZ at a depth of 62.5—125 cm.
The beginning of the continuous curve for *Fagus* at the boundary; maximum amounts of *Carpinus* (11.0%) and *Fagus* (7.9%) regular occurrence of cereals in the closing stage of the zone,

K_9 = *Alnus-Sphagnum* PAZ at a depth of 27.5—62.5 cm.
An increase in *Alnus*, *Picea* and cereals at the boundary; regular occur-

rences though with a tendency to decrease of *Carpinus*, *Fagus*, *Quercus* and *Picea*; maximum amounts of *Alnus*,

K_{10} = *Pinus-Cerealia* PAZ at a depth of 0.0—27.5 cm.
An increase in *Pinus*, a decline in *Carpinus* and *Fagus*; about 2% *Quercus* but 22.7% *Quercus* in the surface spectrum.

Local macrofossil assemblage zones

M 1. Wood-*Cladium* MAZ at a depth of 645—670 cm.
Large quantities of wood fragments, *Coenococcum geophilum* sclerotia present, *Cladium mariscus*, *Menyanthes trifoliata* seeds, nuts of *Carex* sp. also present, scarce *Nymphaea* cf. *alba* seeds and *Stratiotes aloides* vegetative remains.

M 2. *Cladium-Menyanthes* MAZ at a depth of 395—645 cm.
Regular occurrence of *Cladium mariscus* fruits and *Menyanthes trifoliata* seeds in large numbers, 5 subzones are recognized:

a) *Menyanthes* at a depth of 580—645 cm: regular occurrence of telmatophytes and charcoal, aquatic plants scarce,

b) *Chara-Carex* at a depth of 550—580 cm: regular occurrence of *Chara contraria* oospores, frequent occurrence of *Nymphaea* cf. *alba* seeds and large quantities of *Carex* sp. div.,

c) *Cladium* at a depth of 510—550 cm: large quantities of *Cladium mariscus*, *Menyanthes trifoliata* seeds in maximum amounts, scarce oospores and sedge nutlets,

d) *Chara-Nymphaea* at a depth of 440—510 cm: maximum quantities of *Chara contraria* oospores and *Cladium* fruits, *Nymphaea* cf. *alba* and *Carex* sp. and *Heleocharis palustris/uniglumis* of fairly regular occurrence in the later phase of this subzone,

e) *Carex* at a depth 395—440 cm: maximum quantities of *Carex*, frequent occurrence of *C. pseudocyperus*, *C. lasiocarpa*, *Typha* sp.,

M 3. *Juncus subnodulosus* MAZ at a depth of 270—395 cm.
Regular occurrence of *J. subnodulosus* seeds, *Carex* sp. present, *Cladium* found in some samples, *Urtica dioica* and *Chenopodium* fruits present at the upper boundary of this zone, large quantities of wood.

M 4. *Coenococcum* MAZ at a depth of 250—270 cm.
Wood fragments present, numerous sclerotia of *Coenococcum geophilum* and *Cladium mariscus* fruits.

M 5. *Betula* MAZ at a depth of 95—250 cm.
Great representation of the regenerative parts of birch trees; four subzones are recognized:

a) *Betula-Menyanthes* at a depth of 220—250 cm: regular occurrence of *Betula* "*alba*" fruits and *Menyanthes trifoliata* seeds, fairly numerous trigonous *Carex* nutlets, mosses (*Bryales* and *Sphagnum*) present in some samples,

b) *Pinus-Betula* at a depth of 160—220 cm: maximum quantities of *Betula*, regular occurrence of *Pinus sylvestris* needles in the later phase of this subzone and accompanying *Pinus* seeds, bark, cone fragments, frequent occurrence of wood fragments, *Menyanthes trifoliata* and trigonous *Carex* nutlets,

c) Wood at a depth of 130—160 cm: lack of floristic diversity, scare trigonous *Carex* nutlets, one fruit of *Betula* "*alba*", large quantities of wood fragments and regular occurrence of charcoal,

d) *Betula-Carex* at a depth of 90—130 cm: *Betula* fruits and *Pinus* seeds present, trigonous *Carex*, *Menyanthes trifoliata* seeds, wood fragments and brown mosses.

M 6. *Carex-Cerastium* MAZ at a depth of 65—95 cm.
Regular occurrence of trigonous *Carex*, scattered distribution of *Cladium mariscus* and *Menyanthes trifoliata*, scarce wood fragments and mosses.

M 7. *Sphagnum* MAZ at a depth of 0.0—65 cm.
Regular occurrence of *Sphagnum* sp., scarce *Betula* fruits and *Coenococcum geophilum*.

Subfossil plant communities

The large floristic diversity represented by the macroscopic plant fossils permits a tentative reconstruction of the subfossil plant communities which contributed to the biogenic sediments. The characteristics of these subfossil communities is here confined to a brief description supplemented by a simplified paleophytosociological table (Table 3). This simplification is imposed by technical limitations. The macroscopic remains are given in absolute numbers, whereas *Typha latifolia* pollen and *Ceratophyllum demersum* hairs are presented as percentages.

Limnophytes

There is little information about the vegetation which grew during the short phase of detritus gyttja deposition (layer XV) during the Preboreal. The base of this layer contains abundant *Pediastrum Boryanum* with a maximum of 64.3%, single *P. Kawraiskyi* specimens and single pollen grains of *Potamogeton* sp. and *Myriophyllum spicatum*, *Ceratophyllum demersum* hairs and a seed of *Nymphaea* cf. *alba*. No *Charales* oospores have been found, which may bear a relation to the depth of the basin, which was probably rather deep. This hypothesis is also supported by the lithological characteristics of this layer (Overbeck 1975). However, the water basin became rapidly shallower, as is inferred from the abruptly falling curve for *Pediastrum Boryanum*, and from the presence

Table 3

	660-670	650-660	640-650	630-640	620-630	610-620	600-610	590-600	580-590	570-580	560-570	550-560	540-550	530-540	520-530	510-520	500-510	490-500	480-490	470-480	460-470	450-460	440-450	430-440	420-430	410-420	400-410	390-400	380-390	370-380	360-370	350-360	340-350	330-340	320-330	310-320	300-310	290-300	280-290	270-280	260-270	250-260	240-250	230-240	220-230	210-220	200-210	190-200	180-190	170-180	160-170	150-160	140-150	130-140	120-130	110-120	100-110	90-100	80-90	70-80	60-70	50-60	40-50	30-40	20-30	10-20	0-10
Potametea																																																																			
Chara contraria										33	5	13			2	19	45	54	∝	8	33	∝	17									1									1																										
Ceratophyllum demersum H	0.1					0.1								0.2						0.2	0.2	0.6																																						0.8							
Ceratophyllum demersum F											1																																																								
Nymphaeion																																																																			
Nymphaea cf. alba S	1		2	1						2	4	3									5	3																																													
Stratiotes aloides V	1					4																																																													
Myriophyllum spicatum F									0.2																																																										
Phragmition																																																																			
Cladium mariscus	40	2	80	88	77	86	71	54	52	64	120	128	177	380	91	81	191	101	274	335	132	178	290	69	70	84	37	115	42			4		14	22						4	30	1	3													5	48			27						
Schoenoplectus Tabernaemontani	1		32	1					2	3	1	1	1						2																																																
Typha latifolia P	1.1	0.1	0.2		0.9	0.4	0.2		0.2		0.2	0.5	0.3		0.2		0.1	0.1		0.8		0.7	0.5	0.5	0.5	0.7	0.2					0.3			0.2				0.2	0.3		0.6			0.2									0.3	0.2					0.2							
Typha sp. div. F									1	1	2	1										3	1	1	6								1				1																														
Schoenoplectus lacustris																				1	1									1																																					
Oenanthe aquatica																																												1														1									
Dryopteris sp. SP	+	s	s	+					sp													s		+	+	+	+	+	+	s		s	sp	+	+	+	sp	+	+	+	+	s	s	s	sp	sp	sp	+	sp					sp		sp						s					
Phragmites communis E																							s	s	s	s	s	s	s	+	s	s	s	s	+	+	+											s	+	++	+++	+++															
Magnocaricion																																																																			
Carex sp. div. /trigonous achenes/	28	1	45	5		1	1	1	18	61	11	9	13		1				1	8	5	9	133	174	41	54	8	13	17	32	3	6	53	10	19	12	4		11		5	4	32	26	14	2	40		75	3		2			17	72	32	22	20	29	8				1		
Carex rostrata	1			2						1													16	3	1																																										
Carex pseudocyperus	1		7	6							1								1	2			18	23	1																																										
Cicuta virosa												1					1						1	7		2		1	1																																						
Stellaria palustris															2					4			2					1																				2		2					1							1		6			
Peucedanum palustre																							1																																												
Carex sp. div. /biconvex achenes/																								6	94	40	1	13	2				1											1												4							1				
Phragmitetea																																																																			
Eleocharis palustris / uniglumis			1					3	3									2	2	1	6														1		8																														
Sparganium simplex			4	1						2		3																													1																										
Lycopus europaeus					1																		2																																												
Ranunculus lingua																					1		2	2																																											
Mentha cf. aquatica																							2	13				1	1																																						
Rumex hydrolapathum																									1																																										
Scheuchzerio-caricetea fuscae																																																																			
Menyanthes trifoliata	61	7	26	38	30	27	39	67	23	64	45	54	140	71	138	40	23	40	56	9	12	7	41	18		2									1							3	22	16	19		1	11	8	39					1	12	26	14	1	1	1	8	1				
Comarum palustre																																			1							1											30			9	1										
Carex lasiocarpa						1																		9	3	2		1					4	1										3					21								3		1								
Drepanocladus aduncus																							s																			s	s																								
Juncus articulatus																									4																																										
Drepanocladus vernicosus																																																									s										
Drepanocladus revolvens																																													s																						
Meesia triquetra																																													s																						
Molinietalia																																																																			
Juncus subnodulosus																							3					5	6	29	45	13	11	46	10		7	13	12	1																											
Lychnis flos-cuculi															1					1															1				2			1		1											64						8						
Alnetalia																																																																			
Alnus glutinosa																																					5																														
Rubus idaeus																																								1																											
Urtica dioica																								1																2																											
Betula "alba"	49		9	26	1	7	2	2		2	2	2		3	1	1		6	3	1	1	2			7			1			2	1	5				6			1			15	23	13	1	71	166	62	163	42	1			8	59	15				1						
Sphagnum palustre																																											+	+	+					+					+								s				
Calliergon cuspidatum																																													s					s	s	s				s	s										
Calliergon giganteum																																																s							s												
Pinus sylvestris																																															1	1	22	198	77				7	2	9	2					1		1	2	13
Empetrum nigrum																																																																	1		
Calluna vulgaris																																																																	sp	sp	
Oxycoccus quadripetalus																																																																	sp		
Sphagnum apiculatum																																																															+				
Sphagnum wornstorfii																																																																	+		
Sphagnum sp.																																																										+	+	+	+	+	+	+	+	+	+

of large quantities of sporomorphs and macroscopic mire plant fossils. The shallower basin was simultaneously associated with changes in trophic levels as eutrophic species prevail among the telmatic plants. The pH of the deposit changed, that of the lowermost sample being 3.8 and of this layer 5.0.

Magnocaricion

This community, the identification of which is based on fruit and seed remains, does not form any distinct boundary with the vegetation of the shallow water basin nor with the overlying sediments of *Cladium*-containing phytocoenoses. The *Magnocaricion* sedge community consists of a few *Carex* species with trigonous achenes, among which *Carex rostrata* and *C. pseudocyperus* have been identified.

Cladietum

This community is characterized by the regular occurrence of abundant *Cladium mariscus* fruits and frequently also of the vegetative parts, the permanent presence of *Menyanthes trifoliata* and the occurrence of sedges in some of the profiles. The aquatic plants found in this subfossil community provide the basis for distinguishing between two facies, namely a stagnant-water phase and moist one. *Chara contraria* is characteristic of the stagnant-water facies. Oospores of this plant appear in this community. It is accompanied by *Nymphaea* cf. *alba* seeds, single occurences of *Pediastrum* cenobiae and small quantities of aquatic pollen. In these profile there is a build-up of telmatophytes, especially those, the optimum existence of which occurs in shallow stagnant water. They include *Schoenoplectus tabernaemontani* and *Schoenoplectus lacustris*, *Sparganium simplex*, and *Typha* cf. *latifolia*.

Cladium mariscus is characterized by a wide range of ecological requirements. An assemblage of this plant occurs as a few variants differing in appearance and structure (Jasnowski 1962, Nowiński 1967, Tomaszewicz 1979) which are reflected in the peat. They produce distinguishes between peat composed almost entirely of this species, and that with accompanying sedges and reeds, as well as that containing many other species such as *Menyanthes*, *Molinia*, etc. (Overbeck 1975).

