UCL
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ENVIRONMENTAL CHANGE RESEARCH CENTRE

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RESEARCH REPORT

No. 44

Palaeolimnology and Lakes with

Respect to Pollution and to Climate Change

Ed. by S. Patrick

Final Report to INTAS: CONTRACT No. 1010-CT93-0021.

December 1997

INTAS CONTRACT 1010-CT93-0021, PALAEOLIMNOLOGY AND LAKES WITH RESPECT TO POLLUTION AND CLIMATE CHANGE

FINAL REPORT, YEAR 3, 1996-1997

1. Title

Palaeolimnology and lakes with respect to pollution and climate change.

Contract: 1010-CT93-0021.

Project period: October 1st 1994 - September 30th 1997.

Co-ordinator: Environmental Change Research Centre (ECRC), University College London (Dr S. Patrick)

Partners: Institute of Global Climate and Ecology (IGCE) Moscow; Moscow State University (MSU) Department of Hydrobiology; and the Kola Science Centre (KSC) Apatity, Murmansk.

Final report year 3: October 1996 - September 1997.

2. Objectives

- Carry out joint fieldwork expeditions to lake sites in the Kola Peninsula and the Caspian lowlands (substituted by Baikal Mountains and the Rayazan region);

- Apply palaeolimnological techniques to problems of trace metal pollution and atmospheric contamination in lakes of the Kola Peninsula;

- Provide modern coring devices suitable for sampling recent lake sediments;

- Upgrade computer hardware and software in Russian laboratories;

- Upgrade light microscopes;

- Provide copies of key international scientific journals in environment change and new diatom floras;

- Train young scientists in relevant analytical and computer techniques using short courses in London;

- Supervise and help with the research of scientists from FSU through workshops.

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3. Research activities

3.1 Description

Following the surface sediment / water chemistry survey of 27 lakes in the Kola Peninsula in 1995-1996, work in the final year of this project has focused in on detailed palaeoecological analysis of a long core from one lake in the region. The Holocene pollen and diatom stratigraphy of Lake Chuna has been used to investigate the post-glacial vegetation and climate history of the Kola Peninsula. Young scientists from the ECRC visited the KSC to undertake fieldwork associated with the long coring, and sediment analyses were undertaken at both the ECRC and the KSC.

Although the programme of work in the mountains above Lake Baikal did not develop as originally envisaged because of financial and logistical difficulties, a sediment core from Lake Bolshoie was retrieved and has been analysed (to date) for lithostratigraphy and radiometric dating.

An additional sub-project organised via co-operation between IGCE and regional power generation organisations involved palaeoecological surveys of lakes in the Ryazan region south-east of Moscow, to ascertain the impact of atmospheric deposition from local power utilities.

Researchers from the participating Russian laboratories have attended courses in numerical analysis and diatom taxonomy at the ECRC.

The series of lectures in palaeoecology given by Professor R.W. Battarbee and Dr R.J. Flower in Moscow in July 1995, have been summarised in English and Russian and made available to students at IGCE, MSU and KSC.

A three day workshop, followed by field excursions has been organised for July 1998 at the KSC, Apatity. The workshop will examine and develop all the topics investigated within this INTAS project; will consider the scope for further palaeoecological and associated environmental investigations in the Kola Peninsula and throughout the FSU; and will bring together a wide group of scientists from the FSU, Scandinavia and the U.K. Proceedings of the workshop will be compiled in Russian and English

3.2 Results

Detailed results of the research and dissemination programmes highlighted above are given in Annexes 1-4 of this document. A brief summary and details of ongoing collaboration is given below.

Holocene sediment core studies from Lake Chuna
- Pollen stratigraphy of Lake Chuna represents regional vegetation changes in the northern Fennoscandian region during the last 8,500/8,000 years.
- Floristic diatom changes of Lake Chuna during the Holocene are characteristic of Arctic lakes.
- Changes in diatom species composition, total diatom concentration, diatom species diversity and DCA diatom sample scores are largely related to changes in pollen profile and regional vegetation.

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- More information is required, i.e. radiocarbon dates, analysis of metals and organic matter in the sediments to confirm the hypothesis on climate related changes in diatom composition of the Holocene sediment core from Lake Chuna.

Lake Bolshoie
Lithostratigraphical analyses and ^{210}Pb dating have been undertaken on a 40 cm sediment core from this mountain lake in the Baikal region. Sediment accumulation is extremely slow with 12 cm depth equating to a date of ca. 1806.

Ryazan lakes
Sediment cores were obtained from two sites in the Ryazan region and are being analysed for lithostratigraphy, carbonaceous particles and diatoms; some preliminary data are available. in addition scientists from IGCE undertook a full hydrobiological survey of the sites and samples of fly-ash were collected from the power generating plants to assist future characterisation of particles recognised in the lake sediments.

Collaboration
During 1996-1997 KSC scientists have been fully integrated within the EU-funded MOLAR project. With two lake sites in the region being incorporated into the MOLAR sampling and analysis programme. As part of the developing link between the KSC and other European laboratories a fisheries workshop, under the auspices, of MOLAR will be held at Apatity in 1998.

Co-operation with the KSC has extended to mutual collaboration in another new EU-funded science programme - "TUNDRA" (TUNdra Degradation in the Russian Arctic), a multi-disciplinary research project to study global change in the Russian Arctic. It will assess possible feedbacks from the Russian Arctic to the global climate system through changes in greenhouse gas emissions and in freshwater input to the Arctic Ocean. The geographical area under investigation will be the Usa basin which includes major ecotones and industrial pollution gradients.

4. Management and financial information

4.1 Project management

Co-operation

i. IGCE

IGCE have participated in all planning activities associated with the project; helped organise field expeditions in the Kola region; contributed fully to the funding of Nadia Solovieva (full time PhD student); taken part in diatom and statistical analysis workshops in London. The principal contributors have been Professor V. Abakumov (IGCE project leader), Ms N. Solovieva (research student - diatoms, statistics), Mr D. Sediakin (computer-based analytical techniques), Mr S. Politov (Baikal mountain lake investigations).

ii.   MSU

Links with MSU have been virtually moribund since the death of Professor M.M. Telichenko the INTAS project leader within MSU. As reported in the Second interim Report the majority of funds allocated to MSU have now been re-allocated to assist with the funding of the full-time Ph.D student Ms N. Solovieva who is jointly based between ECRC and IGCE/KSC.

iii.   KSC

The participation of KSC (principally Dr T. Moiseenko and Prof. Kalabin) at a later stage in the progress of the project has greatly aided the progress of practical work in the Kola Peninsula. Facilities have been provided by KSC at Apatity to allow extensive field expeditions and follow-up laboratory preparation and analysis to be undertaken. KSC is an active and relatively dynamic group of experienced environmental scientists and co-operation has already resulted in their active involvement in the EU-funded "MOLAR" programme. Ms N. Solovieva is receiving joint supervision from Dr Moiseenko as part of Ph.D orientated research programme. This INTAS project has also benefited from links with the bilateral KSC-Norway (NIVA) agreement, scientifically through the exchange of personnel, equipment and intellectual property; and practically through access to Norway-based communication and financial transfer facilities.

Planning

The time schedule of the project was inevitably affected by the need to change the geographical emphasis of the project away from the Baikal Mountains and the Caspian Lowlands and to focus on the Kola Peninsula. However, given the relative sophistication of facilities and technical back-up at KSC and the full-time allocation of Ms Solovieva to the research component of the project, the substantive objectives have been met within the time frame of this INTAS grant. The initiative of Professor Abakumov at IGCE enabled an additional sub-programme of work to be instigated in the Rayazan region. This work, opens up new areas of environmental assessment in Russia and should continue into the future.

Problems

The principal change has been the inclusion of KSC into the co-operative partnership and the relative decline in active participation from MSU and, to a lesser extent, IGCE. With the exception of bilateral communication between UCL and KSC (greatly facilitated by email and links via Norway), communication between partners remained difficult, despite the presence of Ms Solovieva - a Russian speaker - at ECRC.

Equipment

Some equipment, originally, specified (e.g coring devices) were not purchased. Instead it was loaned by ECRC and INTAS money was directed towards underpinning the more general infrastructure and participant's subsistence costs in the Russian institutions. Without such virement the drastic reduction in national funding would have forced the Russian partners to withdraw from active co-operation!

Computer hardware and software for the Russian laboratories was purchased in London and taken back to Russia either by Russian scientists returning from meetings in London, or via Scientists from ECRC visiting Russia. In this way the bureaucracy of export formalities and associated customs duties were avoided.

4.2 Financial information

Cost breakdown 1996-1997

The budget for KSC was derived by allocating 50% of that originally apportioned for MSU. Contributions from the Russian partners to the subsistence and fee costs for the Ph.D student are included in the heading 'travel and subsistence'.

The bureaucratic difficulty and the 'tax' loss incurred in attempting to transfer monies directly to Russian banks determined that all cash transfer since has been by direct exchange of cash to Russian colleagues, either at meetings in London or via visits by ECRC personnel to Russia. This was not entirely satisfactory, but was considered the only feasible way to proceed as in addition to State taxation the chances of money transferred to Russian Institutes being directed to the needs of a specific project, given the parlous state of academic funding in Russia, was considered by Russian colleagues to be remote. Wherever possible, and to reduce the need to physically carry cash for transfer to partners, expenditure on behalf of the Russian partners (for e.g. travel, accommodation, course fees, software etc.) was made by ECRC and recouped directly from the partners' project budgets.

In addition to the INTAS grant this project benefited from synergy of objectives with the EU-funded "MOLAR" project. The joint Russia/ECRC Ph.D studentship held by Ms N. Solovieva benefited from a modest contribution from the Soros Foundation and from contributions from ECRC internal funds.

Expenditure breakdown (ECU) for period October 1996 - September 1997 (year 3)

	Narrative	**UCL**	**IGCE**	**MSU**	**KSC**
Travel & Subsistence	Fieldwork Meetings (Apatity) Ph.D student Institute running costs	800	2440 1710	270	880
Equipment	Software/hardware/books				
Consumables					
External		650			
Overheads		660			
Total		2110	4150	270	880

Summary

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TECHNICAL ANNEXES

TECHNICAL ANNEX 1

HOLOCENE POLLEN & DIATOM STRATIGRAPHY OF LAKE CHUNA & POST GLACIAL VEGETATION & CLIMATE HISTORY OF THE KOLA PENINSULA

N. SOLOVIEVA, S. PATRICK & T. MOISEENKO

SUMMARY

- Pollen stratigraphy of Lake Chuna represents regional vegetation changes in the northern Fennoscandian region during the last 8,500/8,000 years.

- Floristic diatom changes of Lake Chuna during the Holocene are characteristic of Arctic lakes.

- Changes in diatom species composition, total diatom concentration, diatom species diversity and DCA diatom sample scores are largely related to changes in pollen profile and regional vegetation.

- More information is required, i.e. radiocarbon dates, analysis of metals and organic matter in the sediments to confirm the hypothesis on climate related changes in diatom composition of the Holocene sediment core from Lake Chuna.

1   INTRODUCTION

The Year 2 report provided the background to palaeolimnological assessment of climate change and lake acidification in the Kola Peninsula, and described the development of a modern diatom dataset and diatom-pH transfer function. The current report focuses on the reconstruction of environmental and primarily climatic history of the Kola Peninsula during the Holocene.

In April 1996 a Holocene sediment core was retrieved from Lake Chuna to be analysed for pollen, diatoms and sediment lithology in order to reconstruct vegetational and diatom changes that occurred in the Holocene. The fieldwork in the Kola Peninsula was conducted in collaboration with the Kola Science Centre, Apatity, and the University of Umeå, Sweden.

Fine resolution diatom analysis, pollen analysis and analysis of sediment lithology have been undertaken and results of this research are presented below. The radiocarbon dates will be also obtained for the sediment core and concentrations of organic matter and metals in the sediments will be analysed in the near future.

2 POST-GLACIAL DYNAMICS OF VEGETATION AND CLIMATE OF NORTHERN FENNOSCANDIA AND CHARACTERISTIC PROPERTIES OF THE KOLA PENINSULA. THEORETICAL BACKGROUND.

2.1 Introduction

Late-Quaternary geological, geomorphological and palaeobotanical changes of the Kola Peninsula received much scientific interest during the last century. Most studies were conducted by Russian and Finnish researchers and vegetation reconstruction generated for north-eastern Finland have much in common and correlate well. Early studies on Holocene vegetation and climate did not employ absolute dating techniques and the relative age estimates were carried out by correlating pollen zones with past shorelines of known age (Aario, 1943) or with marine sediment cores (Goretskii, 1941). Pollen stratigraphies were recovered from geological cores, peat bogs, river terraces, and marine cores. Along with palynological analysis marine mollusc shells were used for past climate estimations.

A substantial amount of data on vegetation and climate history of the Kola Peninsula have been accumulated during the last few decades but many of these studies are rather fragmentary. Lebedeva *et al.* (1987) summarized all previous investigations on this subject and carried out the most complete and comprehensive investigation into post-glacial climate and vegetation development in the Kola Peninsula. Diatom, foraminiphera and mollusc analyses of marine sediments were used along with palynology. Absolute and relative dating was provided by means of tephrochronology, archaeology and radiocarbon analysis. Climate conditions were reconstructed by using modern areas with analogue vegetation and pollen percentages. Lebedeva and other authors used the Blytt-Sernander system of pollen and climate classification and although it was criticized (e.g. Wendland & Bryson, 1974; Roberts, 1989) the use of its terms within the context seems to be appropriate.

From the end of the last stage of the Valdai glaciation and until the present time 14 phases in the vegetation development were recognized (Lebedeva, 1983; Lebedeva *et al*, 1989). Eight successive stages were separated during the post-glacial period including three stages during the pre-boreal period where the main factor controlling vegetation was the retreating glacier, and vegetation zones were parallel to the glacier edge.

2.2 Late Pleistocene/Holocene transition

The first three phases - Older Dryas, Bølling and Middle Dryas reflect the late Pleistocene interstadial transition. Vegetation evolved from tundra dwarf birch/green moss communities, which then gave way to mixed birch/dwarf birch forest and finally again transformed into tundra with Bryophytes and Lycopodiaceae (Lebedeva *et al.,* 1989). Dry, cold conditions of the Older Dryas gave way to the warmer Bølling climate.

The next phases (the 4th - Allerød, the 5th - Younger Dryas, 6th, 7th and 8th - Pre-boreal phases) are related to the retreat of glacier, development of the Portlandia phase and transgression of the Littorina phase of the Barents Sea. This period is characterised by a complex vegetation cover consisting of both forest and tundra/steppe communities. The stand was mainly formed by *Betula*, but pollen of spruce (*Picea abies*), pine (*Pinus sylvestris*) and alder (*Alnus sp.*) were also found. Shrub cover was constituted mainly by dwarf birch (*Betula nana*) and *Salix* (Lebedeva *et al.,*

1989). The dominance of *Salix* during the Younger Dryas is also stressed by Seppa (1996). The field vegetation layer was comprised by *Ericales, Gramineae, Carex, Artemisia, Chenopodiaceae*, and sometimes *Ephedra*. Later the area of shrub/grass expanded displacing forest associations due to the cooling in the Younger Dryas. Climate conditions were close to sub-Arctic: cold and dry in the central Kola and moister in the western part close to the Finnish Lapland (Lebedeva *et al.*, 1989). The fact that tundra/steppe environment also included moist conditions was indicated by Seppa (1996).

2.3   Early Holocene period

Three Pre-boreal and two Boreal phases comprise the early- Holocene period. During the three Pre-Boreal phases the vegetation diversity decreased and vegetation zonality became latitudinal (Lebedeva *et al.*, 1987). Plants of the periglacial zone (*Chenopodiaceae, Carex, Artemisia, Gramineae*) still dominated during the Pre-Boreal phases but declined by the start of the Boreal (Lebedeva *et al.*, 1989). This could imply the presence of permafrost cores (Reiger, 1974). The southern boundary of tundra and forest/tundra zones moved towards the north locating along the northern and north-eastern coastal line. Birch forest comprising *Betula subarctica* and *B. tortuosa* dominated through most of the area. *Betula nana* and *Salix* sp. prevailed in the north-eastern part of the Peninsula. The climate was gradually changing towards moister and warmer conditions (Lebedeva *et al.*, 1989)

The Pre-Boreal/Boreal transition for the Kola Peninsula was dated at about 8,890 - 8,670 BP. The 9th and 10th Boreal phases of vegetation dynamics were characterised by total dominance of birch both in the forest and in forest/tundra zones. *Betula subarctica, B. tortuosa* together with *B. nana*, *Empetrum* and other *Ericaceae* show high values in almost all pollen diagrams throughout Fennoscandia (Prentice, 1982). It was proposed that birch expansion could indicate the disappearance of permafrost (Reiger, 1974). Pine (*Pinus sylvestris* and *P. sylvestris* ssp. *lapponica*) occurred sparsely and only to the west and the centre of the Peninsula at the end of the first half of the Boreal time. The data agree well with vegetation reconstructions provided by Sorsa (1965) for the forest zone of Lapland.

2.4   Mid-Holocene

In the second half of the Boreal period pine started to play an important role, forming most part of the boreal forest and pushing birch towards the northern boundary. The start of mire formation and peat initiation is suggested at around 8,860 - 8,131 BP (Lebedeva *et al.*, 1989) which falls into the period suggested by Moore *et al.* (1991) for north-western Europe. The 10th and 11th phases represent the mid-Holocene period and include the Boreal/Atlantic transition (7,500 - 7,880 BP in northern Lapland, 8,130 BP in the west of the Kola Peninsula (Lake Umba), and 7,410 BP in the south) and Atlantic period of climate optimum. It features the predominance of pine in the southern part of the Peninsula and equal pollen concentrations of pine and birch in the north. Pine occurred and expanded in north-eastern Lapland later than in the Kola according to Sorsa (1965). However, Seppa (1996) suggests that the earliest occurrence of pine in North Fennoscandia was 10,290 BP. He also highlights the sharp decline in lycopods and ferns accompanying the pine expansion.

