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Palaeoecology and Human Impact in the Vicinity of Lake Kahala, Northern Estonia

Abstract

To obtain information on the development of the local vegetation and land occupation in the surroundings of Kahala, a lacustrine sediment record from Lake Kahala in North Estonia and a terrestrial record from the overgrown northwestern edge of the lake were investigated by diatom, pollen, macrofossil and chemical analyses and dated by ^{210}Pb and ^{14}C methods. The lacustrine record covers the whole Holocene reaching as far back as the Younger Dryas, thus encompassing at least 11000 ^{14}C years. The terrestrial section covers the Late Holocene. A new standard pollen diagram for northern Estonia is considered. The lake development, changes in vegetation and palaeoenvironmental conditions are discussed. The presence of settlements in the surroundings of Lake Kahala since 7000 BP are suggested. Four main land-use phases have been identified: 1) Late Mesolithic – instability in the forest community; 2) from Neolithic times to the Bronze Age – forest clearance and possible grazing; 3) from Bronze Age to Pre-Roman Iron Age – slash-and-burn agriculture; 4) from Iron Age onwards – arable farming, possible permanent fields, grazing.

Keywords: pollen, diatoms, lake-level changes, human impact, Holocene, Lake Kahala, Estonia.

INTRODUCTION

In the framework of the PACT Palaeoecological Network (EU-project) « Environmental History of the Baltic Region » the subproject « The first land-use and agricultural development in the *alvar* areas during the period of Neolithic-Iron Age » was initiated. Detailed pollen diagrams from North Estonia are few (Veski, 1996; Kihno, 1996; Kimmel *et al.*, 1996; Saarse *et al.*, 1997) and the old pollen diagrams commonly lack radiocarbon dates (Kessel, 1979; Kessel *et al.*, 1982; 1986, Fig. 1, core 1-81). Lake Kahala and the surrounding mire were studied to obtain well dated pollen, diatom and macrofossil records, to document the impact of prehistoric man upon the

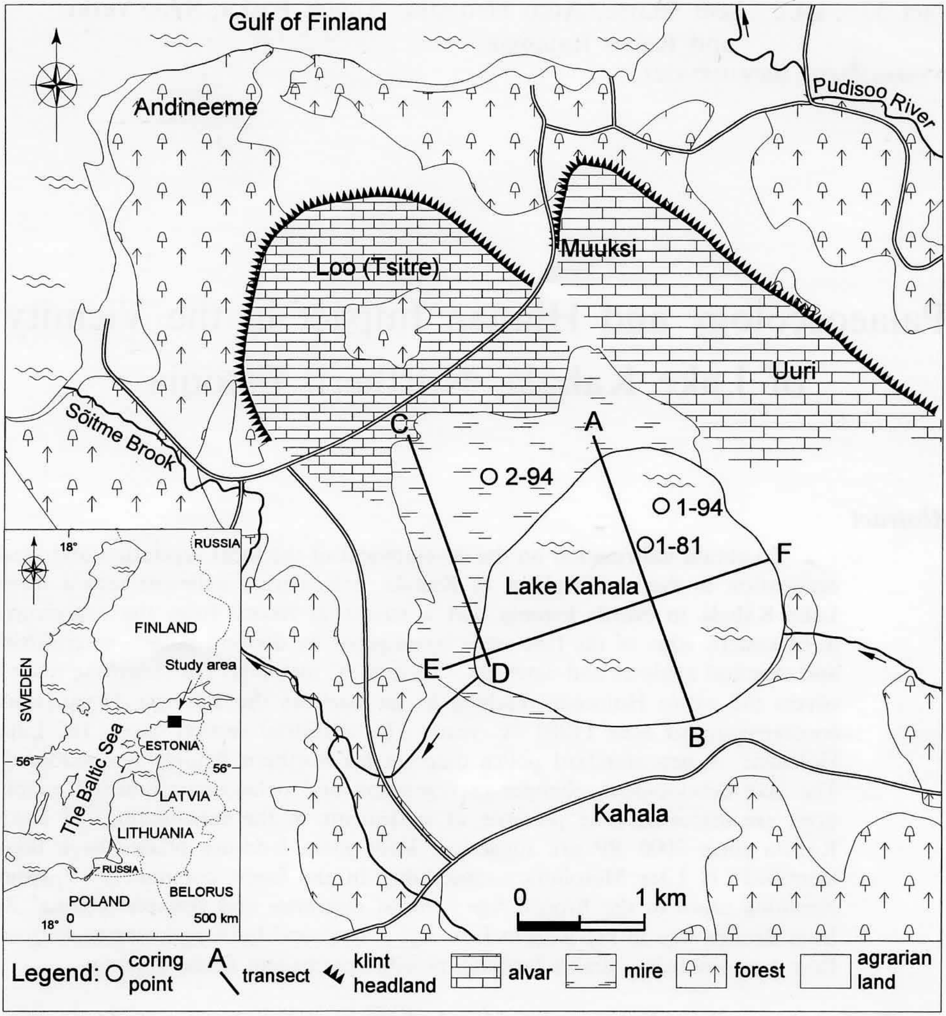

Fig. 1. Location of Lake Kahala showing the sampling sites and the transects.

vegetation and to reconstruct the environmental changes in the past. A lacustrine core 1-94 (Fig. 1) was selected for the palaeoecological investigation, which includes sediment chemistry, pollen, diatom, macrofossil, ^{14}C and ^{210}Pb analyses (Rajamäe *et al.*, 1997). The core covers part of the Late Glacial and the entire Holocene. The lacustrine sequence was expected to give a regional pattern of the vegetation development as the large water surface area of the lake (*c.* 350 ha) suggests the overrepresentation of the regional pollen rain. To obtain information about the local vegetation development and the land use in the surrounding *alvar* areas a terrestrial section (core 2-94) was preferred. The sampling point was chosen according to the local topographical conditions, the location of the archaeological sites and the main wind direction in the area.

The main aim of this case study was to work out a standard pollen diagram for northern Estonia, and to reconstruct the landscape development (shoreline displacement, vegetation history, lake evolution) and human impact (land use, settlement history) in the Kahala region.

METHODS

The sediments were cored in the spring of 1994 using a Belarus peat corer with a tube length of 1 m and the diameter of 70 mm. The unconsolidated surface sediments of the lake were collected with a Limnos sampler. The core was sub-sampled at 1 cm intervals for pollen and diatom analyses, 2 cm intervals for the bulk organic, terrigenous and carbonate fraction analyses and 5-10 cm intervals for the radiocarbon datings. Four parallel cores were used to obtain enough material for the conventional ^{14}C dates. The material was later examined in the laboratory and the samples for different analyses were chosen.

For pollen analysis 0.5 cm^3 of wet sediment was taken every 10 or 5 cm. For the sample preparation the classical acetolysis method was used (Erdtman, 1936). Samples containing minerogenic material were pre-treated with heavy-liquids (Faegri and Iversen, 1989). Analyses were carried out with a Zeiss Jenaval microscope, at a magnification of 400 x (for critical determinations 1000 x), *c.* 1000 arboreal pollen (AP) were counted per sample. The lowermost part of the cores with a high mineral content was handled differently: at least 4 cm^3 of wet sediment was taken, before acetolysis samples were treated with heavy liquid and at least 300 AP were counted. Still, in some cases low pollen concentration made it impossible to carry out pollen analysis at the required level. The basis for the percentage calculations of the data is the sum of arboreal and nonarboreal pollen (AP + NAP). Altogether 43 samples were analysed for diatoms from the 7 m deep lacustrine sequence. The sediment samples were treated with 30% H_2O_2 at room temperature and later at a temperature of 50-60° C, until all organic matter was removed. The diatom frustules were separated from the coarser and finer mineral matter by repeated decantation. In the slide preparation Naphrax was used as the mounting medium (refraction index 1.73). The analyses were carried out under a Zeiss Axiolab microscope at a magnification of 1600 x (N.A. = 1.25), using oil immersion and phase contrast. In each sample 350-500 non-*Fragilaria* spp valves were counted. Because of its mass occurrence, *Fragilaria* spp is excluded from the base sum for the frequency calculations. Identifications were mostly based upon the floras of Hustedt (1930; 1927-1966), Mölder and Tynni (1969-1973), Tynni (1975-1980), Krammer and Lange-Bertalot (1986-1991). With respect to the diatom taxonomy the «classical» names were mostly used.

The organic fraction of the sediment was determined by loss-on-ignition at 550° C. Each 10th cm of the sequence was treated for 2 hours. The carbonate

($CaCO_3$) content was estimated in terms of the difference between the loss-on-ignition at 825° C and at 550° C and multiplied by 2.27.

The pollen, diatom and mineral composition diagrams were plotted with the Tilia and Tilia Graph programs (Grimm, 1992). The black curves represent percentage values, shaded curves show values exaggerated tenfold. The human impact diagram was constructed according to Berglund and Ralska-Jasiewiczowa (1986).

Altogether thirteen conventional radiocarbon dates were obtained from the lake sediment, two from the modern aquatics (Table1) and five ^{210}Pb dates from the surface sediments (Rajamäe *et al.*, 1997). The time-scale is reconstructed by linear interpolation between the available ^{14}C dates.

The samples for macrofossil analysis were dispersed in KOH for one day before washing under tap water through a 0.25 mm sieve. The macrofossils and seeds were picked out, stored and analysed.

Study area

Lake Kahala (59°29' N, 25°31' E, Fig. 1) is located 40 km east of Tallinn in the Harju County, at the western corner of the Lahemaa National Park. It lies on the North Estonian limestone plateau, not far from the klint escarpment. The lake measures 2.4 km in length, 2 km in width and 350 ha in area, the threshold elevation is about 33.5-34.0 m a.s.l. The lake is surrounded by a peaty belt with bands of sand and silt beyond that. The water level is regulated at 33.2 m a.s.l, mean water depth is 1 m and maximum 2.2 m.

Geological setting

Lake Kahala lies in the Muuksi klint bay, a depression in the Ordovician bedrock and is surrounded by the Loo and Muuksi-Uuri klint headlands to the north and Sõitme on the west. These headlands tower some 20-25 m above the Muuksi klint bay, with depression in between, which connect the basin of Lake Kahala with the fore-klint lowland. Limestone of the Kunda Regional Stage out crop in the klint headland, while in the Muuksi klint bay the above-mentioned strata have been eroded and the bedrock surface is composed of sandstone and aleuorolithe of the Pakerort Regional Stage. This gives grounds for concluding that Lake Kahala has a Pre-Glacial erosion basin (Linkrus, 1979). The topography around the lake is rather flat, disjointed in the north by two spits connecting the Loo (Tsitre) and Muuksi-Uuri klint headlands at an elevation of 37.5 m and in the west by a spit forming an elongation to the Loo klint headland at 35 m a.s.l. The catchment of the lake is covered by thin abraded till, limnoglacial and marine sand or peat. The thickness of the Quaternary deposits varies from 10-30 cm on the klint headlands to 2-3 m at the ancient coastal formations.