Habitat characteristics of subfossil phytocoenoses of *Cladium* at Kluki differed markedly from present-day habitats occupied by such assemblage. Special emphasis is placed on the literature sources for the relationship of these phytocoenoses with calcium-rich habitats (Ellenberg 1978). The pH of the peat ranges from 4.5 to 5.2. *Cladium mariscus* is not a constituent of the present-day flora of the Gardno—Łeba Plain, the nearest patches of this assemblage lying about 80 km to the south.

Magnocaricion II

The aquatic facies of *Cladietum* gradually becomes a community of large sedges. This change is initiated by the appearance of *Carex rostrata*, then *Carex pseudocyperus* with accompanying *Cicuta virosa*, for example, and finally, *Carex lasiocarpa* and *Carex* cf. *acuta* (in Fig. 6, some of the sedge specimes are drawn on a common histogram with biconvex *Carex* achenes). This community is characterized by the constant presence of *Cladium mariscus* and *Dryopteris thelypteris*. In contrast to subfossil community *Magnocaricion* I, which occurs at the base of the profile, the presence of most of the large sedges can be inferred from large amounts of their underground parts (radicles).

Juncus subnodulosus-Dryopteris thelypteris

The regular occurrence of large quantities of *Juncus subnodulosus* seeds, which were found in the peat overlying that formed in *Magnocaricetum* II has provided the basis for recognizing a separate subfossil community. *Juncus subnodulosus* remains are accompanied by large numbers of *Dryopteris thelypteris* spores, *Phragmites australis* and *Carex* sp. div. (trigonous achenes). *Cladium mariscus* also occurs twice in small amounts in this community as both pollen and fruits.

The ecological characteristics of *Juncus subnodulosus* are well known as can be seen from ecological indicator figures (Landolt 1977, Ellenberg 1979, Zarzycki 1984). It is a scarce plant in the Polish flora being found chiefly in the north-western part of the country. It is intolerant of late frost and great temperature variations. The plant is light-demanding and grows on peaty soils. Most research workers consider it to be an indicator of neutral soils, especially alkaline ones, or just, an indicator of calcium-rich habitats. It is also an indicator of habitats poor in nitrogen and grows on slightly wet to wet soils. According to Nowiński (1967), patches of *Juncetum subnodulosi* assemblage occur on fertile sedge peats, generally carbonate ones, with water through them and a pH of over 7. In exceptional cases they are found on acidified peats with a pH of about 6. The water level in the soil is high throughout the year. In the phytosociological classification this assemblage is recognized as belonging to the order *Molinietalia* (Matuszkiewicz 1981). Ellenberg (1978, p. 756) states that patches of this assemblage may be liable to degeneration after the cessation of mowing. It is then that *Phragmites* appears to suppress this light-demanding rush and eventually promote the growth of pioneer forest communities. The problem of the persistence of this community in the profile under investigation will be discussed in another section.

Magnocaricion III

The deposit containing *Juncus subnodulosus-Dryopteris thelypteris* is overlain by a layer of peat derived from sedge communities, which, for the time being, is termed *Magnocaricion* III. This subfossil community of sedges contains large quantities of radicles, i.e. up to 75% trigonous *Carex* achenes occur fairly regular and *Cladium mariscus* is present. Its specific characteristic is the presence of *Menyanthes trifoliata*, brown mosses and *Sphagnum palustre.* This floristic composition distinguishes this subfossil community from *Magnocaricetum* II which contains neither *Menyanthes* nor peatforming mosses. Of the brown mosses, *Drepanocladus fluitans* is of sporadic occurrence. At present it is difficult to classify this community under a definite syntaxonomic category. Maybe, further investigations will provide sufficiently convincing evidence for placing it in the category *Scheuchzerio-Caricetea fuscae.*

Betuletum pubescentis

This subfossil community contains numerous fruits and scales of birch, *Betula "alba"*, brown mosses, including *Calliergon cuspidatum, C. giganteum.* The presence of such peatforming mosses is also seen from an increase in moss spores and a concurrent decline in *Polypodiaceae* spores. A *Pinus sylvestris* facies which consists of numerous pine needles and single seeds has been recognized within this community.

Phragmitetea

The deposit containing this community displays variability in its botanical composition on the basis of which some sub-communities can be distinguished. *Betuletum pubescentis* is also present again for a short time. Emphasis should be put on the presence of *Cladium mariscus.* Fruits and pollen grains have been found in an extremely acid peat with a pH value of 3.3—4.0, with accompanying *Sphagnum palustre.* Most probably, such occurrence is the remnant of a regressive stage of communities containing *Cladium mariscus* (Ellenberg 1978).

Oxycocco-Sphagnetea

The uppermost peat is largely composed of peatforming mosses including *Sphagnum palustre, Sph. apiculatum* and *Sphagnum* sp., but contains a small number of *Menyanthes trifoliata* seeds in its lower part. Of the indicative vascular plants, *Eriophorum vaginatum, Oxycoccus quadripetalus* and *Calluna vulgaris* are present together with pollen of *Drosera.* The pH of the deposit is 3.1—3.3.

Vaccinio uliginosi-Pinetum

The mire surface, down to a depth of 10 cm, consist of the present-day swamp forest community (*Vaccinio uliginosi-Pinetum*). Among the macroscopic fossils, *Betula pubescens, Pinus sylvestris* and *Sphagnum Warnstorfii* are present.

Regional vegetation history on the basis of the Kluki-74 profile

K 1: *Betula-Pinus* PAZ, about 10000—9570 yr B. P.

On all diagrams pine prevails but birch declines and the occurrence of small quantities of *Populus* and *Juniperus* pollen becomes less regular. The AP sum increases to over 80%. *Betula "alba"* has been found in the macroscopic remains. In view of the recent study, the lowland area was then covered with a mosaic of patches of pine-birch forest.

K 2: *Pinus-Corylus* PAZ, about 9570—8320 yr B. P.

This zone contains the highest pine percentage of the whole profile, i.e. 56.2 to 88.8% (Fig. 3), but pine is not absolutely dominant in terms of pollen concentration 44802—168428 grains per cc. (Fig. 4), or influx (Fig. 5). Much greater quantities of pine are registered on the influx diagram at the top of the profile where pine pollen is largely derived from tree growing on the mire surface. Thus, it can be inferred, that during the time period covered by this zone pine grew in the Gardno—Łeba Plain area in the form of isolated clusters, possibly confined merely to higher-lying aeolian forms. The hypothesis of a scattered distribution of forestland at that time seems to receive support from the sporadic, if significant, occurrence of such macrofossils as pine seeds. It should be assumed in the light of the above arguments that the major proportion of the pine pollen is derived from an area outside the lowland. However, the birch pollen and probably also the poplar is derived from nearby sites within the lowland. There is a continuous curve for birch with a peak of 19.9% which can be expressed as 27302 grains/cm^2/yr. Birch macrofossils are more abundant than those of pine, but are not present in all samples (Fig. 6). A continuous hasel curve is plotted in this zone, with hazel reaching a maximum, i.e. 11.5%, in a sample from which *Populus* is absent. Maybe hazel was intermittently present in the vegetation cover of the lowland. Such an inference is drawn from the comparison between its pollen representation in frequency and influx terms in this zone and at top of the profile. Nowodays, hazel is an exceptionally scarce constituent of the flora in the Gardno—Łeba Plain but its nearest site is only about 3 km north of Kluki/74. *Ulmus* also has a continuous curve in this zone with a peak of 1.6%. This is the result of pollen transport from the plateau areas.

K 3: *Pinus-Ulmus* PAZ, 8320—7200 yr B. P.

The pine percentage curve shows oscillations between a maximum of 85.6% and a minimum of 44.8%. The pine curves are more regular, however on the pollen concentration and influx diagrams, where the peak occurs at the base. Pine declines gradually upward, with a slight rise being registered only in the two uppermost samples. Birch occurs in small amounts with a maximum of 8.3% but is present in the form of macroscopic fossils. All spectra contain hazel pollen but the hazel curve is discontinuous, with a peak of 12.5%. In the pollen influx diagram hazel attains its maximum of 3129/cm^2/yr. Elm also forms a continuous curve with a peak of 6.5% and in pollen influx terms similarly exhibits its highest values. The *Quercus* curve is consistently over 1% with a peak of 5.6%, while the *Alnus* curve has a peak of 13.4%.

K 4: *Alnus-Cladium* PAZ, 7200—5790 yr B. P.

There is a marked decline in the pine pollen percentages, the quantities of which range from 28.6 to 54.1%. In the pollen concentration and influx diagrams, with the exception of the lowermost sample, the pine curve is more regular, which implies that the tree, which has dominated until now, disappears from most of its habitats in the lowland, particularly the plateau fringes. This zone marks the beginning of a long period in which the pine curve is monotonous on both the concentration and influx diagrams and represents only a small number of grains. The reverse is true for the pine percentage curve which shows more oscillations. The outstanding characteristic of this zone is a rise in the percentages of all the constituents of the deciduous forests. Birch also expands although the number of macrofossils does not indicate any higher frequencies. *Fraxinus* has a continuous pollen curve (0.5—1.5%), single pollen grains of *Hedera helix* and *Viscum* sp. also appear.

K 5: *Thelypteris* PAZ, 5790—5010 yr B. P.

Herbaceous plants consisting largely of *Gramineae* expand. The palynological picture is markedly affected by large quantities of autochthonous pollen and spores especially *Polypodiaceae* and *Cyperaceae*. In spite of this local influence, the curves in the concentration and influx diagrams are continuous. Spruce pollen occurs fairly regularly, though in small amounts, i.e. 0.15—0.6%. *Hedera helix* pollen is recorded in two spectra.

K 6: *Quercus-Corylus* PAZ, 5010—3920 yr B. P.

In the zone AP again achieves high values i.e. 90.4—95.4%, with the percentage of *Quercetum mixtum*, also being higher i.e. up to 20.4%. Most of the curves of the deciduous trees are fairly uniform in the influx diagram, which is not the case for the percentage curves of alder, elm and oak. In the case of alder, an exception is provided by the 300 cm sample which contains *Alnus glutinosa* fruits. The alder pollen contents of three samples is presented in the following list.

Depth in cm	Grain/cm^3	Grain/cm^2/yr	%
290	3375	503	18.3
300	11872	1768	14.3
310	2632	292	10.1

Three and two fruits of *Alnus glutinosa* have been found at depths of 300—305 cm and 305—310 cm, respectively. They are the only alder fruit in the whole profile. The threefold frequencies of alder pollen in the influx diagram are indicative of the presence of this species in situ. However, special note should be made of the fact that this event is not clearly registered in the percentage diagram where the maximum is reached 10 cm above the level with macroscopic remains which is also above the sample with higher concentration and a faster pollen accumulation of alder. In view of this fact, it is concluded that alder did not play a major part in the vicinity of the site, but merely formed small forest patches or, most likely, loose clusters of trees. Alder assumes greater significance later, in the second half of zone 7, as can be inferred from the influx diagram. A similar inference can be made for hazel, oak and elm. A comparison between three pollen diagrams from the site suggests that these taxa were present over small areas and in limited habitats in the northern part of the lowland. At that time lime and ash did not grow in the Gardno—Łeba Plain.

K 7: *Carpinus* PAZ, 3925—1750 yr B. P.

This zone is characterized by the regular occurrence of hornbeam pollen, 0.2—2.2%, and by the presence of beech pollen in many spectra, 0.12—0.6%. The percentages of hornbeam indicate that the pollen is derived from outside the lowland. It reaches its maximum of 11.0% only in the later stages of the diagram, e.g. at a depth of 80 cm. However, the influx diagram shows that hornbeam may be locally present as early as 170 cm depth. It is also at this stage that the influx of hornbeam pollen achieves highest values, namely 800 grains/cm^2/year. This also suggests the presence of hornbeam in the Gardno—Łeba Plain. Thus, the author's earlier opinion (Tobolski 1975 p. 24), based on percentage diagrams, concerning his doubts about the presence of hornbeam in the lowland must be mitigated. The problem of the presence of beech in the Gardno—Łeba Plain is quite different. The study of fossil soils in the Łebska Spit proved (Tobolski 1975) that oak forests had been destroyed about 2000 years ago and later replaced by beech stands. These events are probably recorded in the influx diagram at a depth of 150—160 cm. Unfortunately, no can be provided to the question of whether beech was then present in a habitat in the Kluki Conservation District about 2.5 km north of the sampling site. The answer will be obtainable after a series of precise datings of soil horizons have been made at this site.

There are considerable variations in both the concentration and influx diagrams for pine, birch and alder. These variations are the result of local changes which took place in the Kluki mire, as can be inferred from the macrofossil diagram (Fig. 6). Macroscopic remains of alder have not been found but the pollen diagrams show that this tree also gained an advantage in the local cover from that time.