The second half of the Atlantic period (6,740 - 6,820 BP in the south and 6,290 BP in the north - valley of the River Ponoi) is characterized by pine dominance elsewhere in Fennoscandia including the Kola Peninsula (Aario, 1943; Lavrova, 1960; Lebedeva, 1983; Seppa, 1996; Sorsa, 1965). A

distinct maximum of deciduous pollen was found only for the north of Fennoscandia (e.g. Seppa, 1996). Pollen diagrams from the Kola Peninsula show only markedly high values for *Alnus*. Pollen of other deciduous trees was also observed but it was not abundant (Lebedeva *et al.*, 1989). The pine and alder expansion was almost simultaneous (Seppa, 1996). *Alnus* pollen constituted up to 30% of total value (Lebedeva *et al.*, 1989). At field level vegetation was rather diverse, well developed and comprised in equal proportions alpine, arctic and boreal species. Maximum species diversity and abundance for both continental and marine diatomites provide further evidence of the climate amelioration during the Atlantic period (Lebedeva, 1983). Swamping and wide occurrence of lowland *Carex* and tall grass bogs is another distinctive feature of the Atlantic period in the Kola (Lebedeva *et al.*, 1989).

2.5   Late-Holocene and present time

The late-Holocene period (it includes the 13th and 14th phases of the vegetation succession according to Lebedeva *et al.* (1989) classification commences from the transition of the Atlantic climate optimum to Sub-Boreal cooler conditions and features the retreat of the timberline and expansion of tundra vegetation. Lebedeva *et al.* (1989) also noted the occurrence of spruce (*Picea abies*) pollen. The decline in tree pollen is accompanied by the rise of *Cyperaceae, Ericaceae, Artemisia* and other typical tundra/steppe plants characteristic of moist and cool conditions (Lebedeva, 1983; Seppa, 1996). *Ericaceae* pollen exhibits high values during the whole Sub-Boreal and this is one of this period's distinctive traits (Lebedeva *et al.*, 1989). Mires and blanket bogs became widespread elsewhere in the Kola and Forest Lapland (Sorsa, 1965; Lebedeva, 1983). Sorsa (1965) also suggests that this climate and vegetation transition occurred between 4,660 BP and 3,100 BP. Aario supports the idea that the timberline retreat started in the mid-Holocene (Aario, 1943), whereas Hyvarinen (1975, 1976) implies that the clearest change occurred as early as 5,000 BP.

The transition from Sub-Boreal to Sub-Atlantic climate is dated 2,790 BP in the north-west of the Kola Peninsula (Pechenga River valley) (Lebedeva *et al.*, 1987). Sorsa (1965) estimates it by 2,180 BP at Kaunispae at Lake Inari. He notes the development of *Sphagnum* bogs and further expansion of spruce/birch associations in the north-east of Lapland. The rise of *Picea abies* against the background of high pollen concentrations of *Betula* was also found in the central part of the Kola Peninsula (Lebedeva *et al.*, 1987). *Pinus* dominates in the western part in the areas adjacent to the Finnish border in the valley of the Lotta River which is in agreement with the results of Aario (1943). He indicates the prevalence of *Ericaceae* and the increase of *Picea* along with a relative decline of *Pinus*. Tundra vegetation was characterized by shrub, predominantly *Empetrum* communities mixed with mosses along the coastline and with dwarf birch along the southern boundary of the tundra zone (Lebedeva *et al.*, 1989).

Recently, the northern edge of the forest zone is moving south due to human disturbance (e.g. fires, forest clearance) and at present the zone of tundra and mires is spreading around the Kola Peninsula (Lebedeva *et al.*, 1989).

2.6   Summary

The late-glacial and post-glacial vegetation succession in the Kola Peninsula bears all the characteristic features of vegetation transition in Fennoscandia and northern Europe in general. However, the original dynamics of vegetation in the Kola show several distinctive properties different from other northern Fennoscandian regions (Lebedeva, 1983; Lebedeva *et al.*, 1989):

- high pollen values of periglacial vegetation during the Pre-Boreal period and their sharp decline by the start of the Boreal;

- the absence of distinctive deciduous maximum during the Atlantic period, although individual pollen grains were found during Atlantic and Sub-Boreal time;

- approximately equal pollen concentrations of alpine, arctic and boreal species in the Atlantic pollen diagrams;

- maximum of *Ericaceae* pollen during the whole Sub-Boreal period.

3 HOLOCENE POLLEN AND DIATOM STRATIGRAPHY OF LAKE CHUNA

3.1 Description of the study area

The location of Lake Chuna is given in Figure 1. Brief characteristics of the lake and its catchment are described below:

Figure 1   Location of study sites
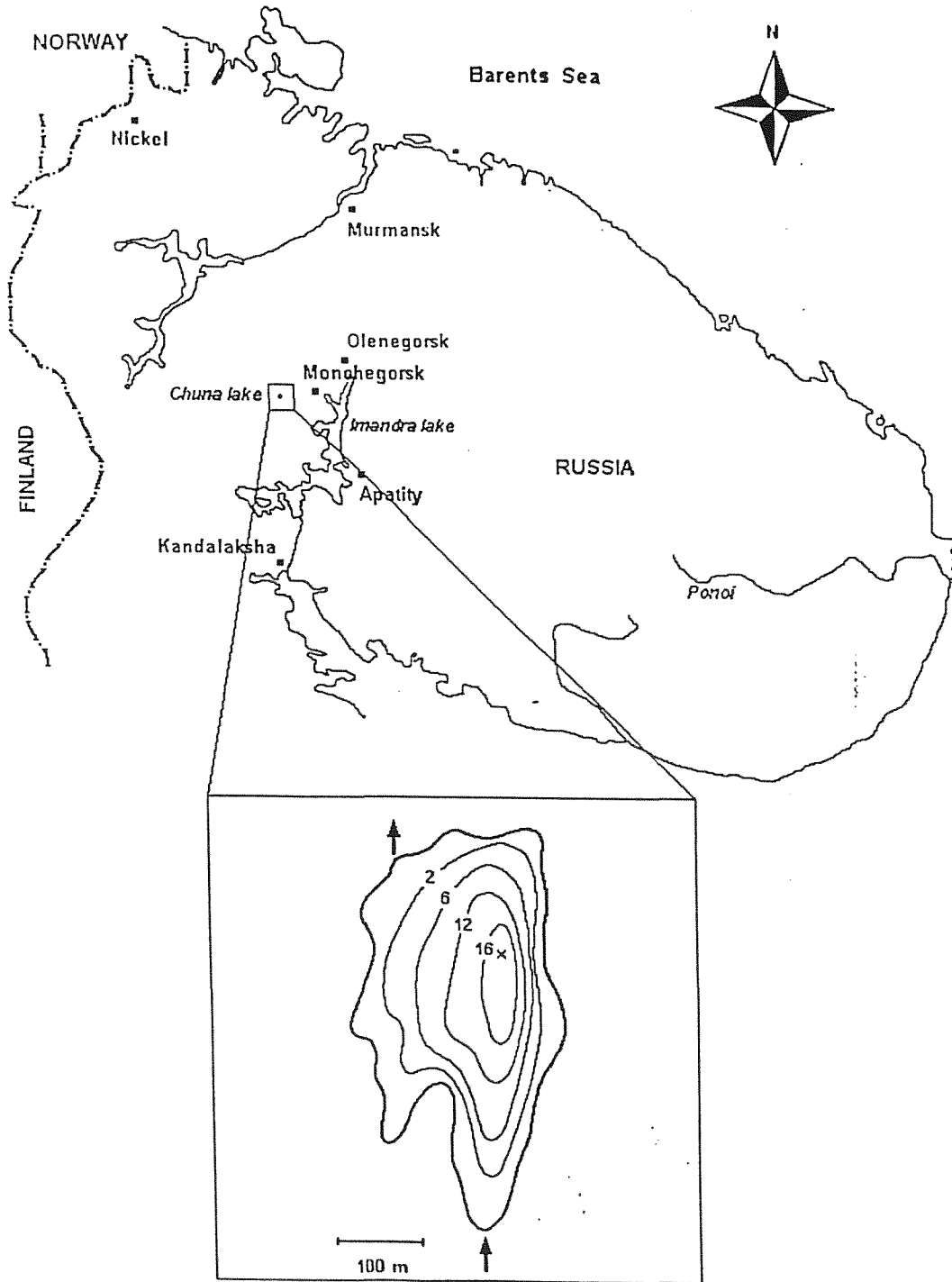
3.1.1   Geology and relief

Lake Chuna is an upland lake located at 32°27'E and 67°57'N in the Chuna Tundra mountain plateau. The altitude of the lake is 506 m. The Chuna mountain plateau is part of an ancient peneplain formed by gneiss type siliceous bed-rock of Archaen origin (Atlas of Murmansk region, 1981). The most common types of the rock are gneiss-like quartz diorite and granodiorite of low buffering capacity.

Quaternary deposits cover most of the catchment and are dominated by moraine. Granulometric moraine content is characterized a by high percentage of boulders, about 50% on average and at some sites up to 80% (Nikonov & Lukina, 1994). Chemically, this moraine is very close to granite and contains silica, potassium and sodium. It lacks iron, calcium and magnesium.

3.1.2   Climate

The nearest meteorological station is located in the Lapland natural reserve which is about 5 km west from the lake and the following climate data were collected there from 1980 to 1990: The mean temperature in January fluctuated from -14.8 to -15.8°C and the mean temperature in July ranged from 11.9 to 13.0°C (Annual reports on meteorology, 1980-1990). Mean precipitation ranged from 98.6 mm in January to 72.6 mm in July. The lake is covered with ice during 7 months.

3.1.3   Vegetation

The lake is located above the tree-line and the vegetation of the catchment belongs to the alpine tundra type (Nikonov & Lukina, 1994). It is a lichen/dwarf shrub tundra with a dominance of *Betula nana, Empetrum hermaphroditum, Arctostaphylis uva-ursi, Loiseleria procumbens, Vaccinium myrtilis* and *V. vitis-idaea. Salix* spp., *Cyperaceae (Carex belowii)* and *Juncaceae (Juncus trifidis)* hummocks along with patches of *Sphagnum*. occur at the edge of the lake.

The ground level is dominated by lichens including *Cetraria nivalis, Cladonia alpestris, Cl. mitis, Alectoria ochroleuca* and *A. nigricans*. Lycopods are chiefly characterized by *Diphasiastrum alpinum* with patches of *Huperzia selago* and *Lycopodium clavatum*.

Flowering plants are rather scarce and chiefly represented by *Silene acaulis, Saxifraga oppositifolia,* and *Chamepericlymes*.

3.2   Materials and methods

3.2.1   Field methods

A Russian peat sampler (Jowsey, 1966) was used to retrieve a sediment core covering the Holocene. The core, 153 cm long, was collected from the ice surface in April 1996. A freeze corer (Ohnstad & Jones, 1982) was used to sample the upper 20 cm layer of sediment. The cores were retrieved from a depth of 15.5 m which is close to the deepest point of the lake (16 m).

After sampling and visual inspection the master core sections were wrapped in two layers of plastic "cling- film" and packed into individual wooden boxes. Before sub-sampling they were stored in a cold room with a temperature of 5°C.

3.2.2   Laboratory methods

sediment lithology

The sediment lithology was described using the Troels-Smith system (1955). The sediment print was examined under binocular microscope and described on the basis of visual inspection and classified according to its organic content.

Preparation for pollen analysis

The core was sub-sampled at 2.5 mm for further fine resolution analysis at the laboratory of Environmental Botany, University of Umeå, Sweden. In order to obtain a skeleton pollen diagram small portions of the original 2.5-mm samples were amalgamated with each resulting sample covering 4 cm of sediments.

Preparation of pollen slides followed Andersen (1960) and Bates *et al.* (1978). The characteristic feature of this method is the use of silicone oil for mounting pollen grains. Two tablets containing *Eucaliptus* pollen grains (Stokmarr, 1972) were added to determine pollen concentrations. *Eucaliptus* tablets were dissolved in 10% KOH in a plastic tube. Then the weighted sub-samples of sediments were added to the tubes and boiled for 5 minutes in a water bath. After centrifugation (5 minutes, 3000 rev./min) the residue was washed with distilled water through a fine mesh screen (170-180 mm). The residue trapped on the screen was later examined under the binocular microscope for seeds, fruits and macrofossils (Cwynar *et al.*, 1979).

Further treatment of the samples included boiling with HF (20 minutes) to remove the mineralogenic part of the sediments and using acetolysis mixture (9 ml of acetic anhydride and 1 ml of concentrated sulphuric acid) for 3 minutes to clean the pollen grains. The pollen was then stained with safranin water solution.

As mounting in silicone oil requires totally dehydrated samples, 100% tertiary butyl alcohol was used to remove water from the samples. The pollen slides were then mounted in silicone oil (2000 cs viscosity) and the cover slips sealed

Pollen identification and pollen diagrams

Pollen grains were identified using the key of Faegri & Iversen, (1989). Pollen grains were identified up to the taxonomic level proposed in the set of conventions by Birks (1973), for example:
Salix - Genus determination certain;
Gramineae - Family determination certain;
Ericaceae undiff. - Family determination certain, some genera presented separately.

Indeterminable grains were classified according to Cushing (1967), but different groups of indeterminable grains (e.g. corroded, concealed, crumpled etc.) were united in the pollen diagram.

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Betula nana was not separated from other *Betula* species due to the uncertainty of identification. *Empetrum* was identified separately from other *Ericaceae* species, but *Vaccinium*-type was included into *Ericaceae* undif. due to the identification problems.

It was difficult to separate *Corylus* from *Myrica* and *Betula* from *Corylus* and *Myrica* when pollen grains with corroded or concealed pores were counted. These grains were assigned as *'Betula-Corylus-Myrica'* (**B-C-M**) on the pollen diagram.

Pediastrum and *Botryococcus* were also included in the count sheets.

Unidentified fungal spores occurred in substantial quantity within the last 5 cm of the core (up to 10% at 153 cm depth). The spores were not included in the pollen diagram because of their unidentified origin.

Pollen grains were counted with a Zeiss microscope with x40 objective and x10 oculars. In total about 500 terrestrial pollen grains were counted per slide.

Preparation of diatom slides and sub-sampling strategy

Preparation of diatom slides followed techniques outlined in Battarbee (1986) from c. 0.01 g of wet sediment. Hot H_2O_2 was used to remove organic matter. Centrifuging five times at 1000 rev./min. for 5 minutes was used to clean the samples. Slides were mounted using Naphrax.

Diatoms were analyzed at different levels of resolution throughout the core. The following strategy was adopted to identify the necessary resolution of diatom analysis:

First, diatoms were analyzed in every 4 cm of the core, the skeleton diatom diagram was obtained and levels of the major floristic changes were identified. The diatom diagram was then compared with the skeleton pollen diagram (Figure 2) to obtain approximate age estimations.

The upper 40 cm of the core roughly represents the last 2,000 years and diatom analysis was conducted within this interval with a higher resolution (0.5 cm) to trace the minor variations of climate and Little Ice Age. The part of the core between 40 and 105 cm was analyzed at every 2 cm because although some fluctuations of diatom composition do occur, no major species changes were found in this section. The major change in the diatom assemblage occurred at around 5,500 yrs BP at a depth of 115-116 cm and therefore diatoms were examined with higher resolution (every 1 cm) from 105 cm to the bottom of the core (153 cm).

Diatom identification, diatom nomenclature and diatom taxonomy

A minimum of 300 valves were identified and counted per slide with a Zeiss light microscope at a magnification of x1000 using oil immersion.

SEM was used to clarify the taxonomy of the complex *Aulacoseira* group and to examine the taxonomy of the genus *Stauroforma* Flower, Jones and Round gen. nov. (formerly *Fragilaria virescens* v.. *exigua*). This genus consists of two species (Flower *et al.*, 1996) which could be separated only under the SEM. Since they are indiscernible under the light microscope *Stauroforma* species were described as 'ssp'.

On the whole, diatom taxonomy is clear and species composition of the sediment core is similar to the Northern Fennoscandian lakes described in Weckstrom *et al.*, 1997; Pienitz *et al.*, 1995b and Battarbee *et al.*, 1997. All were identified to the lowest taxonomical level.

Aulacoseira cf *lirata* v.. *lacustris* Grun, differs slightly from the species described in Van Heurck (1880-1885) and Florin (1981) and therefore this taxon is notated as 'cf'.

Diatoms were identified using Krammer and Lange-Bertalot guides (Krammer & Lange-Bertalot, 1986-1991). Other taxonomic references comprise Camburn & Kingston (1986), Van Heurck (1885), Florin (1981) and Flower *et al.* (1996). Diatom nomenclature follows Krammer & Lange-Bertalot (1986-1991) for most taxa. Some taxa were named according to the nomenclature adopted in the SWAP project (Stevenson *et al.*, 1991). The SWAP nomenclature is used in the computer diatom data-base *Amphora* where diatom counts are stored at the ECRC, UCL.

Taxonomic descriptions are given below for the species which are taxonomically difficult and for which identification follows sources other than Krammer & Lange-Bertalot (1986-1991).

GENUS *AULACOSEIRA*
Aulacoseira cf. *lirata* v.. *lacustris* Grunow in Van Heurck 1880-1885. - Cleve-Euler 1934, 1951.
(Syn. *Melosira polymorpha* subsp. *distans* v. *lirata* forma *lacustris* (Grun.) Bethge 1925.; *Melosira distans* v.. *lirata* forma *lacustris* (Grun.) Hustedt 1930a, 1930b, in Huber-Pestalozzi 1942; *Melosira mikkelsenii* Nygaard 1956. - Renberg 1976; *Aulacoseira distans* v. *lirata* form *lacustris* (Grun.) Simonsen 1979.

The morphology of the specimen in mantle view follows Grunow's drawings in Van Heurck (1980-1985, pl 87, figs 3-5) and photographs in Florin (1981) and Camburn & Kingston (1986). The difference is that the specimen's valve face is covered with coarser puncta than the valve face of *Aulacoseira lirata* v. *lacustris* described in Van Heurck (1989-1985) and Florin (1981). SEM photographs have confirmed that puncta are not perforating like *A. lirata*, but they are slightly coarser and distinctive under the light microscope.

Since the morphology of the lake's *Aulocoseira* closely resembles the description of *Aulacoseira lirata* v.. *lacustris* except for the one feature, the lake Chuna specimens were named '*Aulacoseira* cf. *lirata* v. *lacustris*'.

The species is found in low abundance in the layer from 137 to 105 cm. It occurs at high concentration only at one level of 135 cm. *Aulacoseira lirata* v *lacustris* is not present in the modern samples.

