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# THE PALEOECOLOGICAL DEVELOPMENT OF LAKE DRUZNO (VISTULA DELTOIC AREA)

## Rozwój paleoekologiczny jeziora Druzno (Żuławy Wisły)

ABSTRACT. The paleoecological development of Lake Druzno has been reconstructed on the basis of the pollen (two profiles), diatom and chemical analysis and the identification of *Rhizopoda*, *Crustacea* and *Mollusca* remains. Eight main stages are distinguished in the formation of the lake. The history of Lake Druzno has been described from the initial stage, dated at 11290 BP, up till recent time.

## INTRODUCTION

The present paper, a continuation of the research of the sediments of Lake Druzno, describes the history of this lake on the basis of palynological and geochemical analyses of cores. The results of diatom analysis (Przybyłowska-Lange 1976, Zachowicz et al. 1982) and macro- and microfauna analyses (Janiszewska-Pactwa 1973) have also been taken into account. Lake Druzno is situated in the eastern part of the Żuławy Wiślane (Fig 1) which comprises the central section of the Gdańsk Coast macroregion (Kondracki 1981). The area of the Żuławy Wiślane is a reference area in Project 158 B of the International Geological Correlation Programme.

## GEOMORPHOLOGY

As a regional geomorphological unit, the Żuławy Wiślane covers approxmately the same area as the Vistula deltoic area (Augustowski 1976). Likie all deltas, the Żuławy area an almost flat plain rising only a few meters above sea level. In places, the plain's surface sinks below sea level to form shallow depressions, and the most extensive of these lie to the north and north-west of Lake Druzno. The lowest point is 1.8 m a.s.l.

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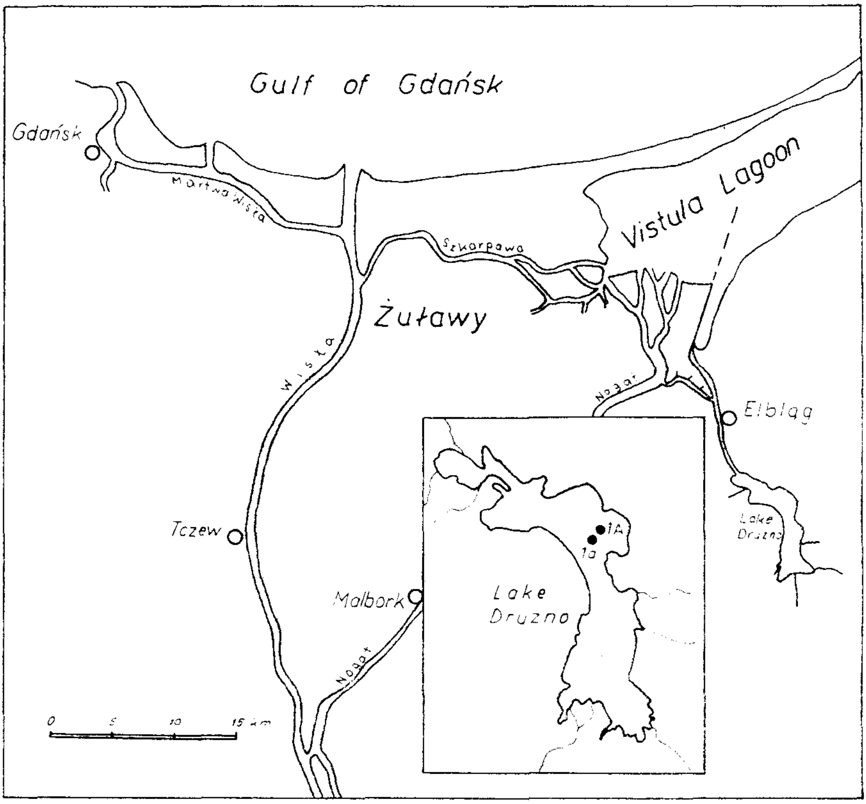

Fig. 1. Lake Druzno. The location of the profiles

The location and formation of the delta is the consequence of the paleomorphological development of the surrounding area. The ice-lobus of Vistulian age was very important here. The large glacial depression along the eastern Baltic floor resulted as glacial erosion and is of the effect of this ice-lobus (Augustowski 1976).

The sediments of the delta comprise Pleistocene formations of glacial origin covered by a layer of Holocene alluvium. This latter consists of silts, muds, sands, and more rarely, of gravels and peat (Makowska 1979). The alluvial silt and muds are the initial material from which mud soils have been formed. Lacustrine and marsh sediments are fairly widespread in the Żuławy. They are mostly lacustrine gyttjas, peats, silty sediments and meadow limestone. These types of sediments are frequent in the Lake Druzno area.

## Lake Druzno

Lake Druzno lies in the eastern part of the Żuławy Wiślane, almost at the centre of the Elbląg river system. It is a very shallow lake, the maximum and average depth being 3 m and 1.2 m respectively, and, after Lake Łebsko, it has the second-largest catchment area (1084 km$^2$) of all the Baltic coastal lakes (Mikulski et al. 1969). It is 10 km long and 2.2 km wide and has a much-indeted shore-line, 32.2 km long. It is difficult to calculate the exact area of the lake and there are wide discrepancies between figures quoted from various sources. Mikulski et al. (1969) calculated the area of the lake at various water levels. Thus a water level of 490 cm gives an area of 12.57 km$^2$, 500 cm — 14.46 km$^2$, 510 cm — 17.90 km$^2$. Above 510 cm, the water of the lake comes up to the dykes (45 km long); the area of the lake is then 29.80 km$^2$.

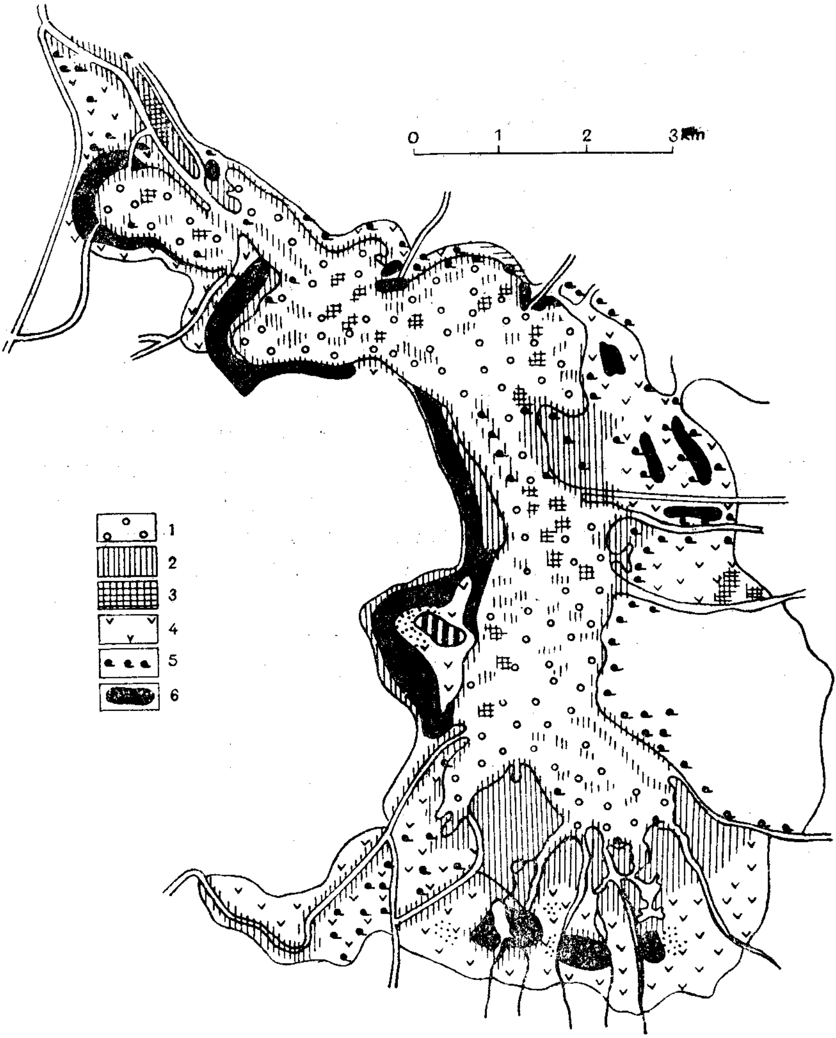

Fig. 2. Lake Druzno. Distribution of vegetation (after Schultz 1941). 1 — aquatic plants with floating leaves, 2 — communities of *Phragmites communis*, 3 — aglomerations of *Typha angustifolia*, 4 — communities of high *Cyperaceae*, 5 — scrub of *Salix* sp., 6 — *Alnus* forests

Lake Druzno is at present an inflow-outflow lake with two navigation channels passing through it. It is connected with the Vistula Lagoon by the river Elbląg and when the weather conditions and water levels are favourable, water flows into the lake from the Lagoon. Gromadzka (1956) showed that the chloride content, in the lake water ranging from 20 to 360 mg/l, was proportional to the distance from the Lagoon. The average chloride content is 20—70 mg/l. The contents of carbonates, nitrogen, phosphorus, iron and oxygen in the lake water are also low (Gromadzka 1956). Because of the lake's shallowness, its almost complete lack of oxygen and of thermal stratification, and the high oxidisability of its organic components, Mikulski (1955) classified Lake Druzno as a pondlake.