The oak-rich forests also expand in the lowland area. This fact, which was already partly known, receives confirmation from the influx diagram which also provides convincing evidence of the high stability of these stands in spite of the local disasters which happened in the forest at Kluki (Dzięciołowski & Tobolski 1975) and in the spit areas (Tobolski 1975, 1979).

K 8: *Fagus* PAZ, 1750—865 yr B. P.

The percentage diagram shows a regular occurrence and maximum amounts of hornbeam and beech pollen. However, the curves for these trees do not have maximum values on the influx diagram. This is indicative of their limited importance in the prevailing forest of the lowland. This inference agrees with the distribution of fossil soils, only some of which have been produced under beech stands and thus points to a mosaic of deciduous forest areas. This mosaic was probably also the result of topography. On the one hand large areas were occupied by mires, areas of which became ombrogenic at that time and, on the other hand, changes produced by the post-Littorina transgressions took place.

K 9: *Alnus-Sphagnum* PAZ, 865—230 yr B. P.

The percentage diagram shows low values of pine, i.e. 15.7—35.4%, and not more than 30% of alder and birch. The maxima of hornbeam and beech are 3.2 and 5.1%, respectively, but these are represented as minimum values in the influx diagram. This is also the case for the oak curve.

K 10: *Pinus-Cerealia* PAZ, 230—0 yr B. P.

In the last zone pine pollen assume dominance. Large quantities of pine, especially in the three uppermost spectra, are indicative of the presence of pine stands in the swampy forest of the contemporary phytocoenosis.

Migration of important forest-forming trees

In recent years the paleobotanical literature has provided numerous pieces of information about dated sites, on the basis of which the absolute age of the empirical and rational boundaries, as well as of other characteristics of the pollen curves for many forest trees can be determined. Hjelmroos's (1981) and Latałowa's (1982) publications contain such data for the nearest study area. A comparison of those dates with the data presented below will be the subject of a separate article. Here mention should merely be made of the fact that the dates of Hjelmroos (1981) have been corrected (cf. p. 53), whereas some of the dates of Latałowa (1982) are based on curves exceeding 1% calculated on the basis of AP = 100%.

The beginning of continuous curves for the most important AP types found in the Kluki/74 profile are as follows:

Corylus	ca. 9800 yr B. P.
Ulmus	ca. 9880 yr B. P.
Alnus	ca. 8500 yr B. P.
Quercus	ca. 8300 yr B. P.
Tilia	ca. 8200 yr B. P.

Fraxinus	ca. 7300 yr B. P.
Carpinus	ca. 3800 yr B. P.
Fagus	ca. 1750 yr/ca. 2000/yr B. P.

Economic activity of man visible in the pollen diagram

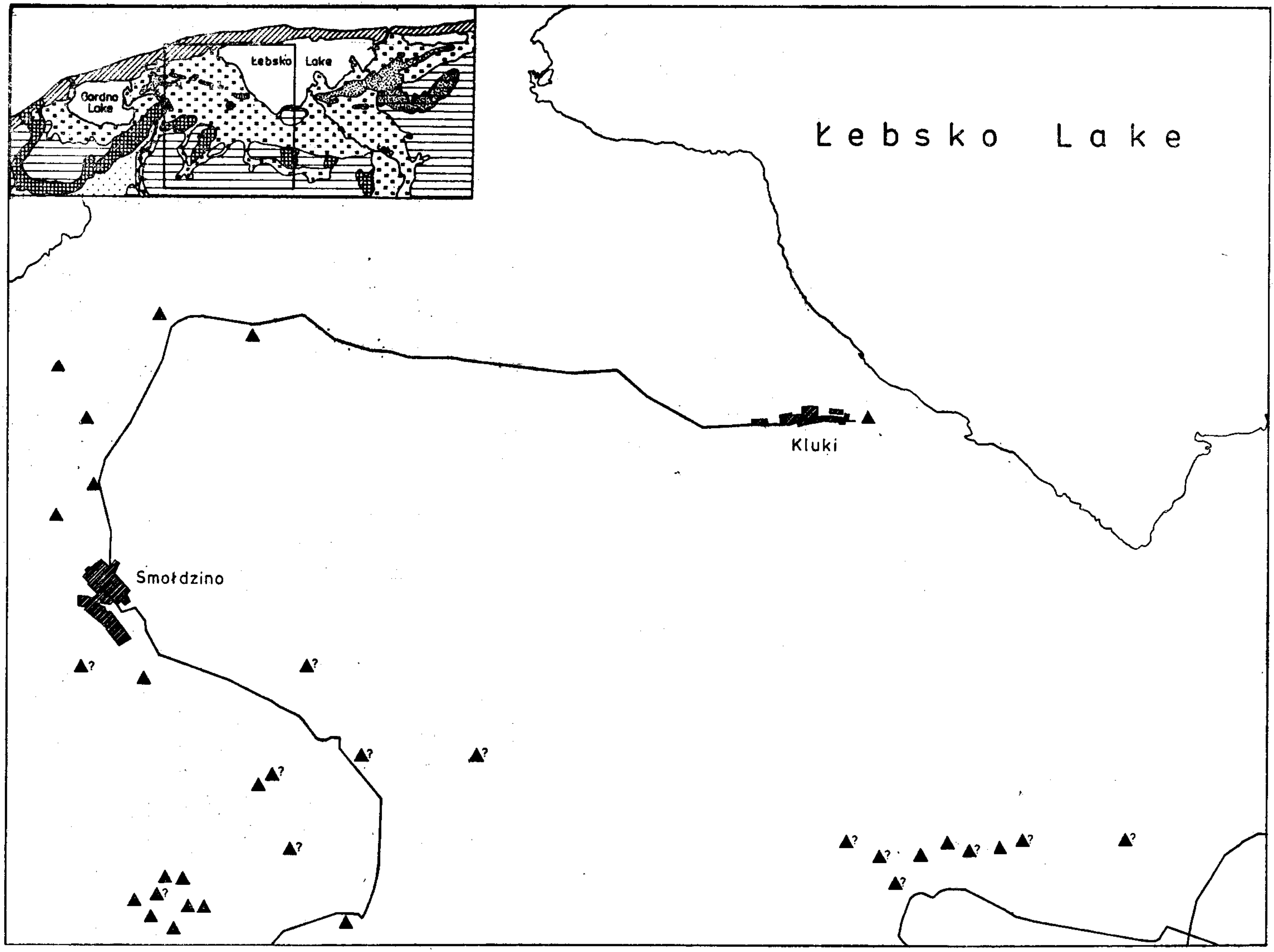
The impact of man visible at the top of the diagram were the subject of a preliminary report (Tobolski 1982) which presented a percentage curve for the pollen indicators of human activity and initially discussed the components of this curve and their relationship with some episodes of change in the vegetation cover of the Gardno—Łeba Plain. Since this report was written the number of radiocarbon dated horizones in the Kluki/74 profile has increased but so far the inventory of archeological sites in the lowland and surrounding areas has not been completed. The compilation of this inventory is being carried out within the framework of the Polish Archeological Image operation. The author was able to make use of four sheets covering about one quarter of the Gardno—Łeba Plain area in the vicinity of the Kluki/74 profile (Fig. 7) which he received by courtesy of Mrs Kozerska of the Office of Monument Documentation at Słupsk.

The paleobotanical material from the profile, both pollen and macrofossils, reveals human economic activity. It is not a wide inventory but characteristic and deserving attention. It is visible virtually throughout the profile beginning with the earliest layers.

Imprints of human activity prior to the Neolithic

According to the present author, charcoal indicates human activity and charcoal (Fig. 6) is visible in nearly all horizones. A full picture of this curve is provided when another curve from the macrofossil diagram is taken into consideration. It gives information on the horizones of occurrence of charred perennial plant fragments. In view of the above data, it is evident that fires occurred on the mire or in its close vicinity throughout virtually the whole period of peat accumulation.

The charcoal curve has peaks, the first of which is recorded at the onset of K 2 PAZ, ca. 9500 radiocarbon years B. P. and lasts until ca. 8750 yrs B. P. The following peak is dated to 6000—6600 yr B. P. The peak of charred perennial plants is found at a depth of 480—500 cm which, on the basis of interpolation between the radiocarbon dates is correlated with the time interval ca. 6900—7300 yr B. P. These charred perennial plants comprise overground vegetative parts of *Cyperaceae, Cladium mariscus* and charred fruits of *Cladium mariscus.* These fossils provide indications of fires in the rushes which only man would have been able to produce. The aim of such fires migth have been in connection with hunting to drive game towards a prearranged trap. Similar phytocoenoses


Łebsko Lake
Gardno Lake
Łebsko
Lake
Łebsko Lake
Kluki
Smołdzino
?

of the class *Phragmitetea* in the northern portion of the Gardno—Łeba Plain are also refuges for deer. Artifacts found in an inland dune in the village Smołdziński Las indicate the presence of Mesolithic man (Tobolski, 1975, p. 61). Traces of his presence are most probably not recorded in the diagram since *Artemisia* and *Chenopodiaceae* pollen occur only sporadically. Bioindications provided by these pollen types in the coastal zone are faint because a lot of species of these taxa belong to the native flora.

Palynological traces of man's activity

The beginning of a continuous curve for the sum of the pollen indicators of human activity is at a depth of 250 cm (Fig. 8). The date assigned to this level is ca. 4100 yr B. P. This curve shows varying percentages and a differing number of taxa. It is divided into five sections which are termed phases and are labelled with letters. Phase E is further divided into three subhases.

Phase A, 4100—3300 yr B. P.

This section of the curve is represented by small amounts of pollen with a maximum of 1% and only 6 taxa. *Artemisia* specimens (0.4%) are most numerous. One wheat pollen grain has been found at a depth of 220 cm with an estimated age of about 3500 yr B. P. The palynological data for this points to small-scale economic activity in the immediate vicinity of the site. This phase covers a period from the close of the Neolithic (2300—1700 yr B. C. **) to the beginning of the Lusatian culture. The peak of this curve is dated by interpolation to 3670 yr B. P. The majority of the pollen is of *Rumex acetosa-acetosella* type. The first pollen of *Plantago lanceolata* is also present in this sample.

The inventory of archaeological finds dating back to the Neolithic is exceptionally short for the immediate vicinity of the Kluki/74 profile. Archeological sites are considerably more numerous to the south of the plain. However, few sites within this area receive particular attention. Most of them are located on the ridges of the dune train lying east of the village Kluki, in Smołdziński Las and its vicinity reaching as far as Smołdzino. In the classification of cultures these sites fall under the Globular amphores culture on the basis of the AZP inventory but they are only identified on presumptions (Wiślański 1966, Siuchniński 1969). Some of the sites date back to the close of the Neolithic or to the Neolithic, correlations with a given culture not being provided. All Neolithic sites in the vicinity of profile Kluki/74, which have not been correlated

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** I am able to make use of the chronological framework for the periods and archaeological cultures quoted in this section by courtesy of Doc. Dr. Kośko of Adam Mickiewicz University of Poznań, to whom I am most thankful for this information and for discussions on the chronology of the cultures in the AZP.