Aulacoseira distans v.. *nivaloides* Camburn v.. nov.
The morphology of the specimen that occurred in the lower part of the sediment core closely follows the description in Camburn & Kingston, 1986. Specimens with a diameter of 4-7 µm were most common.

The species occurs within the layer from 140 to 105 cm with a maximum abundance of 25% (136-138 cm) and an average comprising 5-6% of total concentration. It has not been found in modern samples.

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Aulacoseira distans v.. *tenella* (Nygaard) Florin, nov. comb. (Syn. *Melosira tenella* Nygaard 1956).

The morphology of the lake's specimen resembles Nygaard (1956) and Florin (1981). The valve diameter varies from 5 to 9 μm (Camburn & Kingston (1986) found a specimen with the diameter up to 11 μm), the striae are composed of two puncta. The species occurs at average abundance of 3-4% between 153 and 115 cm, and it has not been found in modern samples.

Aulacoseira nygaardii Camburn sp. nov.

The description of the species given in Camburn & Kingston (1986) applies closely to the specimen from the lake. The valve diameter varies from 7 to 12 μm. The specimens occur at an average abundance of 5-7% and are largely confined to the bottom of the core from 153 to 135 cm. They also occur at low abundance in a few levels up to 107 cm.

GENUS STAUROFORMA Flower, Jones & Round. gen. nov.

The newly described genus formerly known as *Fragilaria virescens* v.. *exigua* Grun. occurs at high abundance (up to 70%) in the bottom layers from 153 to 116.5 cm. The genus comprises two species *Stauroforma exiguiformis* Flower, Jones & Round nov. comb. and *Stauroforma inermis* Flower, Jones and Round sp. nov (Flower *et al.*, 1996) which both have been found in the sediments.

Stauroforma exiguiformis Flower Jones & Round comb. nov. (Syn. *Fragilaria (virescens v.)* *exigua* Grun. in Cleve & Moeller No 144; *Fragilaria virescens* v.. *exigua* Grunow in Van Heurck (1880-1885); *Fragilaria exigua* (Grun.) in Krammer & Lange-Bertalot (1991); *Fragilaria exiguiformis* Lange-Bertalot, 1993.).

The specimens found in the sediments match closely the description of 'Norway' specimen in Flower *et al.* (1996) (length 10-15 μm, width 4.0-4.2 μm, 20-22 str/10 μm). The spinose *Stauroforma exiguiformis* prevailing in the sediments comprising up to 80% of genus *Stauroforma* when examined under SEM.

Stauroforma inermis Flower, Jones and Round, sp. nov

The non-spinose *Stauroforma* species was clearly different under SEM from the above species. The morphology closely follows Flower *et al.* (1996). *Stauroforma inermis* (length 8-13 μm, width 3.5-4.5 μm, 19-21 str/μm) is shorter and more oval in comparison with *S. exiguiformis*. Only solitary cells in low abundance were found under SEM.

3.3   Numerical analysis

3.3.1   Pollen and diatom diagrams

Pollen diagrams were generated using computer programs TILIA and TILIAGRAPH (Grimm, 1990). Pollen counts were put directly on the TILIA spreadsheet. The pollen diagrams were divided into pollen **POL** zones using CONISS (Constrained incremental sum of squares, Grimm, 1987) based on cluster analysis. CONISS is included into TILIA. The percentage pollen data were square-root transformed and the analysis was constrained by depth.

Diatom counts were first put into the ECRC diatom data base *Amphora* and then transferred to a TILIA spreadsheet. CONISS was used to split diatom diagrams into **DT** zones. Square-root

transformation was also applied to diatom percentage data and the stratigraphic constraint was introduced as in pollen diagrams.

Total concentration of pollen grains and diatom frustules were calculated in TILIA. Total pollen concentration was measured in thousand pollen grains per gramme of sediment (thous. pol/gr) and total diatom concentration was measured in million diatom frustules per 1 gramme of wet sediments (mln fr/gr).

3.3.2   Reconstruction of acidification history and pH profile

Acidity of Lake Chuna was reconstructed using the diatom-based pH transfer function and training set of lakes generated in the AL:PE project (Cameron *et al.,* 1993). Application of the AL:PE transfer function for pH reconstruction gives better results and smaller RMSE in comparison with the results of using the KOLA transfer function fully described in the Second INTAS Technical Report (ECRC, 1996). The gradient of acidity in the KOLA training set of lakes (ECRC, 1996) appeared to be too short for generation of a working transfer function. In future, the appropriate lakes from the AL:PE training set will be amalgamated with the KOLA training set to extend the pH gradient. The resultant transfer function will have better predictive abilities and give more accurate estimations of species optima and tolerance limits.

Quantitative estimates of the pH changes in the past were made with weighted averaging (WA) calibration using the program CALIBRATE (Juggins & ter Braak, 1992) at the levels where diatom analysis was conducted (see section 4.2.3). The pH profile was plotted using TILIA and TILIA*GRAPH (Grimm, 1991).

Diatom and pollen species richness at constant sample counts was analysed by rarefaction using the programme RAREPOLL (Birks & Line, 1992) with a base count of 300 and 294 respectively.

The gradient of dissolved organic carbon (DOC) in the training set discussed in the Second Technical Report (ECRC, 1996) was not sufficient for generating a transfer function and therefore changes in DOC throughout the core were approximately estimated using the DOC and colour optima for diatoms obtained by other authors (Pienitz & Smol, 1993; Korsman *et al.,* 1994) for Arctic regions of America and northern Sweden respectively.

DOC and colour optima of the ten most abundant diatom species in the layer between 153 and 116 cm were compared to the DOC optima of the 10 most abundant species in the upper layer (116 - 0 cm).

3.3.3   Numerical analysis of the diatom and pollen stratigraphy

All numerical analyses were performed using the program CANOCO version 3.10 (ter Braak, 1988; ter Braak, 1990). To obtain the length of gradient diatom and pollen startigraphies were first analyzed by DCA (Detrended Correspondence Analysis) with detrending by segments and rescaling of axes to obtain the length of gradient. The gradient length of 2.4 SD (standard deviation) units indicated that unimodal methods should be applied for analysing the diatom profile and so DCA was used to generate diatom sample scores. No species transformation was applied and rare species were downweighted. Species scores were calculated as weighted mean of sample scores.

Pollen data appeared to be more uniform with a gradient length of 0.878 which implies the usage of linear methods. Therefore Principal Component Analysis (PCA) with correlation biplot was used to obtain pollen sample scores. PCA was performed on untransformed percentage pollen data with centring by species. In order to avoid the problem of plotting pollen sample scores of negative numbers a factor of 2 was added to each score.

CCA (Canonical Correspondence Analysis) was applied to analyse the possible influence of changes in pollen data on diatom assemblage. Diatom data were used as 'response variables' and pollen data - as 'explanatory variables'. Diatoms were analysed in CCA at 36 levels, i.e. at those levels where pollen analysis had been conducted. Rare species were downweighthed and no species transformation was applied to diatom data. Pollen data analysed in CCA were log-transformed using the program CALIBRATE (Juggins & ter Braak, 1992), diatom data remained untransformed. Only 25 pollen variables were included in the CCA. 'Indeterminable' pollen and *Botriococcus* were excluded because these variables have no ecological meaning in interpreting diatom - vegetation relationships.

Sample and species scores presented in CANOCO PCA, DCA and CCA 'solution' files were used to interpret the resulting biplots.

Forward selection was used to determine influential explanatory variables. Significance of axes and variables were assessed by Monte Carlo tests with restricted permutations (999) for time series. A Bonferonni test was used to establish the P value for which successive variables were retained as significant (Manly, 1992, see also ECRC, 1996).

4   RESULTS AND DISCUSSION

4.1   Sediment lithology

The major part of the sediment core is very homogenous and highly organic, most of the core (from 0 to 150 cm) belongs to the Lso class diatomite (*Limus siliceus organogenes*) and to Ld^0 (*Limus detrituous*) according to the Troels-Smith classification (Troels-Smith, 1955). The sediments are rather diatomaceous. Many samples contain remains of Bryophytes which form distinctive layers in the lower part of the core starting from 120 cm.

The lower layers contain more mineral material and was classified as silt-gyttia. The increase in mineral content may be an indicator of Younger Dryas/Preboreal transition. Higher mineral content is associated with higher erosion from the catchment which points to unstabilised vegetation cover occurring during the Preboreal after the retreat of glaciers.

No measurements of loss on ignition (LOI) have been carried out because of the sparcity of sediment material. LOI analysis will be done after slides for fine resolution pollen and diatom analysis have been prepared.

4.2   Pollen stratigraphy

4.2.1   Introduction

Figure 2 shows the percentage pollen diagram. It includes all the spore and pollen taxa identified with the abundance >1%, total pollen concentration, lithology, and CONISS dendrogram. The total list of identified taxa includes 51 species, 20 taxa are included in the pollen diagram. Because Lake Chuna is located above the tree-line the original way of calculating pollen as percentages of arboreal pollen sum (AP) can be misleading. Therefore, the proportions of trees, shrubs and herbs indicated in the diagram (Figure 2) is based on the total terrestrial pollen.

Pollen stratigraphy (Figure 2) has been analysed at 8 cm intervals through the first two thirds of the core and at every 1 cm from 108 cm to 153 cm to check the stratigraphical integrity of the core sequence, to obtain an approximate chronology for the core, and to assess the climate fluctuations. The samples were counted at 1 cm intervals from 108 cm because the major change in diatom assemblage takes place from 116 cm (see Figure 5) and it is essential to find out whether the diatom change is reflected in the changes in pollen and vegetation and consequently in climate.

The diagram is dominated by tree pollen (*Betula, Pinus, Alnus* and *Picea*), shrubs are largely represented by *Corylus* and *Juniperus* (the *Betula-Myrica-Corylus* group was also included in the 'shrub' group). Other terrestrial pollen (O.T.P. in the diagram) comprises *Gramineae, Cyperaceae, Ericaceae* and *Empetrum* which was separated from other *Ericaceae,* and a group described as 'Herbs'. 'Herbs' includes the sum of percentages of terrestrial pollen which were found in the sediments but were not included in the diagram individually because of their low abundance. The group includes *Artemisia, Rumex, Compositae* (mainly *Cirsium* group), *Rosaceae* (*Potentilla* and *Fillipendula* type), *Chenopodiaceae, Caryophylaceae* and *Plantaginaceae.* The low abundance of the pollen grains (1-3 per slide) does not allow assessment of the individual role of the above taxa in the regional vegetation but the sum of 'herbs' can reflect the trends in vegetation change.

The pollen diagram was divided into 5 local-pollen assemblage zones (L.P.A.Z) using CONISS. Table 1 briefly describes pollen, vegetation and climate changes within each zone and gives approximate age estimations according to these changes.

The Lake Chuna pollen diagram is typical for alpine tundra and forest - tundra diagrams of this region (e.g. see pollen diagram of Lake Rautuselka - Seppa, 1996). The lake is located above the tree-line and the catchment vegetation is very sparse, largely dominated by dwarf shrubs (*Ericaceae*) with low pollen production and lichens. Therefore the pollen diagram is much influenced by the long distance transport of tree pollen, (largely *Betula* and *Pinus*) which represent a regional pollen signal.

Pollen concentration varies substantially throughout the core increasing towards the bottom of the core with a mean maximum of 108.20 thous. pol/gr in zone **POL II** (Figure 2).

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Figure 2   Lake Chuna pollen diagram. Sediment depth in cm, pollen frequency expressed as a frequency of total pollen, concentration expressed in thous. pol/gr.
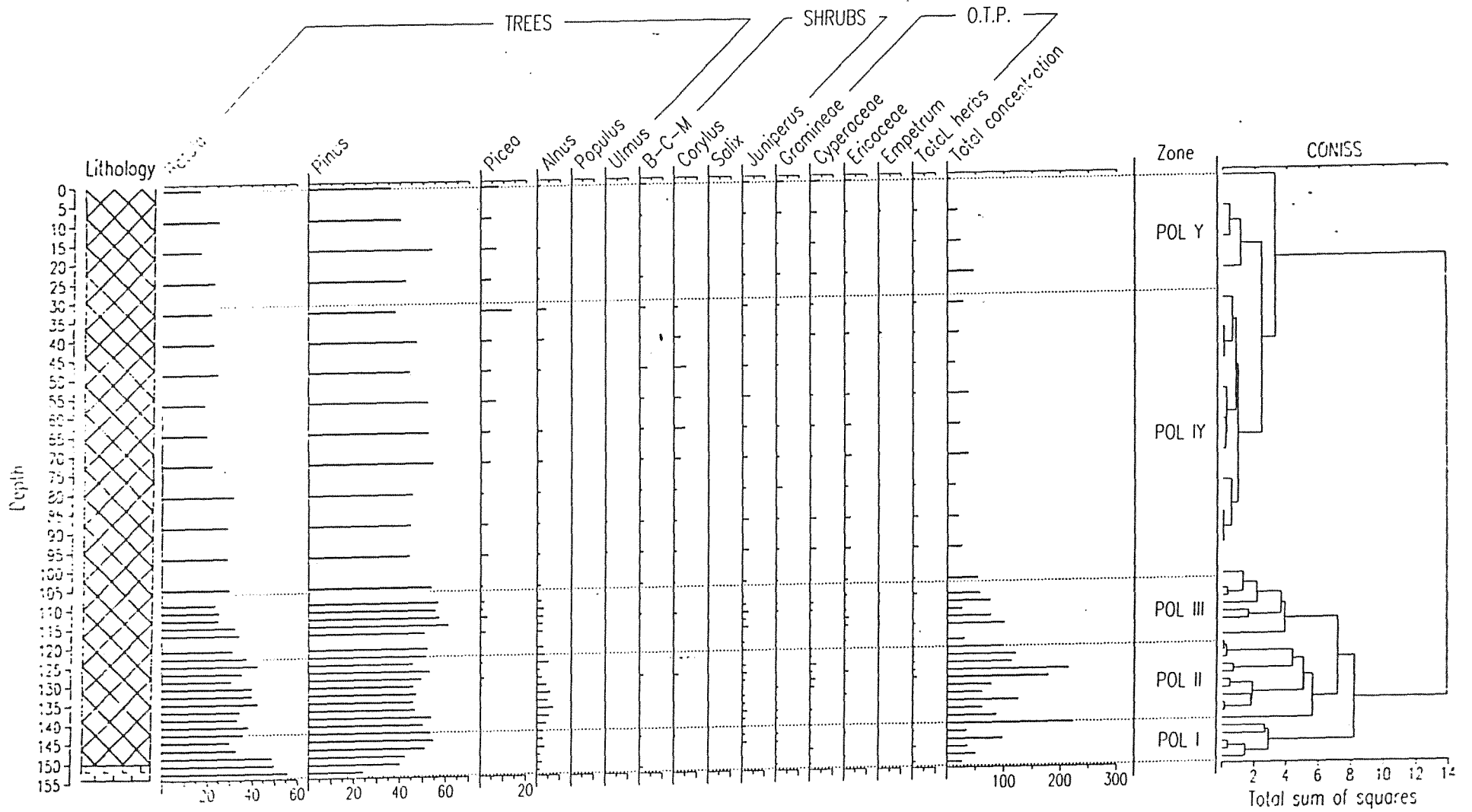
Figure 2   Cont.
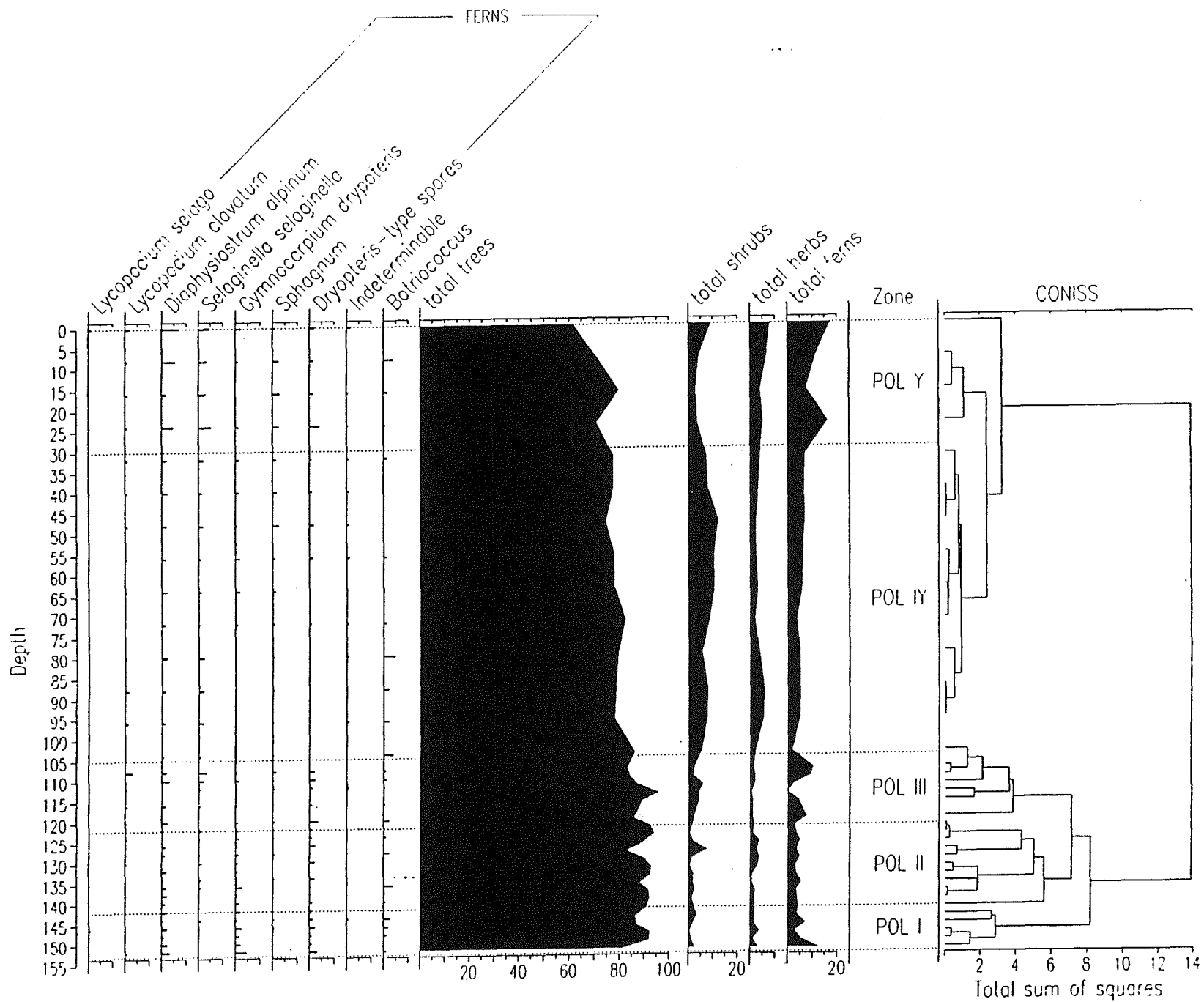
Table 1   Diatom and Pollen zones identified by CONISS