The bottom topography of Lake Kahala is rather regular (Kessel *et al.*, 1982). About 96% of the bottom is covered by gyttja reaching far beyond the present lake contour on the northern and northwestern part but missing in the narrow northeastern belt. The gyttja layer is up to 6.5 m thick (average about 3.5 m), and is underlain by silt, and in the littoral zone also by sand (Fig. 2). In the deeper part it is underlain by silty clay and clay. The surface of the mineral deposit lies at an altitude 26.0-28.0 m, higher than in the littoral zone. The Ancylus Lake beach ridge in the northwestern part of the overgrown lake is now covered by peat.

RESULTS

SEDIMENT LITHOLOGY

Eight different beds were recognized within the postglacial lacustrine and terrestrial sediment sequence. The sediment stratigraphy of cores 1-94 and 2-94, which were investigated in detail is as follows:

TABLE 1. SEDIMENT STRATIGRAPHY OF CORES 1-94 AND 2-94

Depth below sediment surface, cm	Sediment description
	Core 1-94
0- 20	Unconsolidated gyttja, dark brown
20- 60	Coarse detritus gyttja, brown
60-465	Algal gyttja, brown
465-490	Silty gyttja, greenish brown
490-575	Gyttja, greenish brown
575-595	Organic silt, greenish grey
595-620	Silt, greenish grey
620-770	Silty clay, bluish
	Core 2-94
0- 80	*Sphagnum* peat, decomposed
80-238	*Sphagnum-Eriophorum* peat
238-265	*Sphagnum* peat, decomposed
265-277	Peaty gyttja
277-300	Sandy gyttja
300-310	Fine sand with plant remains
310-315	Medium sand with plant remains
315-320	Silt

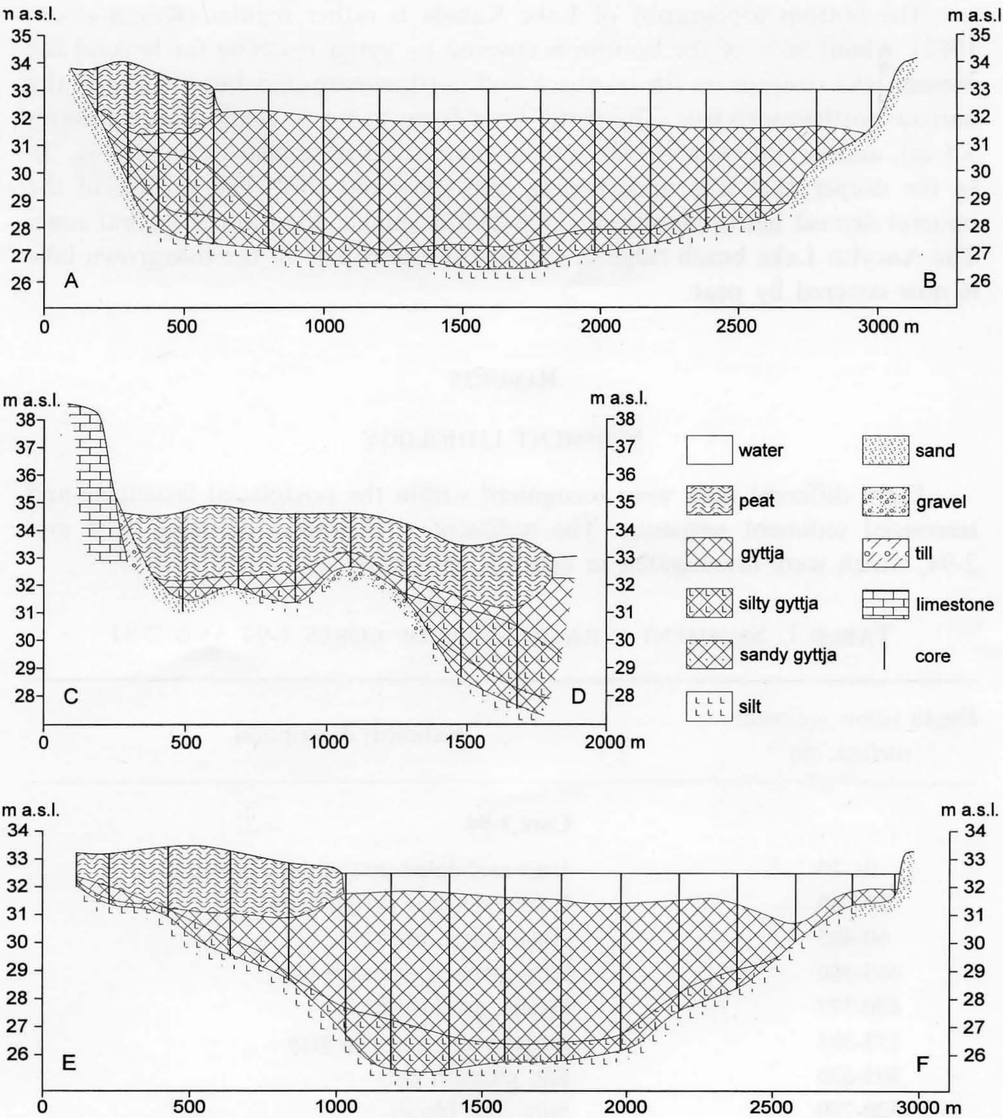

Fig. 2. Stratigraphic sequences of the transects (A-B, C-D and E-F) after R. Sinisalu.

SEDIMENT COMPOSITION

The homogenous bluish silty clay (770-620 cm) deposited in the Baltic Ice Lake is the oldest Late Glacial sediment unit recorded in the lake bottom. It contains 2-4% organic matter, 4-10% carbonate, most probably allothigenic, and 87-93% terrigenous fraction (Fig. 3). In the mineralogical composition quartz (46-47%), feldspar (10-20%), calcite (2-5%), dolomite (5-6%), hydromicas (11-16%) and chlorite (3-4%) have been determined (Saarse *et al.*, 1984).

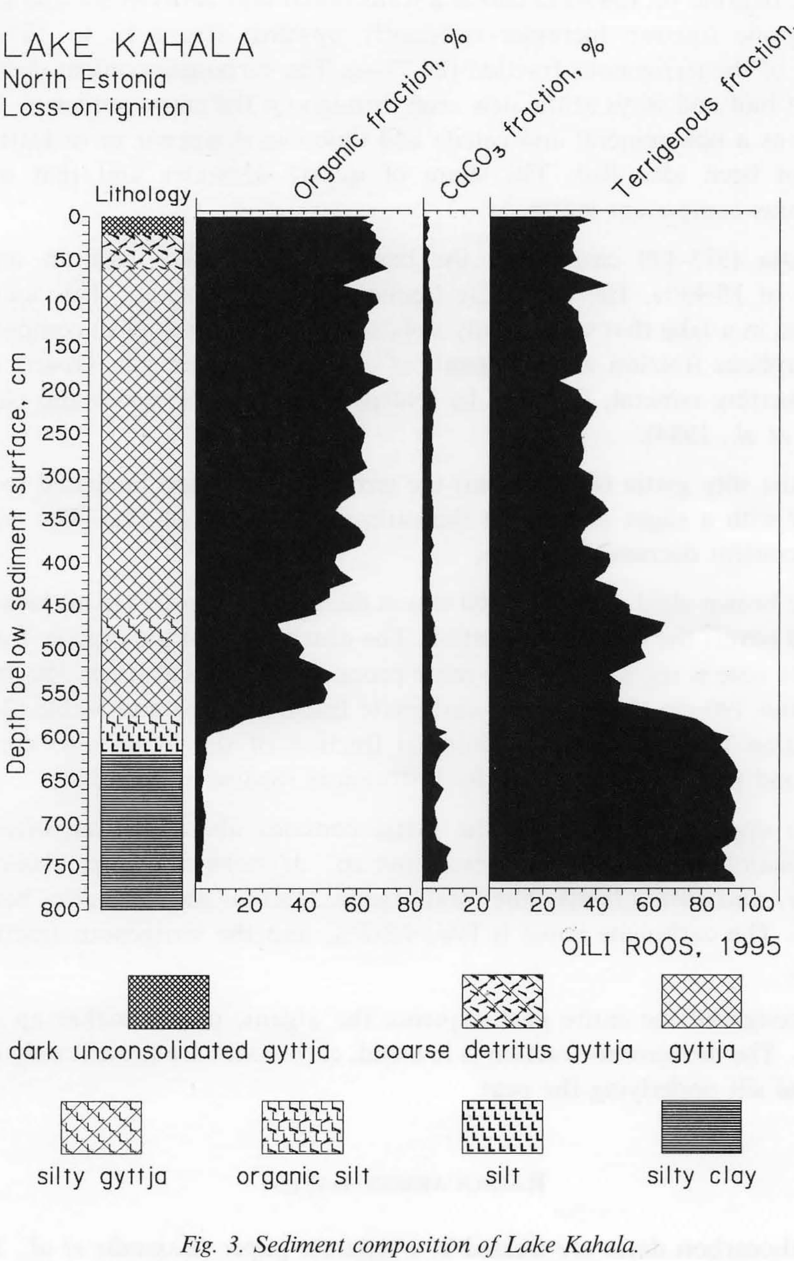

Fig. 3. Sediment composition of Lake Kahala.

A greenish grey silt (620-595 cm) is deposited almost all over the basin, except in the littoral zone. Silt accumulated in a bay and lagoon of the Yoldia Sea as it was becoming shallower. Its mineralogical composition is rather similar to that of the silty clay. In addition to the terrigenous fraction, the silt also contains 3-6 % organic material and 6-10 % carbonate.

The organic silt (595-575 cm) is a transitional unit between silt and gyttja. The organic fraction increases constantly upwards (from 12 to 18%) on account of the terrigenous fraction (83-77%). The carbonate content decreases to about half and stays at the new level throughout the entire sequence. Pyrite appears as a new mineral and calcite and dolomite disappear or at least they have not been identified. The share of quartz decreases and that of the amorphous component increases.