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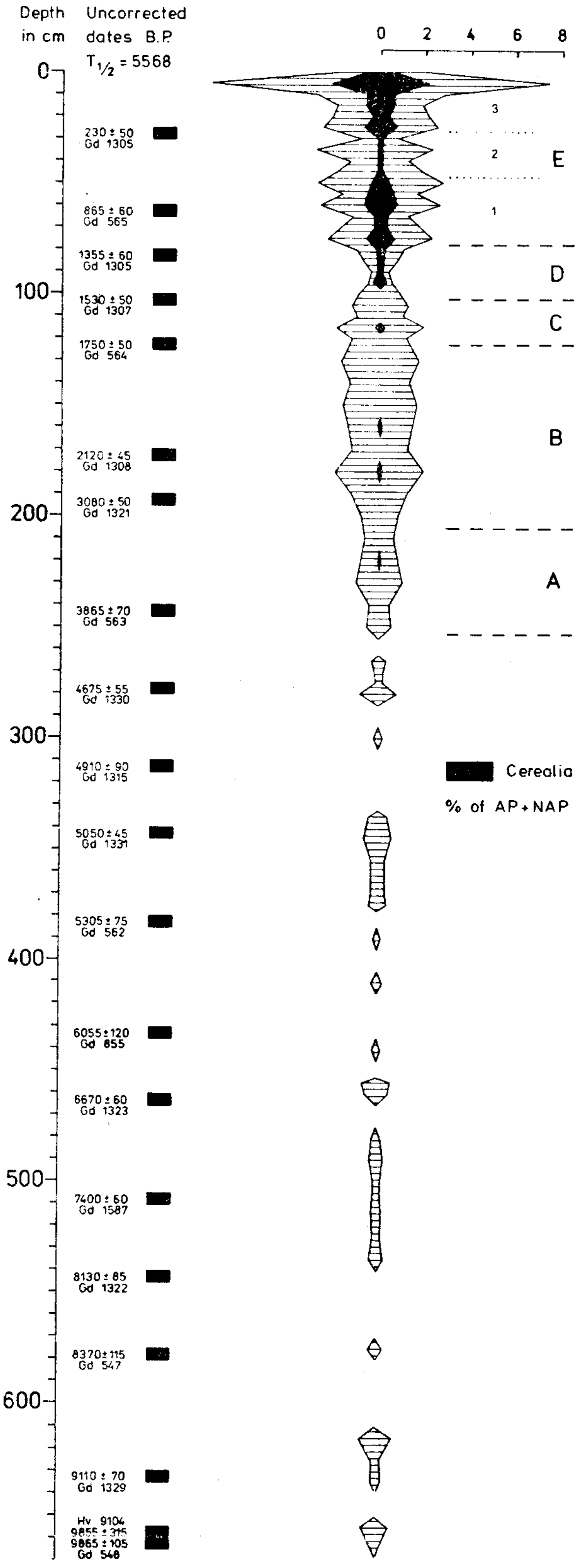
Fig. 7. Distribution of Neolithic artifacts in the vicinity of Kluki/74 site (according to AZP)



Depth in cm
Uncorrected dates B.P.
$T_{1/2}$ = 5568
0
100
200
300
400
500
600
230 ± 50 Gd 1305
865 ± 60 Gd 565
1355 ± 60 Gd 1305
1530 ± 50 Gd 1307
1750 ± 50 Gd 564
2120 ± 45 Gd 1308
3080 ± 50 Gd 1321
3865 ± 70 Gd 563
4675 ± 55 Gd 1330
4910 ± 90 Gd 1315
5050 ± 45 Gd 1331
5305 ± 75 Gd 562
6055 ± 120 Gd 855
6670 ± 60 Gd 1323
7400 ± 60 Gd 1587
8130 ± 85 Gd 1322
8370 ± 115 Gd 547
9110 ± 70 Gd 1329
Hv 9104 9855 ± 315
9865 ± 105 Gd 548
0 2 4 6 8
3
2
1
E
D
C
B
A
Cerealia
% of AP + NAP

with specific cultures on the basis of the AZP data are presented in Fig. 7. Most sites belong to the close of the Neolithic and it cannot be ruled out that it was man's economic activity in the vicinity of Smołdzino and Żelazo which led to the slight traces in the pollen diagram. For paleogeographical purposes special reference should be made to archaeological artifacts found in the vicinity of the Kluki village. This dune site provides evidence of a genetic association with the inland dune train, the eastern portion of which is formed by dunes in the vicinity of Gace and Krakulice (Tobolski 1972).

Phase B, 3300—1700 yr B. P.

The earlier stage represents a recession after which the cultural indicator curve rises to a maximum of 1.9% at a depth of 180 cm. This peak has a data of ca. 2500 yr B. P. It is represented by 5 taxa. A rye pollen grain appears for the first time in this profile. A few artifacts dating the early stage of the Lusatian culture have been found in the vicinity of the site. These artifacts have been laid down on dune ridges lying to the east of the Kluki village and in village Smołdziński Las.

Phase C, 1700—1500 yr B. P.

The curve for this phase shows lower percentages than in phase B. *Artemisia* pollen with a maximum of 1% is most abundant. Two cereal pollen grains have been found in one sample. Gradually diminishing economic activity in the immediate vicinity of the site is recorded in this phase.

Phase D, 1500—1200 yr B. P.

This section of the curve for indicators of human activity represents a recession with a minimum percentage of 0.4%. A higher oak pollen percentage and AP sum coincides with this recession. These provide indications of increased forestation. This phase also coincides with the transgression Kluki 5 and with a rise in water level in the mire.

Phase E, 1200—0 yr B. P.

The cultural indicator curve for this phase shows highest percentages, a differing shape and maximum values of cereal pollen. The curve for cereals can be divided into three sections upon which the following subphases are based:

Subphase 1 covers the time period from 1200—600 yr B. P. in which the cereal curve has a peak of 0.7%. Among the cereals rye is of major importance. The intense economic activity of the Early Middle Ages is registered in the lower section of the cereal curve in this subphase. From 14th century the percentages decrease. In subphase 2,600—230 yr B. P., the cereal percentage does not

Fig. 8. Kluki/74: local anthropogenic phases based on pollen indicative of human activity

exceed 0.1%. It increases to higher values from the horizon dated by radiocarbon to 230 yr B. P. which marks the beginning of subphase 3. The percentage of cereals drops rapidly in the surface spectrum. This drop is indicative of changes is land-use patterns in the northern part of the Gardno—Łeba Plain. In the last years cereal cultivation has been limited for the purpose of intense meadow exploitation.

SUBFOSSIL BEETLES

During the sorting of the macroscopic plant fossils insect remains were also collected. Fixed samples of these remains were sent to Profesor Pawłowski of the Polish Academy of Sciences in Cracow. Preliminary results are presented in Pawłowski's *** article (1985) on which the text given below is based.

Up until now 34 taxa have been identified in the material from Kluki/74. From the Preboreal until the second half of the Atlantic beetles associated with reed and sedge communities prevailed. They included *Coleostoma orbiculare, Scirtes orbicularis, Colliuris melanura, Plateumaris sericea* and *Limnobaris pilistrata.* A principal change in the *Coleoptera* fauna occurred at the turn of the Atlantic Period. *Colliuris melanura* associated with *Phragmites communis* disappeared, *Plateumaris sericea* declined and *P. rustica* and *P. consimilis* gained an advantage. Afterwards *Pterostychus strennuus* and *Epaphius rivularis* appeared. Among the herbivorons species, *Limnobaris pilistriata* declined and *Apion vicinum* which feeds on *Mentha* sp. appeared. About 1500 yrs ago forest and aquatic species were no longer present and *Donaciinae* declined gradually. *Plateumaris consimilis* was present in the deposit for the longest period of time, i.e. up until 13th century.

RATE OF BIOGENIC SEDIMENT ACCUMULATION

The biogenic sediments display varying rates of accumulation which are illustrated by the curve in Fig. 9. The greatest rate of accumulation is 2.14 mm per year and the slowest rate 0.21 mm per year, with a mean of 0.7 mm per year for the whole profile.

Figure 9 illustrates that the Kluki profile has three sections of rapid accumulation. They occur at different depths but the most rapid occurs in the middle section. This implies that the computed values of annual peat accretion may be underestimated because no allowance has been made for sediment compaction in relation to the actual accumulation rate. The peat that accumulated most rapidly formed under the *Juncus subnodulosus-Dryopteris thelypteris* community.

Two radiocarbon dates are available for this subfossil community,

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*** Profesor Pawłowski intends to devote a separate article to fossil beetles from this site, see Pawłowski et al., this volume pp, 223—226.

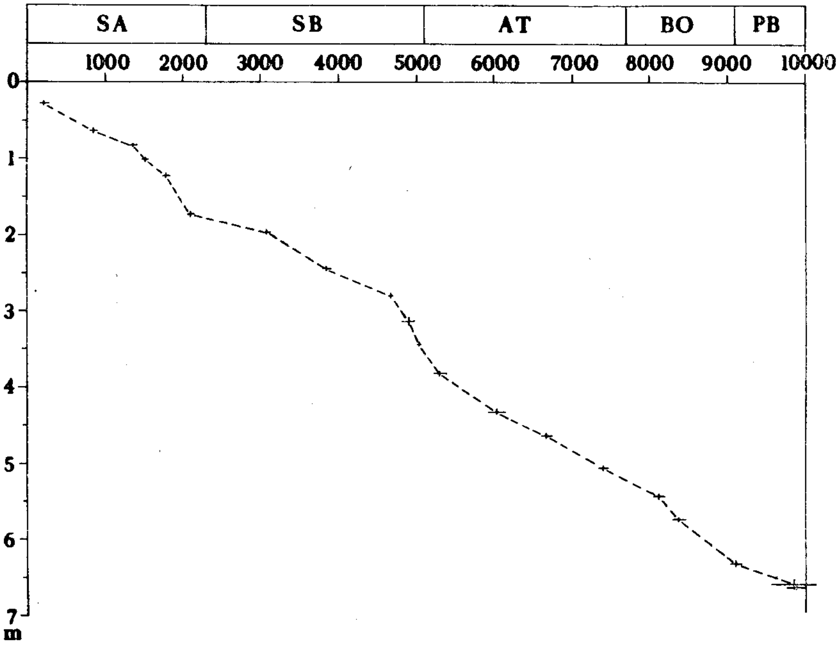
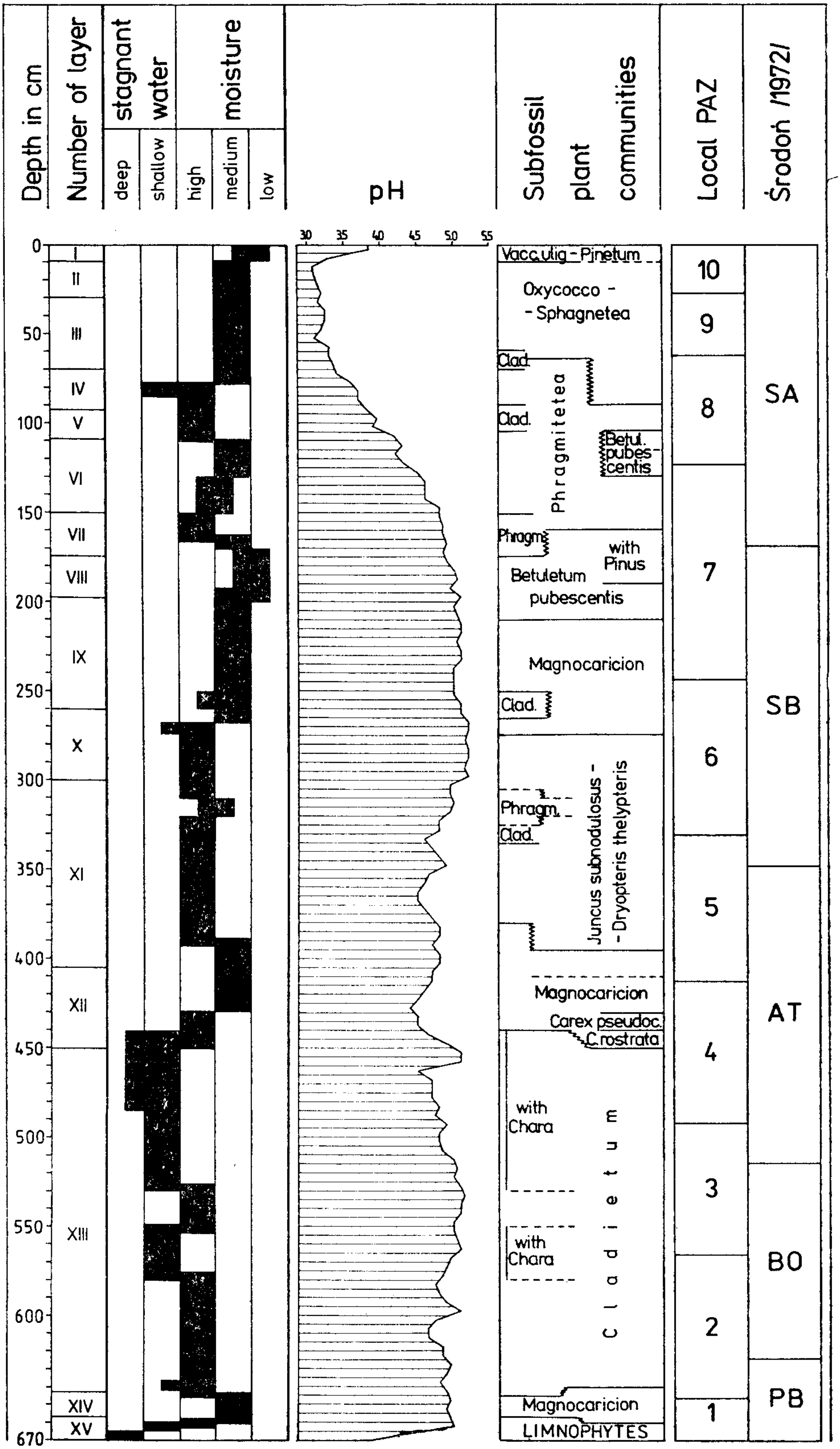


Fig. 9. Rate of sediment accumulation

namely an earlier one of 5305±75 yr B. P. and a later one of 4675±55 yr B. P. Thus, 105 cm of peat was deposited over 630 years. This means that the mean annual accumulation rate was 1.7 mm. This peat is associated with a fast accumulation rate of 2.14 mm per year. The rapid accretion of 30 cm of peat lasted for 140 years. Accumulation continued at a somewhat slower rate in the closing stage of existence of this community, at a depth of 277.5 to 312.5 cm. That depth range covers a period of 235 years, the mean annual accumulation rate being 1.489 mm. Note should be made of the fact that the above fast rate of peat accumulation is exceptional in fens (Żurek 1984). Bearing in mind the low competitive power of *Juncus subnodulosus* and the short duration of present day communities containing this species, it can be inferred that special conditions must have existed and that other factors also affected the existence of this subfossil community, and that this community also had special peat-forming properties in the Gardno—Łeba Plain.