Diatom zone and depth, cm	Characteristic features	Corresponding pollen zone	Estimated date and climate events
DT 1 153-145.5, cm	Maximum of *Fragilaria virescens v exigua, F. elliptica, F. construens* and *Aulacoseira nygaardii*. Appearance of *Frustulia rhomboides v. saxonica* .By the end of the period appearance of *A. distans var. nivaloides*. Fluctuations of Brachysira brebissoni	**POL 1** (153 - 142.0 cm). End of Preboreal is asssosiated with *Betula* dominance and appearance of *Pinus*	8,500-8,000/7,500 cal BP , end of Preboreal; start of climate amelioration - gradually climate becomes warmer and moister
DT II 145.5 - 116. cm	Decrease in concentration but still dominance of *Stauroforma ssp*, increase of *B. brebissoni*, increase and then almost dissapearance of *A. distans v. nivaloides*, maximum of *A. lirata v. lacustris and A. perglabra*. Increase of *Achnanthes marginulata, A. minutissima* and *N. angustatula*. Occurrence of *Eunotia rhomboides* and *E. arcus*	**POL II** (142.5-122.5 cm) Rise in *Pinus*, appearence of *Juniperus, Corylus* and *Picea* which is characteristic for Boreal in the N. Fennoscandia	8,000-7,000/6,500 yrs BP Boreal stage: climate instability, short-term climatic fluctuations.
DT III 116 - 104.0 cm	Dissapearance of *F. virescens v exigua, A. lirata v. lacustris, A. nygaardii*. Sharp increase of *B. brebissoni* and *B. vitrea*, increase of *A. marginulata, F.rhomboides v. saxonica*	**POL III** (122.5 - 105 cm) Further rise in *Pinus, Picea* and *Juniperus*, decrease of *Betula*. Total pollen concentration decreases	7,000-6,000-5,500 yrs BP Transition between Boreal and Atlantic period
DT IY 104.0 - 32.5 cm	Fluctuations in *B. brebissoni, B.vitrea, A. marginulata, A. minutissima, Pinnularia biceps* and *F. rhomboides v. saxonica* with slight decrease of the species by the end of the zone. Almost total absence of *Fragilaria* group. Total diatom concentration declines.	**POL IY** (105 - 30 cm) Gradual dominance of *Pinus* and slight decrease of *Betula*, rise in *Corylus, Alnus* and other terrestrial pollen and spores.	6,000 - 2,000/1,500 yrs BP Climate optimum of Atlantic period
DT Y 32.5 - 0 cm	Slight decrease in concentration of *B.brebissoni* and *B. vitrea*, the same abundance of *Achnanthes* group, *F. rhomboides v. saxonica, E. praerupta* and *E. arcus*. Increase of diatom concentration by the end of the zone.	**POL IY** (30 - 0 cm) Further increase in non-tree pollen, maximum of *Picea, Alnus, Gramineae*, other terrestrial pollen and spores, Pinus dominance with *Betula* decline.	2,000/1,500 yrs BP- present time Sub-Boreal /Sub-Atlantic climate transition, modern climate deterioration

The base of the core (see **POL I** in Figure 2) is estimated as the beginning of the Boreal period, which is about 8,500 - 8,000 yrs BP in the Kola Peninsula (Lebedeva *et al.*, 1989; Seppa, 1996). Apparently, the core does not contain the whole Holocene sequence. The latest available dated pollen stratigraphy of lake sediments from northern Fennoscandia is from Lake Rautuselka located at 28°32' E and 69°34' N in Finland (Seppa, 1996). The diagrams Lake Rautuselka were used to correlate the Lake Chuna pollen diagram and to estimate the age of the base of the core.

Other pollen diagrams from northern Fennoscandia used for correlating the Lake Chuna pollen diagram include radiocarbon dated pollen startigraphies from the catchments of the Rivers Lotta and Tuloma (south west of the Kola Peninsula) presented by Lebedeva *et al.* (1989).

Zone **POL I** (153 - 142 cm, 8,500 - 8,000/7,500 yrs BP).
Within this zone *Betula* dominates the vegetation, it is a '*Betula* time' according to Lebedeva *et al.* (1989). However, the concentration of pine and *Alnus* pollen increase by the end of the period. *Betula, Pinus* and *Alnus* are the only representatives of trees, *Picea* grains were not found in this zone. Pollen grains of the 'shrub group' including *Juniperus* and *Corylus* did not appear in this zone. *Ericaceae* is presents at very low levels (ca. 1.5%).

Tree pollen totally dominates during this period with the total sum of tree pollen exceeding 90%. Other terrestrial pollen found in this period include *Cyperaceae, Gramineae* and *Artemisia*. Fern spores comprise *Diaphisiastrum alpinum, Gymnocarpium dryopteris* and *Dryopteris*-type. Undetermined fungi spores occur at relatively high concentration (up to 10 % at the 153 cm level) in this zone. The spores were not included in the diagram because their taxonomy is uncertain.

Total pollen concentration in **POL I** is lower than in the previous zone and averages 52.32 thous. pol/gr with a range from 29.6 to 96.6 thous. pol/gr.

Changes in vegetation reflected in the pollen of the zone **POL I** indicate the climate transition during the first stage of the Boreal period (Seppa, 1996).

POL II (142 - 122.5 cm, 8,000 - 7,000/6,500 yrs BP).
Zone **POL II** is characterised by an increase in the relative proportion of *Pinus* pollen and corresponding decrease of *Betula*. In the middle of the zone at 128 cm, grains of *Juniperus, Corylus* and *Picea* occurred. *Alnus* reaches its maximum in **POL II**. Other terrestrial pollen (*Cyperacea, Gramineae* and herbs) increase in quantity. The relatively early (compared to the evidence of other authors e.g. Korsman *et al.* (1994)) occurrence of *Picea* and *Corulys* pollen in the sediments (estimated age about 7,000 yrs BP) can be explained by long distance transport from regions located to the south of the Kola Peninsula. *Picea* is considered to be present in the catchment area if its pollen concentration is ≥ 5% (Tallantire, 1972). Actual arrival of *Picea* to the area adjacent to the Chuna catchment (the lake is located above the tree-line and it is unlikely that trees were ever presented in its catchment) occurred about 3,000-4,000 yrs later.

The gradual transition of birch to pine forests with their subsequent dominance is characteristic for the second half of the Boreal in the Kola Peninsula (Lebedeva *et al.*, 1989) and the beginning of the Atlantic period. Therefore zone **POL II** approximately covers the period from 8,000 to 7,000/6,500 yrs BP.

Pollen concentration appears to be the highest in the this zone with the greatest range of change from 29.9 (minimum) to 221.5 (maximum) thous. pol/gr (Figure 2). Average total pollen concentration in **POL II** is 108.2 thous pol/gr.

Zone **POL III** (122.5 - 105 cm, approx. 7,000/6,500 - 6,000/5,500 yrs BP) .
POL III reflects the development of the Atlantic period in the Kola Peninsula. The continuing increase of *Pinus* dominance, and general higher floral diversity (see Figure 3) are the main features of this transition (Lebedeva *et al.*, 1989). The increase in concentration of *Lycopodiaceae* spores (*Diaphisiastrum alpinum* and *Selaginella selaginella*) spores and *Botrioccocus* is also characteristic for this relatively warm and moist period of climate optimum in the Kola Peninsula.

The range of fluctuations of total pollen concentration is smaller than in the previous zone, it changes from a minimum of 23.3 thous. pol/gr. to a maximum of 74.9 thous. pol/gr. with an average of 38.3 thous pol/gr.

Zone **POL IY** (105 - 30 cm, approx. 6,000/5,500 - 2,000/1,500 yrs BP).
This zone covers the peak and decline of Atlantic climate optimum and its transition into Sub-Boreal period with colder and dryer climate. The main distinctive characteristic is a considerable increase of *Gramineae*, shrubs (*Juniperus* and *Ericaceae*) and *Alnus* in the middle of the zone and decline of the above species by the end of the period. *Betula* occurs at its minimum concentration during this period. Appearance and spread of *Picea* and *Corylus* in the immediate region of Lake Chuna (abundance of *Picea* pollen ranges from 5 to 12%) is the other important change in the vegetation in **POL IY**. *Picea* pollen reaches its maximum abundance in the core by the end of the period (12% of total pollen concentration at the depth of 32 cm). Generally, *Picea* is characterised by lower pollen production compared to *Betula* and *Pinus* (Moore *et al.*, 1991) and 12% of spruce pollen in the sediments corresponds to about 36-48% of spruce in the vegetation (Segeström, 1990)

Fern and *Lycopodiaceae* spores gradually increase their concentration in **POL IY** and *Gymnocarpium dryopteris* appears again after being absent in the previous zone. *Sphagnum* spores also occur which indicates the development of oligotrophic *Sphagnum* bogs (see Lebedeva *et al.*, 1989; Lavrova, 1960).

Total pollen concentration is lower in this zone. It ranges from 12.9 to 36.6 thous pol/gr, with a mean of 25.8 thous pol/gr.

Zone **POL Y** (30 - 0 cm, approx. 2,000/1,500 BP until present time).
The last CONISS zone **POL Y** comprises the Sub-Boreal and Sub-Atlantic periods. During that time the percentage of trees slightly declines from 80% at its maximum at 18 cm (about 900 yrs BP) to 60 % at present. It is mainly characterised by the decrease of *Pinus* pollen as the percentage of birch and spruce remains on average the same in comparison with the previous period. *Alnus* and *Corylus* pollen gradually decline, *Juniperus*, on the contrary, slightly rises by the end of the zone.

The percentages of herbs, *Gramineae, Cyperaceae, Polypodiaceae, Lycopodiaceae* and *Sphagnum* increase. This is possibly due to the climate cooling and anthropogenic deforestation which caused the shift of the northern forest boundary to the south (Lebedeva *et al.*, 1989)

The concentration of pollen grains in **POL Y** is the lowest of the core, probably because the surface layer of sediments was diluted with water.

4.2.3   Analysis of pollen species richness

Figure 3 shows the changes of pollen diversity estimates (E (S) in RAREPOLL) plotted against the core depth. The upper two thirds of the diagram (from 113 cm to the surface) is uniform, the species diversity ranges between 21.95 and 16.66 slightly increasing by the top of the core. A maximum of pollen diversity is found between 47 and 30 cm (zone **POL IY**). The maximum coincides with Atlantic period and maximum of *Corylus* and *Picea* pollen in the sediments. Pollen species richness sharply drops (E (S) = 7.0) at the depth of 114 cm, then recovers to 17.5 and after that gradually declines further down the core except for peaks at 128 cm and 146 cm. Mean of species diversity above 114 cm is 19.7 ± 1.5 and mean of E(S) below 114 cm is 13.68 ± 2.8.

The estimated age of the layer 153-114 cm is 8,500-6,500 yrs BP and this period is characterised by a colder climate and general climatic instability with short-term fluctuations (see Table 1) which is reflected by the lower vegetation diversity (Lebedeva *et al.*, 1989). From about 6,500/6,000 yrs BP the climate gradually became warmer, moister and more stable and this affected regional vegetation diversity which also becomes more uniform.

Figure 3   Profiles of pollen and diatom species diversity. Sediment depth in cm

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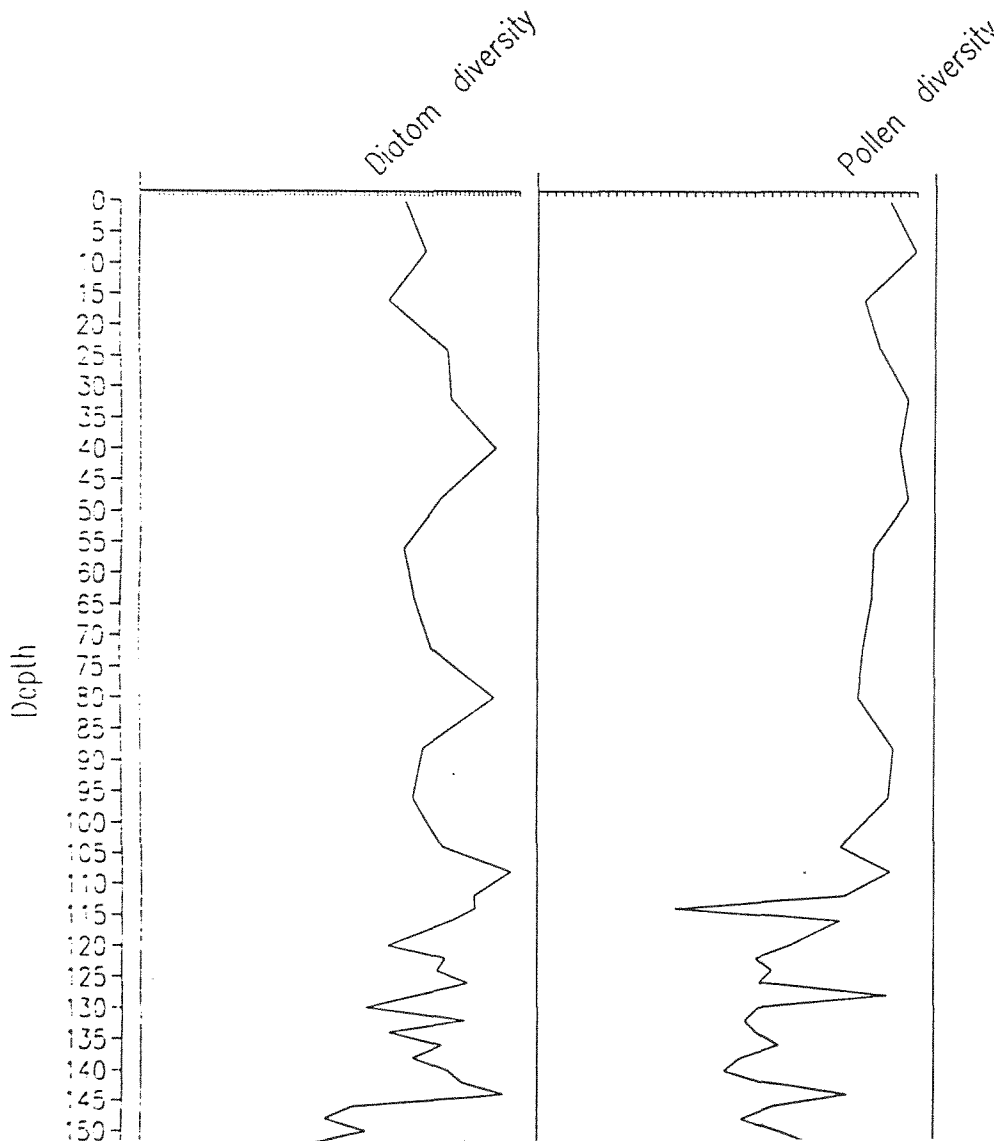
4.2.4   Numerical analysis of the pollen profile

Table 2 shows the PCA summary statistics of the pollen data. The first two axes explain 92.8% of variance in the species data. The eigenvalue of the first axis is more than 2 times higher then the second axis which means that the first axis is the most important in interpreting the relationship between the variables. Eigenvalues of axes 3 and 4 are small and therefore can be ignored.

Table 2   PCA: summary statistics for the pollen data of the Lake Chuna long core, 36 samples and 27 taxa

AXES	1	2	3	4	Total inertia
Eigenvalues	.6383	.2897	.0205	.0144	1.000
Cumulative % variance of species data	63.8	92.8	94.9	96.3	

The PCA biplot in Figure 4 shows that abundant species have higher scores (e.g. *Betula, Juniperus* and *Ericaceae* in Axis 1; *Pinus, Picea* and *Diaphisiatrum* in Axis 2) than species occurring at low abundance.

Alnus and *Betula* show a certain interrelation, they are also negatively correlated with the first axis and with the majority of other variables except for *Pinus* and *Gymnocarpium* (for detailed explanations of how to interpret PCA, DCA and CCA biplots see ECRC, 1996). *Pinus* and *Gymnocarpium* are strongly negatively interrelated and they show almost no relationship with any other variables.

The PCA biplot reflects the trends in development of vegetation during the Holocene. Birch and alder forests which were dominant in the early Holocene were substituted by more diverse spruce forests and tundra vegetation. The biplot also illustrates the equilibrium between birch and spruce in a mixed forest (birch patterns are gradually substituted by spruce and *vice versa* with total tree abundance remaining at the same level). The spread of pine occurred independently of the development of other vegetation.