Gyttja (575-490 cm) forms the basal organic layer, with an organic fraction of 15-40%. The carbonate fraction is low and stable. This unit was deposited in a lake that was already isolated. In the mineralogical composition an amorphous fraction with remnants of clay minerals prevails. Quartz is the predominating mineral, followed by feldspar, hydromicas, pyrite and chlorite (Saarse *et al.*, 1984).

In the silty gyttja (490-465 cm) the terrigenous fraction increased to 66% together with a slight increase in the carbonate fraction (4-5%). The organic matter content decreased to 30%.

The brown algal gyttja (465-60 cm) is the thickest (up to 4-5 m) lacustrine unit and covers the whole lake bottom. The distribution of the organic fraction along the core is regular with two more pronounced peaks at levels 360-380 cm (63%) and 190 cm (71.5%). The carbonate fraction is low and stable (2-4%). In addition to carbonates, the mineral fraction of the gyttja also contains quartz and pyrite, and sporadically hydromicas (Saarse *et al.*, 1984).

The uppermost 60 cm of the gyttja contains abundant macroremains, predominantly limnophytes (*Potamogeton* sp., *Myriophyllum* spp, *Zanichellia palustris)* and *Betula* fruits. The total organic fraction content varies between 61-71%. The carbonate value is low, 1.2-2%, and the terrigenous fraction is 27-32%.

Throughout the entire peat sequence the organic matter makes up about 96-98%. The terrigenous fraction is low and, carbonates are present only in the sand and silt underlying the peat.

RADIOCARBON DATES

Radiocarbon dates are treated in a separate paper (Rajamäe *et al.*, 1997). For this reason only the results of the radiocarbon dates are presented here (Table 2).

Five ^{210}Pb dates from gyttja between 2.5-22.5 cm show that this portion of the sediment accumulated during the last 90 years and that the subsurface sediments are not disturbed by bioturbation or sediment reworking processes, as suggested on the basis of the radiocarbon dates (Rajamäe *et al.*, 1997).

TABLE 2. UNCALIBRATED ^{14}C DATES FROM THE KAHALA SECTIONS (CORES 1-94 AND 2-94).

Depth interval, cm	Sediment	^{14}C date	Laboratory index
Core 2-94			
85-95	*Sphagnum* peat	1155 ± 40	Tln-1951
115-125	*Sphagnum* peat	2065 ± 35	Tln-1954
155-125	*Sphagnum* peat	2355 ± 35	Tln-1957
185-195	*Sphagnum* peat	2975 ± 45	Tln-1958
250-260	*Sphagnum* peat	3455 ± 85	Tln-1937
260-267	Detritus gyttja	3660 ± 40	Tln-1955
Core 1-94			
0-5	Gyttja, < 0.7 mm	805 ± 75	Tln-1915
10-15	Gyttja, < 0.7 mm	1150 ± 50	Tln-1920
20-25	Gyttja, < 0.7 mm	1470 ± 55	Tln-1917
30-35	Gyttja, < 0.7 mm	1900 ± 55	Tln-1921
40-45	Gyttja, < 0.7 mm	2085 ± 55	Tln-1919
65-75	Gyttja, < 0.7 mm	2245 ± 40	Tln-1948
95-105	Gyttja, < 0.7 mm	3660 ± 95	Tln-1949
125-135	Gyttja, < 0.7 mm	4015 ± 105	Tln-1950
155-165	Gyttja, < 0.7 mm	4435 ± 80	Tln-1926
255-265	Gyttja, < 0.7 mm	5590 ± 55	Tln-1925
355-365	Gyttja, < 0.7 mm	7250 ± 65	Tln-1927
455-465	Gyttja, < 0.7 mm	8435 ± 85	Tln-1928
555-565	Gyttja, < 0.7 mm	9725 ± 80	Tln-1936
Macrophytes			
Submerged	*Myriophyllum*	107 ± 1.25	Tln-1986
Submerged	*Myriophyllum*	110 ± 0.68	Tln-1987

POLLEN STRATIGRAPHY

The biostratigraphical material has been described in terms of pollen assemblage zones (PAZ) and correlated with the chronozones (CSZ; Mangerud *et al.*, 1974; Raukas *et al.*, 1995). The pollen diagram from the lacustrine deposits is divided into 12 local PAZs (Fig. 4), the terrestrial – into 7 PAZs (Fig. 5).

1. NAP PAZ, 770-670 cm, silty clay, Younger Dryas CSZ (Fig. 4). *Betula* dominates and has a small maximum (*c.* 40%) in the middle of the PAZ. The curve of *Pinus* has stable values around 15%. *Alnus* and *Corylus* have a similar trend with somewhat lower values. *Salix, Ulmus* and *Picea* pollen is continuously present. Some pollen grains of *Juniperus* and *Tilia* appear. The amount of NAP is 25%, *Artemisia*, Chenopodiaceae, Poaceae and Cyperaceae predominate. *Sphagnum* spores have a maximum of 10% at the bottom of the PAZ and decrease upwards. Cysts of dinoflagellates («*Hystrix*») occur. The amount of charcoal particles is high (*c.* 80%).

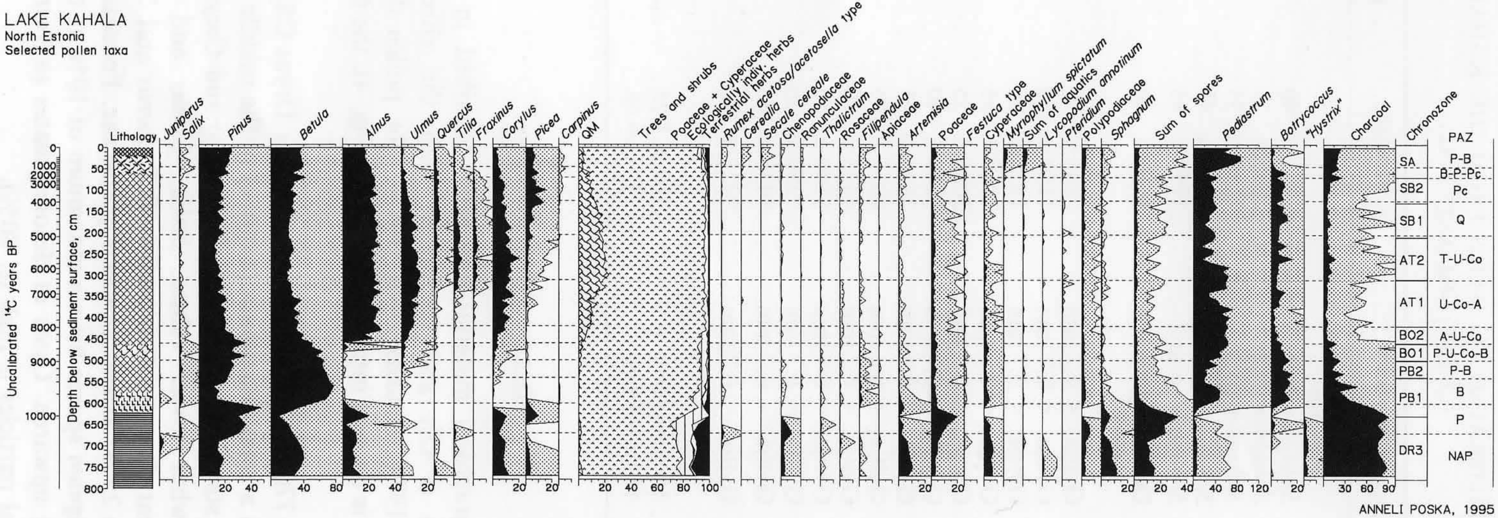

Fig. 4. Pollen diagram from Lake Kahala. For explanations of the lithology, see Fig. 3.

2. *Pinus* PAZ, 670-600 cm, silty clay, silt, Younger Dryas CSZ (Fig. 4). It should be noted that the amount of pollen counted in this zone does not reach 100 AP grains per sample and is therefore not comparable with the other parts of the sequence investigated. The most remarkable feature is the relatively high share (up to 40%) of *Pinus* pollen, in contrast to the minimum of *Betula* (10%). Redeposit *Alnus, Corylus* and *Picea* frequencies reach 10-20%, but diminish at the upper border of the zone. Some pollen grains of *Ulmus* and *Tilia* appear. *Salix* is present at low stable values. The amount of NAP decreases from 30 to 15%, Poaceae dominate. The share of the green algae is low, with a sharp increase of *Pediastrum* from 5 to 50%, and *Botrycoccus* from 1 to 15% in the middle of the PAZ. The curve for «*Hystrix*» has a reverse development and diminishes simultaneously with the increase in other algae. The charcoal decreases evenly (from 85 to 35%).

3. *Betula* PAZ, 600-540 cm, organic silt and gyttja, Early Preboreal CSZ (Fig. 4). *Betula* has a maximum of *c.* 75%. *Pinus* has values around 10%, *Salix* around 2%. *Corylus* and *Ulmus* occur more frequently, and the pollen of *Juniperus*, *Alnus* and *Quercus* still sparsely. The amount of NAP is modest (*c.* 10%). Poaceae and Cyperaceae predominate. *Pediastrum* has a maximum of 47%, but decreases sharply towards the end of the PAZ. *Botrycoccus* has stable values around 10%. The amount of charcoal particles decreases evenly.

4. *Pinus-Betula* PAZ, 540-500 cm, gyttja, Late Preboreal CSZ (Fig. 4). *Betula* still dominates, but decreases slowly upwards. The curve for *Pinus* shows the opposite development. *Corylus* and *Ulmus* occur more frequently. *Salix* is continuously present at low values. The NAP value is low (*c.* 5%). Poaceae and Cyperaceae predominate. The amount of *Pediastrum* is modest, but shows some increase towards the end of the PAZ. Charcoal continues to decrease.

5. *Pinus-Ulmus-Corylus-Betula* PAZ, 500-460 cm, gyttja and silty gyttja, Early Boreal CSZ (Fig. 4). *Betula* still dominates, *Pinus* increases and has a maximum at *c.* 35% here. Near the lower boundary *Ulmus* and *Corylus* reach their rational limits and increase slowly upwards. Pollen of *Alnus* appears more frequently, *Salix* declines. The amount of NAP is about the same as in the previous PAZ, Poaceae and Cyperaceae still predominate. The amount of *Pediastrum* increases from 20 up to 65%. The number of charcoal particles decrease.

6. *Alnus-Ulmus-Corylus* PAZ, 460-420 cm, algal gyttja, Late Boreal CSZ (Fig. 4). *Pinus* and *Betula* decrease evenly. *Ulmus* and *Corylus* show an opposite trend. At the lower boundary of the zone a sharp increase in the curve for *Alnus* (from 2 to 20%) is evident. *Quercus* is present sporadically. Some pollen grains of *Picea*, *Tilia* and *Fraxinus* are observed. The amount of NAP is low. The curve for *Pediastrum* is uniform at about 65%, *Botrycoccus* decreases. The value of charcoal particles is stable, but low (*c.* 5%).