This shallow, eutrophic lake is a suitable habitat for the aquatic and reedswamp vegetation (Fig. 2). The communities include floating-leaved aquatics: *Myriophyllo-Nupharetum* with prevalent *Nymphaea alba* and *Nuphar luteum*, *Nymphoidetum peltatae* with *Nymphoides peltata*, and *Hydrocharitetum morus-ranae* with dominant *Hydrocharis morus-ranae*. Communities of submerged aquatics represented by associations from the alliance Eu-Potamion with *Potamogeton crispus*, *P. pectinatus*, *P. perfoliatus* and others have developed in deeper parts of the lake (Piotrowska 1976). All the communites of aquatics are extremely poor in components, consisting of large numbers of a few or just one single species. The littoral zone consists of reed swamps which, in the contact zone with the water, become well-formed emerged-plant communities. The commonest species found here are *Rumex hydrolapathum*, *Cicuta virosa*, *Carex pseudocyperus*, *Typha angustifolia*, *Dryoptheris thelypteris*, *Lythrum salicaria*, *Galium palustre* and *G. aparine*. On the southern shores of the lake there are alder copses with *Alnus glutinosa*, *Solanum dulcamara*, *Dryoptheris thelypteris*, *Ribes nigrum* and *Frangula alnus*. The considerable fluctuations in the water level of the lake, the flow of water through it, and strong north-westerly and south-easterly winds, cause whole clumps of vegetation to be ripped from the shores and carried out into middle of the lake (Mikulski et al. 1976). The patches of such floating vegetation are a frequent sight on the lake surface.

The latest studies on the vegetation of Lake Druzno (Kluszczyńska & Szmeja 1979) have shown that species such as *Najas marina*, *Nymphaea candida*, *Nuphar pumilum*, *Elodea canadensis*, *Stratiotes aloides*, *Potamogeton lucens*, *Myriophyllum spicatum* and *Ceratophyllum submersum*, reported by Schulz (1941), are no longer found. Moreover, *Schoenoplectus lacustris*, *Hottonia*, *Lemna minor*, *L. glabra*, *Utricularia vulgaris* and *Acorus calamus* are now regarded as endangered species.

## MATERIAL AND METHODS

The study material came from two sediment cores collected in the north-western sector of Lake Druzno (Fig. 1). Profile 1A was taken with the Russian sampler near the present shore of the lake with a water depth of 0.8 m, while

Table 1

Lake Druzno Profile 1a Limits and average contents of physical and chemical elements.

| CHEMICAL ZONE | | 1 | 2 | 3a | 3b | 4 | 5 | 6 | 7 | 8a | 8b | 8c | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth /m/ | | 9, 56-9, 29 | 9, 29-9, 15 | 9, 13-8, 25 | 8, 25-8, 02 | 8, 02-7, 49 | 7, 49-7, 20 | 7, 20-6, 50 | 6, 50-6, 20 | 6, 20-4, 25 | 4, 25-2, 20 | 2, 20-0, 80 | 0, 80-0, 00 |
| Water cont. /%/ | I | 21, 4-69, 5 | 130, 4-252, 7 | 32, 6-117, 2 | 80, 9-116, 7 | 132, 9-172, 6 | 126, 7-326, 0 | 183, 4-383, 2 | 187, 7-221, 9 | 100, 4-168, 0 | 115, 8-169, 4 | 72, 2-130, 4 | 217, 2-345, 6 |
| | II | 34, 0 | 201, 2 | 54, 2 | 105, 1 | 149, 4 | 188, 8 | 370, 7 | 205, 2 | 128, 6 | 135, 2 | 104, 7 | 266, 6 |
| Carbonates /%/ | I | 1, 01-1, 94 | 1, 43-2, 91 | 7, 67-20, 85 | 6, 71-15, 88 | 62, 06-76, 29 | 1, 09-12, 67 | 1, 59-4, 10 | 45, 11-46, 90 | 29, 65-52, 53 | 14, 93-38, 15 | 9, 55-16, 44 | 23, 77-50, 97 |
| | II | 1, 33 | 2, 60 | 16, 51 | 10, 67 | 71, 19 | 4, 15 | 2, 87 | 46, 29 | 40, 38 | 26, 02 | 12, 76 | 33, 94 |
| Corg /%/ | I | 0, 14-5, 94 | 12, 38-30, 29 | 0, 85-7, 91 | 4, 59-7, 29 | 4, 68-6, 56 | 12, 96-33, 50 | 18, 15-36, 23 | 6, 33-7, 66 | 2, 08-5, 15 | 1, 96-4, 19 | 1, 41-2, 90 | 4, 55-6, 86 |
| | II | 1, 66 | 22, 01 | 2, 20 | 6, 11 | 5, 80 | 20, 80 | 27, 88 | 7, 02 | 3, 54 | 3, 24 | 2, 21 | 5, 32 |
| N /%/ | I | 0 | 0, 48-1, 44 | 0, 00-0, 18 | 0, 15-0, 45 | 0, 34-0, 52 | 0, 62-2, 21 | 0, 95-1, 67 | 0, 50-0, 56 | 0, 04-0, 41 | 0, 02-0, 53 | 0, 00-0, 19 | 0, 28-0, 70 |
| | II | 0 | 0, 91 | 0, 06 | 0, 27 | 0, 46 | 2, 25 | 1, 26 | 0, 53 | 0, 21 | 0, 24 | 0, 08 | 0, 57 |
| P /%/ | I | 0, 024-0, 025 | 0, 052-0, 087 | 0, 033-0, 080 | 0, 050-0, 050 | 0, 060-0, 078 | 0, 042-0, 064 | 0, 032-0, 045 | 0, 066-0, 072 | 0, 066-0, 088 | 0, 038-0, 084 | 0, 018-0, 075 | 0, 050-0, 116 |
| | II | 0, 024 | 0, 067 | 0, 058 | 0, 050 | 0, 072 | 0, 050 | 0, 042 | 0, 069 | 0, 075 | 0, 059 | 0, 048 | 0, 088 |
| Na /%/ | I | 0, 44-0, 53 | 0, 26-0, 54 | 0, 50-0, 96 | 0, 57-1, 00 | 0, 05-0, 10 | 0, 12-0, 80 | 0, 20-0, 42 | 0, 20-0, 22 | 0, 37-0, 65 | 0, 27-1, 50 | 0, 52-0, 95 | 0, 29-0, 59 |
| | II | 0, 48 | 0, 45 | 0, 73 | 0, 77 | 0, 10 | 0, 52 | 0, 25 | 0, 21 | 0, 48 | 0, 71 | 0, 84 | 0, 47 |
| K /%/ | I | 0, 97-1, 08 | 0, 53-1, 00 | 1, 25-2, 01 | 1, 06-1, 75 | 1, 06-0, 23 | 0, 20-1, 88 | 0, 37-1, 54 | 0, 40-0, 72 | 0, 85-1, 23 | 0, 78-1, 38 | 1, 23-1, 40 | 0, 89-1, 21 |
| | II | 1, 02 | 0, 83 | 1, 76 | 1, 51 | 0, 13 | 1, 22 | 0, 69 | 0, 59 | 1, 04 | 1, 14 | 1, 30 | 1, 06 |
| Fe /%/ | I | 0, 42-0, 56 | 1, 12-2, 75 | 1, 92-2, 79 | 2, 50-2, 80 | 0, 50-1, 36 | 1, 33-3, 50 | 1, 70-4, 95 | 1, 89-2, 77 | 2, 22-3, 80 | 2, 37-3, 20 | 2, 18-3, 77 | 1, 98-3, 70 |
| | II | 0, 50 | 1, 82 | 2, 49 | 2, 62 | 0, 91 | 2, 81 | 2, 90 | 2, 25 | 2, 80 | 2, 73 | 3, 07 | 2, 95 |
| Mn /%/ | I | 0, 010-0, 014 | 0, 017-0, 037 | 0, 033-0, 068 | 0, 031-0, 050 | 0, 040-0, 049 | 0, 036-0, 047 | 0, 040-0, 084 | 0, 128-0, 168 | 0, 062-0, 099 | 0, 048-0, 076 | 0, 048-0, 064 | 0, 049-0, 068 |
| | II | 0, 011 | 0, 025 | 0, 050 | 0, 037 | 0, 043 | 0, 040 | 0, 052 | 0, 147 | 0, 075 | 0, 063 | 0, 054 | 0, 055 |
| Cu /ugg$^{-1}$/ | I | 4-12 | 12-20 | 15-34 | 20-24 | 9-12 | 34-37 | 17-28 | 14-18 | 18-24 | 17-22 | 13-21 | 19-41 |
| | II | 7 | 16 | 22 | 22 | 10 | 35 | 22 | 16 | 20 | 20 | 19 | 24 |
| Zn /ugg$^{-1}$/ | I | 15-52 | 36-49 | 46-93 | 72-130 | 19-35 | 41-240 | 37-86 | 57-368 | 55-148 | 55-88 | 56-110 | 58-360 |
| | II | 31 | 41 | 73 | 93 | 25 | 115 | 62 | 62 | 75 | 66 | 81 | 118 |
| Co /ugg$^{-1}$/ | I | 2-6 | 10-16 | 18-24 | 19-23 | 21-24 | 17-50 | 17-50 | 19-21 | 19-25 | 17-21 | 17-23 | 19-23 |
| | II | 4 | 13 | 22 | 21 | 23 | 29 | 29 | 20 | 23 | 19 | 20 | 21 |
| Ni /ugg$^{-1}$/ | I | 12-16 | 12-22 | 22-45 | 33-77 | 32-39 | 38-45 | 20-38 | 37-42 | 42-51 | 35-52 | 34-48 | 38-51 |
| | II | 14 | 18 | 37 | 50 | 37 | 41 | 26 | 39 | 47 | 41 | 43 | 45 |
| Cr /ugg$^{-1}$/ | I | 10-15 | 20-37 | 38-67 | 52-66 | 11-14 | 15-77 | 16-60 | 26-33 | 38-58 | 33-52 | 48-70 | 36-54 |
| | II | 13 | 26 | 56 | 59 | 12 | 56 | 29 | 30 | 48 | 45 | 56 | 47 |
| Li /ugg$^{-1}$/ | I | 0 | 0 | 15-26 | 19-24 | 0 | 0-32 | 0-28 | 10-14 | 16-25 | 15-24 | 19-30 | 16-25 |
| | II | 0 | 0 | 23 | 22 | 0 | 22 | 7 | 12 | 21 | 20 | 26 | 21 |

I - Limits contents
II - Average contents

profile 1a was taken with a Więckowski piston sampler (1961) from the centre of the lake where the depth of water was 1.4 m. Depending on the lithological changes samples for anaylsis were taken at 2—10 cm intervals. Pollen analyses were done for both profiles. Geochemical analysis and four radiocarbon datings were done on profile 1a.