Figure 4   PCA biplot of 25 pollen types and 36 pollen samples. Pollen are shown as
            arrows, sample levels - as open triangles, numbers indicate core depth in cm
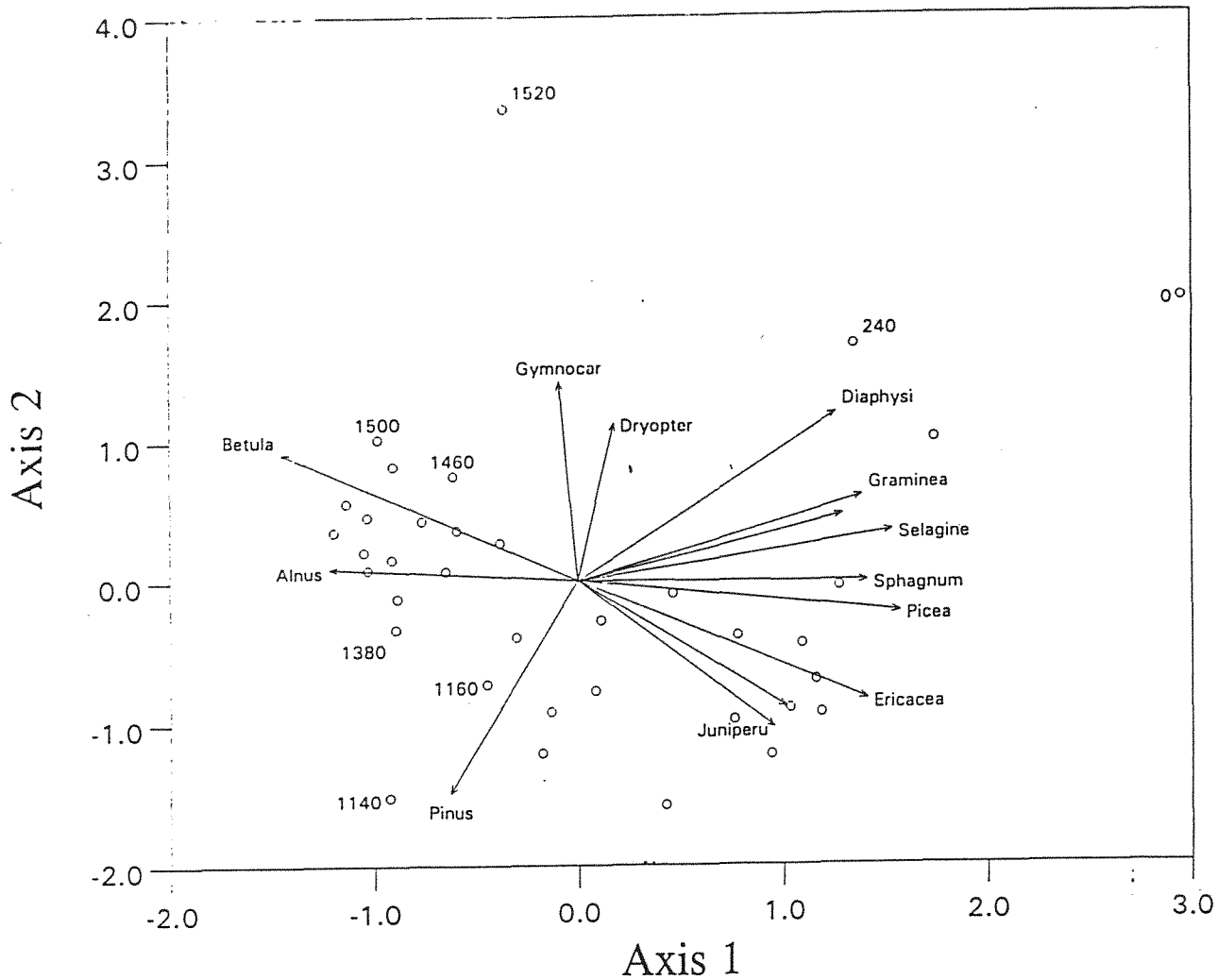
4.3   Diatom stratigraphy and pH profile

4.3.1   Overview

Figure 5 presents the percentage diagram of diatoms found in the sediments with an abundance >3%. The total list of identified diatom species comprises 132 diatoms, the diagram presented in Figure 5 includes 50 species. The taxa are sorted by abundance and the diagram includes 162 levels.

On the whole, the species composition of the Lake Chuna sediment core presented in Figure 5 is typical for oligotrophic Arctic and Sub-Arctic lakes (see for example, Weckstrom *et al.*, (1997); Battarbee *et al.*, (1997); Pienitz *et al.*, (1995a); Smol, 1988). The diatom assemblage of the core is largely formed by non-planktonic species of genera *Brachysira, Stauroforma, Aulacoseira, Achnanthes, Frustulia, Eunotia* and *Cymbella*.

Figure 5   Lake Chuna diatom diagram. Sediment depth in cm, relative abundance in %
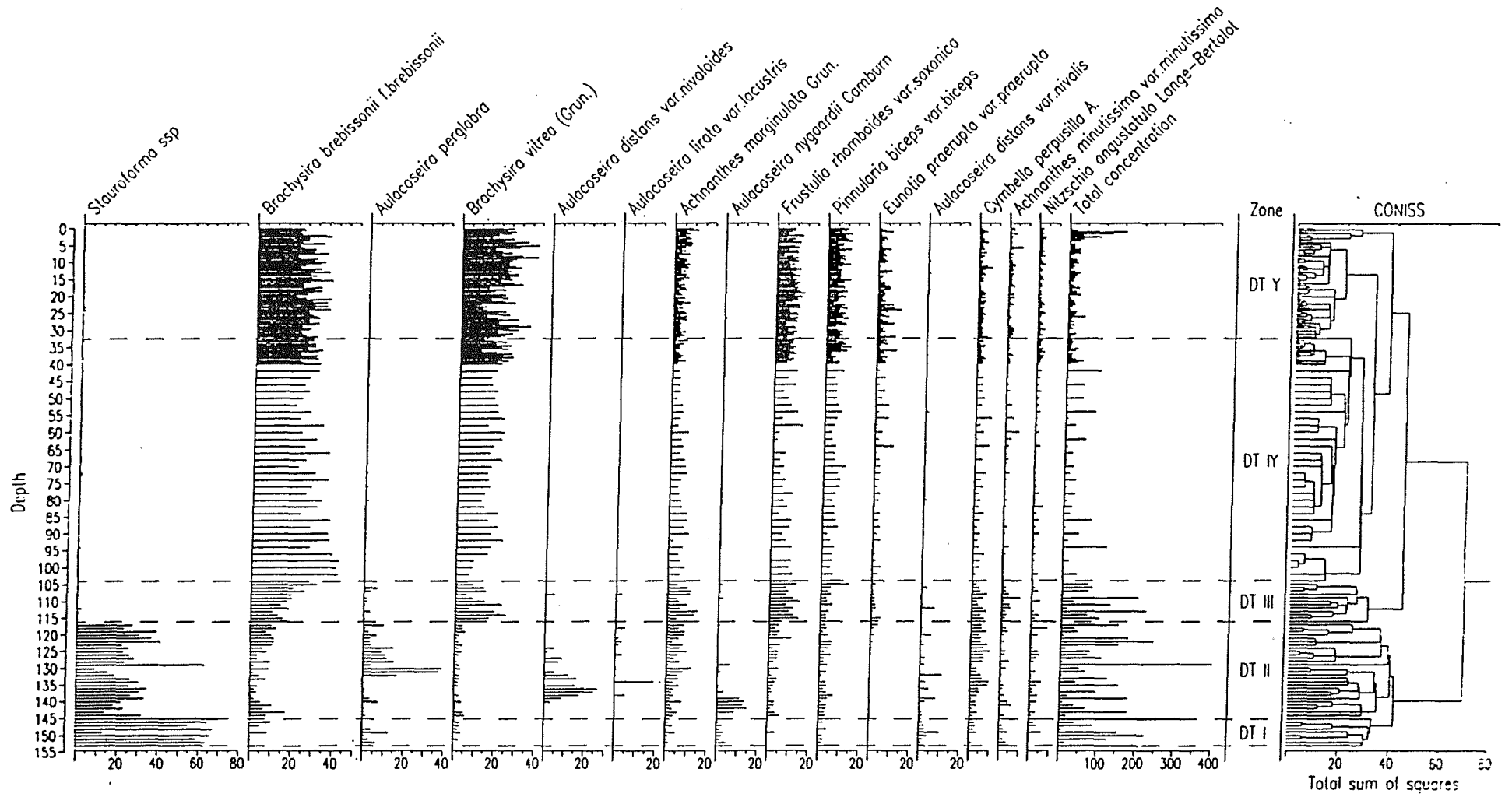
Figure 5 Cont.
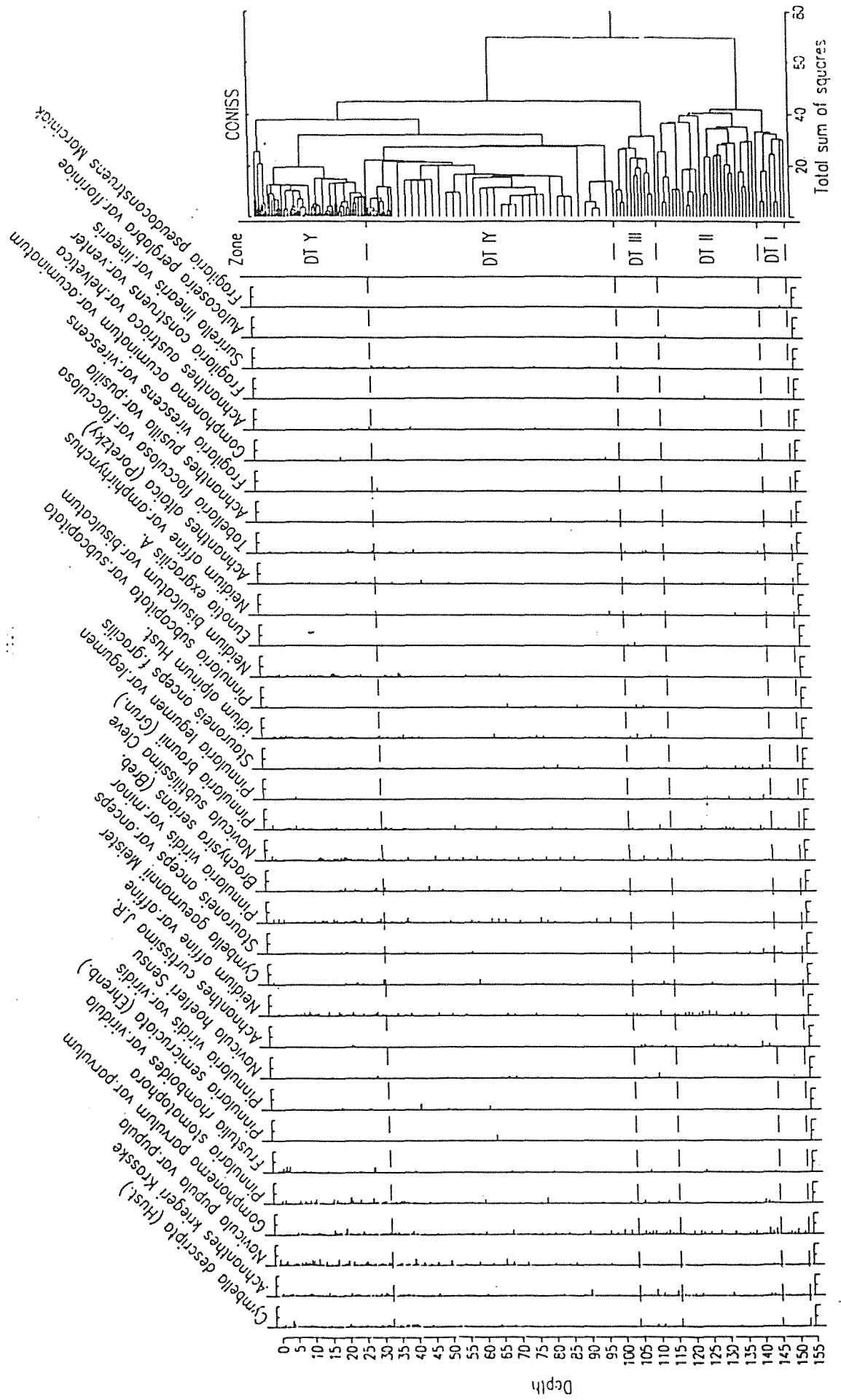
Figure 5 Cont.
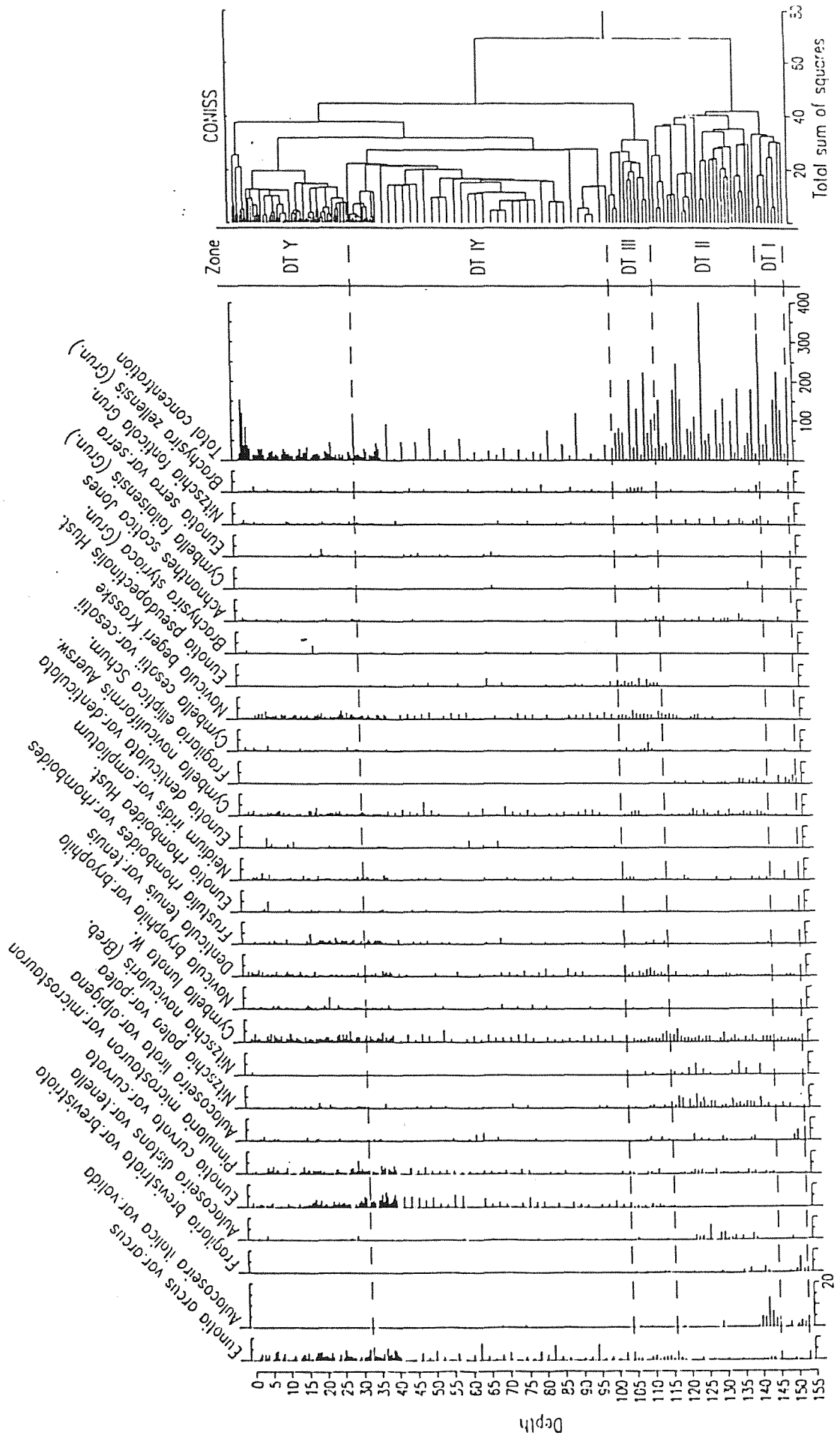
The complex of benthic diatoms i.e. *Brachysira brebissoni, B. vitrea, Frustulia rhomboides* v. *saxonica, Pinnularia biceps* and *Achnanthes marginulata* dominates the diatom assemblage of the lake from the depth of 115 cm to the surface. Though the relative percentage of these species fluctuates, on the whole they remain dominant within the above limits and together constitute more than 70% of the total diatom abundance.

From 115 cm to the bottom of the core the diatom composition of the lake changes drastically and *Stauroforma* spp which was absent in the upper levels becomes an absolute dominant (Figure 5). *Aulacoseira* species (e.g. *A. perglabra* v. *perglabra, A. distans* v. *nivaloides, A. nygaardii, A. distans* v. *nivalis, A. italica* v. *valida* etc.), *Fragilaria* group (*F. brevistriata, F. elliptica* and *F. construens*) together with *Nitzchia palea* and *N. navicularis* also predominantly occur in the lower third of the core. The only *Aulacoseira* species - *A. lirata* v. *alpegina* occurs almost at the same frequency and the same concentration throughout the whole core.

Several species which are abundant in the upper layers (from about 110 cm to the surface) (Figure 5) decrease (e.g. *B. brebissoni, B. vitrea, Frustulia rhomboides* v. *saxonica*) or almost totally disappear like *Eunotia praerupta, E. arcus, E. curvata, E. pseudopectinalis, Navicula begerii* and *Sellaphora pupula.*

Achnanthes marginulata, A. minutissima, Cymbella naviculiformis, C. lunata, C. perpusilla, Aulacoseira lirata v. *alpegina, Pinnularia biceps* and *Nitzchia angustatula* are distributed evenly throughout the whole core. The *Frustulia* group (*F. rhomboides* v. *saxonica* and *F. rhomboides*) show a slight decline below 115 cm, otherwise its concentration does not change greatly and varies around 10-14% through the core.

The diatom diagram was divided into six zones using CONISS via TILIA. Table 1 describes diatom changes within each zone and gives the comparison with the CONISS pollen zones, as well as brief climate characteristics and approximate age estimation according to these changes. The detailed description of each diatom zone is given in the section below.

Considering that the reconstruction of the lake acidity was based on the quantitatively estimated pH optima of diatom algae, the results of pH reconstruction are presented and discussed within the diatom section.

Figure 6 shows the reconstructed pH profile which reflects the dynamics of the lake's acidity from about 8,000 yrs BP to the present time. The diagram comprises 162 levels. On the whole, the pH of Lake Chuna has not changed considerably during the last 8,000 years. The pH at the base of the core was estimated as 6.2, identical to the current *estimated* value. The measured pH of Lake Chuna is 6.4, so the current model slightly underestimates the pH.

During the period covered by the sediment core the estimated pH values vary from a maximum of 6.7 to a minimum of 5.6 (Figure 6). Although the pH values vary within narrow limits they fluctuate frequently. For example, pH changes from 6.5 to 5.6 and then to 6.7 within an interval of 2 cm at 136-134 cm, which covers about 100 years. Such periods of relatively quick changes alternate with more stable intervals when pH changes only by one or two decimal points during 100-200 years.