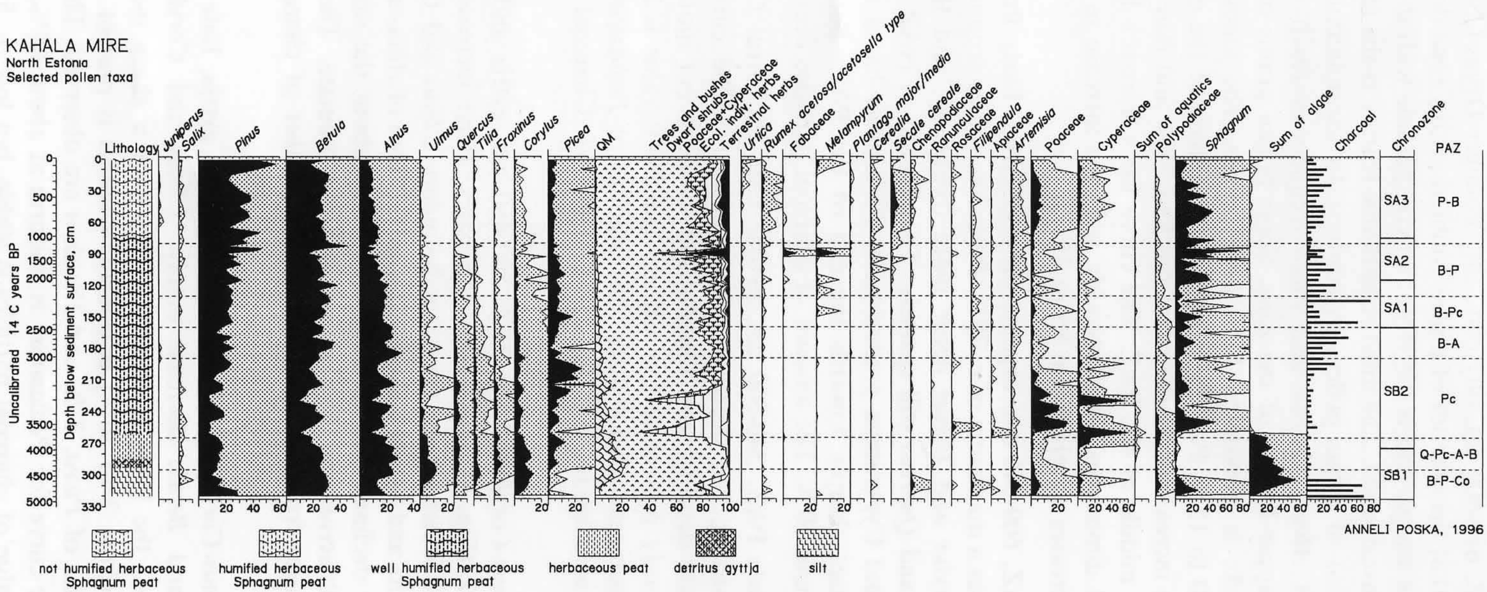

Fig. 5. Pollen diagram from Kahala mire.

7. *Ulmus-Corylus-Alnus* PAZ, 420-310 cm, algal gyttja, Early Atlantic CSZ (Fig. 4). The curve for *Betula* is relatively uniform at around 25%. The curves for *Pinus* and *Alnus* have a similar development with somewhat lower values (15 and 20%, respectively). *Ulmus* and *Corylus* frequencies increase evenly. The same development, but at smaller amounts are shown by the pollen of *Quercus, Tilia, Fraxinus* and *Picea*. The NAP value is *c.* 5%. *Pteridium* can be detected among the spores. *Pediastrum* diminishes sharply (to 35%) in the middle of the zone, but recovers upwards. *Botrycoccus* shows a reverse development with lower values. The amount of charcoal particles is small.

8. *Tilia-Ulmus-Corylus,* 310-205 cm, algal gyttja, Late Atlantic CSZ (Fig. 4). The curves for *Pinus, Betula* and *Alnus* reflect the same development as in the previous PAZ. *Ulmus* (13%), *Tilia* (6%), *Corylus* (15%) and *Fraxinus* (3%) have subsequent maxima. The frequencies of *Quercus* and *Picea* increase. The amount of NAP is low. Alongside Polypodiaceae and *Sphagnum* some *Pteridium* spores occur. The amount of *Pediastrum* is high (*c.* 65%) during the first half of the zone, but decreases to 45% and stays at that level during the second half of the PAZ. The curve for *Botrycoccus* has an opposite development with low values. Charcoal values rise towards the end of the PAZ to reach *c.* 10%.

8 a. In the terrestrial sequence a *Betula-Pinus-Corylus* PAZ (314-295 cm, silt) has been described with *Betula* dominating at around 30% and *a Pinus* maximum (*c.* 28%) at the beginning of the PAZ (Fig. 5). The curve of *Alnus* fluctuates around 15%. *Corylus* increases and has a maximum (14%). *Ulmus, Quercus* and *Tilia*, and to a lesser degree also *Picea*, increase. *Salix, Carpinus, Acer* occur sparsely. The amount of NAP is high, up to 25%, Poaceae, Cyperaceae, *Artemisia* and Chenopodiaceae predominate. Spores of Polypodiaceae appear continuously. *Sphagnum* is high (up to 25%) but diminishes, *Pediastrum* is also high (30%), with *Pediastrum kawraisky* dominating. The amount of the charcoal particles decreases drastically from 60 to 5%.

9. *Quercus* PAZ, 205-125 cm, algal gyttja, Early Sub-Boreal CSZ (Fig. 4). The curves for *Pinus, Betula* and *Alnus* are similar to that of the previous PAZ. *Ulmus, Tilia, Fraxinus* and *Corylus* decrease evenly upwards. The pollen curve of *Picea* shows the opposite development. *Quercus* has a maximum (*c.* 4%) in the middle of the zone. Some pollen grains of *Salix* and *Carpinus* are observed. The amount of NAP is small with some increase in the pollen frequencies of terrestrial NAP. Pollen grains of *Melampyrum* and *Plantago lanceolata* occur near the lower limit of the zone. *Pediastrum* (*c.* 50%) and *Botrycoccus* (*c.* 12%) are stable. The charcoal amount is relatively stable.

9 a. The same chronozone is represented by the *Quercus-Picea-Alnus-Betula* PAZ in the terrestrial core, (295-265 cm, detritus gyttja, Fig. 5). The dominant pollen taxon, *Betula* declines relative to *Pinus. Alnus* is stable and high at 25%. *Tilia* (4%), *Ulmus* (10%) and *Fraxinus* (5%) have subsequent

maxima and *Quercus* is stable at *c.* 5%. Nevertheless, as a whole, the QM component and also *Corylus* decrease. *Picea* increases evenly (12%). Pollen of *Carpinus* and *Acer* occur sparsely. The amount of NAP does not exceed 5%, Poaceae and Cyperaceae predominate. Polypodiaceae spores are present at low (1-2%) values. Since this PAZ *Pteridium* is continuously represented. The amount of *Pediastrum* algae decreases to 15% and diminishes sharply at the upper boundary of the PAZ. Charcoal particles values are low (*c.* 5%).

10. *Picea* PAZ, 125-70 cm, algal gyttja, Late Subboreal CSZ (Fig. 4). *Pinus* and *Betula* increase slightly. QM, *Corylus* and *Alnus* on the contrary, slowly decrease. The curve of *Picea* has a maximum (*c.* 15%) in the middle of the PAZ. Pollen of *Salix* and *Carpinus* is more common. The amount of NAP is continuously low. In the middle of the zone the first pollen grains of Cerealea are registered. The curves for *Pediastrum, Botrycoccus* and charcoal have a similar development as during the previous PAZ.

In the terrestrial core the Late Subboreal CSZ is represented by two PAZs (Fig. 5).

10 a. *Picea* PAZ (265-190 cm, *Sphagnum* peat, the earlier part of the Late Subboreal CSZ, Fig. 5). The curve of *Pinus* has an uneven shape and fluctuates around 10% showing a little increase. The *Betula* and *Alnus* curves have the same development but at slightly higher values. Pollen frequencies of the QM and *Corylus* decrease to 5%, except *Quercus* which has a maximum (6%). The maximum of *Picea* (*c.* 25%) is well developed in the later part of the PAZ. Pollen of *Salix, Carpinus, Acer* and *Fagus* occur sparsely. The amount of the dwarf shrubs, especially *Calluna*, increases (up to 10%). The share of NAP is high due to the abundant Cyperaceae (up to 68%) and Poaceae (up to 25%) during the first half of the PAZ. The first Cerealea, *Secale cereale* and *Melampyrum* finds are registered here. *Sphagnum* dominates among the spores. The charcoal particles do not exceed 10%.

10 b. *Betula-Alnus* PAZ (190-160 cm, *Sphagnum* peat, the later part of the Late Sub-Boreal CSZ; Fig. 5). The curves of *Betula* and *Alnus* fluctuate around 20%, *Pinus* around 15%. QM and *Corylus* decrease to 1-2% as does *Picea* (*c.* 7%). The share of the dwarf shrubs increases slowly reducing the NAP value (*c.* 5%). Nevertheless, some increase in the graphs of terrestrial herbs is seen. *Sphagnum* fluctuates around 10%. Charcoal increases rapidly up to 50% and big particles of charcoal appear.

11. *Betula-Pinus-Picea* PAZ, 70-45 cm, coarse detritus gyttja, Early and Middle Sub-Atlantic CSZ (Fig. 4). *Pinus* and *Betula* rise, QM, *Corylus* and *Alnus* diminish. *Picea* has a low maximum at *c.* 10% in the middle of the PAZ. The pollen of *Salix* and *Carpinus* occurs more frequently. The NAP curve rises slightly, mainly due to the increase in Poaceae and terrestrial herbs. The first *Secale cereale* pollen grain is registered near the lower boundary of the PAZ. A significant rise in aquatics, mainly on account of the dominating *Myriophyllum*

spictatum is recorded. The curves of *Pediastrum* and *Botrycoccus* have a similar development to the previous PAZ. The amount of charcoal particles increases to 20%.

In the terrestrial core two PAZs have been distinguished.