The samples for pollen analysis were treated in two diffrent ways. 2—5 g samples from profile 1A were prepared by flotation using a heavy cadmium--potasium liquid in accordance with Griczuk's recommendations (Dyakowska 1959). The organic residue was acetolysed by Erdtmann's method modified by Faegri and Iversen (1975). Carbonates were removed with 10% HCl. 1 cm³ samples from profile 1a were boiled in 10% KOH on a water bath for 20—40 minutes and then acetolysed. If a sample contained any mineral matter, it was treated, prior to acetolysis, with hot 40% HF for about 1 hour and rinsed with 10% HCl.

Tablets containing *Lycopodium* spores were used to assess the pollen concentration (Stockmarr 1971, 1973). Two *Lycopodium* tablets containing 10850±200 spores each were added to each sample.

The aim was to count around 1000 tree pollen grains in each sample. This number was lower only if the pollen concentration was very low. The results of the pollen analyses are presented as percentage pollen diagrams (Figs. 3, 4) based on the pollen sum, including pollen of trees, shrubs and herbaceous plants (AP+NAP) (= terriphytic spermatophytes). Pollen of aquatics, telmatophytes, spores of pteridopytes and bryophytes and *Pediastrum* have been excluded from the calculations. Fig. 4 shows also the curves of tree, shrub and pollen concentration.

Samples for physical and chemical analyses were taken in paralled with the samples for the biostratigraphic investigations. First, water content and organic matter (as loss on ignition at 550°C) were determined (Tabl. 1, Fig. 5). The following procedures were used for chemical analyses: $C_{org}$ and N determined using a Perkin-Elmer CHN analyser (Hobson & Menzel 1969), phosphorus estimated by the molybdate method (Emelyanov 1977), $SiO_{2\,amorph}$ soluble in 5% sodium carbonate solution, calcium and magnesium carbonates determined indirectly after solution in acetic acid and complexometric determination of Ca and Mg. Besides, total sodium, potassium, iron, manganese, copper, zinc, nickel, chromium and lithum were determined by AAS after prior complete decomposition of sediment samples with an acid mixture.

## STRATIGRAPHY OF THE SEDIMENTS

The sediments are described according to the characterisation system of unconsolidated sediments proposed by Troels-Smith (1955).

## Lake Druzno, profile 1a

| Depth below water surface, m (water depth 1.4 m) | Description of sediment |
|---|---|
| 1.40—1.45 | olive-green calcareous detritus gyttja<br>Composition: Lc 2, Ld$^{0}$ 2 test. moll + |
| 1.45—1.58 | dark brown calcareous detritus gyttja<br>Composition: Lc 2, Ld$^3$ 2, test. moll + |
| 1.58—2.15 | olive-green calcareous detritus gyttja<br>Composition: Lc 2, Ld$^1$ 2, Dh +, test. moll + |
| 2.15—3.05 | olive-green detritus calcareous gyttja<br>Composition: Ld$^1$ 3, Lc 1, Dl + Dh +, Ga +, test. moll + |
| 3.05—3.31 | green-grey calcareous detritus gyttja with mollusc shells<br>Composition: Lc 1—2, Ld$^1$ 2—3, test. moll 3 |
| 3.31—3.50 | green-grey calcareous detritus gyttja<br>Composition: Lc 1—2, Ld$^1$ 2—3 |
| 3.50—5.90 | green-grey calcareous detritus gyttja with mollusc shells<br>Composition: Lc 1—2, Ld$^1$ 2—3, test. moll. 3 |
| 5.90—6.05 | green-grey calcareous detritus gyttja<br>Composition: Lc 2, Ld$^1$ 2. |
| 6.05—6.50 | green-grey calcareous detritus gyttja with mollusc shells<br>Composition: Lc 2—3, Ld$^1$ 1—2, test. moll. 3 |
| 6.50—6.75 | green-grey calcareous detritus gyttja<br>Composition: Lc 2—3, Ld$^1$ 1—2, test. moll. + |
| 6.75—7.60 | green-grey calcareous detritus gyttja with mollusc shells<br>Composition: Lc 2—3, Ld$^1$ 1—2, test. moll. 2 |
| 7.60—7.95 | light brown detritus calcareous gyttja, scanty fauna<br>Composition: Ld$^1$ 2, Lc 2, Ag/As +, test. moll. + |
| 7.95—8.60 | dark brown compact peat, strongly humified. Pieces of wood and reeds<br>Composition: Sh 2, Tl +, Dl 1, Ld$^1$ + |
| 8.60—8.67 | brown detritus gyttja with admixture of clay<br>Composition: Sh 1, Ld 2, As/Ag 1 |
| 8.67—8.89 | brown compact peat, strongly humified, with wood pieces<br>Composition: Sh 2, Tl$^2$ + +, Dl 1, Dh 1, Dg + Ld$^{0}$ + |
| 8.89—9.22 | light grey calcareous detritus gyttja, interbedded with brown<br>Composition: Lc 2, Ld$^1$ 1, Dg 1, test. moll. + |
| 9.22—9.32 | grey calcareous gyttja with admixture of detritus gyttja. Numerous faunal remains<br>Composition: Lc 2, Ld$^1$ 2, test. moll. 1 |
| 9.32—9.46 | dark grey calcareous gyttja with some of detritus gyttja<br>Composition: Lc 3, Ld$^1$ 1 |

| | |
|---|---|
| 9.46—9.49 | grey clay with admixture of detritus gyttja<br>Composition: As/Ag 3, $Ld^1$ 1 |
| 9.49—9.67 | brown detritus gyttja<br>Composition: Dg 1, $Ld^1$ 3, Ag + |
| 9.67—10.06 | olive-grey calcareous gyttja with admixture of detritus gyttja. Not numerous, damaged faunal remains<br>Composition: Lc 3, $Ld^1$ 1, test. moll. + |
| 10.06—10.16 | grey clayey calcareous gyttja with plant detritus gyttja<br>Composition: Lc 2, $Ld^1$ 1, As 1 |
| 10.16—10.39 | grey clayey calcareous gyttja. Not numerous faunal remains, plant detritus and sand<br>Composition: Lc 2, $Ld^1$ +, As/Ag 2, Ga +, test. moll. + |
| 10.39—10.48 | steel-grey stratified clay. Brown coarse-detritus gyttja interbedded. Fragments of wood, twigs, leaves, faunal remains and sand<br>Composition: As/Ag 2, $Tl^1$ +, Dl 1, $Ld^1$ 1, Ga +, test. moll. |
| 10.48—10.53 | stratified fine sand and brown coarse-detritus gyttja<br>Composition: Ga 2, Dl +, Dg 1, $Ld^1$ 1 |
| 10.53—10.71 | dark brown compact peat with large pieces of wood<br>Composition: Sh 2, $Tl^2$ 1, Th + Dl 1 |
| 10.71—10.76 | dark brown compact peat with large pieces of wood, sandy<br>Composition: Sh 2, $Tl^2$ 1, Th + Dl 1, Ga + |
| 10.76—10.96 | beige-grey fine-grained sand<br>Composition: Ga 4. |

## Lake Druzno, profile 1A

| Depth below water surface, m (water depth 0.8 m) | Description of sediment |
|---|---|
| 0.80—4.53 | olive-green calcareous gyttja<br>Composition: Lc 4, Ld + Dg +, test. moll. + |
| 4.53—5.43 | olive-green calcareous gyttja with some detritus gyttja and numerous mollusc shells<br>Composition: Lc 4, Ld + +, Dg +, As +, test. moll. + + + |
| 5.43—7.29 | brown-green calcareous gyttja some plant detritus and fragments of mollusc shells<br>Composition: Lc 4, Dh +, Ld +, part. test. moll. + |
| 7.29—7.71 | brown calcareous gyttja with mollusc shells<br>Composition: Lc 4, Dh + Ld +, test. moll. 2 |
| 7.71—7.91 | dark brown strongly decomposed peat with gyttja<br>Composition: Sh 2, Dg 2 $(Dl + D_h)$ + + |

| | |
|---|---|
| 7.91—8.12 | brown coarse detritus gyttja<br>Composition: (Dl+Dh) 2, Dg+, Ld$^{2}$2 |
| 8.12—8.33 | brown siliceous gyttja with admixture<br>Composition: Lso 2, Sh 2, Dh+ |
| 8.33—8.60 | dark brown weakly decomposed peat<br>Composition: Th$^{1}$3, (Dh+Dl) 1, Dg+ Ld+ |
| 8.60—9.25 | brown detritus gyttja. *Menyanthes trifoliata* seeds<br>Composition: Ld$^{2}$2, Dg 2, (Dl+Dh)+ |
| 9.25—9.36 | dark brown moss peat with detritus and sand admixture<br>Composition: Tb$^{2}$1, Dg 1, (Dl+Dh) 2, Ga+ |
| 9.36—9.43 | light brown sand with detritus<br>Composition: Ga 2, Dg 2, (Dl+Dh)+ |
| 9.43—9.58 | brown siliceous gyttja with detritus and single grain sand<br>Composition: Lso 2, (Dl+Dh) 2, Dg+ Ga+ |
| 9.58—9.66 | dark brown peat with detritus gyttja<br>Composition: Tb$^{1}$2, (Dl+Dh) 2, Ld+ |
| 9.66—9.75 | brown coarse detritus gyttja with sand admixture<br>Composition: (Dl+Dh) 3, Dg+ Ga 1 |
| 9.75—9.89 | dark brown moses peat with coarse detritus gyttja<br>Composition: Tb$^{2}$2, (Dl+Dh) 1, Ld$^{2}$1 |
| 9.89—10.08 | light brown detritus gyttja with clay admixture<br>Composition: Ld$^{1}$3, (Ag+As) 1. |

## RESULTS OF POLLEN ANALYSIS

Local pollen assemblage zones (PAZ) (Gordon & Birks 1972, Berglund 1979) could be distinguished in the pollen diagrams 1A and 1a from Lake Druzno (Figs. 3, 4). Ten PAZ and two pollen assemblage-sub-zones (PASZ) were described in profile 1a (Fig. 4), eleven PAZ and two PASZ in profile 1A (Fig. 3).