The upper section which displays a faster rate of accumulation occurs at the top of the profile, at a depth of 82.5—172.5 cm, where the mean accumulation rate is 1.2 mm per year. Communities within the category *Phragmitetea* have such rates. They are interrelated to *Betuletum pubescentis* at the base and to peat derived from a community of the category *Oxycocco-Sphagnetea* at the top. The basal layer, at a depth of 122.5—172.5 cm, which is 50 cm thick, accumulated at the fastest rate. It took 370 years to form, thus giving a mean annual rate of 1.35 mm.


Depth in cm
Number of layer
stagnant water
deep
shallow
moisture
high
medium
low
pH
Subfossil plant communities
Local PAZ
Środoń /1972/
0
50
100
150
200
250
300
350
400
450
500
550
600
670
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII
XIV
XV
30
35
40
45
50
55
Vacc.ulig.-Pinetum
Oxycocco - - Sphagnetea
Clad.
Clad.
Phragmitetea
Betul. pubescentis
Phragm.
with Pinus
Betuletum pubescentis
Magnocaricion
Clad.
Phragm.
Clad.
Juncus subnodulosus - - Dryopteris thelypteris
Magnocaricion
Carex pseudoc.
C.rostrata
with Chara
with Chara
Cladietum
Magnocaricion
LIMNOPHYTES
10
9
8
7
6
5
4
3
2
1
SA
SB
AT
BO
PB

The third profile section 27.5 cm thick, to which dates of 230±50 yr B. P. to 0 yr B. P. have been assigned, has a mean annual rate of 1.2 mm.

Transition peat accumulated at the slowest rate in the subfossil *Betuletum pubescentis* community (the *Pinus sylvestris*-rich facies) at a depth of 172.5—192.5 cm. It took 960 years to form this 20 cm peat layer which means that the mean annual accumulation rate was 0.21 mm.

The rate of accumulation of peat formed under *Cladietum* approaches the mean rate abtained for the entire profile, i.e. 0.7 mm per year. However, situations in which accumulation rates varied from 0.5 mm per year at a depth of 462.5—542.5 cm to 1.5 mm per year at a depth of 542.5—577.5 cm are also recorded.

WATER LEVEL FLUCTUATIONS IN THE MIRE

The reconstruction of the former hydrological cycle in the Kluki mire is largely based on the subfossil plant communities. Unfortunately, such an approach to the paleohydrological reconstruction of a sedimentary basin shows two flaws, namely:

1) subfossil communities in non-uniform phytosociological positions are represented which lessens the bioindicative expression,
2) it is still unknown how big the error is between the needs of fossil communities and those of comparable present-day communities in terms of hydrology.

It is not the intention to discuss these problems here but note should be made of the fact that the most moderate variant of evaluation of the hydrological cycle has always been selected and that the hydrological requirements of different communities have been interpreted with great caution. Little information is available about the height of the water table. In order to solve this problem it is necessary to construct a transect through a large number of similar cores. The interpretation of material collected from a single core is provided here.

Water level fluctuations are presented in Fig. 10 as a histogram which is drawn in terms of five bars of uniform width. They illustrate two levels of standing water, i.e. a deep and a shallow water table, and three habitats differing in their degree of moisture condition, i.e. high, medium and low habitats. Intermediate stages are plotted as partial histograms which exceed half the size of the bars.

It is evident that the biogenic deposits were produced under multiple fluctuations in water level, and it is this factor which markedly affected the lithological variability of the profile, the varying rates of accumulation and the changes produced in the vegetation cover.

Fig. 10. Water level fluctuations in the Kluki mire, based on subfossil plant communities

On three occasions deposits were formed under water, including two periods of long-lasting standing water. During the Pre-Boreal an open basin with presumably rather deep water existed for a short time. Its sandy bottom was located about 5.6 m below the present-day Baltic-Sea level. However, that basin disappeared rapidly and after a short period of time during the Pre-Boreal, sedge rush vegetation began to grow occupying the wet habitats. Thus, a marked fall in water level, of the order of about 5—6 m occurred over a period of only 300—400 years.

In the final stage of the Pre-Boreal, water level rose to level of shallow standing water. The growth of *Cladietum* took place and peat accumulated rapidly in wet habitats and later, twice in shallow water. The aquatic facies thus formed are recognized by the presence of *Chara contraria.* About 7000 years ago water level rose; in Fig. 10, it is marked as a transition from a deep water level. This fact is deduced from the single records of aquatic plants in the pollen diagram, including *Potamogeton* sp., *Ceratophyllum* sp. haires, *Nymphaea* sp. and *Lemna* sp., and from the regular occurence of *Nymphaea* cf. *alba* seeds at a depth of 450—470 cm in the macrofossil diagram (Fig. 6). Emphasis should be put on the fact that shallow and slightly deeper standing water was retained in this habitat from 8300 to 6200 years ago, with a short break. During that period peat accumulated to a 2 m thick bed.

Water level became gradually lower as the *Magnocaricion* II community grew, but as soon as the *Juncus subnodulosus-Dryopteris thelypteris* community appeared again rose to a sufficiently high level that the habitat became very wet and even periodic flooding may have occurred. This community is characterized by the fastest rate of peat accumulation. The presence of *Phragmites* and *Cladium* is indicative of water level fluctuations occurring during the growth of that community.

A marked, though short-term rise in water level is recorded in the deposit of the *Magnocaricion* III community, immediately above a 5 cm sample dated to 4675±55 yr B. P. The occurrence of open water is indicated by the presence of *Utricularia* sp. pollen and hairs, as well as by *Chara contraria* oospore. After a short period of standing water, the water level fell but about 4200 years ago another increase occurred. Over most of the period of *Magnocaricion* III the water level was chiefly in the "medium" range. A lower water level occurred when the *Betuletum pubescentis* pine facies was present at the medium/low habitat transition. Peat accumulation was then at its slowest.

At the opening of the Sub-Atlantic period groundwater level rose which caused the periodic disappearance of the subfossil *Betuletum pubescentis* phytocoenosis. A short-term rise in water level to that of wet habitats was then observable. It was followed by a lowering of the water level which coincides with the commencement of the continuous curve for *Fagus*, 1750±50 yr B. P. Soon afterwards another short-term rise in water level occurred in high moisture habitats. About 1300 years ago there was a period of open water as can be inferred from the presence of *Utricularia* sp. (both pollen and hairs) and *Cladium* *mariscus* pollen, *Pediastrum* sp. Nowadays the water level has been lowered by the action of man. The present-day swamp forest habitat is an intermediate form between medium and low habitats.

BALTIC WATER LEVEL FLUCTUATIONS DURING THE HOLOCENE

Introduction

Because of the close proximity of the Kluki mire to the Baltic coast it is necessary to trace the history of the sea, especially the southern part adjacent to the Gardno—Łeba Plain. In terms of the origin of the mire, the most important problems are chiefly associated with water level fluctuations and related changes in the position of the coastline. Up until now, the history of the Polish part of the Baltic basin has not been compiled, neither have satisfactory results been obtained by studying the Gardno—Łeba Plain. Hence, the author has produced his own tentative reconstruction of water level fluctuations during the Holocene. Only the most important points are given in this section. A more detailed interpretation, together with a description of sites will be provided in a separate publication (Tobolski 1986 MS).

The Kluki/74 profile has proved important in distinguishing the Baltic transgresions, as well as in establishing synchroneity between marine, brackish and peat deposits and in reconstructing the former coastline. In the author's opinion, the chemical study of the Kluki/74 deposits has also provided equally valuable information. These results will be published separately (Dzięciołowski, Sapek & Tobolski MS). The present study only introduces the contents of four elements, i.e. Co, Cu, K and Na.

The reconstruction of the Baltic water level fluctuations has not been based on the curve showing water level fluctuations in the mire (Fig. 10). Both reconstructions are based on different sets of facts. Attention should be given to a close relationship which may have existed between the hydrological conditions observable when the mire was formed and the nearby sea. A comparison between the curves showing water level fluctuations in the mire and those showing sea level fluctuations should reveal to what degree particular hydrological phenomena occurring in the mire were of local or regional extent and what factors may have produced them. The above problem will be dealt with in another section.

The Baltic sea level fluctuations are presented as a graph (Fig. 11). The horizontal axis represents conventional radiocarbon years (T 1/2: 5568), while the vertical axis gives depth in metres; the zero point stands for the present-day sea level. The graph has been plotted for a few key sites of marine, brackish, fresh water and peat deposits and wood fragments in the Gardno—Łeba Plain. Fig. 12, showing curves for the four element — Co, Cu, K, Na — contents of

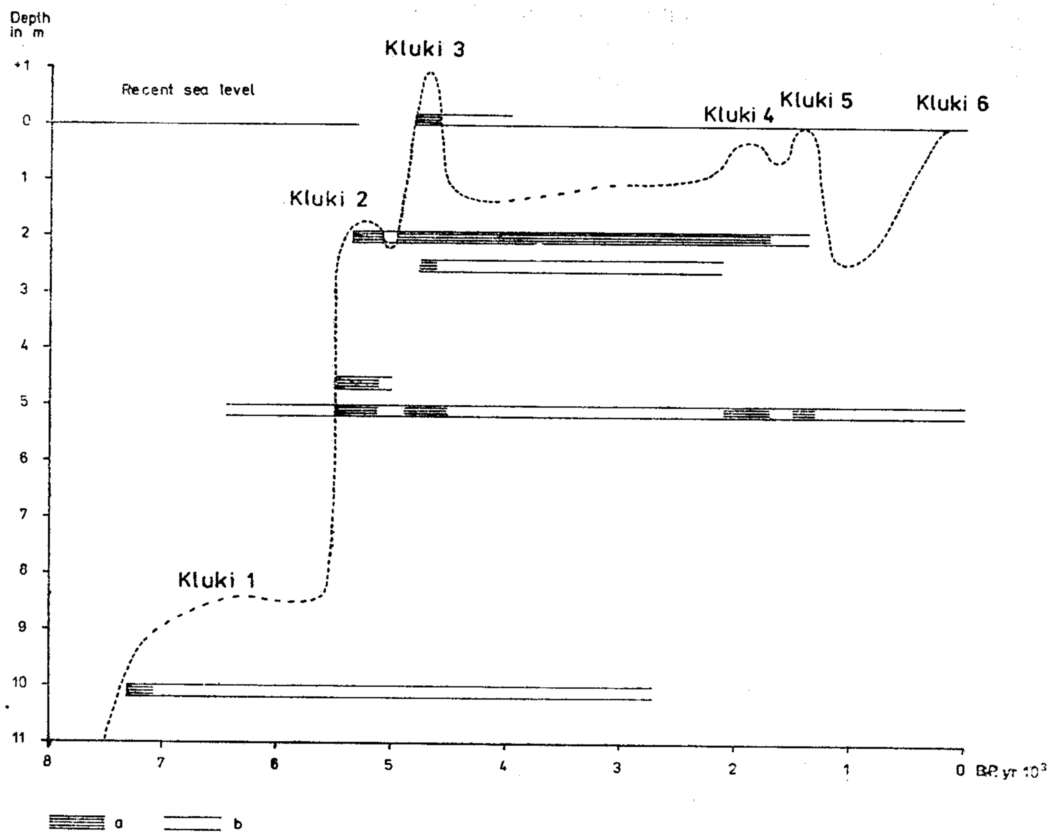


Fig. 11. Fluctuations in the level of the Baltic. a — marine and brackishwater deposits; b — freshwater and peat deposits

the Kluki/74 profile may be thought of as an auxiliary illustration of the Baltic sea level fluctuations. The curves illustrate the amount of the above elements in mg accumulated over an area of 1 sq cm throughout a year.

Transgressions

Six Holocene transgressions have been recognized in the Gardno—Łeba Plain. Their names are derived from the stratotypical Kluki/74 peat site. They are labelled from the earliest to the latest as follows:

Kluki 1: 7300—5850 yr B. P.
Kluki 2: 5500—5100 yr B. P.
Kluki 3: 5000 4500 yr B. P.
Kluki 4: 2100—1700 yr B. P.
Kluki 5: 1500—1300 yr B. P.
Kluki 6: 250—0 yr B. P.

The first three (earliest) transgressive phases represent the Littorina stage of the Baltic, whereas the remaining three (later) phases can be identified with the post-Littorina stage.