11 a. *Betula-Picea* PAZ (160-130 cm, *Sphagnum* peat, Early Subatlantic CSZ; Fig. 5). The curves for *Pinus, Betula* and *Alnus* are rather stable (20, 25, 15% respectively). *Picea* recovers and has a second maximum at *c.* 17%. The dwarf shrubs frequency is high. The amount of the terrestrial herbs continues to increase. *Secale cereale*, *Plantago lanceolata* and *Melampyrum* appear continuously from this PAZ onwards. The amount of the *Sphagnum* spores is modest. Charcoal particles have a maximum at 75%, accompanied by a simultaneous maximum of big charcoal particles (7%).

11 b. *Betula-Pinus* PAZ (130-80 cm, *Sphagnum* peat, Middle Subatlantic; Fig. 5). *Pinus* is relatively stable at *c.* 25%, whereas *Betula, Alnus* and *Picea* decrease slowly. The dwarf shrubs are high, especially *Calluna*, which has a maximum at 27%. The average amount of NAP is about 10%, with a maximum at 30%, due mainly to the increase in Fabaceae and *Melampyrum*. The proportion of charcoal particles is modest (*c.* 20%).

12. *Pinus-Betula* PAZ, 45-0 cm, coarse detritus gyttja, Late Subatlantic CSZ (Fig. 4). *Pinus* shows some increase, *Betula* is stable at around 35%. The curve of *Picea* has a similar development to *Betula*, but with lower values (*c.* 7%). *Alnus* decreases evenly. Each of the constituents of the QM is around 1-2%. Pollen of *Salix* and *Carpinus* occur continuously. The amount of NAP increases, mainly due to an increase in the pollen of terrestrial herbs, especially *Secale cereale* and other Cerealea. *Pediastrum* increases sharply up to 85%, *Botrycoccus* decreases. The amount of charcoal particles stays at the level obtained in the previous zone.

12 a. *Pinus-Betula* PAZ (80-0 cm, *Sphagnum* peat, terrestrial core, Late Subatlantic CSZ; Fig. 5). The *Pinus* curve fluctuates at around 30% with a pronounced maximum at 65% at the end of the PAZ. *Betula* is stable at about 25%, *Alnus* at 10% and *Picea* 5%. The QM value is insignificant. The share of the dwarf shrubs diminishes, especially due to the sharp decrease in *Calluna*. The amount of NAP is high (up to 20%), Poaceae, Cyperaceae and terrestrial herbs (mainly *Secale cereale*) predominate. The amount of charcoal particles is modest, at about 20%.

VEGETATION HISTORY

During the Younger Dryas the area investigated was covered by the Baltic Ice Lake with a considerable water depth. The possible pollen producing area was situated south, at some distance from the Kahala basin. The main part of the pollen grains and spores identified, especially those of *Alnus, Corylus,* *Picea, Ulmus, Quercus* and *Tilia,* but also the cysts of Dinoflagellatae, must be redeposited. At least part of the *Pinus* and *Betula* pollen are probably derived from the such a source. The unknown amount of secondary pollen and also the fact that the pollen production area is far away complicates the interpretation of the pollen spectra in terms of vegetation history. An open tundra-type vegetation with shrubs, dwarf shrubs and grasses might be expected. The only tree species whose presence may be considered during the Younger Dryas in North Estonia is birch. The major proportion of the pine pollen, apart from that which is redeposited, must be of long-distance transport origin. At an early stage Aario (1940) demonstrated the over-representation of pine pollen in open areas.

The transition from the lateglacial tundra-type vegetation to Preboreal birch woods is sudden and coincides with changes in the sediment composition. It is possible that a hiatus exists there. Nevertheless, after the drainage of the Baltic Ice Lake, the afforestation of the landscape began. Pine, and also hazel and elm immigrated to the area. The expansion of pine seems to have been rather insignificant. The local edaphic conditions did not favour pine and it only had a place as an integrated member in woods dominated by other species.

The vegetation in the Early Boreal was characterized by a marked dominance of the light demanding tree species, such as birch and pine. The forest succession favoured hazel and elm as competition from other species was low. Their expansion, however, seems not to have been particularly rapid, indicating that they probably became integrated members of the forest rather than forming pure stands in the area. The lack of favourable sites may be one of the reasons.

The immigration of alder took place in the latter part of the Early Boreal and it expanded quickly in the Late Boreal. Due to its edaphic demands, alder does not suffer serious competition from other species, except from willow and birch. The local topography was auspicious for alder, which grew luxuriantly along the low, swampy lake shore, causing a considerable filtering effect on the pollen dispersion of the other species. The alder-curtain-effect (Påhlsson, 1977) is seen more in the present diagram than in the older one (Kessel *et al.*, 1982). The expansion of hazel and elm at the expense of birch and pine is obvious. Oak probably immigrated into the area, but grew only as scattered trees. In the established dense deciduous forest the proportion of herbs was low. The appearance of NAP in the lake sediment was also greatly reduced by the rim of alder.

Forest development in the Atlantic is characterized by an increased representation of the Quercetum mixtum constituents. The share of elm and hazel in the forests increased, indicating a certain abundance of suitable growing places. With the immigration of lime all broad-leaved trees, except hornbeam, had arrived in the area. A substantial change in forest composition seems to take place around 7000 BP when the values of *Tilia, Quercus* and

Fraxinus increase remarkably. Lime and oak occupied higher elevations and well-drained soils and eventually caused a reduction in the growth of birch and pine. A dense broad-leaved forest with greatly reduced herb underlayer developed. The slight increase in heliophilous species and irregularities in the QM curve indicate some sort of opening up of the forest cover.

Later on, in the Early Subboreal the forest composition began to gradually change. The most characteristic feature is the decreasing representation of the QM constituents and an increase in coniferous trees (Fig. 4). *Ulmus* declines at 5000 BP, but afterwards recovers a little and finally declines at 4500 BP. The cause of the general regression of the broad-leaved trees is obviously in the interaction of climate and human activities. Spruce expanded at the expense of the broad-leaved trees at the end of the Early Subboreal. The modest rise in apophytes (finds of *Rumex acetosa, Melampyrum* and *Plantago lanceolata*) and other herbs and the uneven pattern of the curves of tree pollen gives an impression of the appearance of pre-agrarian forest clearances in the area (Göransson, 1986; Regnell, 1991). Still, the bog diagram maintains a high representation of broad-leaved trees, especially hazel, elm, oak and ash evidently growing on the klint escarpment, favoured by lime banks, a maritime climate and closeness to the sea. The abundance of *Pediastrum* algae indicates the persistence of periodically limnic conditions in the overgrown part of Lake Kahala at the beginning of Late Subboreal time.

In the Late Subboreal the share of hazel and QM in the area decreased. Increased pollen of light-demanding trees (*Acer, Carpinus*), herb species (*Artemisia*) and Cerealea-type suggest an open landscape and small scale crop-farming. The expansion of spruce is in good correlation with the anthropogenic indicators. The northern part of the lake was rapidly overgrown, typical fen (Cyperaceae, most probably *Carex*-species, and Polypodiaceae) and later on also mire (*Sphagnum)* communities expanded. Still, before the final establishment of mire conditions with *Sphagnum* and Ericaceae as the dominating species, a short return to the Cyperaceae fen is seen. Species of Ericaceae expanded on to the bog during the second part of the Late Subboreal. Fire must have favoured the expansion of the dwarf shrubs, as their curve is in good correlation with that of the charcoal one. The amount of birch and alder is relatively unstable. It seems, that the stands around the lake shore were interrupted again and again. The amount of herb pollen is comparable with that of the closed forest, possibly because the alder curtain, is still in existence.

From the beginning of the Subatlantic time the area is rather open. With the diminishment of the alder the proportion of herbs rises considerably. The amount of trees, other than birch, is negligible. The increase in pine pollen is probably caused by the increased importance of the regional pollen rain than by an actual expansion of pine in the area. It seems, that the cultivation of *Secale cereale* in the area already began during the Early Subatlantic.

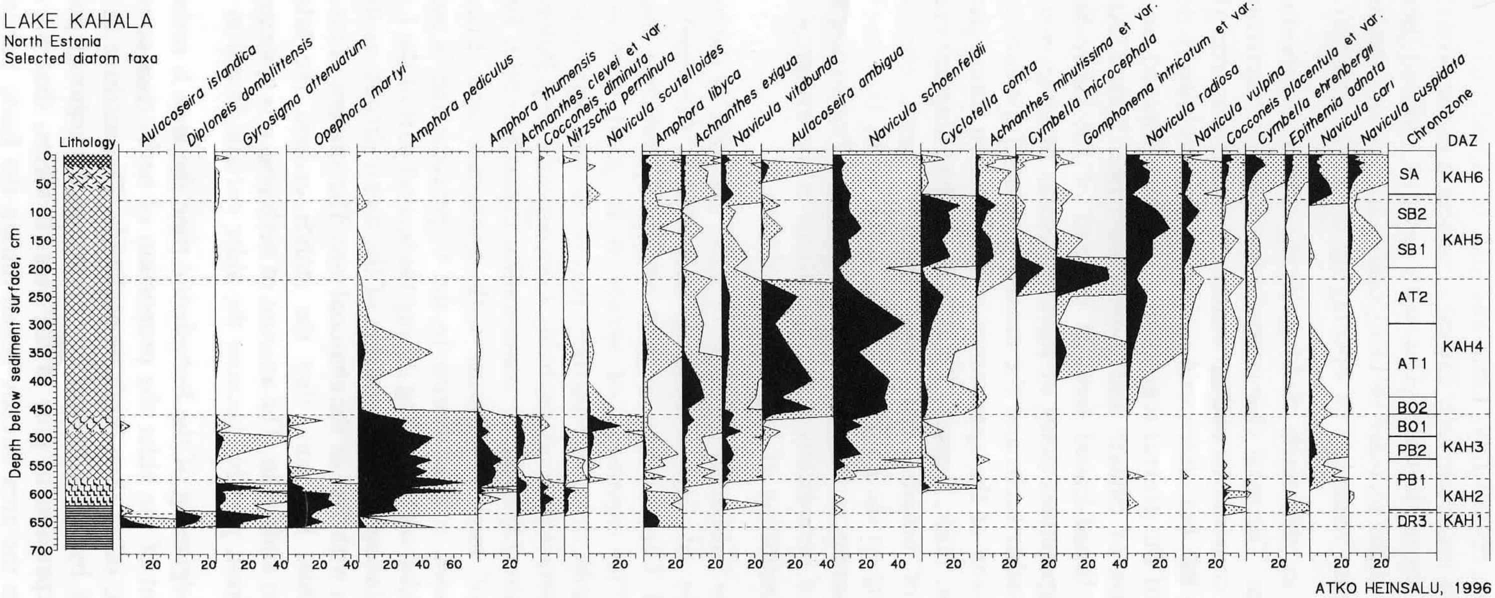

Fig. 6. Diatom diagram from Lake Kahala. For a description of the lithology, see Fig. 3.