### PAZ Dr-1a (profile 1A 9.26 m)

This zone is represented by two samples dominated by *Betula* undiff. pollen (32%). *Pinus sylvestris* pollen reaches a value of 14% only. Herbaceous plants are represented mainly by *Cyperaceae* (45%) and *Gramineae* (5%). Single pollen grains of *Epilobium* and *Hippuris* and *Equisetum* spores were recorded. This zone could be referred to the Alleröd chronozone (Mangerud et al. 1974).

### PAZ Dr-1 (profile 1a 9.17 m, 1A 9.26—9.09 m)

Distinctive for this zone and evident in both profiles is the rise in *Pinus* pollen frequencies (50% in profile 1A, 57% in 1a). *Betula* undiff. pollen values fall to below 10%, but those of *Salix* rise to 8.5%. The *Cyperaceae* curve increases in both profiles. This zone represents the younger part of the Alleröd chronozone. The $^{14}C$ date in profile 1a at 9.14—9.29 m is 11290±105 BP.

### PAZ Dr-2 (profile 1a 9.17—8.04 m, 1A 9.09—8.40 m)

Tree pollen values fall to a minimum in this zone (18%). Both profiles are dominated by herb pollen (1a — 53%, 1A — 82%) with *Artemisia*, *Cyperaceae and Gramineae* being the chief components. Apart from these, *Helianthemum*, *Rosaceae*, *Ranunculaceae*, *Hippophaë*, *Thalictrum*, *Sanguisorba* off. pollen and *Selaginella selaginoides* spores were present. The *Pinus* and *Betula* curves display different values in the two profiles: 1a — *Pinus* (20—40%), *Betula* (7—30%); 1A — *Pinus* (6—42%), *Betula* (6—57%). Pollen grains of aquatics such *Myriophyllum spicatum* and *M. verticillatum* attain maximum values (profile 1a). Two PASZ can be distinguished in profile 1a:

a) PASZ Dr-2a is characterised by the presence of *Empetrum* and *Ericaceae* undiff. pollen. Besides these, *Artemisia*, *Rosaceae* and *Ranunculus* undiff. reach maximum frequencies. *Populus* pollen appears at the start of this subzone. In profile 1A, this subzone is manifested only by single occurrences of *Empetrum* pollen.

b) PASZ Dr-2b — here is an obvious fall in the *Empetrum* pollen frequenies and a simultaneous increase in those of *Juniperus* pollen.

### PAZ Dr-3 (profile 1a 8.04—7.38 m, 1A 8.40—7.80 m)

The evident fall in the herbaceous pollen, especially *Cyperaceae* and *Gramineae*, with a concurrent substantial rise in the *Betula* pollen curve delimits the lower boundary of this zone. *Betula* is clearly prevalent throughout this zone in both profiles, reaching values of 60—70%. The concentration of tree pollen now rises to 390000 grains per cm³. However, the pollen composition of the aquatic and reed-swamp vegetation reveals certain differences between the two profiles. Whereas *Nymphaea*, *Nuphar* and *Potamogeton* dominate in profile 1a, *Menyanthes triofoliata* and *Typha latifoliata* prevail in 1A.

### PAZ Dr-4 (profile 1a 7.38—7.28 m, 1A 7.80—7.68 m)

Three samples in both profiles represent this zone in which there is a rapid increase in the *Pinus* pollen frequencies (1a — 75%, 1A — 50%). The quantities of *Betula* and the aquatic and reed-swamp pollen fall to an absolute minimum. The tree pollen concentration increases to a maximum of 550000 grains per cm³ in this PAZ. This zone may be identified with the Boreal.

### PAZ Dr-5 (profile 1a 7.28—6.56 m, 1A 7.68—6.92 m)

The lower boundary of this zone has been fixed by the radiocarbon date 7050±70 BP. Characteristic are the high values of *Alnus* (48—42%) while *Corylus*, *Ulmus* and *Quercus* pollen continue to rise. Pollen grains of *Viscum* and *Hedera* and *Pteridum* spores are present; telmatophytes-bed vegetation are back and well represented. Single pollen grains of aquatics are also noted.

PAZ Dr-6 (profile 1a 6.56—4.88 m, 1A 6.92—4.94 m)

The radiocarbon of the lower boundary of this zone is 6440±50 BP. The tree pollen concentration declines from the middle of this PAZ to 39000 grains per cm$^3$ but rises again to 186000 grains per cm$^3$ towards the end. The constant values (10—15%) of *Quercus*, *Ulmus* and *Tilia* pollen are typical. *Alnus* pollen values do not exceed 30% and are almost stable. *Pinus* pollen frequencies on the other hand vary from 10 to 37%. Low percentage curve with small peaks are given for *Fraxinus* and *Picea.* Herbacoeus plant pollen falls consistently (below 10%). *Polypodiaceae* and aquatic plant pollen also decreases towards the end of the zone. *Carpinus* and *Fagus* pollen and indicators of human activities make their first appearance.

PAZ Dr-7 (profile 1a 4.88 m, 1A 4.94—3.44 m)

The pollen concentration shows two distinct minima at the beginning of this zone. The lower boundary is delimited by a fall in *Ulmus* pollen to under 1%, which is then followed by a recovery. *Tilia* pollen values fall steadily right to the end of this zone. *Corylus* values are about 10% in the early phase of this zone, and rise towards the middle. *Quercus* pollen dominates markedly over the other components of the mixed deciduous forest. The *Pinus* curve reaches maximum values at the beginning and end of this PAZ. The *Alnus* curve behaves in the opposite manner. Herb pollen vegetation is down to a minimum of 5%. No *Cerealia* pollen is recorded yet, only a few single pollen grains as human indicators.

PAZ Dr-8 (profile 1a 3.20—2.80 m, 1A 3.44—2.80 m)

This zone is distinguished by a persistent rise in the pollen curves of *Carpinus*, *Fagus*, *Pinus* and *Betula*. *Corylus* values drop towards the end of the zone. *Fraxinus*, *Ulmus* and *Tilia* are always present but in very small amounts. Single *Abies* pollen grains are recorded. *Quercus* pollen occurs in constant amounts of around 10%. Pollen frequencies of *Cereals* and other human indicators are now sufficiently high to give low-percentage curves.

PAZ Dr-9 (profile 1a 2.80—0.80 m, 1A 2.80—0.88 m)

This zone is distinguished by the predominance of *Carpinus* pollen over other components of the deciduous forest. *Carpinus* attains three distinct maxima in this PAZ. Quantities of *Quercus*, *Tilia*, *Corylus* and *Ulmus* pollen diminish towards the end of the zone. At its beginning we see increasing values of *Pinus* pollen (50%) while at the same time *Alnus* falls to 15%. This situation is reversed at the end of this zone. The total herb pollen increases in comparison with the previous zone. Human indicators provide low-percentage curves which decline at the end of this zone. There is an abundance of numbers and taxa of aquatic telmatophytes.

### PAZ Dr-10 (profile 1a 0.80—0.00 m, 1A 0.88—0.00 m)

This PAZ is rendered distinctive by its tree pollen composition. There is a clear and consistent increase in *Pinus* (57%), whereas *Carpinus*, *Quercus*, *Alnus* and *Betula* decline. *Fagus* and *Picea* pollen give continuous, low-percentage curve. The harbaceous plant curve reaches maximum values of over 60% at the end of this zone. High pollen frequencie and a huge abundance of antropogenic indicators, aquatic and reed-swamp vegetation are noted here. *Juniperus* pollen appears at the end the zone.

## GEOCHEMICAL ANALYSIS

Nine stratigraphic zones, based on the changes in chemical composition of the sediments have been distinguished in the profile (Kępińska, in press). They are referred to on the diagram as chemical zones (Fig. 5) and denoted by the symbol DrCh.

Zone DrCh-1 (9.56—9.29 m) — fine-grained and clayey sand, beige-grey and brown, with streaks of organic matter. Water content is low (Tab. 1) 20—25% with respect to the dry matter of the sediment, $C_{org}$ content is minimal (0.14—0.33%), the carbonate content is up to 1.5%, that of phosphorus is 0.025%. Sodium is present in quantities of 0.44—0.53%, the potassium content varies from 0.97 to 1.08%, iron 0.42 to 0.56%, and there is 0.01% of manganese. The concentrations of trace elements are lower in this zone than in any other.