Littorina phases of the Baltic

The Littorina stage of the Baltic left distinct imprints on the Gardno—Łeba Plain in the form of a variety of deposits laid down at different depths. They provided the basis for reconstructing the range of water level fluctuations which has been about 11 metres over the period from approx. 7300 yr B. P. to approx. 4500 yr B. P.

Kluki 1, 7300—5850 yr B. P.

The lowest-lying site of marine deposits in the Gardno—Łeba Plain, which has been considered until now to be the earliest one, was recently discovered in the substratum underlying the Sarbsko Spit. This site has been studied with respect to pollen and diatoms and radiocarbon dates are also available (Miotek & Bogaczewicz-Adamczak 1986). Marine deposits have been found in a few adjacent cores in the substratum underlying the Sarbsko Spit. They are best developed in core III. A layer of calcareous silt present in this core contains an abundant diatom flora at a depth of 1230—1270 cm, the zero point being at a depth of 270 cm asl. Its presence indicates about 20‰ water salinity (Miotek & Bogaczewicz-Adamczak l.c.). This layer gave a radiocarbon date of 7590±100 yr B. P. The above authors suggest that the date may be earlier than the true one because of the presence of calcium carbonate in the deposit. In the present author's opinion, the age of this sample is really too old but he made use of the argument provided by the Kluki/74 profile when he estimated the age of the beginning of this transgression. Figure 12 shows that copper and potassium contents increase at the depth of 500 cm and afterwards, this is the case with cobalt contents, whereas sodium merely forms a low peak. The date calculated by interpolating between two radiocarbon dates available for two adjacent samples is 7250 yr B. P. It is applicable to depth of 500 cm.

The curves showing the content of Co, Cu and K (Fig. 12) have also been used for dating the close of this transgression since the Kluki/74 profile shows a fall in the annual rate of accumulation of these elements at this level, the age of which may be estimated at 5850 yr B. P. Note should be made of the fact that the above curves reach their peaks during the later stage of the transgression under investigation. This can be indicative of a rise in water level and of the proximity of the coastline to the sedimentation basin. An acute peak of potassium and concurrent accumulation of SiO_2 are also characteristic.

Kluki 2, 5500—5100 yr B. P.

Deposits of this transgression lie at a depth of 5 m below sea level (the base of the bottom deposits in Lake Sarbsko) at 4.7 m below sea level at Czołpino and 2 m below sea level at Brenkowo. There is a difference of about 5 m between the above deposits and the marine sediments laid down at the beginning of the Kluki 1 phase.

In comparison with the Kluki 1 phase, lower salinity is recorded in the Kluki 2 transgression. This can be inferred from a faunal study of deposits occurring at Czołpino. This study represents the basis of Brodniewicz & Rosa's (1967) listing of the following measures of salinity.

Table 4

Salinity of water, based on fauna found in Littorina deposits at Czołpino

Sample no	Sampling depth	Water salinity
8	5.20—5.40	0.5—3.0°/₀₀ oligohaline
9	5.40—5.80	3.0—8.0°/₀₀ meio-mesohaline
10	5.80—6.0	8.0—15.5°/₀₀ pleio-mesohaline
11	6.0—6.90	3.0—8.0°/₀₀ meio-mesohaline

These water salinity values also receive confirmation from the study carried out by Bresińska-Burchardt (1972) on subfossil diatoms found at Czołpino. Taxa living in meio-to pleio-mesohaline water prevail at a depth of 5.8—6.0 m.

Oligohaline forms in this sample are represented by only two species. The drop in salinity values in sample 8 at a depth of 5.20—5.40 m is reflected in an increase in oligohaline taxa to 33 (Bresińska-Burchardt l.c.). Studies carried out by Przybyłowska-Lange (1981) show that the basal sediments of Lake Sarbsko contain the largest number of euhalobous and mesohalobous species, euhalobous species attaining a maximum of 38.2%. Epiphytic diatoms remain dominant but the lowest sample contains a concentration of planktonic forms of the order of 33.6% (Przybyłowska-Lange l.c., p. 151). A list of the most numerous euhalobous and mesohalobous diatoms occurring in the basal sediments of Lake Sarbsko based on Table 5 from Przybyłowska-Lange's publication (1981) is given below.

Chaetoceros halsaticus	12.4%	
Chaetoceros sp. div.	12.4%	
Cocconeis scutellatum	11.8%	(4)
C. scutellatum var. *parva*	7.8%	
Actynocyclus ehrenbergii	5.6%	(2)

Gramatophora oceanica	4.0% (3)
Diploneis didyma	3.0% (1)
Opephora schulzi	2.0%

To allow comparison, the representation of selected taxa from Czołpino is given in brackets for the sampling depth 5.8—6.0 m. The quantities in brackets are based on Scharmach's system which was employed by Bresińska-Burchardt (1972). Attention is drawn to the great silimarity in quantitative ratios between the two sites in spite of the fact that it is difficult to compare the seven samples from Lake Sarbsko with the one sample from Czołpino.

The transgressive phase under consideration is clearly recorded in the chemical profile (Fig. 12). About 5500 yr B. P. the rate of accumulation of Co, Cu, K and later also Na increased. This date is in agreement with the beginning of peat formation in core III from the Sarbska Spit substratum (Miotk & Bogaczewicz-Adamczak 1986), the basal peat in this core giving a date of 5480±90 yr B. P. This implies that paludification began at a depth of 125 cm below the present-day Baltic level as a result of transgressing sea levels as early as the onset of Kluki 2 phase. The close of this phase is sharply marked in the chemical profile and is also reflected in the presence of a freshwater fauna at a depth of 185—200 cm in the Brenkowo profile (Brodniewicz 1972 p. 31).

Kluki 3, 5000—4500 yr B. P.

This transgressive phase is preserved in a few localities in the Gardno—Łeba Plain. Fig. 11 has been constructed from a deposit at Brenkowo (a depth range of 176—185 cm), the Lake Łebsko sediments (a depth range of 265—288 cm) and from the basal layers of a deposit at Łeba Neptun on the Sarbsko Spit. The phase is also clearly seen in the chemical profile with maximum amounts of sodium, copper and potassium for the entire stage of the Littorina Sea.

During this phase water level in the Gardno—Łeba Plain exceeded that of the present-day Baltic. It is visible at Łeba—Neptun (Tobolski 1979) where, fine sands deposited in a brackish basin are overlain by algal gyttja. The gyttja is separated from them by a distinct boundary, which is indicative of an abrupt change in hydrological conditions and trophic levels. The base of the algal gyttja lies at a height of 37 cm above sea level and produced a radiocarbon date of 4610±250 yr B. P. (Tobolski 1979). This date correlates with that of the termination of the *Juncus subnodulosus* community in the Kluki mire, the radiocarbon age for the top of this peat being 4675±55 years B. P.

It is presumed that the coastline of the existing sea was closest to the mire area during this transgression and that the high sea level had a marked effect on hydrological conditions and perhaps on the floristic characteristics of the mire. Attention will be devoted to this problem again in the following subchapter. However, it should be noted that the close of transgression Kluki 3 coincides with a period over which hydrological-climatic changes occurred on a large scale. One of their effects is the far-reaching territorial displacement of the farming prevailing in Scandinavia at that time (Gräslund 1980).

During this transgressive phase the water was brackish. The diatom analyses from Lake Łebsko performed by Dr. Adamczak, reveals the following proportions expressed as a mean percentage of three samples from a depth of 281—288 cm:

	% of taxa number	% of specimen number
Euhalobous	9.11	0.61
Mesohalobous	18.43	17.3
Oligohalobous-halophilous	7.76	12.08
Indifferent	60.02	70.0

Faunal studies also provide indications of the existence of a brackish-water environment. Brodniewicz (1972) found large quantities of *Ammonia flevensis* Hofker at a depth of 176—185 cm at Brenkowo which is an indicator of "warmer, shallow and semi-saline water" (Brodniewicz 1969 p. 95). This species appeared at Czołpino as early as phase Kluki 2. It remains dominant among the foraminifera in samples 11 and 9 (Brodniewicz & Rosa 1967). The problem of the representation of this species will be discussed in detail in another publication (Tobolski 1986 MS).

To sum up, there is enough evidence to distinguish three transgressions of the Baltic Littorina Sea in the Gardno—Łeba Plain. Salinity was highest in phase Kluki 1 when the water level was initially about 9 m below the present-day Baltic level. During two next phases brackish-water occurred. In the last phase, Kluki 3, water level remained highest rising to about 1 m above the present-day Baltic level. The boundaries of this phase were most extensive in the Gardno—Łeba Plain. However, the sea did not cross the belt of inland dunes in the eastern and middle parts of the lowland. The conclusion that water level was highest during transgression Kluki 3 but that salinity was low and identical with that of brackish water is confirmed by observations carried out in other localites along the Polish coast. Attention should be given to Latałowa's (1982) and Bogaczewicz-Adamczak & Latałowa's (1985) publications concerning traces of the Littorina transgression in Lake Żarnowieckie.

Post-Littorina transgressions

Post-Littorina transgressions have been recognized on the basis of curves illustrating the accumulation of Cu, Co, K and Na in the Kluki/74 profile. Up until now, no direct lithologic evidence of these later phases has been found in the Gardno—Łeba Plain, in contrast to the situation with respect to transgressions of the Littorina Sea. However, there is indirect evidence for the existence of these transgressions, for example the percentage curve for euhalobous and mesohalobous species from Lake Sarbsko (Przybyłowska-Lange 1981). There are also many specific succesional characteristics in the lowland mires or inference can be made by analogy with the Kluki 2 and Kluki 3 transgressive phases.

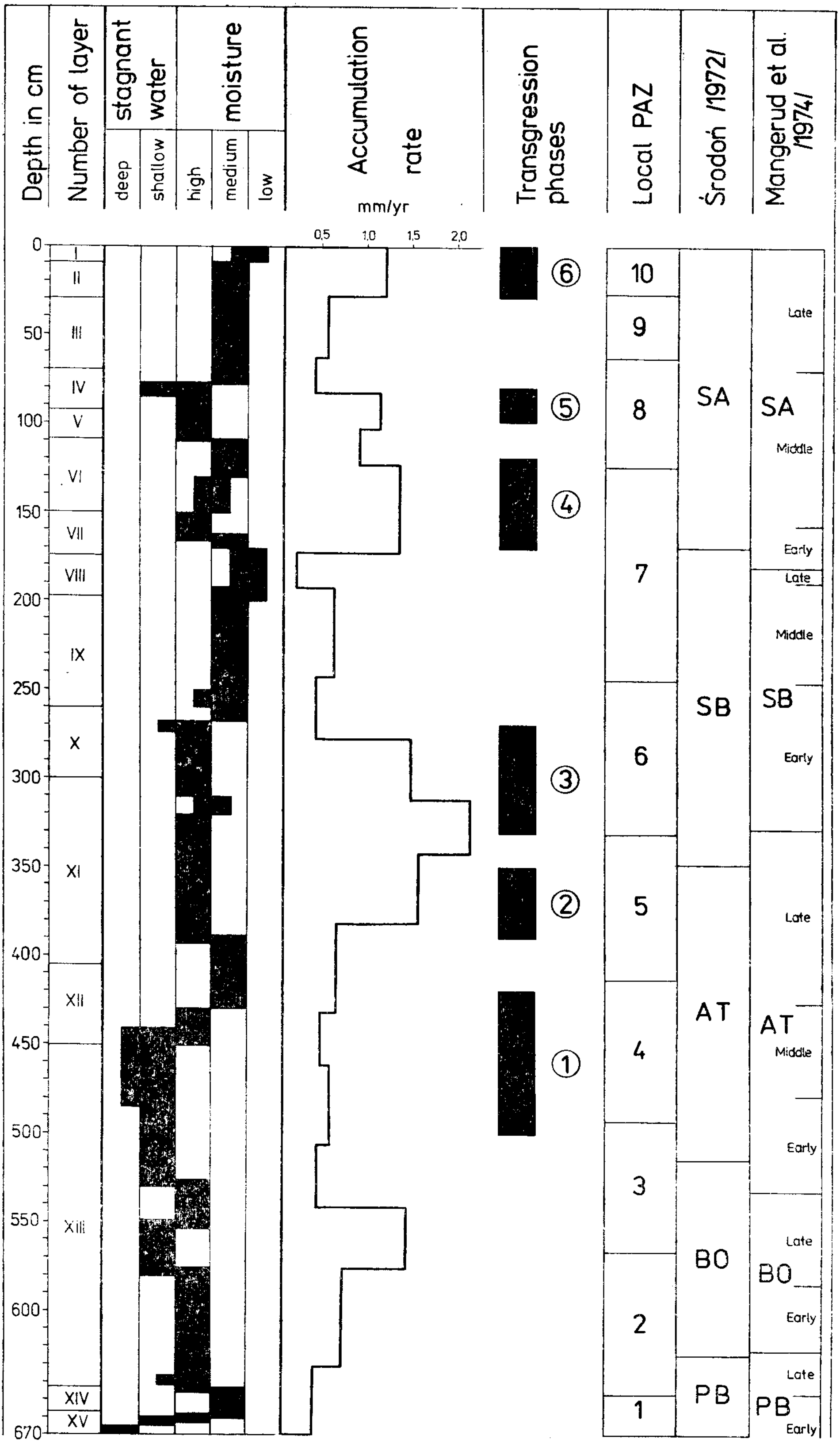
The first post-Littorina rise in the rate of accumulation of the above elements took place about 2100 yı B. P. and lasted until about 1700 yr B. P. The date for the close of this phase agrees with that of an important episode in the Brenkowo profile. At a depth of 105 cm (0.65 cm below sea level) there is a distinct boundary between shell gyttja formed in a brackish-water environment and overlying algal gyttja. This boundary also represents the beginning of the continuous curve of beech pollen, which has a radiocarbon age of 1750±50 yr B. P. at Kluki/74. The occurrence of large quantities of euhalobous, mesohalobous and halophilous diatoms in Lake Sarbsko at a depth of 130—200 cm is associated with this transgression (Przybyłowska-Lange 1981).