On the whole, pH slightly decreases from the bottom of the core to 105 cm. From 105 cm to the surface it stabilises at around 6.12 and varies from a maximum of 6.71 to a minimum of 5.78.

Figure 6   **Reconstructed pH of Lake Chuna**
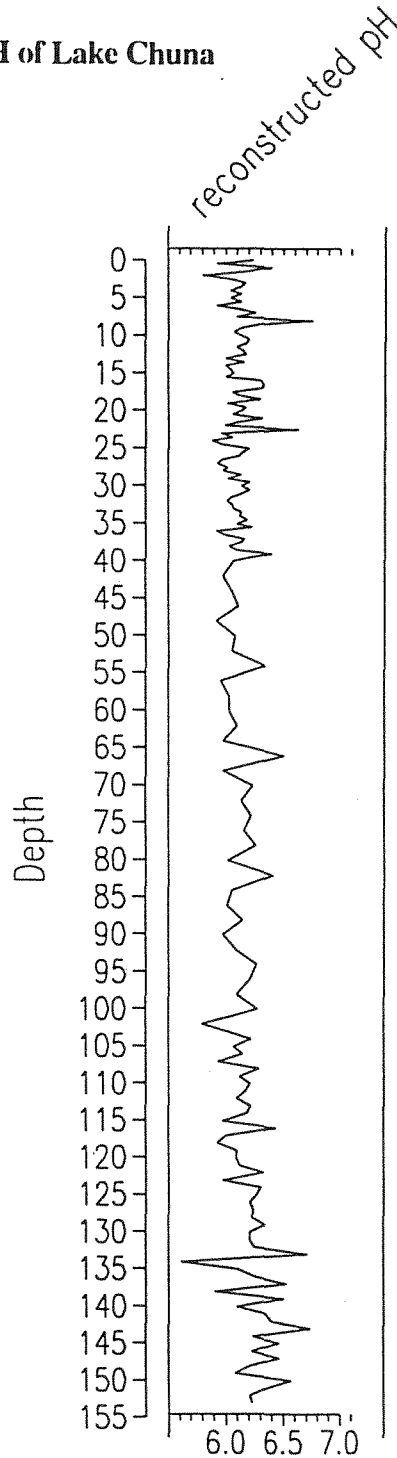
The parts of pH profile within each of diatom zone are described with greater detail in Section 4.3.2.

In general, total diatom concentration fluctuates greatly, ranging from 0.202 to 400 mln. fr/g (Figure 5). Diatom concentration like pollen concentration increases towards the bottom of the core, with the substantial increase is observed below 104 cm in **DT III** (the average for the top zone **DT IY** is 23.71 mln. fr/g and the average for the next, **DT III**, is 83.77 mln. fr/g).

4.3.2   Diatom zones identified by CONISS and pH profile

Zone **DT I** (153-145.5 cm, 8,500-8,000/7,500 yrs BP).

Zone **DT I** is totally dominated by benthic *Stauroforma spp* (up to 70%) of total concentration, *Fragilaria brevistriata* (5%) and *F. elliptica* (5%) also occur at highest concentrations in this zone compared to the rest of the core. *Stauroforma* spp. reaches its peak between 153 and 145 cm (65-70%), then it drastically declines to 15-30%. The zone's diatom assemblage is principally constituted by *Stauroforma/Fragilaria* groups and by the genus *Aulacoseira* which together constitute up to 85%, although the *Brachysira* group also occurs in the zone at concentrations of up to 15% (*B. brebissoni*) and 5% (*B. vitrea*).

Concentrations of benthic *A. distans* v. *nivaloides* and *A. nygaardii* increase by the end of the zone and reach a peak at about 15%. *A. perglabra* and *A. distans* v. *nivalis*, on the contrary, decline. *Aulacoseira lirata* v. *alpegina* remains at the same concentration through the zone.

Aulacoseira italica v. *valida* which is almost the only representative of planktonic flora in the diatom assemblage of the core also presents at maximum concentration in this zone (6-7%) at 143-140 cm. Its concentration drops to zero by 139 cm.

The rest of the assemblage is constituted by *Achnanthes* (*A. marginulata* and *A. minutissima*), *Pinnularia* (*P. biceps* and *P. microstauron*), *Cymbella* (*C. perpusilla C. lunata* and *C. naviculiformis*), *Frustulia* (*F. rhomboides* v. *saxonica* and *F. rhomboides*) and *Nitzchia* (*N. angustatula* and *N. palea*). On average, the above species are present at concentrations of 3-6% .

The part of the pH profile within **DT I** varies frequently and fluctuates between 6.7 (maximum at the depth of 144 cm) and 5.9 at the depth of 138 cm. The average pH value during this period is 6.29.

Total diatom concentration is highest in **DT I** compared to the rest of the core, it averages 109.45 mln. fr/g ranging from 7.88 to 225.15 mln. fr/g.

Zone **DT II** (145.5 - 116 cm, approximately 7,500-7,000/6,500 yrs BP).

The species composition of this zone is similar to **DT I**, the dominant genera are again *Stauroforma* and *Aulacoseira*. The *Fragilaria* group declines and almost disappears by the end of the zone.

Stauroforma occurs at an average of 25%, and only once, at 128 cm, it reaches the peak concentration of the previous zone (63%).

Although *Aulacoseira* still dominates the assemblage, its species composition and species concentrations are different in comparison to the previous zone. *Aulacoseira distans* v. *nivaloides* and *A. perglabra* become the most abundant species in the group. *A. nygaardii* and *A. italica* v. *valida* almost disappear except for one odd peak at 128 cm and A. *tenella* and *A. lirata* v. *lacustris* occur for the first time at low concentrations. *Aulacoseira lirata* v. *lacustris* appears once at a relatively high concentration of 20% at 135 cm depth. *Aulacoseira distans* v. *nivalis* remains at the same concentration but occurs at fewer number of levels.

Average concentrations of *B. brebissoni* and *B. vitrea* remain the same as in the previous zone, although *B. brebissoni* rises slightly by the end of **DT II**. The abundance of *A. marginulata, C.*

perpusilla, F. rhomboides v. *saxonica* and *N. palea* increase by 1-2% compared to **DT I**. Concentrations of *Achnanthes minutissima, C. lunata, N. angustatula* remain at the same level.

The part of the pH diagram confined by **DT II** shows little change compared to the pH profile within **DT I**. The slight difference is that it fluctuates with lower frequency and the periods with quick pH changes give way to more stable periods. The average pH for this zone is 6.15.

Total diatom concentration reaches its peak for the whole core at the depth of 129 cm (400 mln. fr/g) although mean total diatom concentration is 94.72 mln. fr/g which is lower than its value for **DT I**. Total diatom concentration ranges from 0.98 to 400 mln. fr/gr within **DT II**.

Zone **DT III** (116.0 - 104.0 cm, approximately 7,000/6,500 - 6,000/5,500 yrs BP).
This zone represents a transition between the *Stauroforma/Fragilaria/Aulacoseira* complex dominating the lower third of the core and the *Brachysira/Frustulia/Eunotia* assemblage which prevails in the upper two-thirds of the core. *Stauroforma spp.* together with *A. distans* v. *nivaloides, A. nygaardii* and *A. distans* v. *tenella* almost totally disappear except for one peak at 107 cm. *A. perglabra* sharply declines and *A. distans* v. *nivalis* occurs at only two levels with low abundance. *Nitzchia palea* and *N. navicularis* are also present at very low abundance and virtually disappear by the end of the zone.

The concentration of the *Brachysira* group visibly increases by the end of the zone and the *Eunotia* group (*E. praerupta, E. arcus, E curvata and E. pseudopectinalis*) appears for the first time at substantial abundance (*E. praerupta* occurs for the first time in the previous zone but at a very low abundance).

Frustulia rhomboides v. *saxonica* increases its abundance from 5-6% in **DT II** to 11-13% in **DT III** and *F. rhomboides* v. *rhomboides* occurs for the first time in **DT III**.

Pinnularia, Achnanthes and *Cymbella* species are present at the same concentration as in **DT II**. *Denticula tenuis* slightly increases its concentration.

The pH profile within this zone varies more frequently than in the previous zone and the average pH value for this period is 6.11.

Average total diatom concentration gradually decreases in **DT III** and equals 83.76 mln. fr/gr with a range from 3.56 to 222.35 mln. fr/gr.

Zone **DT IV** (104 - 32.5 cm, approximately 6,000/5,500 - 2,000/1,500 yrs BP).
During the period of **DT IV** the *Brachysira/Frustulia/Eunotia* complex of species becomes established. Although the absolute abundance of the species fluctuate these genera remain dominant in this zone and in the rest of the core.

Brachysira brebissoni occurs at its highest concentration and declines slightly by the end of the period, *B. vitrea*, on the contrary, increases its abundance towards the surface. *Eunotia arcus* forms three distinctive peaks with a concentration of 6-7% remaining at 3-4% in the rest of the zone. The abundance of *E. praerupta* changes only slightly at the end of the zone otherwise it stays at the level of 3-4%.

Concentrations of *Achnanthes minutissima*, *N. angustatula* and *F. rhomboides* v. *saxonica* slightly decrease compared to **DT III**. *C. lunata*, *C. perpusilla* and *A. marginulata* remain the same and *P. biceps* somewhat increases. The variations of the above species concentrations follow a sinusoid curve.

Total diatom concentration decreases substantially in comparison with the previous zone with a mean of 23.71 mln. fr/gr and a range of 0.202 to 117.06 mln. fr/gr.

Zone **DT Y** (32.5 - 0 cm, approximately 2,000/1,500 yrs BP - present time).
In principal, this zone is very similar to the previous **DT IY**. The same genera: *Brachysira/Frustulia/Eunotia*, *Pinnularia biceps* and *Achnanthes* are dominant. The only difference between **DT Y** and **DT IY** is in the relative concentrations of species. For example, the concentration of *B. brebissoni* slightly decreases in **DT Y** and *B. vitrea* correspondingly increases in relation to **DT IY**. *Achnanthes marginulata* and *C. perpusilla* decrease by 2-3%, *A. minutissima*, *P. biceps*, *F. rhomboides* v. *saxonica* are unchanged. The *Eunotia* complex (*E. praerupta*, *E. curvata* and *E. arcus*) slightly increase. *Eunotia pseudopectinalis* almost disappears.

The parts of the pH profile within **DT IY** and **DT Y** do not differ substantially, the same patterns repeat in the above three zones. The average pH value within **DT IY** is 6.14 and in **DT Y** is 6.13.

Total diatom concentration decreases further and on average equals 19.62 mln. fr/gr, ranging from 0.365 to 151.67 mln. fr/gr.

4.3.3   Analysis of diatom species richness

Diatom species diversity was calculated to analyse the change of ecological status of diatom assemblages during the Holocene. The profile of diatom species diversity plotted against sediment depth is presented in Figure 3. Diatom species diversity fluctuates frequently between a maximum of 41.8 and a minimum of 18.5. It gradually increases from the surface to of 111 cm where it reaches the maximum. Below this point the species diversity starts to decline slowly. It forms two sharp peaks between 141 and 145 cm and then decreases reaching its minimum at 152 cm.

The decline of diatom species diversity occurs just before the drop in pollen diversity and can also be explained by the change of climate (see section 4.2.3). The sharp drop of diatom species richness in response to climate cooling is also pointed out by Anderson *et al.* (1996).

4.3.4   Ordination of the diatom data

Detrended correspondence analysis (DCA) was used to analyse the variance within the diatom data. Diatoms occurring at abundance > 1% were included in the analysis and a matrix of 162 samples and 94 taxa was analysed. Table 3 presents DCA summary statistics.

Table 3   DCA: summary statistics for the diatom data of the Lake Chuna long core, 162 samples and 94 taxa

AXES	1	2	3	4	Total inertia
Eigenvalues	.550	.092	.048	.034	1.434
Length of gradient	2.40	1.77	1.22	1.12	
Cumulative % variance of species data	38.3	44.7	48.1	50.5	1.434

The eigenvalue of the first axis is rather high (.550) but comparable with other studies (e.g. Stevenson *et al.*, 1991; Pienitz *et al.*, 1995). It reflects the high variance within the diatom taxa, the second axis has a value more than five times lower and therefore gives little contribution to understanding the relationships between diatom taxa. The first two axes account for 44.7% variance in the species data and this is comparable with findings of other authors (e.g. Vyverman & Sabbe, 1995; Birks, 1995). A gradient length of 2.4 is typical for floristic data and it indicates that diatom composition has considerably changed throughout the sediment core.

A DCA biplot of 162 samples and 46 diatom taxa is presented in Figure 7. It shows the major patterns of diatom distribution throughout the core. Only taxa occurring at an abundance > 3% are shown in the diagram. Diatom taxon codes used in Figure 7 are those used in the ECRC AMPHORA database.

DCA clearly separates diatom taxa into three groups (Figure 7) according to the depth of their occurrence. The largest group of diatoms located in the middle of the left part of the diagram consists of *Brachysira/Frustulia/Pinnularia/Eunotia* genera occurring above the depth of 115 cm. In essence, this group includes diatoms of CONISS zones **DT III-DT IY** described in detail in Section 4.3.2. All taxa of the group have relatively low scores in the first two axis of DCA.

The upper right quadrant of the biplot is occupied by the diatom complex of the bottom of the core (153-115 cm) dominated by *Stauroforma, Fragilaria* and benthic *Aulacoseira (A. lirata* v. *lacustris, A. italica* v. *valida, A. nygaardii* and *A. nivaloides)*. These taxa dominate CONISS zone **DT I.**

Other *Aulacoseira* species (*A. distans* v. *tenella, A. distans* v. *nivalis* and *A. perglabra*) which occur at high abundance in the bottom core layers (130-132 cm and 149 cm) where concentration of *Stauroforma* decreases, are located in the lower right quadrant of the diagram (Figure 7). These diatoms prevail in **DT II.** The middle right part of the diagram between the *Aulacoseira* and *Stauroforma* groups is occupied by the complex of taxa which occur at similar abundance throughout the core, e.g. *Cymbella, Achnanthes* and *Nitzchia.*

Figure 7   DCA biplot of 162 samples and 46 species from the Lake Chuna core. Diatom species are shown as open triangles
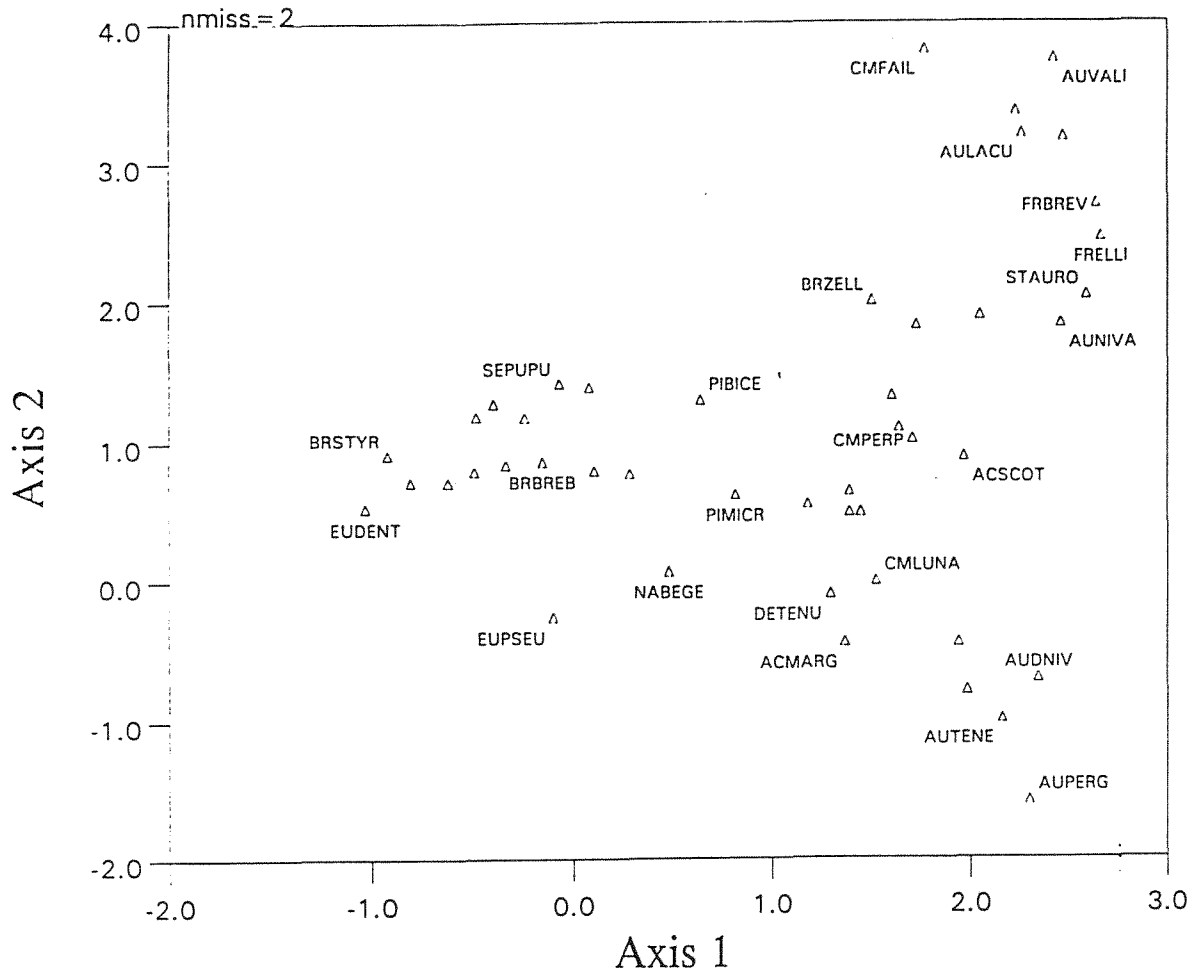
On the whole, patterns of variance revealed in diatom distribution down the core by DCA are also highlighted by cluster analysis in CONISS zones (see Section 4.3.2). However, separation of the upper part of the diagram (above 104 cm) into three zones **DT IY - DT YI** by CONISS seems to be artificial. Considering the results of both analyses, the diatom profile can be separated into four zones:

- **CH I** - coincides with **CONISS DT I** (153 - 138.5 cm)
- **CH II** - coincides with **CONISS DT II** (138 - 115.5 cm)
- **CH III** - coincides with **CONISS III DT III** (116 - 104.5 cm)
- **CH IY** - amalgamated CONISS zones **DT IY - DT Y** (104.5 - 0 cm)

CCA with reconstructed pH as a single explanatory variable was performed to establish the role of acidity in influencing diatom distribution throughout the core. The first axis constrained by pH accounts only for 2.6% of variance in diatom data. The eigenvalue of the first canonical axis is .034 which is much lower than the eigenvalue of the second unconstrained axis (.540). This means that pH is an unimportant variable and the observed changes in the lake diatom composition during the Holocene can not have been driven by the changes in lake acidity.