Diatom stratigraphy

The diatom stratigraphy of the Lake Kahala sediments is divided into six local diatom assemblage zones (DAZ) and the composition of these diatom assemblages is shown in Fig. 6.

DAZ KAH 1, 660-635 cm, silty clay, Younger Dryas. This diatom assemblage is characterized by a high abundance of the clear-water diatoms *Aulacoseira islandica* (O. Müller) Simonsen, *Diploneis domblittensis* (Grunow) Cleve and *Gyrosigma attenuatum* (Kützing) Rabenhorst. *Opephora martyi* Héribaud, *Amphora libyca* Ehrenberg, *A. ovalis* Kützing, and *Gyrosigma acuminatum* (Kützing) Rabenhorst are also represented at high frequencies. The planktonic forms constitute up to 30% of the diatom assemblage. *Fragilaria* spp are represented by minor (10%) occurrences (Fig. 7).

DAZ KAH 2, 635-575 cm, silty clay, silt and organic silt, Younger Dryas and Early Preboreal. The planktonic *Aulacoseira islandica* disappears and the amount of other planktonic diatoms is insignificant. The abundance of total *Fragilaria*, mostly *Fragilaria construens* (Ehrenberg) Grunow and *Fragilaria brevistriata* Grunow increases to 60-80%. *Amphora pediculus* (Kützing) Grunow increases distinctly and *Opephora martyi* and *Gyrosigma attenuatum* are still present in high quantities. This assemblage is also characterized by the low frequency of periphytic clear-water diatoms such as *Achnanthes calcar* Cleve, *A. clevei* Grunow, *A. lanceolata* var. *elliptica* Cleve, *A. lanceolata* var. *rostrata* (Oestrup) Hustedt, *Cocconeis disculus* (Schumann) Cleve, *Cymatopleura elliptica* (Brébisson) W.Smith, *Cymbella sinuata* Gregory, *Diploneis elliptica* (Kützing) Cleve, *Navicula tuscula* (Ehrenberg) Grunow, *Epithemia adnata* (Kützing) Brébisson, *E. intermedia* Fricke, and *E. turgida* (Ehrenberg) Kützing. The freshwater diatoms *Cocconeis diminuta* Pantoscek, *C. placentula* Ehrenberg et var. and *Nitzschia perminuta* (Grunow) Peragallo also occur regularly.

DAZ KAH 3, 575-460 cm, gyttja and silty gyttja, Preboreal and Early Boreal. *Fragilaria* spp and *Amphora pediculus* remain dominant. Freshwater small lake diatoms such as *Navicula schoenfeldii* Hustedt, *N. vitabunda* Hustedt, *N. cari* Ehrenberg, *Cymbella diluviana* (Krasske) Florin and *Amphora thumensis* (Mayer) Cleve-Euler appear and *Opephora martyi* decreases distinctly. In the upper part of the zone, in connection with the decreased loss-on-ignition values there is a small peak of the clear-water diatom *Navicula scutelloides* W. Smith.

DAZ KAH 4, 460-220 cm, algal gyttja, Late Boreal and Atlantic. *Fragilaria* spp remain dominant. *Aulacoseira ambigua* (Grunow) Simonsen has a distinct maximum, *Cyclotella comta* (Ehrenberg) Kützing occurs in moderate frequencies and the planktonic forms increase to 20% of the whole assemblage. *Amphora pediculus* almost disappears, *Navicula schoenfeldii* reaches its highest value.

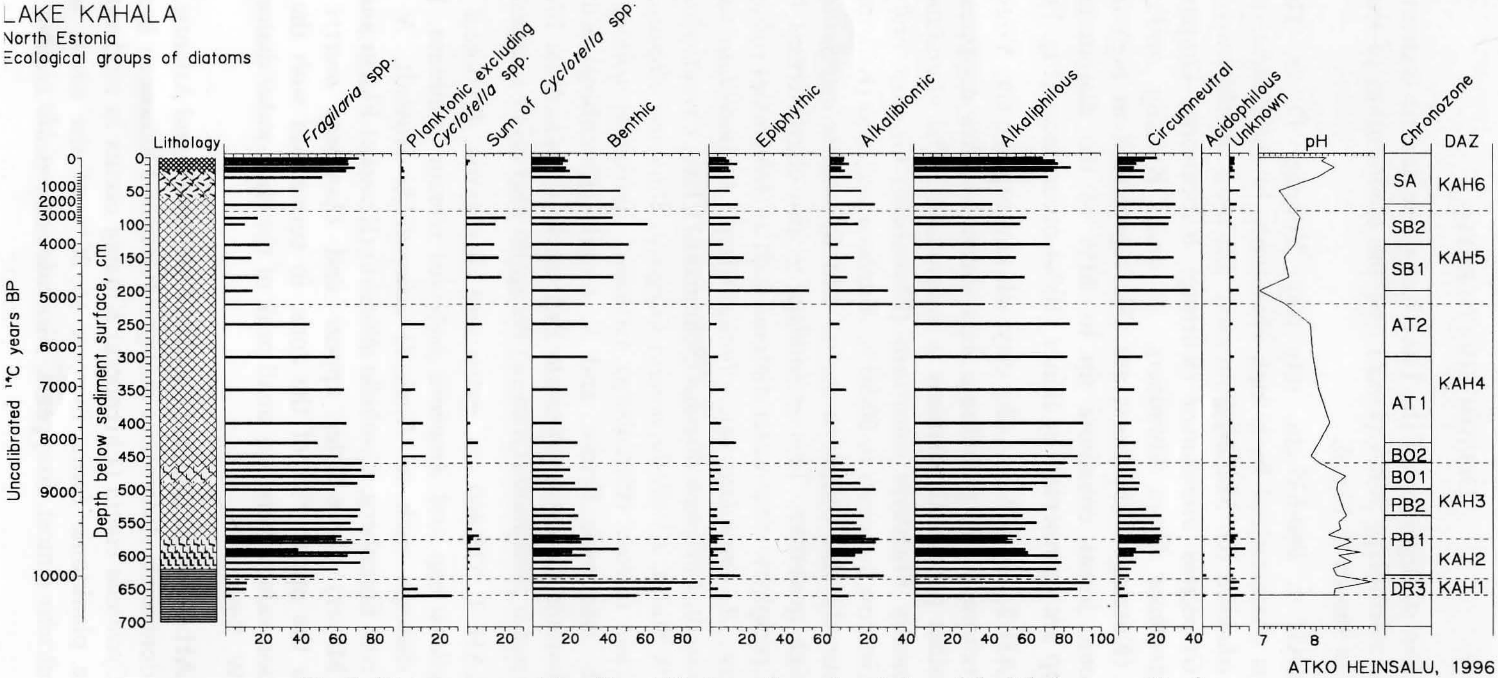

Fig. 7. Diatoms grouped by pH and life-form. For a description of the lithology, see Fig. 3.

DAZ KAH 5, 220-80 cm, algal gyttja, Subboreal. *Fragilaria* spp decrease to 20%. *Aulacoseira ambigua* almost disappears. *Cyclotella comta* occurs in high frequencies. The epiphytic *Cymbella microcephala* Grunow and *Gomponema intricatum* Kützing together with *Gomponema intricatum* var. *pumilum* Grunow show a rapid increase at the beginning of the zone and *Achnanthes minutissima* Kützing has its maximum. The benthic *Navicula schoenfeldii* decreases moderately, *N. radiosa* Kützing and *N. vulpina* Kützing reach their maxima.

DAZ KAH 6, 80-00 cm, algal gyttja and coarse detritus gyttja, Subatlantic. *Fragilaria* spp increase gradually to an abundance of 80%. *Cyclotella comta* and *Achnanthes minutissima* diminish sharply. *Cymbella ehrenbergii* Kützing, *Epithemia adnata, Navicula cari, N. cuspidata* Kützing and *Cocconeis placentula* show their maximum values.

THE pH HISTORY OF LAKE KAHALA

Diatoms are well-known ecological indicators of lake water pH (Battarbee, 1984; 1986). New methods for reconstructing past pH have been developed based on a multivariate analysis approach (Stevenson *et al.*, 1989; Birks *et al.*, 1990). The lack of modern training sets from Estonian lakes does not allow us to use these principles. Therefore the diatoms have been classified by pH preference groups (alkalibiontic, alkaliphilous, circumneutral and acidiphilous) according to Hustedt's traditional system (Hustedt, 1939). Information about the pH tolerance of the diatoms was obtained mostly from the studies of Pork (1967). For the calculation of numerical pH values the formula of Håkansson (1993) was used as it is applicable to work in the range of mesotrophic and eutrophic lakes.

Lake Kahala has remained alkaline throughout its whole history. During the isolation phase alkaliphilous and alkalibiontic taxa make up of 80-90% of the diatoms and the pH was around 8.5 (Fig. 7). A slight but continuous decrease in pH took place throughout DAZ KAH 5. At the transition of DAZs KAH 4/KAH 5 the amount of pH-indifferent (circumneutral) taxa increases and a fall in pH below 8 followed. The pH stayed below 8 until 3500 BP when its started to increase again. At a depth of 50 cm the number of circumneutral diatoms decreases.