Another rise in the curves showing the accumulation of the four elements can be correlated with phase Kluki 5. It began about 1500 years ago and lasted till about 1300 yr B. P. The next increase in the amount of euhalobous, mesohalobous and halophilous diatoms in Lake Sarbsko (Przybyłowska-Lange 1981) is correlated with this phase. These diatoms reach a maximum at a depth of 50 cm.

In order to plot a curve for the latest fluctuations of the Baltic (Fig. 11), the age and location of subfossil oak trunks in the Gardno and Sarbsko spit beach have been taken into consideration (Tobolski et al. 1980, Tobolski 1979). The present-day lowest-lying sites of oaks in relation to sea level are located in the Kluki Conservation District occupying only those surfaces which are 1 to 2 m above sea level (Dzięciołowski & Tobolski 1975). An elevation of 1 m above sea level is accepted as a the lower limit for subfossil oaks. The recession for the time interval 900—1200 yr B. P. is based on an archeological find from outside the Gardno—Łeba Plain. The author received information concerning such a low Baltic level from Assistant Professor Filipowiak of Szczecin. It refers to the water level of the Early Middle Age port in Wolin. The port and residential buildings indicate that during the optimum period of its existence water level was 270 cm lower, than the present-day Dziwna level. This implies that the Baltic was then at a level of 250 m below present sea level.

WATER LEVEL FLUCTUATIONS IN THE MIRE IN RELATION TO TRANSGRESSIONS

The interrelationship between sea level fluctuations and fluctuations in water level in the mire over a period of few thousand years of its history is illustrated in Fig. 13, where a comparison is made between the histogram of



Depth in cm
Number of layer
stagnant water
deep
shallow
moisture
high
medium
low
Accumulation rate
mm/yr
0,5
1,0
1,5
2,0
Transgression phases
Local PAZ
Środoń /1972/
Mangerud et al. /1974/
0
50
100
150
200
250
300
350
400
450
500
550
600
670
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII
XIV
XV
⑥
⑤
④
③
②
①
10
9
8
7
6
5
4
3
2
1
SA
SB
AT
BO
PB
Late
SA
Middle
Early
Late
Middle
SB
Early
Late
AT
Middle
Early
Late
BO
Early
Late
PB
Early

water level fluctuations in the mire for profile Kluki/74 (Fig. 10), and the transgressions obtained from Fig. 12 together with a histogram showing the rate of peat accumulation.

The interrelationship between water level fluctuations in the mire and sea level rise is least distinct during transgression Kluki 1. During this phase water level in the mire was high (the second facies containing *Chara contraria*). The rate of accumulation was not high, and did not exhibit variations of any importance. Such a weak interrelationship is indicative of the lack of influence of transgression Kluki 1 on the hydrological conditions of the mire. An explanation can be provided for this in that sea level was then about 5 metres lower than the existing mantle of the mire.

The hypothesis about the lack of influence of transgression Kluki 1 on the peat formation in the mire at that time seems to receive support from those episodes which accompanied transgressions Kluki 2 and 3. At the onset of phase Kluki 2 there was a concurrent rise in the mire water level. Later on, the rate of accumulation of organic matter increased to 1.57 mm per year. The close of transgression Kluki 3 coincided with a lowering of water level in the mire and the rate of accumulation dropped from 1.49 to 0.43 mm per year. The maximum rate of peat accumulation (2.14 mm per year) is not fully synchronous with transgression Kluki 3. There is a partial gap between the two transgressions in the histogram showing the rate of accumulation because the number of dated horizons is insufficient. If the number of dates were increased, the histogram of the rate of accumulation would certainly become more exact.

At the turn of the Sub-Boreal Period water in the mire was at one of its lowest levels during the Holocene. Such a situation was observed during the regressive stage of the Baltic. An extremely slow rate of accumulation of 0.21 mm per year was also recorded then.

A gradual rise of water level occurred at the onset of transgression Kluki 4. The rate of peat accumulation increased to 1.35 mm per year but become slower, in the order of 0.91 mm per year, at the close of phase Kluki 4.

The subsequent transgression Kluki 5, is correlated with a water level rise in the mire and a concurrent faster rate of accumulation of the order of 1.14 mm per year. The latest transgression, Kluki 6, is also identified with an increase in the rate of accumulation to 1.2 mm per year. The lowering of water level at the uppermost part of the profile can be accounted for by drainage.

To sum up, there is a close relationship between the Baltic transgressions, water lavel fluctuations in the mire and the rate of peat accumulation. The fact that these three elements are in considerable agreement suggests that the divisions of the post-glacial marine transgressions in the Gardno—Łeba Plain area are correct.

←

Fig. 13. The relationship between transgressions and water level fluctuations in the Kluki/74 profile set against the rate of sediment accumulation

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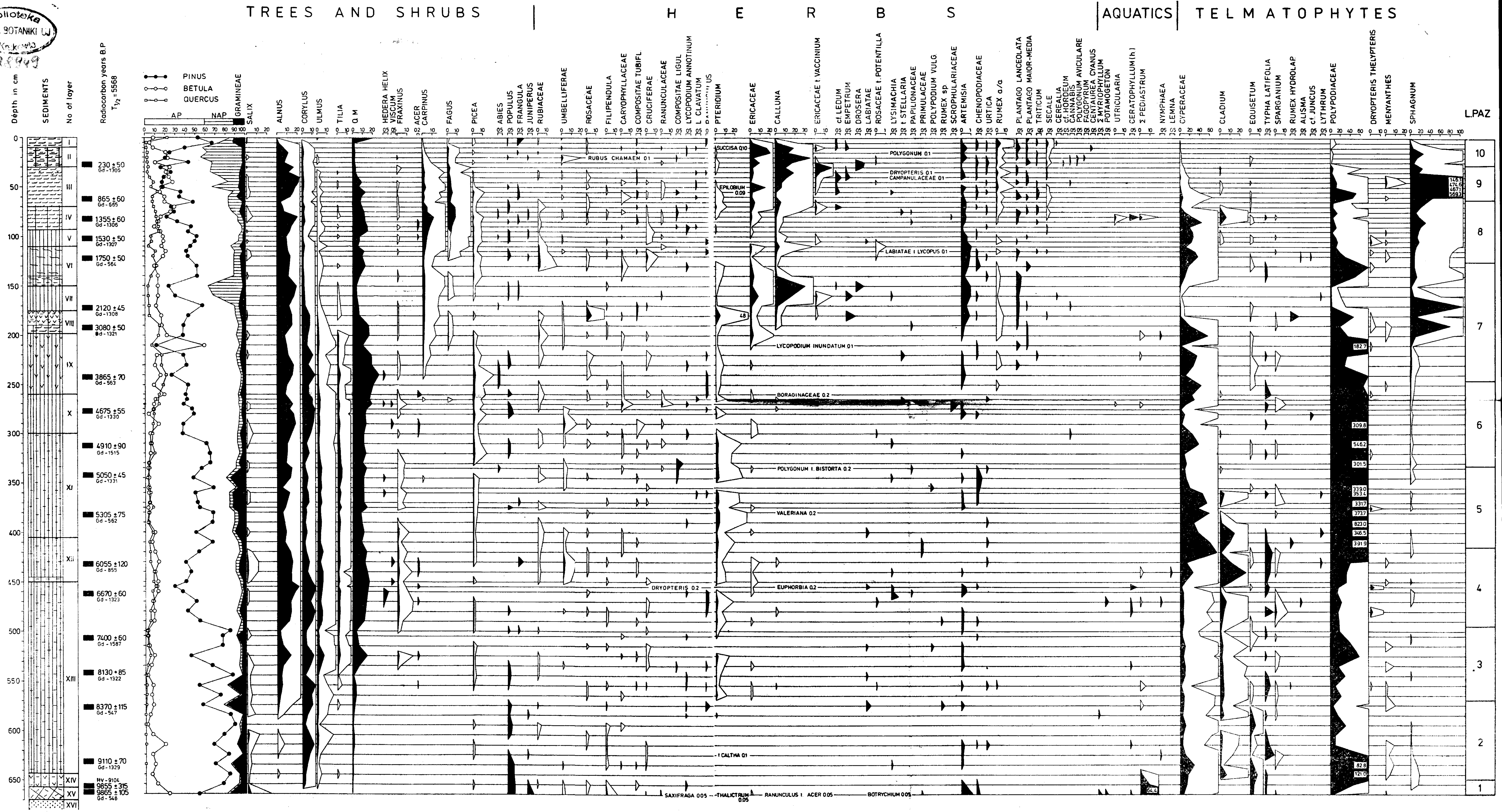

Fig. 3. Percentage pollen diagram from Kluki/74

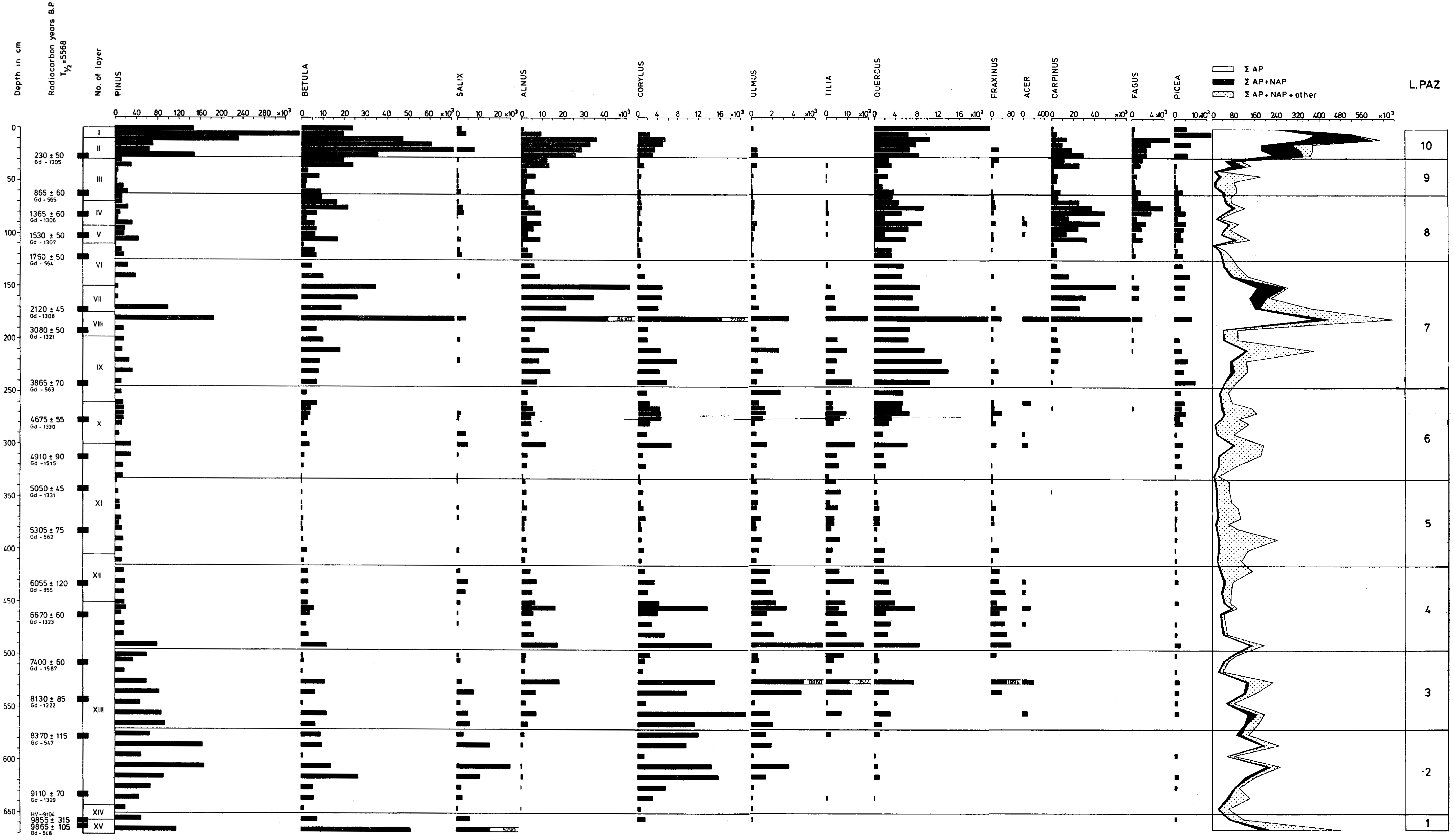

Fig. 4. Simplified pollen diagram showing the concentration of pollen per cu cm of sediment from Kluki/74