4.3.5   Dissolved organic carbon and diatom change

It is well established that dissolved organic carbon (DOC) and/or colour which is closely correlated with DOC are important chemical variables influencing diatom distribution (e.g. Stevenson *et al.*, 1991; Pienitz & Smol, 1993; Schmidt & Psenner, 1992; Korsman *et al.*, 1994). It can be especially significant in the arctic tree-line regions because DOC is largely determined by the composition and density of the catchment vegetation (Rouse *et al.*, 1997) and consequently catchment tree-line changes will affect the diatom composition. Although Lake Chuna is located above the modern tree-line, it is possible that trees were present in the catchment or that the vegetation density (and pollen diversity) changed during the climate amelioration of the Atlantic period.

It was revealed that the diatoms abundant in the lower third of the core (*Stauroforma* ssp, *Aulacoseira nygaardii*, *A. lirata* v. *lacustris*, *A. italica* v. *valida*, *A. perglabra*, *Fragilaria brevistriata*, *F. pseudoconstruens* etc.) on average group have a lower DOC optima (mean 3.51± 0.285 mg/l) than the diatoms dominant in the upper two-thirds of the core (*Brachysira brebissoni*, *B. vitrea*, *Frustulia rhomboides* v. *saxonica*, *Pinnularia biceps* etc.). The average 'upper layer' diatom DOC optima is 4.57 ± 0.67 mg/l according to the diatom optima obtained by Pienitz & Smol (1993). The difference in DOC between the two parts of the core is significant and implies that change in diatom composition can be partly induced by change in DOC which is connected to the development of the catchment vegetation and therefore, indirectly, to climate. DOC reconstruction using a relevant transfer function is required to obtain more precise picture of DOC changes in the lake.

Comparison of colour between the two above groups of diatoms revealed that the mean colour of the *Stauroforma/Aulacoseira/Fragilaria* group is 40.2 ± 10.3 mg Pt/l and the mean colour of the *Brachysira/Frustulia* group is 45.2 ± 18.1 mg Pt/l, i.e. there is no statistically significant difference in colour between the two groups.

4.4   Vegetation-lake interaction

The effect of vegetation change and related climate change on the lake diatom population was analyzed by CCA where diatom data were used as response variables and pollen data as explanatory variables. Table 4 presents the summary statistics of CCA with 25 pollen taxa and 46 diatoms

Table 4 CCA: summary statistics for 36 samples, 46 diatom taxa and 25 pollen taxa

AXES	1	2	3	4	
Eigenvalues	.511	.180	.123	.092	
Cumulative % variance of species data:	35.6	48.1	56.7	63.1	
Cumulative % variance of species-environment relation:	41.7	56.4	66.4	73.9	
Total inertia					1.436
Sum of canonical eigenvalues					1.226

The eigenvalue of the first canonical axis is significantly higher than the eigenvalue of the second axis indicating the relative unimportance of the second axis and subsequent axes in explaining the variance in species data. The changes in pollen data account for 35.6 % of the variance in the diatom assemblage which is comparable with the results of other authors (Anderson *et al.*, 1996).

Forward selection in CCA identified *Betula* and *Picea* as variables significantly influencing the distribution of diatom taxa (P = 0.001 and P = 0.011 respectively). Table 5 shows the results of the CCA with forward selection.

On the whole, the results of CCA with forward selection are similar to the CCA of the whole set of environmental variables - only the first axis plays an important role in explaining the variance within the response variables. The third and fourth unconstrained eigenvalues are higher than the second one but smaller than the first axis. The ratio $\lambda_1 \backslash \lambda_3$ is 2.12 which is high enough to indicate the relative significance of the first axis in influencing the species distribution (ter Braak, 1988).

Table 5 CCA with forward selection: summary statistics for 36 samples, 46 diatom taxa and 2 pollen taxa

AXES	1	2	3	4	
Eigenvalues	.387	.055	.182	.167	
Cumulative % variance of species data	27.0	30.8	43.4	55.1	
Cumulative % variance of species-environment relation:	87.7	100.0	0	0	
Total inertia					1.436
Sum of canonical eigenvalues					.442

Betula and *Picea* together account for 27% of total variability in diatom data which is a similar value to the results of other studies (Korsman *et al.*, 1994; Anderson *et al.*, 1996). *Betula* and *Picea* sediment pollen concentrations represent the regional vegetation signal directly related to climate. For instance, expansion of birch at the beginning of the Holocene in the Kola Peninsula could indicate the disappearance of permafrost (Reiger, 1974). Appearance and spread of spruce occurred in northern Fennoscandia during climate amelioration between 5,000 and 3,000 BP (Lebedeva *et al.*, 1989; Seppa, 1996; Aario, 1943; Korsman *et al.*, 1994).

Profiles of diatom and pollen species diversity plotted at 36 levels (diatom species richness is plotted at the levels where pollen has been counted) are shown in Figure 3. In the lower part of the diagram (from 153 to 105 cm) where the species diversity is determined every 2 cm profiles interrelate with a certain time-lag, i.e. the profile of pollen species diversity repeats the patterns of the diatom species diversity profile with a lag of about 2-2.5 cm which is estimated as 100-150 years. Analysis of interaction between Swedish boreal lake ecosystem and vegetation presented by Anderson *et al.* (1996) shows that the time-lag between diatom response to temperature shifts inferred by tree-ring method is about 20 years.

Generally, diatom species diversity is an integrated characteristic of an ecosystem controlled by a complex of biotic and abiotic factors, i.e. level of predator stress, competition within populations, availability of nutrients and microhabitats, thermocline depth, depth of light penetration, depth of snow cover, duration of winter etc. (Anderson *et al.*, 1996). Pollen diversity in the sediments reflects local and regional vegetation diversity which is more directly related to climate and can be regarded as a substitute for temperature in the absence of other data (e.g. tree-ring based temperature estimates which are unavailable for the Kola Peninsula). However, more data are required (precise radiocarbon age estimates, metal concentrations in the sediments and loss on ignition as a measure of catchment influence on the lake ecosystem) to assess the relations between climate and lake diatom community.

Figure 8 presents the diagram of pollen PCA sample scores and diatom DCA sample scores plotted against depth. The diagram of the pollen sample scores shows the dramatic difference between vegetation of the early Holocene period (the part of diagram between 153 and 145 cm with high sample scores, see also the description of **POL I** in Table 1) and the later period. In the early Holocene the Kola Peninsula was dominated by *Betula* forests and vegetation diversity was poor in comparison with later warmer period.

Figure 8   Profiles of DCA diatom scores and PCA pollen sample scores. Sediment depth
in cm
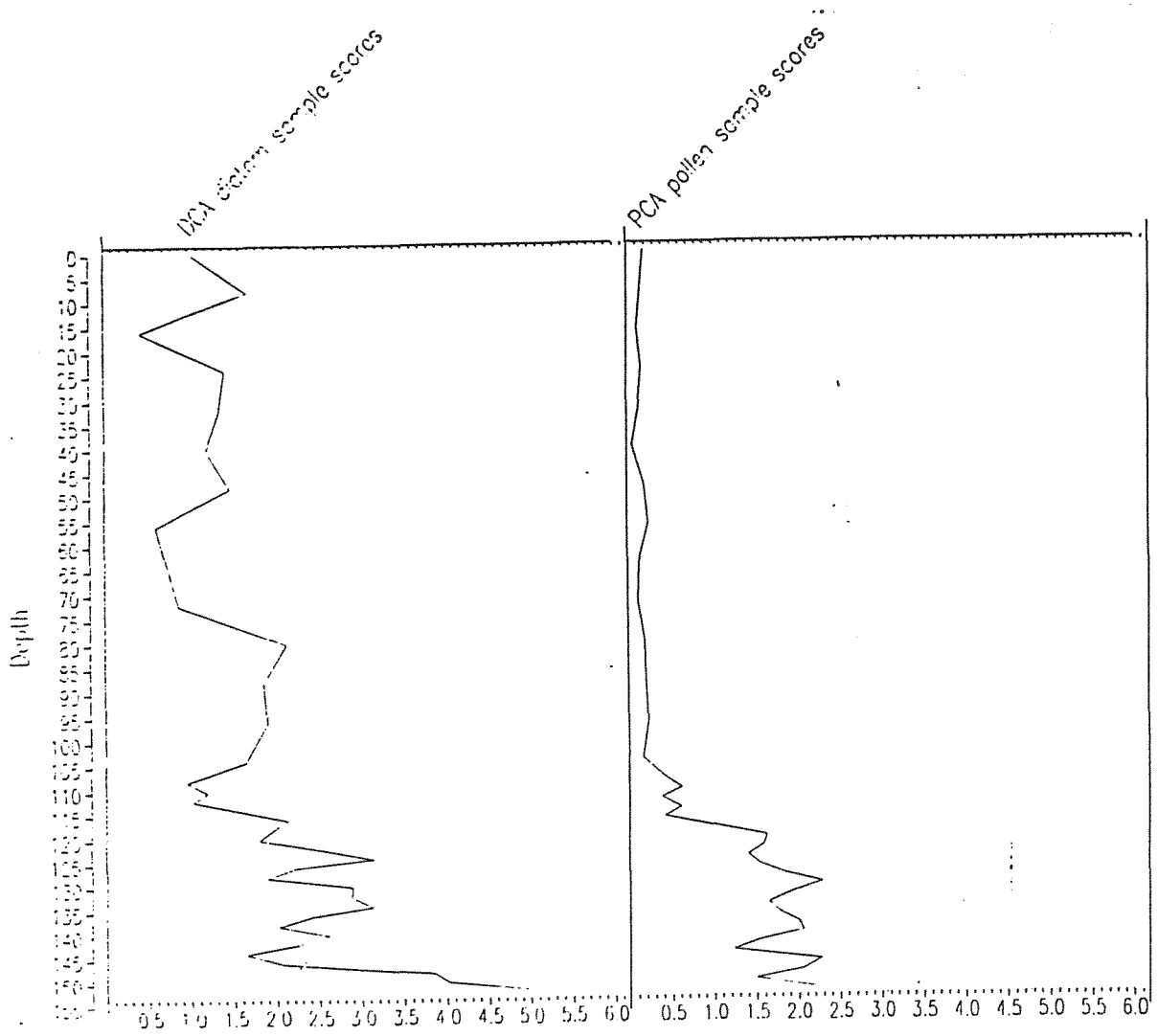
Above the level of 145 cm changes of sample score values are less dramatic, the scores range from
0.4 to 3.2 largely following the fluctuations of *Betula*. The upper borders of zones **POL II** and
POL III coincide with the lowest values of sample scores (see Figure 2).

On the whole, the profile of diatom sample scores in DCA shows similar features to the pollen
sample score profile (Figure 8). In the upper two-thirds diatom sample scores fluctuate more
frequently than pollen scores reflecting higher rate of change within the diatom assemblage. Below
110 cm the diatom sample score profile follows patterns similar to the pollen profile with a time-lag
of 2-2.5 cm, i.e. the same time-lag observed in changes of pollen and diatom diversity coefficient

(see above). This is further evidence suggesting that changes in the Lake Chuna ecosystem are related to the changes in vegetation.

5   GENERAL DISCUSSION

Results of the analysis of pollen and diatom stratigraphy of the sediment core from Lake Chuna presented above suggest that changes in diatom assemblage are related to changes in the regional vegetation and therefore to climate changes.

The Lake Chuna stratigraphic pollen profile is typical for the tundra northern Fennoscandian region, it agrees well with the lake sediment pollen stratigraphy of adjacent regions of Finland recently described in Seppa (1996) and with earlier research in Holocene pollen stratigraphy in the Kola Peninsula and northern Fennoscandia (Lebedeva et al., 1989; Lebedeva et al., 1987, Lavrova, 1960; Aario, 1943). Accordingly, the lake pollen stratigraphy represents regional vegetation changes in the Kola Peninsula during the last 8,500-8,000 years and reflects climatic changes that occurred during that period.

Diatom floristic changes similar to the changes that occurred in Lake Chuna between 115 and 105 cm of the core (substitution of small benthic *Fragilaria* by large pennate *Pinnularia* and *Brachysira*) were pointed out in a high Arctic lake on Ellsmere Island and north-western Greenland (Smol, 1993; Smol, 1988). The dominance of 'pioneering' species *Fragilaria* and *Stauroforma* at the early stages of lake development was also observed by Florin (1977) and Haworth (1975). The dominance of *Stauroforma* in modern high Antarctic lakes which can be considered an analogue of northern Fennoscandian lakes in the early Holocene (Smol, 1988) is mentioned noted by Flower & Jones (1996). *Fragilaria elliptica* and *Stauroforma* ssp. dominate diatom assemblages in a remote alpine lake covered with ice for 10 months a year in the Khamar-Daban mountains in south-eastern Siberia (Flower et al., 1994).

In all the above studies climate which determines microhabitat availability, light penetration etc. is considered one of the reasons for dominance of small *Fragilaria/Stauroforma* species in these severe environments. Water chemistry parameters (pH, alkalinity and nutrients) may also account for the above changes in diatom assemblages in Arctic lakes. However, no significant pH and/or DOC changes have been observed in Lake Chuna which could significantly influence diatom communities but there is substantial evidence summarised below on correlation between vegetation changes in the Kola region and diatom changes in the lake:

* Four out of five diatom stratigraphic zones identified by CONISS nearly coincide with CONISS pollen zones;

* profiles of diatom and pollen total concentration in the sediments show similar features, both concentrations rise sharply below 105 cm indicating the increased accumulation rate and peaks of both pollen and diatom concentrations occur at the same depth (129 cm);

* diatom and pollen sample scores obtained in DCA and PCA correspondingly also increase abruptly by the bottom of the core. Changes of diatom and pollen species diversity and changes in pollen and diatom samples scores are inter-related with a time-lag of 2-2.5 cm in the bottom third of the core (below 105 cm);

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- in CCA changes in *Betula* and *Picea* which represent regional vegetation account for 27% of variability in the diatom data which agree well with results of other studies in the Fennoscandian region (Korsman *et al.*, 1994; Anderson *et al.*, 1996).

All the results of the analyses of diatom and pollen stratigraphy in the Lake Chuna sediments indicate that changes in the lake diatom assemblage are related to the regional changes of vegetation and can be linked with the Holocene climatic changes in the Kola Peninsula. However, more data are required for confirmation of this hypothesis.

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TECHNICAL ANNEX 2

THE RYAZAN COAL FIRED POWER UTILITY: PRELIMINARY PROJECT REPORT

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1   INTRODUCTION

The Ryazan electricity generating utility was established in 1970 it is located near Novomeechurinsk some 300 km south of Moscow (Figure 1). The surrounding landscape consists of low rolling hills and flat lands rather reminiscent of southern Manitoba prairie. Much of the region is devoted to poorly managed crop production and contains numerous stands of birch and aspen. Soils are light and of the chernozem type overlying sand and gravels with Jurassic limestones below. The landscape features some palaeo-river channels, ox-bow lakes, and occasionally numerous circular dissolution depressions or 'sink holes' are very characteristic. The latter being usually 50-200 m in diameter and containing either dense vegetation (trees and grasses) or standing water.

The power utility burns Russian brown coal and produces some 60,000 tons of sulphur dioxide annually; there are no particle arresting devices for controlling emissions but it is planned to fit these within the next two years. There is considerable concern about environmental contamination caused by the utility and this seems to be mainly related to fly-ash and trace metals. Soil samples in the vicinity of the utility do show enhanced levels of several trace metals especially vanadium but background conditions are unknown. Fish are farmed in the two large shallow cooling water reservoirs adjacent to the plant but a few chemical tests apparently indicate that the fish are not unduly contaminated. The soils and waters are base cation rich and therefore well buffered from the effects of acid deposition.

Given the absence of background data and lack of historical data on particulate emissions it was decided to collect lake sediment cores from several lakes near the power utility to show the current extent the recent trends in fly-ash and trace metal contamination. Two sample regions were selected within the prevailing pollution plume, the first being located about 15 km north and the other about 35 km north-east of the utility.

2   SITE DESCRIPTIONS

Site 1: Lake Balshoe Selo (SELO)

This lake (54^0 12' N, 39^0 45' E) is artificial but was established before the 1920s and has apparently never been drained. It is about 15 km distant from the power utility and occupies an old river channel and is confined by a stone and soil barrage at the lake's east end. The lake is partially fringed by *Phragmites* and partly surrounded by woodland and several small houses occur near the lake. Occupying a river channel, the lake is narrow but relatively long, being some 150 x 800 m, with a maximum depth of ca 2.5 m. An outflow pipe prevents the lake from exceeding this depth.

The dense cover of *Lemna* and the methane rich black organic sediments strongly indicate that the lake is eutrophicated. *Lemna* cover was extensive and has apparently suppressed any significant phytoplankton growth. Secchi depth (as assessed by visibility of the corer top) appeared to be about 50 cm. The possibility of surface transport of deposited fly-ash by the wind distributed *Lemna* may be postulated.

Despite some initial difficulty in obtaining sediment cores undisturbed by gas bubbling, two 30 cm long cores (SELO 1 & 2) were retrieved using the wide diameter Glew corer. However, in both the upper 1 cm of sediment was somewhat disturbed. Cores were sectioned at 1 cm (core 1) or 2 cm (core 2) intervals.

Site 2: Lake Ivanovitch (IVANB)

This lake (54^0 10' N, 39^0 50' E) is natural and occupies a sink hole some 37 km distant from the power utility. The lake lies within a large field of crops and is approximately circular with a diameter of about 130 m but with a small sub-basin in the north-east corner. It is partly surrounded by shrub *Salix* and wholly fringed by *Typha* with some *Phragmites* and *Carex*. *Myriophyllum* and water plantains are locally common.