Zone DrCh-2 (9.29—9.13 m) — peat deposited during the Alleröd period; the sediment has high water content — up to 252% water with respect to dry matter. $C_{org}$ content reaches 30.3%, nitrogen 1.44%. The C/N ratio is from 21 to 28, 0.052—0.087% phosphorus and 0.8—1.6% amorphous silica were found in the sediment. The quantities of sodium and potassium are of the same order as in the previous zone. The content of iron, manganese and trace metals is increasing.

Zone DrCh-3a, b (9.13—8.02 m) — olive-grey gyttja containing some sand in the bottom part. The zone corresponds to the Younger Dryas. A feature of this zone is the carbonate content of up to 20.8%, which decreases to 10.2% at the top. The $C_{org}$ content at the bottom has a value of about 1%, but rises gradually to a value of 7.29% in the topmost part of the zone which is denoted DrCh-3b (8.25—8.02 m). The water content of the sediment increases likewise in this section of the profile from 40—60% to 116%. The phosphorus concentration varies in the range 0.050—0.080%, and is lower than in the previous zone. 1.2% of diatomaceous silica is present. The other elements determined are present in greater concentrations than in the zone DrCh-2 and remain roughly constant in zone DrCh-3.

Zone DrCh-4 (8.02—7.49 m) — grey calcareous gyttja. The concentration of carbonates rises to 76.2% of the dry sediment. The $C_{org}$ content in the sediment remains at 4.68—6.56%, with nitrogen at 0.34—0.52. The C/N ratio falls to 10—13, which indicates a change in the nature of the organic matter deposited. Characteristic of the sediment in this zone is the considerable drop in the sodium and potassium contents (biogenic sediment). Beside Na and K, there is also a sharp fall in the concentrations of such lithogenic elements as Fe, Cr and Li, the quantity of the last-mentioned being too small to be determined with the methods used in this study. Cu and Zn contents also fall. The sediments of zone DrCh-4 were deposited during the Pre-Boreal period (the boundary at 8.02 m is quite clear).

Zone DrCh-5 (7.49—7.20 m) — Boreal peat with interlayered gyttja at 7.29 m. The content of $C_{org}$ reaches 33.5%, nitrogen 0.62—2.21%; the C/N ratio is 15—20, and water content is 170—180%. The amount of amorphous silica is variable within the range 0.7—2.6%; there is from 0.042—0.062% phosphorus. Na and K concentrations regain their previous level of 1.88%; the contents of Fe and the trace elements Cu, Cr and Li also increase.

Zone DrCh-6 (7.20—6.50 m) — the sediment here comprises Atlantic peat which contains much water than the zone below; its water content has riser from 180% to 368—383% with respect to the dry sediment. The peat zone DrCh-6 contains more $C_{org}$ than in the zone below — 36.2%, and the C/N ratio, with nitrogen at 1.21—1.67%, is up to 29. The contents of the litogenic elements K, Na, Fe, Cr, Li and of trace elements like Cu, Zn, Co and Ni fall again.

Zone DrCh-7 (6.50—6.20 m) — gyttja in which the carbonate content rises abruptly from trace amounts to 47.1%. $C_{org}$ falls in this sediment to 6.3%, while the C/N ratio varies within the interval 11.7—14.1. The concentrations of amorphous $SiO_2$ and Mn are the highest in the entire profile at ca. 15% and 0.168%, respectively. The concentrations of Cr, Li and Ni are somewhat below the average for the profile as a whole.

Zone DrCh-8a, b, c (6.20—0.80 m) — gyttja containing various amounts of carbonates, the overall trend being a gradual decrease towards the top of the zone, from 46.8 to 11.7%. The $C_{org}$ content also falls. Zones DrCh-8b and c show a rise in sodium concentration. The Mn concentration again decreases to 0.06—0.08%, whereas Co, Ni, Cr and Li increase, particularly at the top of the zone. The other components determined remain fairly stable.

Zone DrCh-9 (0.80—0.00 m) — gyttja differing from that in zone 8 by a two fold drop in Na content, a low K content, and increases in P, $C_{org}$, carbonates and amorphous $SiO_2$. The C/N ratio falls from several tens to ca. 10 and then below 10. There data indicate a change in the nature of organic matter which here is autochtonous in origin. The water content in the sediment of zone

DrCh-9 is much greater — as high as 290%. There is a sligh increase in the concentration of trace metals such as Cu and Zn, but the Ni and Cr contents are lower than at top of zone DrCh-8.

## PALEOECOLOGICAL CHANGES IN THE DEVELOPMENT OF LAKE DRUZNO

Eight stages in the formation of Lake Druzno can be distinguished on the basis of the geochemical, diatom and pollen analyses of profile 1a, pollen and diatom analyses of profile 1A and the analysis of the micro- and macrofauna of profile 1A (Tab. 2).

### I. The prelacustrine stage (ca. 9.28—9.00 m)

The first stage in the formation of a glacial body of water began during the Alleröd period. At that time it would seem that there was a mosaic of small water bodies with aquatic vegetation comprising such species as ***Myriophyllum spicatum*, *Hippuris*, *Nuphar*** and swamps and woodland peatbogs within the present-day area of Lake Druzno. This variety of habitats is also reflected by the diatom flora. Acidophilous diatoms typical of woodland peatbogs were present

Table 2

Stages of Lake Druzno development based on the fauna investigations after Janiszewska-Pactwa (1973)

| Stage | Fauna |
|---|---|
| IV<br>Depth:<br>0.00—1.16 m | Very large numbers of testaceous *Rhizopoda (Testacea)* mainly: *Difflugia oblonga* var. *nodosa*, *Pontigulasia spectabilis*, *Phryganella nidulus*, *Difflugia oblonga* var. *angusticolis*, *D. oblonga* var. *brevicolis*, *D. oblonga* var. *kempnei* |
| III<br>Depth:<br>1.16—2.25 m | The testaceous *Rhizopoda (Testacea)* mainly: *Difflugia hydrostalica* var. *lithophila*, *D. elegans*, *D. viscidula*. A small number of *Ostracoda* was noted |
| II<br>Depth:<br>2.25—4.20 m | *Ostracoda* and *Valvata* disappeared. Tests of *Crustacea* occured |
| I<br>Depth:<br>4.20—7.10 m | Very large numbers of *Ostracoda* were noted mainly: *Cyprideis torosa* — an indicator species of sea water ingression, *Ilyocypris gibba*, *Candona neglects*, *Drawinula stevensoni*. Rich development the species belonging to mollusca, especially *Valvata* sp. |
| Depth:<br>7.10—9.50 m | Without fauna remains |

Table 3

Lake Druzno. Most characteristic and important diatoms in diatom zones (after Przybyłowska-Lange 1976, 1982)

| Diatom zones | Most characteristic and important diatoms |
|---|---|
| DrD-12<br>Depth:<br>0.00—0.68 m | The littoral alkaliphilous diatoms prevail. Characteristic diatoms are: *Rhoicosphaenia curvata*, *Epithemia turgida*, *E. zebra*, *Cocconeis placentula*, *Amphora ovalis* var. *libyca* and var. *pediculus*, *Stephanodiscus astrae* var. *minutulus*, *Fragilaria pinnata* and *F. construens* |
| DrD-11<br>Depth:<br>0.68—2.25 m | The main components of diatom flora are littoral species. The genus *Fragilaria* is dominant. Other taxa characteristic are: *Campylodiscus noricus* var. *hibernica*, *Gyrosigma attenuatum*, *Cymbella ehrenbergii* |
| DrD-10<br>Depth:<br>2.25—2.80 m | Oligohalobous diatoms prevail. The most characteristic diatoms are: *Navicula scutelloides*, *Opephora martyi* |
| DrD-9<br>Depth:<br>2.80—3.54 m | The oligohalobous diatoms are dominant. Among them: *Melosira granulata*, *Melosira italica* |
| DrD-8<br>Depth:<br>3.54—6.55 m | The oligohalobous diatoms prevail. The most numerous are the planktonic species, chiefly *Stephanodiscus astrea* and *Melosira granulata*. Among the meso- and euhalobous diatoms planktonic species of *Coscinodiscus* (at present *Actinocyclus kuetzingii*) prevail. In smaller numbers are noted: *Campylodiscus clypeus*, *C. echeneis*, *Cocconeis scutellum*, *Terpsinoe americana*, *Achnanthes breviceps* var. *intermadia* |
| DrD-7<br>Depth:<br>6.55—6.90 m | The oligohalobous indifferent diatoms are markedly dominant. The vast majority of them being alkaliphilous, littoral species. The most prominent are *Fragilaria construens* + var. *venter*, *F. brevistriata*, *F. pinnata*, *Amphora ovalis*, var. *libyca* + var. *pediculus*, *Ceccoeis placentula*. The presence of halophilous and mesohalobous diatoms |
| DrD-6<br>Depth:<br>6.90—7.45 m | The main components of diatom flora are *Fragilaria*, *Amphora ovalis* var. *libyca* and var. *pediculus* |
| DrD-5<br>Depth:<br>7.45—7.72 m | The dominance of *Melosira italica* and var. *valida*, *Synedra ulna* and var. *biceps*, *S. capitata* |
| DrD-4<br>Depth:<br>7.72—8.32 m | *Cocconeis placentula*, *Amphora ovalis* var. *libyca* and var. *pediculus* are dominant |
| DrD-3<br>Depth:<br>8.32—8.96 m | The most characteristic diatoms are: *Rhopalodia gibba*, *R. pararella*, *Nitzschia amphibia*, *Campylodiscus noricus* var. *hybernica*, *Fragilaria* sp., *Tabellaria flocculosa* and *Tabellaria fenestrata* |
| DrD-2<br>Depth:<br>8.96—9.13 m | There occur many species characteristic of the Late-Glacial sediments, e.g. *Navicula pupula* var. *rectangularis*, *N. abiskeoensis*, *N. cuspidata*, *N. dicephala*, *N. mutica*, *Pinnularia* cf. *pulchra*, *P. lagerstedtii*, *P. subcapitata*, *Fragilaria pinnata*, *Pinnularia viridis* var. *commutata*, *Diploneis ovalis*, *Navicula amphibola* and *N. semen* being the most numerous |
| DrD-1<br>Depth:<br>9.13—9.36 m | The characteristic species are: *Hantzschia amphioxys* with var. *capitata*, *Navicula amphibola*, *N. semen*, *N. mutica*, *Eunotia praerupta*, *E. gracilis*, *Pinnularia borealis*, P. cf. *pulchra*, *P. gracillima* |

along with alkaliphilous and alkalibiontic diatoms. Besides aquatic diatoms there occurred some aerophilous diatoms, the most common of which was *Hantzschia amphioxys* (Tab. 3). *Eunotia* and *Pinnularia* spp. are characteristic of marshy bodies of water, and their presence suggests that the pools mentioned above were dystrophic.