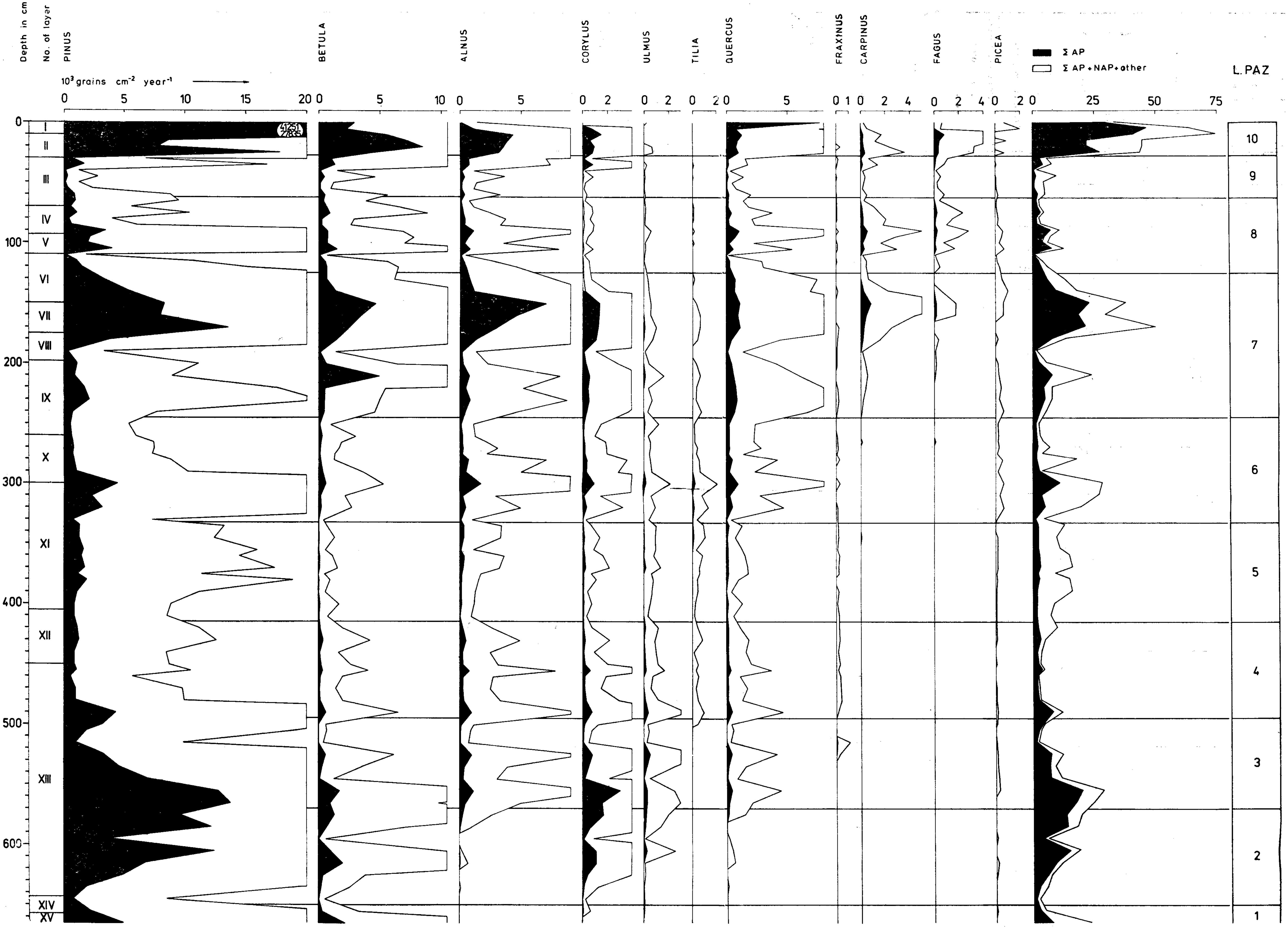

Fig. 5. Simplified influx diagram from Kluki/74

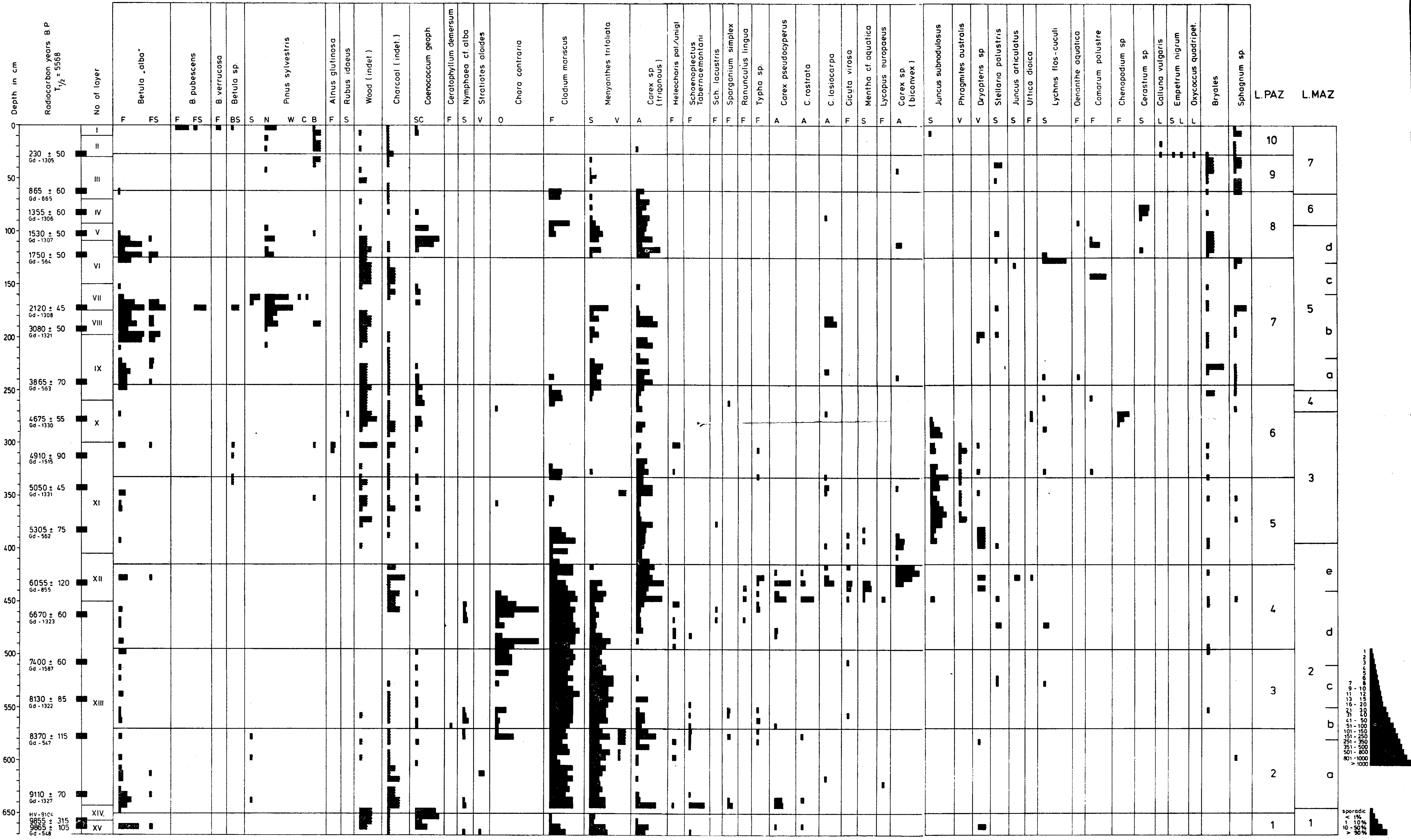

Fig. 6. Macrofossil diagram from Kluki/77. Abbreviations: A — achene; B — bark; BS — bud scale; C — cone; F — fruit; FS — fruit scale; L — leaf; N — needle; O — oospore; S — seed; SC — sclerotium; V — vegetative part; W — seed wing

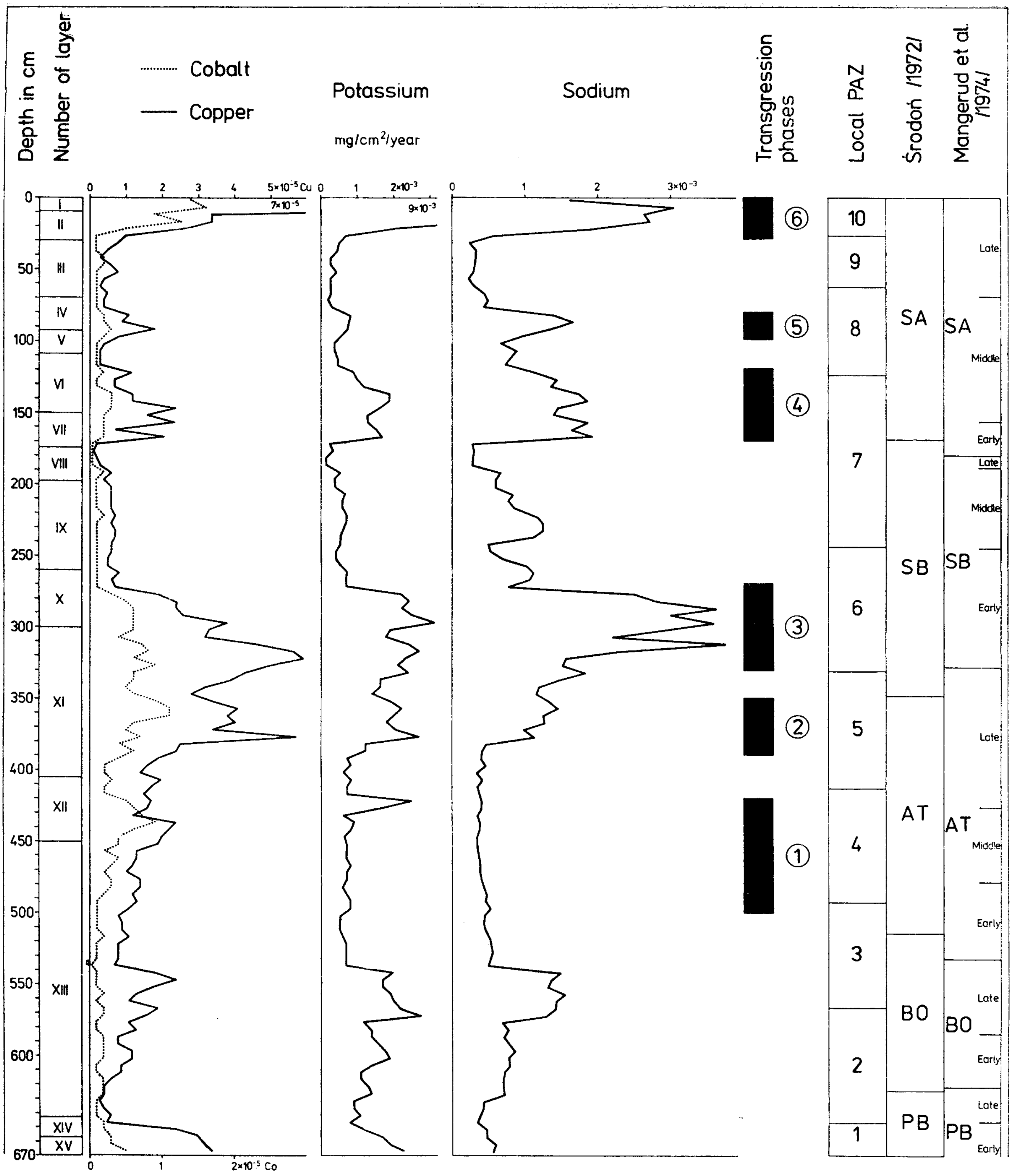

Fig. 12. The amount of accumulation of cobalt, copper, potassium and sodium in the Kluki/74 profile and the tranressions of the Baltic