For lakes situated in the regions of crystalline bedrock palaeolimnological evidence suggests that oligotrophication and acidification are natural processes (Digerfeldt and Håkansson, 1993). The reconstruction of the pH history of Lake Kahala reveals that even in a lake with a limestone catchment area leaching processes have exhausted the pool of available calcium ions in the soil, and decreased the buffering capacity and pH of the lake water. A climate change towards decreased humidity caused a lowering of water-level in Lake Kahala

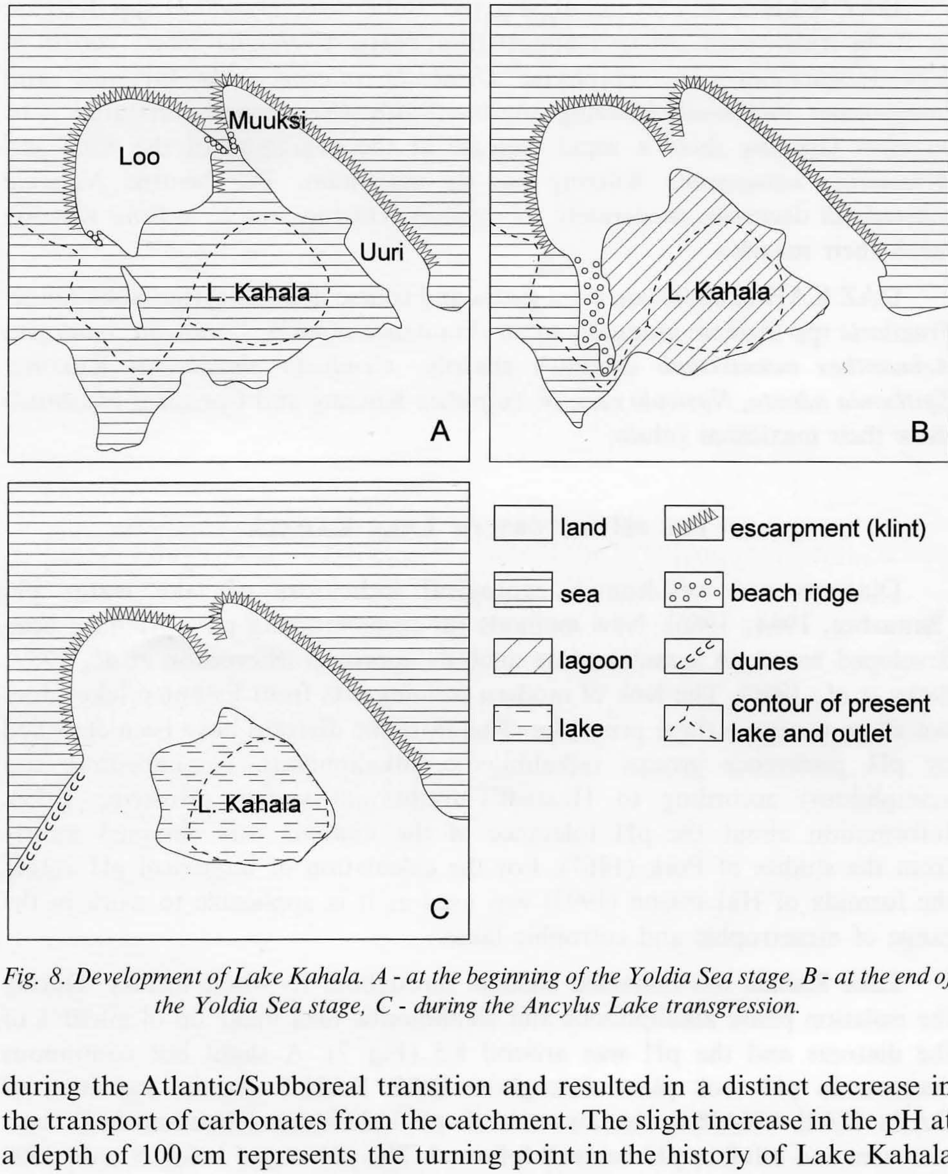

Fig. 8. Development of Lake Kahala. A - at the beginning of the Yoldia Sea stage, B - at the end of the Yoldia Sea stage, C - during the Ancylus Lake transgression.

during the Atlantic/Subboreal transition and resulted in a distinct decrease in the transport of carbonates from the catchment. The slight increase in the pH at a depth of 100 cm represents the turning point in the history of Lake Kahala and is obviously linked with the beginning of cultivation in the area.

DEVELOPMENT OF LAKE KAHALA

In the Younger Dryas about 10 500 BP the Baltic Ice Lake stood at a level of *c.* 67-68 m a.s.l. in this area and the of Lake Kahala basin was a part of it. Homogenous silty clay accumulated and clear-water diatom taxa immigrated.

The drainage of the Baltic Ice Lake caused remarkable environmental changes. North of Kahala an island and a peninsula appeared and the lake itself became a bay of the Yoldia Sea, connected with the open sea to the north and west (Fig. 8A), with a small island in the western strait. In this bay silt was deposited. The Yoldia Sea level stabilized at an altitude of 37-39 m, and spits were formed between the Loo and Muuksi klint headlands at a level of 37.5 m. This rather stable phase in the Yoldia Sea history existed about 10300-10200 BP. Soon after, *c.* 10000-9900 BP, an elongated spit with a limestone core was formed, south of the Loo klint headland, at an elevation of 35 m a.s.l. As the northern strait was already closed, the Loo spit isolated a lagoon in the Kahala basin and organic silt began to be deposited. The massive development of *Fragilaria* spp and the absence of planktonic diatoms refers to the shallow water conditions in the lagoon of that time. The diatom assemblage of the sediments of the Yoldia Sea stage in Lake Kahala indicates freshwater conditions.

This lagoonal phase lasted for a short time (10000-9900 BP). After that 9900-9850 BP the basin of Lake Kahala became an isolated alkaline eutrophic lake, where silty gyttja accumulated. The isolation level is rather difficult to interpret on the basis of the diatoms. Several of the clear-water species, however, decrease distinctly at a depth of 575 cm and many small lake diatoms appear at this level. The isolation contact is fixed in the sediment stratigraphy as the boundary between organic silt and gyttja, and is reflected in the pollen diagram as peaks in the curves of *Pediastrum* and *Pinus*.

An estimation of the magnitude of the Yoldia Sea regression in the area is complicated. An organic layer at the outer slope of the Muuksi-Uuri klint headland at an elevation of 28.4 m and buried below coastal deposits (Kessel and Linkrus, 1979) suggests, that the sea dropped to at least below this level. The regression of the Yoldia Sea to the ocean floor and the continuous land uplift affected the water level in the now isolated Lake Kahala. This reached its minimum height at about 31.5 m a.s.l in the middle of the Preboreal. At this level a well developed terrace of presumed Preboreal origin has been found in the northwestern overgrown part of the basin.

The Ancylus Lake transgression, which started about 9500 BP, and culminated in about 9300-9200 BP buried the above mentioned peat layer (9230 ± 80, Tln-202; Kessel and Linkrus, 1979) under gravel, but the transgressive waters did not reach Lake Kahala, whose threshold is at 33.5-34 m a.s.l. Beach formations at three different levels are good markers of events in the history of the Ancylus Lake. The immediate vicinity of the Ancylus Lake influenced the limnological conditions in Lake Kahala and some clear-water diatoms were introduced to it by spray. The distinct decrease in the loss-on-ignition curve between the depths of 480-470 cm and a small peak of *Navicula scutelloides* can be misinterpreted as an Ancylus Lake transgression during the Boreal (Kessel and Punning, 1969; Kessel and Raukas, 1979), but undoubtedly this is not the case. The peak in the graph of terrigenous matter in the sediments is obviously connected with aeolian activities westwards of the lake and the benthic *N. scutelloides* is also a taxon often found in small lakes.

East of the lake a thin buried organic layer, dated to 8595 ± 75, TA-59 (Ilves *et al.*, 1974) was relocated and re-examined. The fine sand, 0.5-0.7 m thick, coating the organic deposit gives clear evidence of the water level rise in Lake Kahala. The diatom composition, especially the plankton/periphyton ratio is consistent with this interpretation. Changes in the plankton/periphyton ratio can be interpreted in two ways: either as being due to a change in the morphometry of the lake basin or as being due to changes in lake productivity (Battarbee, 1986). In very shallow lakes, a decline in littoral assemblages is more likely to be connected with a relative water-level rise and reduction of the littoral area (Hyvärinen and Alhonen, 1994). The remarkable increase of planktonic *Aulacoseira ambigua* from the Late Boreal (about 8500 BP) until the end of the Atlantic is regarded as an indicator of relatively high water-level in Lake Kahala and can be connected with comparatively humid conditions. An alternative explanation is that Lake Kahala had an outlet to the Ancylus Lake, which due to the land upheaval, was closed about 8500 BP after which the lake water level started to rise. The decline of *Aulacoseira ambigua* and the increase in epiphytic diatoms reveals a lowering of water-level at 5500 BP which has been interpreted as a rather dry climatic period in the Baltic region (Saarse and Harrison, 1992).

A considerable change in the lake ecosystem started in the Subboreal. The distinct increase in *Cyclotella comta* between about 4700-3000 BP can be connected with a new rise in water-level. However, *C. comta* and other *Cyclotella* spp are often found in very shallow Estonian lakes and/or they belong to the littoral planktonic community (Pork, 1967). *C. comta* is widely distributed in oligotrophic and mesotrophic lakes (Agbeti and Dickman, 1989), and the peak of this species in Kahala is obviously associated with the lowering of the trophic stage and less probably suggests a fluctuation in the water-level. In the Late Subboreal, about 3600 BP the sedimentation rate was reduced. One explanation could be the deterioration of climate which now turned towards continentality. The lake was shallow and filled with soft unconsolidated sediments, the erosion and mixing of those sediments already deposited and, their transport by underwater currents and wind is suggested. In the section studied earlier the Subatlantic part of the sediment was 250 cm thick (Kessel *et al.*, 1982) as opposed to 70 cm in the present section. A similar phenomenon was encountered in Lake Ülemiste, where the uppermost Subatlantic part of the sediment was redeposited (Kessel *et al.*, 1986). Both lakes are shallow and large in area and the wave action reaches to the sediment surface. So, the erosion, drift and mixing of the surface soft sediment is quite obvious. It partly explains, why the radiocarbon dates from the uppermost 60 cm of the sediment are considerably older than expected (Rajamäe *et al.*, 1997). This part of the sediment consists of abundant macrophytes and the diatom assemblage indicates shallow eutrophic lake conditions.

THE DEVELOPMENT OF PREHISTORIC LAND-USE

The archaeological time-scale (Jaanits *et al.*, 1982) was used for the zonation and interpretation of the human impact diagram in order to simplify the comparison of the biostratigraphical records with the archaeological data (Fig. 9). A comparison of the different time scales together with outlines of the indications of human impact are given in Fig. 10. Bio- and chronostratigraphical studies of the lacustrine sequence confirm, that the early imprints of the human impact on the vegetation occurred about 5000 and 3000 BC, when an instability of the forest communities is suggested. The first traces of forest clearances are recorded at *c.* 2900 BC, seen as a sharp decline in the broad-leaved trees (Fig. 9). The indicators of ruderal communities and fresh meadows occur more often. The rise in the amount of apophytes and anthropochores is correlated with the end of the Neolithic time. At *c.* 2000 BC the indicators of the fresh meadows increase simultaneously with a diversity of the terrestrial herb taxa. *Urtica, Rumex acetosa/acetosella* type, Brassicaceae, Fabaceae and some Cerealea pollen also occurs. At the same level a second abrupt drop in the broad-leaved trees, especially elm, lime and hazel and to some extent in the abundance of alder and spruce is seen. The landscape seems to be very open, there are still no obvious traces of the use of fire (slash-and-burn agricultural practice), but the presence of Cerealea suggests tillage.