This initial stage in the formation of the lake has been dated at 11250±105 BP. Chemically, the peats from this stage contain much $C_{org}$ (on average over 22%) and a C/N ratio of over 20. The nature of the body of water is also reflected in the low contents of Na, K, Fe, Mn and all trace metals estimated in the sediment.

### II. Deep, cold-water lake (ca. 9.00—8.00 m)

The beginning of pollen zone Dr-2 was accompanied by a considerable cooling of the climate; a cold-water lake now formed. Numerous arctic diatoms, e.g. *Navicula amphibola* and *N. semen*, and others typical only of Late-Glacial sediments occurred in it (Tab. 3). At the commencement of this stage acidophilous diatoms were still present, but their numbers decreased in favour of alkalibiontic species. Alkaliphilous diatoms dominated the diatom flora. From the start of this stage there was a gradual rise in the numbers of planktonic diatoms like *Melosira italica*, *M. islandica*, *M. granulata* and *Stephanodiscus astrea* which indicate that the water level in the lake was rising; the gradual replacement of acidophious and aerophilous diatoms by alkalibiontic and alkaliphilous species shows that the water was becoming more alkaline.

The most frequentic aquatic plants besides *Potamogeton* were *Myriophyllum spicatum* and *M. verticillatum*. The expansion of these Boreal-circum-polar plants (Hultén 1950) indicates that the water level in the lake was rising, thus providing suitable conditions in which they could thrive; eutrophication had just begun (Berglund 1966). Reed-swamp communities with *Typha latifolia* appear at the end of this stage. The gyttja deposited during this phase contains up to 20% calcium and magnesium carbonates, thus confirming the alkaline pH of the water in the lake already suggested by the above-mentioned changes in the diatom composition. There is an almost two fold increase in the sodium and potassium content in comparison with the previous stage. The concentration of other elements, especially of manganese, also rises.

### III. Overgrowing lake (ca. 8.00—7.40 m)

The *Typha latifolia* community became the dominant one in this sheet of water. The large-scale expansion of this species contributed to the rapid overgrowth and infilling of the lake. The next succession stage in the overgrowing process was the community of *Menyanthes trifoliata*. Nowadays, this species occurs in large numbers in overgrown lakes, peatbogs and underained marshland, and here it found a suitable habitat. Although the succession was clearly headed towards fens and even moss peatbogs, the structure of the plant mosaic-like communities still persisted. Besides reed-swamp communities, stands of aquatic vegetation represented by *Nymphaea*, *Nuphar*, *Myriophyllum spicatum* and *M. verticillatum* were present (profile 1a), mostly formed by one dominant species restricting the growth of the others. These clearly-defined succession stages evidence the decreasing depth and overgrowing of the lake.

In the first phase of stage III, planktonic diatoms like *Stephanodiscus astrea*, *Melosira granulata* and *M. ambigua* still occurred, but later they disappeared and epiphytic and bentic species took their place. The most important process during this stage was therefore biogenic sedimentation. The deposits ars extremely rich in carbonates (ca. 70%) and $C_{org}$, N and P content also increase. The analysis of the content of sedimentary chlorophyll derivatives (Zachowicz et al. 1982) and its comparison with data on organic matter confirm that the lake was highly eutrophic at this time. The contents of the lithogenic elements such as Na, K, Fe were now lower than at any other time in the lake's development; the concentrations of lithogenic trace elements also decreased.

### IV. Terrestic stage (ca. 7.40—7.20 m)

This very interesting stage, dated at 8995±90 BP, when the lake suddenly disappeared and was overgrown by a woodland peatbog, is difficult to explain at the present stage of the investigations. No diatom flora or macrophyte remnants were present in the sediment. The peat deposited at that time is much richer in all the elements determined than the prelacustrine peat of stage I. This is due to the terrestrial nature of the stage and a different climate — as a result of these factors, components released during chemical weathering may have got into the peat.

### V. Stage of riviving — water body (ca. 7.20—6.25 m)

The beginning of the next stage in the formation of Lake Druzno is dated at 7050±70 BP. There is thus a gap of almost 2000 years in the history of the lake. The formation of aquatic plant communities with *Potamogeton*, *Myriophyllum* and *Nymphaea* are undoubtedly proof that at this time the water table was rising. Dominant here were rush communities with *Typha latifolia* and *T. angustifolia*, *Sparganium*, *Triglochin* and *Menyanthes trifoliata*, these last four taxa being well preserved only here. *Menyanthes trifoliata* and *Phragmithes* have long, strong rhizomes which hold the substrate together very well and thus intensify the peat formation processes. The margin of the peatbog may have been covered by *Alnus* stands accompanied by the shade-tolerant *Dryopteris thelypteris* and shrubs like *Frangula alnus* and *Viburnum*. Aquatic vegetation throve in polls.

Epiphytic diatoms, mostly *Fragilaria* spp., the chief component of the diatom flora, prevailed at the start of this stage, but halophilous and mesohalobous diatoms with *Anomoeoneis costata*, *Achnanthes hauckiana* and *Bacillaria paradoxa* appeared during its second half (Tab. 3). Indifferent oligohalobous diatoms predominanted; most of them were alkaliphilous, littoral species. Besides mesohalobous diatoms, Pactwa (1973) reports the occurrence of *Cyprideis terosa*, a species characteristic of oligo- and mesohaline waters; hence there must have been an ingression of salt water into the lake (Tab. 2).

The result of the chemical analysis also show that sea-waters had flowed into the lake during the second phase of this stage. The concentration of Mn rose abruptly (to 0.168%), so did that of amorphous $SiO_2$ — this suggests an abundance of diatoms. Considerable quantites of carbonates were being precipitated, testifiying the alkalinity of the water; at the same time the $C_{org}$ was rather high. The inflow of new waters allowed more Mn to be precipitated under oxidising conditions. Such effects have been observed during the formation of specific muds on sea bottoms (Emelyanov et al. 1979). These effects refer to the transgressive cycle of the formation of sediments deposited during a warm, humid or temperate climate.

## VI. Salinic — water bay (ca. 6.25—3.50 m)

The lake became part of the Vistula Lagoon around 6440 BP. This date indicates the transformation of the peatbogs and marshes into a typical lake with three zones of vegetation: submerged aquatics, floating aquatics and reed-swamps. Some idea of the extent of the lake is given by the limitation of all *Polypodiaceae* and some *Alnus* habitats. Indifferent oligohalobous diatoms still dominated the diatom flora. Most of them were planctonic species like *Stephano-discus astrea* and *Melosira granulata*. The most characteristic aspect of the diatom flora at this stage was the rise in frequencies of meso- and euhalobous planktonic diatoms with dominant *Actinocyclus kuetzingii*. Large-scale occurrences of meso- and euhalobic diatoms were noted three times, with the maximum number at the end of this stage. The maximum development of meso- and euhalobic diatoms was coincident with the impoverishment of telmatic and aqatic vegetation, including *Pediastrum*. The maximum inflows of salt water were interspersed with periods of reduced salinity. During these latter periods the numbers of meso- and euhalobous diatoms became much lower and macrophyte communities developed.

These three inflows of salt water are linked with the succesive transgressions of the Littorina Sea which did not, however, directly affect the areas of Lake Druzno and the Vistula Lagoon (Przybyłowska-Lange 1976).

The changes taking place in the lake at this time are also demonstrated by the changes in the chemical content of the sediments. Sodium, potassium and iron increased, reaching concentrations characteristic of the Gulf of Gdańsk at that time (Trimonis 1981). Sodium increased at the end of this stage in particular, as did the frequencies of meso- and euhalobic diatoms, showing that salt water must have flowed into the lake.

## VII. Fresh — water bay (ca. 3.50—0.80 m)

Succesive hydrological changes followed the maximum inflow of salt water at the end of stage VI. The meso- and euhalobic diatoms disappeared completely at the start of stage VII, indicating that salt-water inflows had ceased. The communities of aquatics and telmatophytes were reduced while species of planktonic diatoms appeared in very large numbers. This means that the waters of this bay were spreading and becoming deeper. The deep, fresh-water bay stage lasted for only a very short time and communities of aquatic vegetation with *Myriophyllum* and *Nuphar* soon began to expand. Planktonic diatoms gave way to littoral species. Indifferent oligohalobous epiphytic diatoms prevailed. *Nymphoides peltata*, *Stratiotes aloides* and *Trapa natans* grew in shallow inlets. The last-mentioned species prefers nutrient-rich waters that warm up quickly, and its distribution is favoured by a continental climate (Digerfeldt 1977). The reed-swamps formed by *Typha latifolia*, *Sparganium*, *Triglochin*, and *Alisma plantago aquatica*. By the end of this stage the exuviae of *Crustacea* disappear from the sediment and the association of *Difflugia hydrostatica* var. *litophilia*, *D. elegans*, *D. testacea* (Janiszewska-Pactwa 1973) is recorded. *Fragilaria* spp. dominated the diatom flora. The community with *Nuphar* and *Nymphaea* corresponding to today's *Myriophyllo-Nupharetum* (Tomaszewicz 1969a, b), dominated in the lake at that time. This community, producing large quantities of organic matter, contributed effectively to filling up the lake. The content of carbonates falls in the sediments of this period from over 20% to around 10%. The content of the remaining components is at roughly the same level as in the previous period. Right at end of this stage changes in the Fe/Mn and Fe/P ratios take place. An increase in these ratios may have meant enhanced reducing conditions in the lake body (Digerfeldt 1977).

## VIII. Isolation of lake (ca. 0.80—0.00 m)

This stage is markedly different from the others in all the analyses performed (Figs. 3, 4, 5). Both the composition of the diatom flora (Przybyłowska-Lange 1976) and the macrofauna (Janiszewska-Pactwa 1973) diverge from that in the Vistula Lagoon, which suggest that the process isolating these two bodies of water had come to an end. Ever since that time, the lake has become a shallow body of water in which epiphytic diatoms are predominant. The *Myriophyllo-Nupharetum* community is still prevalent, and besides *Nyphar* and *Nymphaea*, the calciphilous *Myriophyllum spicatum* appears in it. *Potamogeton perfolatus* (found as seeds) forms large stands on the lake bottom. *Sagittaria sagnittifolia* is numerous. The abundance of *Pediastrum*, a green alga characteristic of shallow, fresh-water bays is noticeable. The reed-swamp communities comprise *Typha latifolia*, *Sparganium* and *Alisma plantago-aquatica*. The sediments deposited in Lake Druzno since its isolation from the

Vistula Lagoon contain large amounts of carbonates, $C_{org}$ and the largest concentration of phosphorus ever recorded here. A comparison of the data on the sedimentary chlorophyll derivatives (Nagler 1979) with the organic matter suggests the advance of the eutrophication processes. The increase in concentration of certain heavy metals, Zn in particular, is probably due to man's activities in this region.

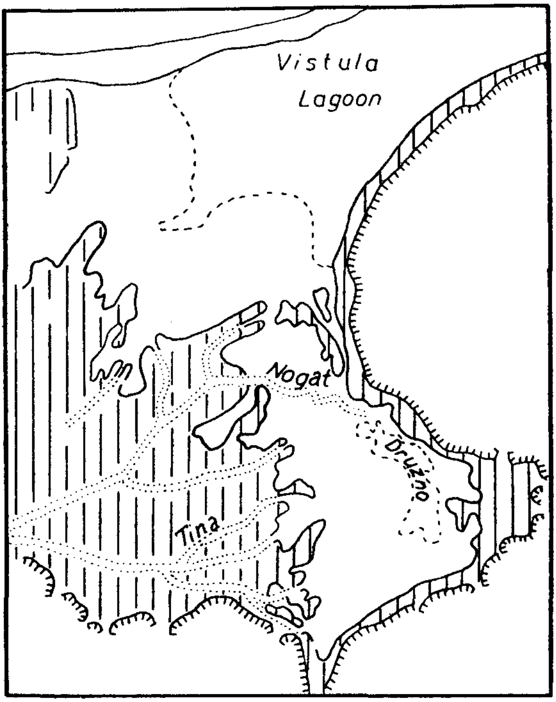

Fig. 6. Map of the investigated area around 1300 AD (after Bertram 1924)

The development of Lake Druzno in historical times can be traced on ancient maps (Majewski 1969). The map drawn by Bertram et al. (1924) shows two lakes at around 1300 AD (Fig. 6). At that time, the lake was in all probability still joined to the Vistula Lagoon, although the connecting channel was getting smaller all the time because of the accumulation of sediment brought here by the river Nogat. Silting up took place mostly from a westerly direction; the large rivers flowing here determined this.

Henneberger's map of 1567 AD (Fig. 7) shows that the northern part of the lake was similar in shape to its present-day appearance. Since then, infilling has taken place most rapidly at the southern end of the lake. This is because water flows into the lake in its southern and western parts and flows out at the northern end. The NW and SE shores of the lake underwent a shift in the 16th and 17th centuries. During the 18th and 19th centuries, the southern shore of the lake assumed a shape very similar to the of today's lake. Besides the accumu-

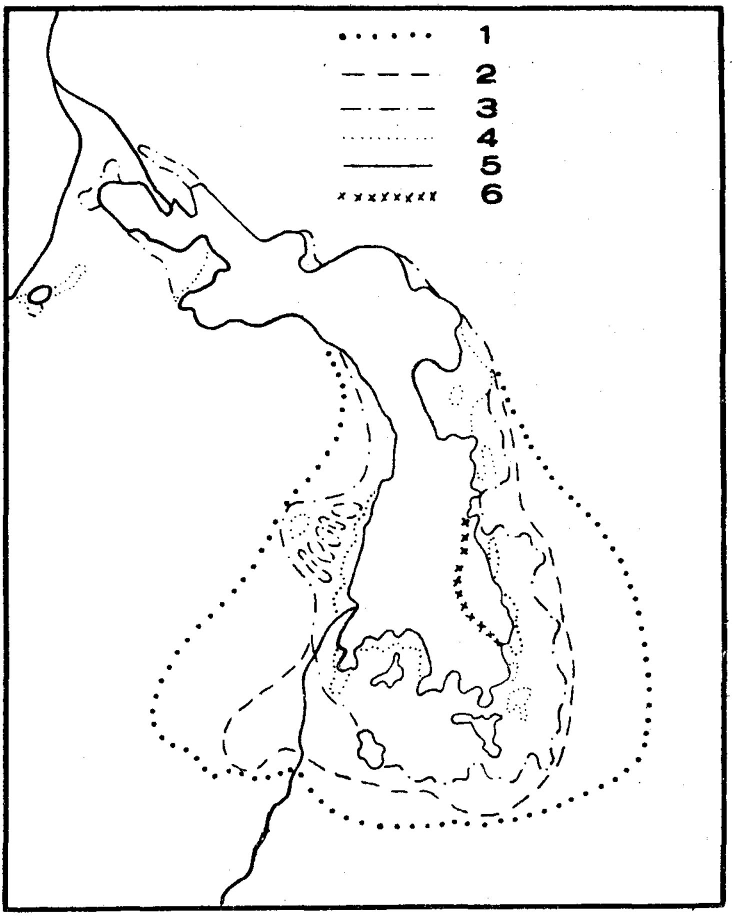

Fig. 7. Hydrographical evolution of Lake Druzno according to ancient maps: 1 — Henneberger 1576 AD, 2 — Meienreis 1634 AD, 3 — Endersch 1753 AD, 4 — Maull 1862 AD, 5 — General Staff 1910 AD, 6 — modification after 1917 AD

lation of silt brought here by rivers, especially the Nogat, plant communities have also played a very important part in aiding the infilling process. This stage appears to be intimately connected with the activities of man.

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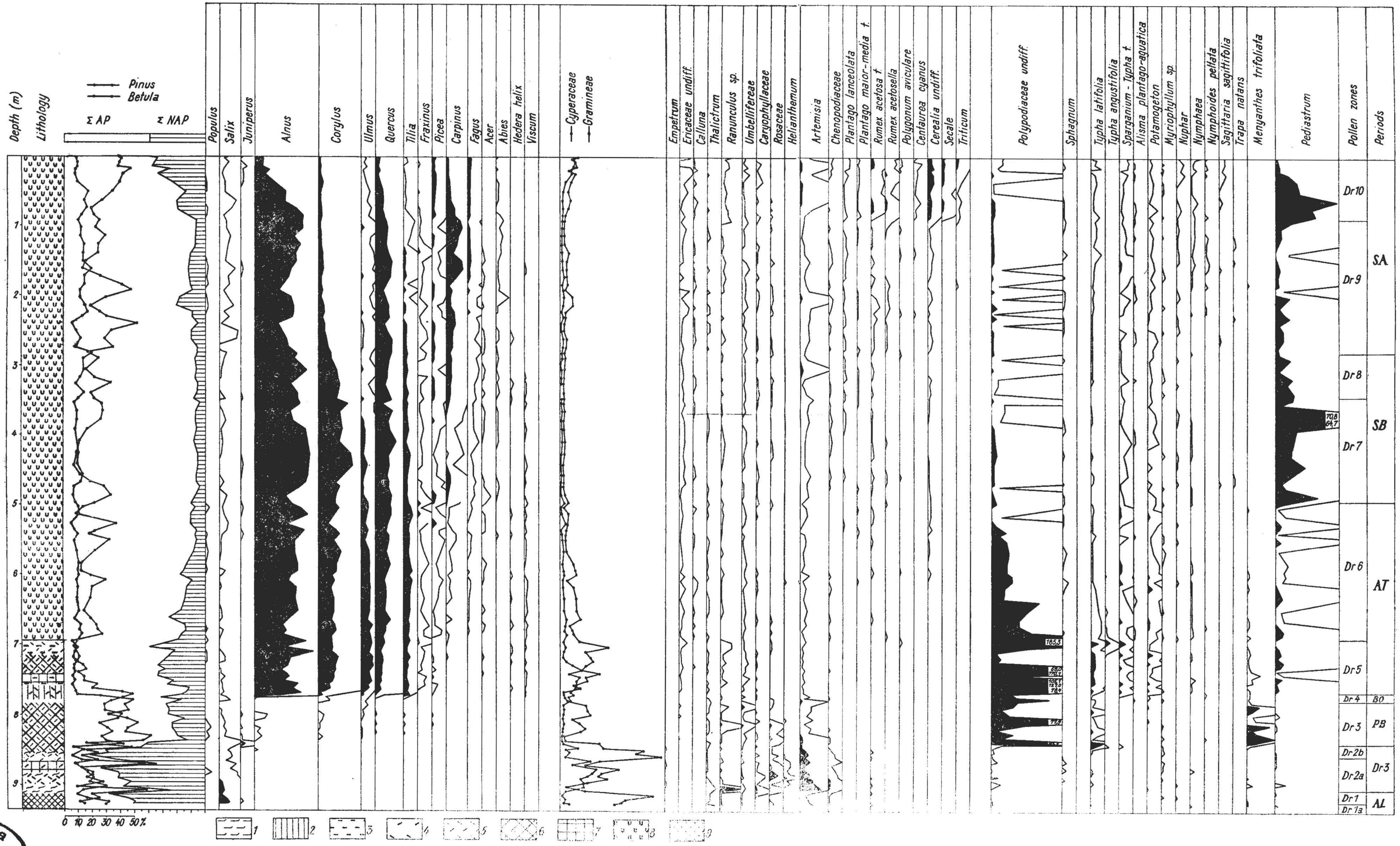