At 1650-1300 BC a period of relative stagnation in human impact occurs. Signs of recovery of the stands of the broad-leaved trees and a rather well defined expansion of spruce are registered. A change in land-use practice took place at *c.* 1300 BC. The recovery of the broad-leaved forest was interrupted and the abrupt rise in the amount of charcoal particles shows that fire was used for forest clearance. The presence of Cerealea pollen, including rye (most probably as a weed in other crops) gives an impression of slash-and-burn farming in the area.

A regression (duration about 200 years) in human impact took place at the end of the Bronze Age to recover again at the beginning of the Pre-Roman Iron Age, when the total amount of apophytes and anthropochores, especially ruderals, fresh meadows and grazing indicators rises. Cerealea, *Melampyrum, Rumex acetosa/acetosella* type and *Urtica* occur continuously. Crop farming and cattle rearing must have been fairly common in the area. The extremely high amount of charcoal particles gives the impression that slash-and-burn agriculture was widely practiced. An alternative explanation is that the charcoal particles originate from cremation burials at the Hundikangru stone-cist cemetery at Muuksi.

New changes in the farming practice occurred about *c.* 200 BC. The amount of charcoal particles drops considerably in contrast to the cultivation indicators and ruderals. *Plantago lanceolata*, Cerealea and *Secale cereale* are continuously present and there is a notable decline in the fresh meadow and

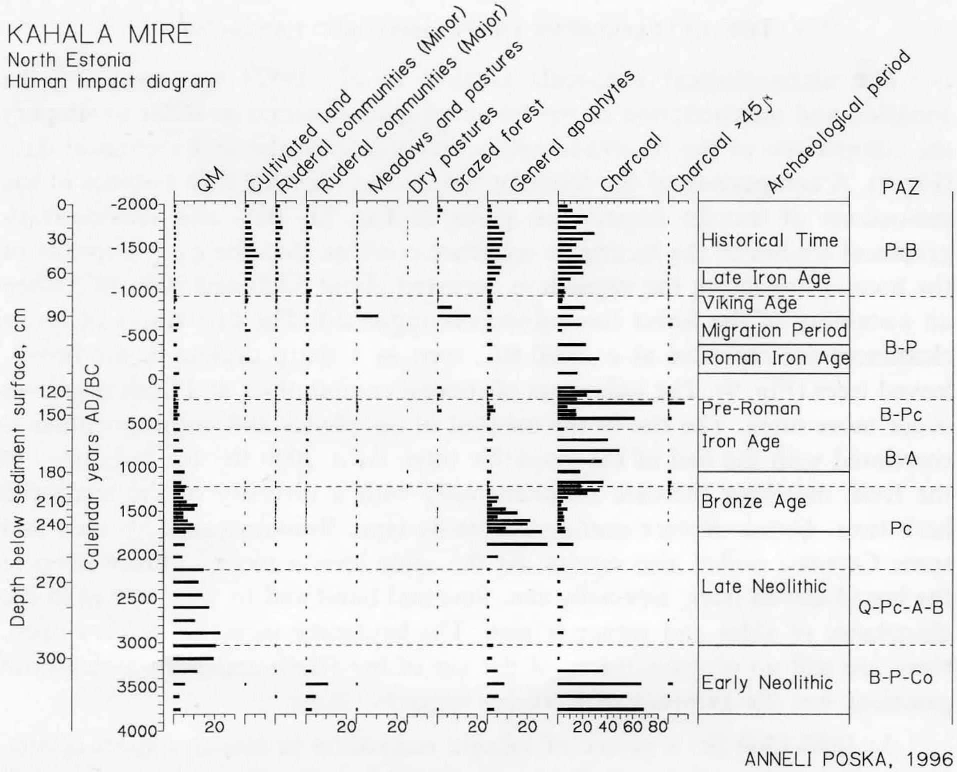

Fig. 9. Human impact diagram of Kahala mire.

'Cultivated land' *includes* Centaurea cyanus, *Cerealea and* Secale cereale*;*

'Ruderal communities (Minor)' *includes Brassicaceae,* Chamaenerion angustifolium, Plantago lanceolata, P. major/media, Polygonum aviculare, Rumex acetosa/acetosella *type and* Urtica*;*

'Ruderal communities (Major)' *includes* Artemisia *and Chenopodiaceae; 'Meadows and pastures' includes* Achillea *type,* Cirsium *type, Fabaceae,* Hypericum *spp.*, Medicago *type,* Potentilla *type, Ranunculaceae,* Ranunculus acris *type,* Rhinanthus *type,* Solidago/ Sassurea *type,* Trifolium pratense *and* Viccia cracca *type;*

'Dry pastures' *includes* Campanula *type,* Centaurea scabiosa, Cerastium *type and* Juniperus*;*

'Grazed forest' *includes* Anemone *type,* Melampyrum *and* Pteridium, *'General apophytes' includes Apiaceae, Asteraceae Liguliflorae, Caryophyllaceae, Rosaceae and Poaceae.*

grazing indicators, possibly indicating that crop growing gained importance at the expense of cattle rearing.

The sharp increase in the indicators of fresh meadows and grazed forest at the end of the Middle Iron Age (*c.* AD 600-700) is followed by peaks of pine and birch and a decline in alder. High concentrations of *Melampyrum* and different Fabaceae species occur. Since the herbs mentioned above have a high representation in only two (mainly one) consecutive samples are insect pollinated, and have a similar type of flower construction, the contamination by some insect may be expected. Nevertheless, these taxa must have grown in considerable quantities not far from the site.

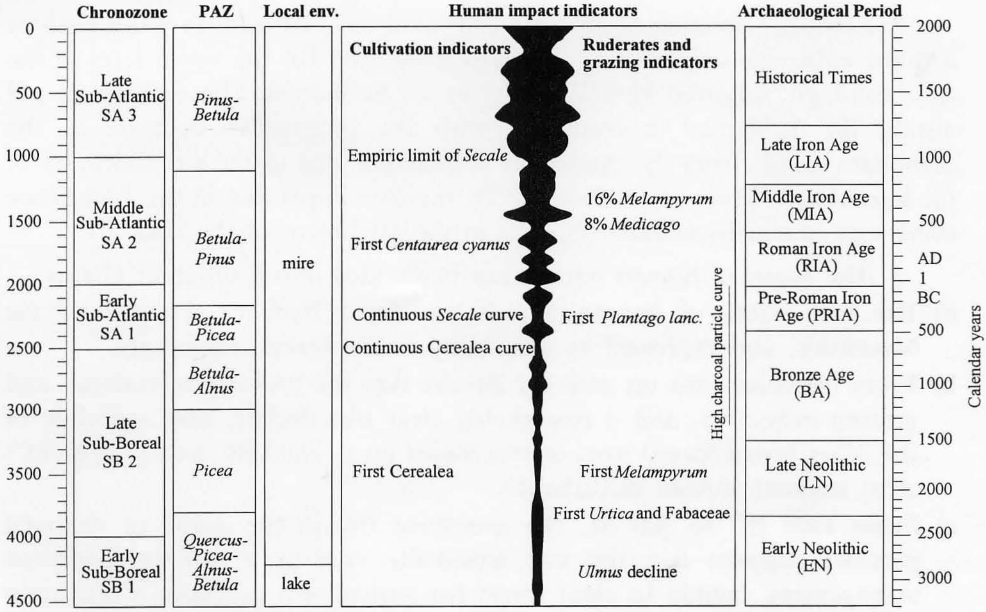

Fig. 10. Summary diagram of human impact for Kahala, based on the biostartigraphical evidence from Kahala mire.

From the Late Iron Age alder is also reduced and the broad-leaved trees seem to be totally removed from the area. Today they only occur as a narrow belt at the klint escarpment. The continuous graphs for cereals, especially rye start. A strong minimum in the charcoal particle curve is remarkable. It gives evidence of a change in the crop cultivation system. Crops grown in fertilized permanent fields could possibly be the case.

From the beginning of Historical times the amount of cultivated land and fresh meadow indicators increases. The frequency of the charcoal particles rises somewhat and the diversity of herb taxa is high. A decrease in the indications of human impact, primarily cultivated land and fresh meadow plants, is seen during the last 100 years.

CONCLUSIONS

1. Four main stages can be distinguished in the history of Lake Kahala:

a) a large lake phase (the Baltic Ice Lake, 11000-10300 BP) with the water level at about 65-66 m,

b) a bay of the Yoldia Sea (10300-10000 BP) with the water level at 37.5-35 m,

c) a lagoon of the Yoldia Sea (10000-9900 BP) with the water level at 35-31.5 m (Fig. 8) and

d) an isolated coastal lake (9900-9850 BP up to the present) with the water level at 33.2 m as at present time.

2. From the isolation around 9850 BP until 8500 BP Kahala was a shallow alkaline eutrophic coastal lake. Between 8500-5500 BP the water level in the lake was high, followed by a low level in the Subboreal. The decrease in pH during the Subboreal is connected with the progressive decrease in the carbonate supply from the catchment soils and/or due to the paludification of the littoral belt. From about 3500 BP the increase in pH and in the *Pediastrum* curve was caused by human activities in the catchment of the lake.

3. The traces of human impact can be divided into 6 different phases:

a) The first traces of human impact are dated back to the end of the Mesolithic, and expressed as unstability in the forest community.
b) From Neolithic time up until the Bronze Age the presence of ruderals and grazing indicators, and a remarkably clear elm decline, and a decline of the other broad-leaved trees in two major (at *c.* 2800 BC and *c.* 2100 BC) steps suggests human disturbance.
c) From 1300 BC to 300 BC the enormous rise in the graph of charcoal particles suggests that fire was repeatedly used as a tool in landscape management, mainly to clear forest for agricultural practices. Cultivation indicators occur more often and the use of slash-and-burn agriculture is predicted. Nevertheless the majority of the human impact indicators are derived from ruderals or from fresh meadow and grazing indicators.
d) At the end of the Pre-Roman Iron Age signs of strong and repeated burning disappear. Simultaneously the continuous curve of the indicators of cultivated land starts. The reason for this may be the existence of permanent fertilized fields.
e) The strong expansion of indicators of pastoral and fresh meadows seen at *c.* AD 600-700 is difficult to explain due to the fact that the source of such an abnormal amount of pollen of the insect pollinated plant species is unclear.
f) During the Late Iron Age the amount of charcoal particles is extremely low. However, the continued presence of the other human impact indicators affirms that farming must have been practised in the area.

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