Fig. 3. Pollen diagram of profile 1A from Lake Druzno. Sediment signatures: 1 — moss peat, 2 — herbaceous peat, 3 — amorphous humous substance, 4 — coarse wood and plant detritus, 5 — wood, plant and animal detritus, 6 — detritus gyttja, 7 — siliceous gyttja, 8 — calcareous gyttja, 9 — sand

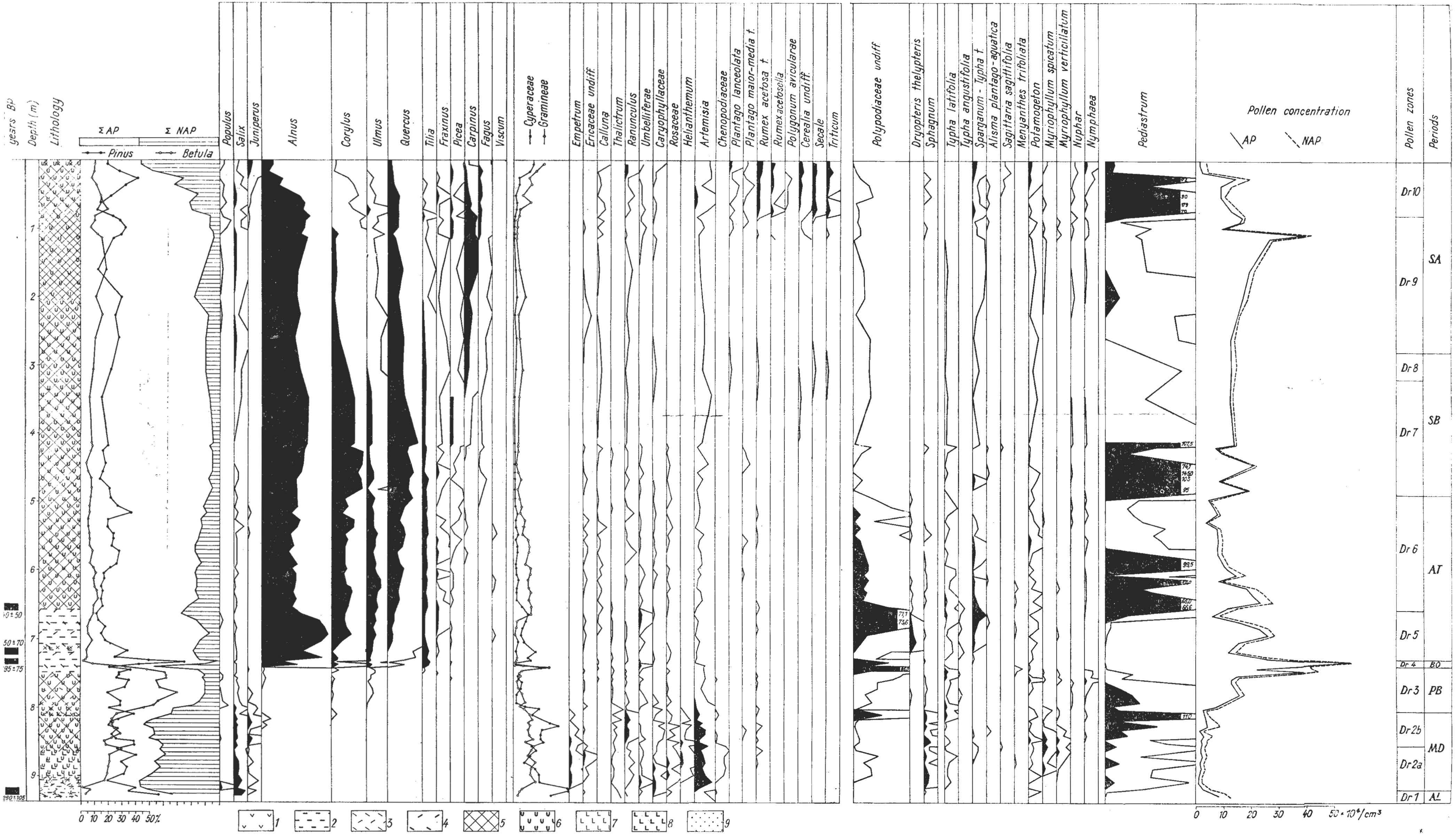

Fig. 4. Pollen diagram of profile 1a from Lake Druzno. Sediment signatures: 1 — lignous peat, 2 — amorphous humous substance, 3 — wood, plant and animal detritus, 4 — coarse wood and plant detritus, 5 — detritus gyttja, 6 — calcareous gyttja, 7 — clay, 8 — silt, 9 — sand

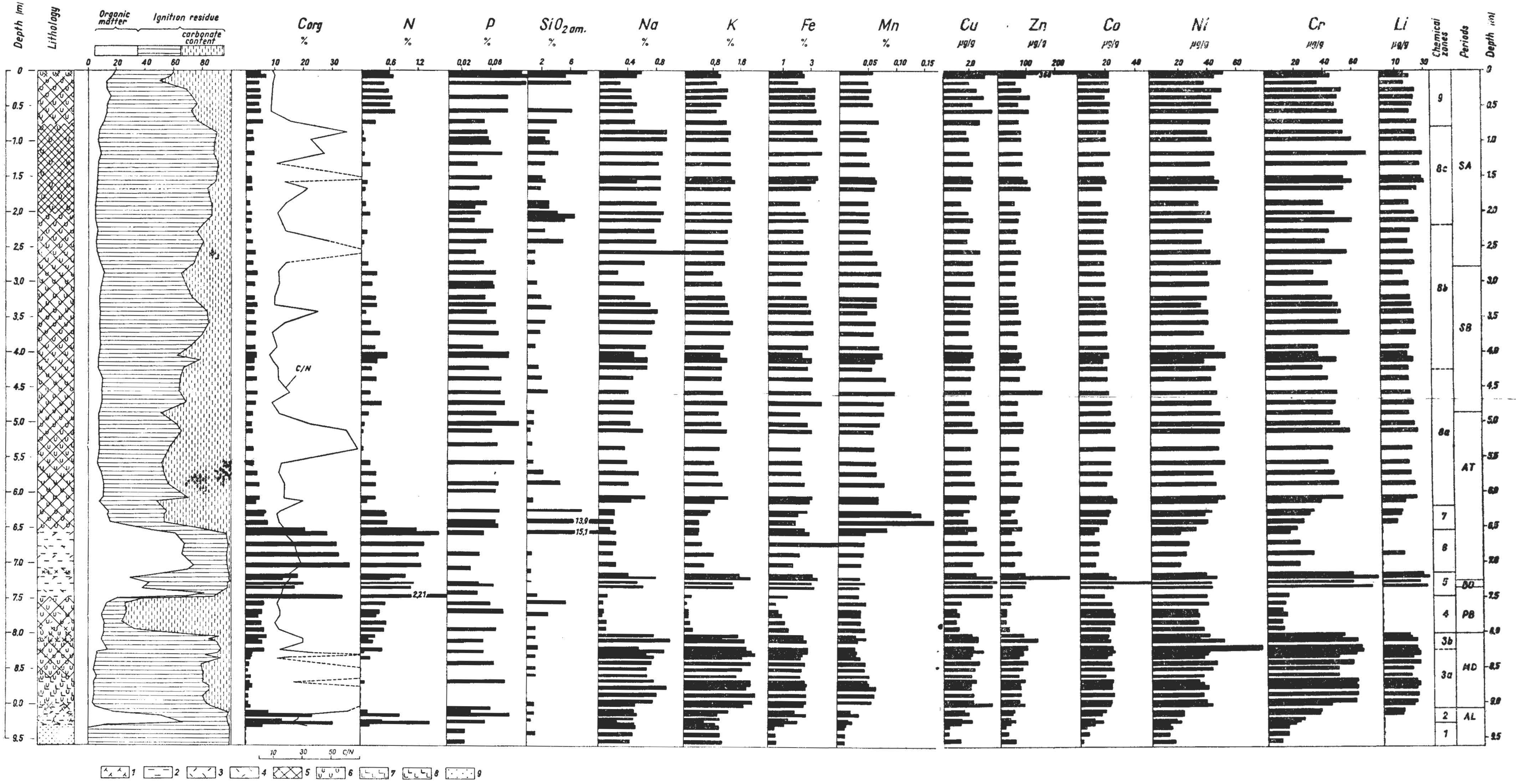

Fig. 5. Changes in physical and chemical properties in the profile 1a from Lake Druzno. For explanations, see Fig. 4