The water was distinctly green and turbid with a secchi depth of about 15 cm. Water depth was uniformly around 80 cm. Penetration of the corer was prevented by the compact nature of the surface sediment. Pushing the corer in by hand however enabled a sediment core (IVANB 1), 11 cm long to be retrieved. Extruding the core revealed that the lower brown sediment had a distinct crumb structure and possessed a few plant remains indicating that at least the lower part of the core had been subjected to early pedogenic processes.

Site 3: Unamed (IVANA)

Since site 2 was suspected of drying out sometime in the recent past another sink hole lake in the same region was selected for sampling. This lake (IVANA) is located some 1 km north-east of IVANB but is rather smaller with a diameter of about 50 m and surrounded by a dense fringe of *Salix* shrub. Water depth was about 2.4 m and the water was distinctly less turbid than in IVANB. A 26 cm long core of brown sediment (IVANA 1) was retrieved. Sectioning the core revealed no sediment crumb structure nor any large macrophyte remains, indicating continuous sub-aquatic sediment accumulation.

Figure 1   Site locations

Figure 1 Site locations
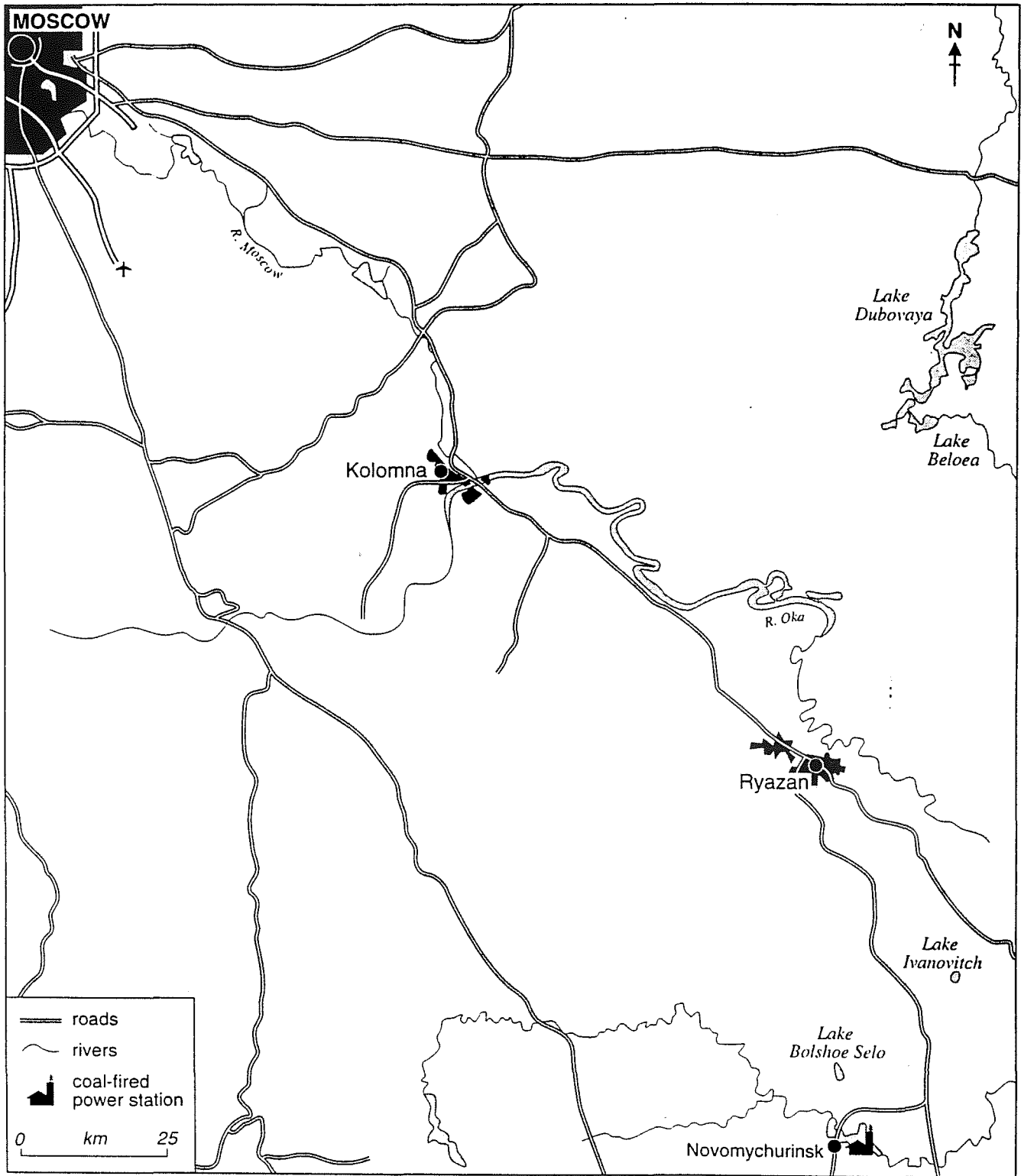
3   ANALYSES

Most analyses are still in progress: Lithostratigraphy, diatoms, carbonaceous particles (SCPs) and surface sediment trace metals are being analysed at ECRC and hydrobiological (and possibly sediment core trace metal) analyses are being undertaken by IGCE.

Figure 2 presents a preliminary SCP profile from core IVANB 1. SCP concentrations are consistent (3-5000 gDM^{-1}) throughout the whole length of the core. This suggests that sediment accumulation rate is rapid but it is not possible to say how rapid from the data available. It is also not possible to ascribe dates to the core using standard SCP procedures as there are no recognisable features on the profile. Although SCP concentrations appear to be reasonably low (similar to contemporary concentrations in relatively 'clean' sites in the UK) the fact that the sediment accumulation rate is rapid suggests that Lake Ivanovitch is receiving high levels of atmospheric deposition.

In an attempt to later attribute these particles to source, samples of fuel material and fly-ash were collected from various stages of the combustion process within the power plant.

Table 1 gives surface sediment concentrations of trace metals from the cores SELO 1 and IVANB 1.

Figure 2   **Lake Ivanovitch core IVANB 1: carbonaceous particle concentration (gDM^{-1}) profile**
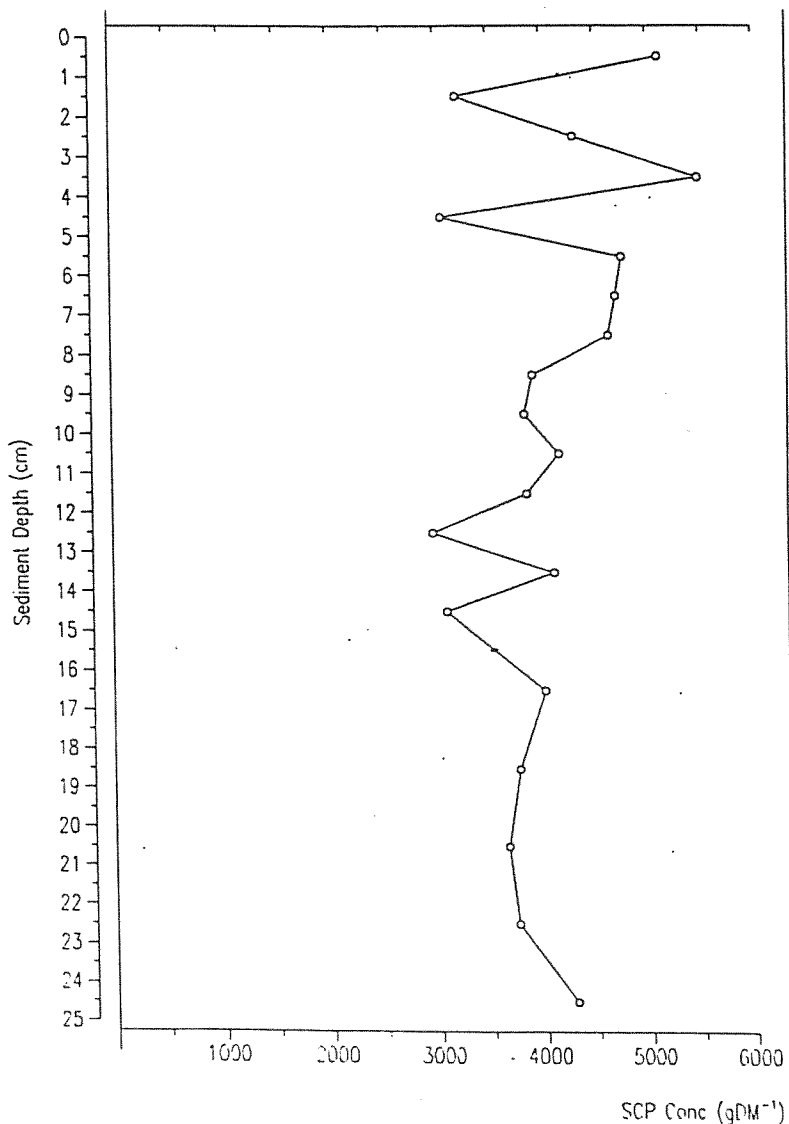
Table 1   Surface sediment concentrations of trace metals in Ryazan lakes ($\mu g\ g^{-1}$)

Determinand	SELO 1	IVANB 1
Li	37.4	24.3
Na	2790.0	5110
K	15100.0	16400.0
Be	1.9	1.6
Mg	7390.0	4860.0
Ca	14300.0	5310.0
Sr	82.1	81.6
Ba	388.0	389.0
Al	57100.0	48100.0
La	27.0	28.5
Ti	4600.0	4350.0
V	90.8	71.3
Cr	64.5	57.5
Mo	5.5	4.5
Mn	1210.0	556.0
Fe	45300.0	22500.0
Co	10.3	10.0
Ni	45.0	32.5
Cu	44.2	19.9
Ag	0.7	0.9
Zn	130.0	90.5
Cd	1.7	2.0
Pb	31.5	40.5
P	2690.0	1500.0

TECHNICAL ANNEX 3

RADIOMETRIC DATING OF A CORE FROM LAKE BOLSHOIE, RUSSIA

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Methods

Sediment samples from Lake Bolshoie core SHOI1 were analysed for ^{210}Pb, ^{226}Ra, ^{137}Cs and ^{241}Am by direct gamma assay in the Liverpool University Environmental Radioactivity Laboratory, using Ortec HPGe GWL series well-type coaxial low background intrinsic germanium detectors (Appleby et al. 1986). ^{210}Pb was determined via its gamma emissions at 46.5keV, and ^{226}Ra by the 295keV and 352keV γ-rays emitted by its daughter isotope ^{214}Pb following 3 weeks storage in sealed containers to allow radioactive equilibration. ^{137}Cs and ^{241}Am were measured by their emissions at 662keV and 59.5keV. The absolute efficiencies of the detectors were determined using calibrated sources and sediment samples of known activity. Corrections were made for the effect of self absorption of low energy γ-rays within the sample (Appleby et al. 1992).

Results

The results of the radiometric analyses are given in Table 1 and shown graphically in Figures 1 and 2.

Lead-210 Activity

The results from this site, situated in the Khamar Daman mountains immediately south of Lake Baikal, are similar to those from a number of other lakes from this region. ^{210}Pb activity was unusually high in the surficial sediments (more than 5000 Bq kg^{-1}), but declined rapidly in the top few centimeters to a value of just 500 Bq kg^{-1} at 5 cm depth (Figure 1). Below 5 cm the rate of decline greatly reduced and equilibrium with the supporting ^{226}Ra was not finally reached until a depth of c.30 cm. The ^{210}Pb inventory of the core was 14231 Bq m^{-2}. This corresponds to a mean supply rate of 443 Bq m^{-2} y^{-1} and is again comparable to neighbouring sites.

Artificial Fallout Radionuclides

Maximum ^{137}Cs activity occurs in the surficial sediments and there is no indication of a sub-surface peak recording the 1963 fallout peak from the atmospheric testing of nuclear weapons. Significant levels of ^{241}Am recorded in the top 2.5 cm do however suggest that that sediments from this level date from the mid 1960s (Appleby et al. 1991).

Core Chronology

^{210}Pb dates were calculated using both the CRS and CIC dating model (Appleby *et al.* 1978) and the results are shown in Figure 3, together with the best estimate of the 1963 depth determined from the ^{137}Cs/^{241}Am record. Above the change in gradient at c.5 cm, dated c.1930, the ^{210}Pb chronologies are in good agreement. Both models suggest a uniform sedimentation rate, with a mean value of 0.0074 ± 0.0005 g cm^{-2} y^{-1}. This places the 1963 level at a depth of just under 3 cm, a little lower than suggested by the ^{241}Am results but in reasonable agreement given the very slow rate of accumulation.

Below 5cm there is major discrepancy between the two models arising from the slower rate of decline in ^{210}Pb activity in the older layers. The raw CRS model calculations suggest sustained high levels of sedimentation from the early 19th century through to c.1930. The CIC model suggests a much more dramatic event in the mid 19th century and low sedimentation rates since then. Since there is no evidence of major disturbances in this region during the 19th century it seems more likely that the elevated levels of unsupported ^{210}Pb activity at these depths are due to downwards transport of ^{210}Pb either from *in situ* porewater diffusion or smearing during coring, as seen in similar cores from Lakes Bol and Kholodney (Flower *et al.* 1997). It may be that the effects of these processes are more visible at these sites due to the high ^{210}Pb flux and low sedimentation rates. In light of these and previous results it has been assumed that the uniform sedimentation rate determined from data in the top 5 cm of the core applies to the deeper sections. Table 2 gives ^{210}Pb dates calculated on this basis, down to 12 cm depth.

References

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Flower, R.J., Politov, S., Rippey, B., Rose, N.L., Appleby, P.G. & Stevenson, A.C. (1997) Sedimentary records of the extent of atmospheric contamination at a remote Siberian highland lake. The Holocene 7: 161-173.

Table 1. **Fallout Radionuclide Concentrations in Lake Bolshoie Core SHOI1**

Depth		^{210}Pb Total		Unsupported		Supported		^{137}Cs		^{241}Am	
cm	g cm^{-2}	Bq kg^{-1}	±	Bq kg^{-1}	±	Bq kg^{-1}	±	Bq kg^{-1}	±	Bq kg^{-1}	±
0.25	0.01	5088.1	56.6	5008.7	56.7	79.4	3.6	939.7	10.4	16.5	2.0
1.25	0.09	3737.4	42.6	3645.0	42.8	92.4	4.3	894.9	9.9	14.7	2.0
2.25	0.18	2720.0	33.6	2639.8	33.7	80.2	2.6	659.0	7.4	11.7	1.4
3.25	0.27	2341.9	37.3	2241.4	37.5	100.4	3.3	476.2	7.4	5.5	1.7
4.25	0.39	1273.6	24.6	1141.2	24.9	132.4	3.7	215.2	4.8	0.0	0.0
5.25	0.53	654.0	20.5	501.3	20.8	152.7	3.5	155.0	4.0	0.0	0.0
6.25	0.69	372.8	16.4	230.1	16.7	142.7	3.2	109.5	3.3	0.0	0.0
8.25	0.94	239.9	16.0	119.9	16.5	119.9	3.9	61.0	3.4	0.0	0.0
10.25	1.16	209.6	16.4	89.5	16.9	120.1	4.0	37.3	3.1	0.0	0.0
12.25	1.43	173.0	17.0	66.0	17.6	107.0	4.4	19.1	2.9	0.0	0.0
14.25	1.71	175.7	11.9	67.0	12.2	108.7	2.7	6.1	1.8	0.0	0.0
16.25	1.96	162.3	9.3	54.4	9.7	108.0	2.5	4.8	2.0	0.0	0.0
20.25	2.45	138.6	10.8	27.6	11.1	111.0	2.4	5.2	1.4	0.0	0.0
24.25	3.04	128.6	11.4	18.8	11.7	109.9	2.7	0.0	0.0	0.0	0.0
27.75	3.48	117.4	6.5	8.6	6.7	108.8	1.7	0.3	0.9	0.0	0.0
34.25	4.36	107.0	8.0	-2.5	8.3	109.5	2.1	0.0	0.0	0.0	0.0
35.25	4.55	87.1	5.6	29.7	5.7	57.4	1.2	0.0	0.0	0.0	0.0
37.50	4.89	119.0	11.1	7.8	11.3	111.2	2.3	0.4	1.3	0.0	0.0
38.50	5.04	108.1	7.4	-0.1	7.8	108.2	2.4	0.0	0.0	0.0	0.0

Table 2 ^{210}Pb chronology of Lake Bolshoie Core SHOI1

Depth		Chronology			Sedimentation Rate		
		Date	Age				
cm	g cm^{-2}	AD	y	±	g cm^{-2} y^{-1}	cm y^{-1}	± (%)
0.0	0.00	1995					
0.5	0.03	1991	4	1	0.0074	0.104	6.8
1.0	0.07	1985	10	2	0.0074	0.094	6.8
1.5	0.11	1980	15	2	0.0074	0.087	6.8
2.0	0.16	1974	21	2	0.0074	0.083	6.8
2.5	0.20	1968	27	3	0.0074	0.080	6.8
3.0	0.25	1961	34	3	0.0074	0.073	6.8
3.5	0.30	1954	41	4	0.0074	0.064	6.8
4.0	0.36	1946	49	4	0.0074	0.059	6.8
4.5	0.43	1937	58	5	0.0074	0.056	6.8
5.0	0.50	1928	67	6	0.0074	0.052	6.8
5.5	0.57	1918	77	6	0.0074	0.049	6.8
6.0	0.65	1907	88	7	0.0074	0.049	6.8
6.5	0.72	1898	97	8	0.0074	0.055	6.8
7.0	0.78	1889	106	8	0.0074	0.058	6.8
7.5	0.85	1881	114	9	0.0074	0.058	6.8
8.0	0.91	1872	123	9	0.0074	0.061	6.8
8.5	0.97	1864	131	10	0.0074	0.066	6.8
9.0	1.02	1857	138	10	0.0074	0.069	6.8
9.5	1.08	1850	145	11	0.0074	0.069	6.8
10.0	1.13	1842	153	11	0.0074	0.064	6.8
10.5	1.19	1834	161	12	0.0074	0.056	6.8
11.0	1.26	1825	170	13	0.0074	0.053	6.8
11.5	1.33	1815	180	13	0.0074	0.053	6.8
12.0	1.40	1806	189	14	0.0074	0.054	6.8

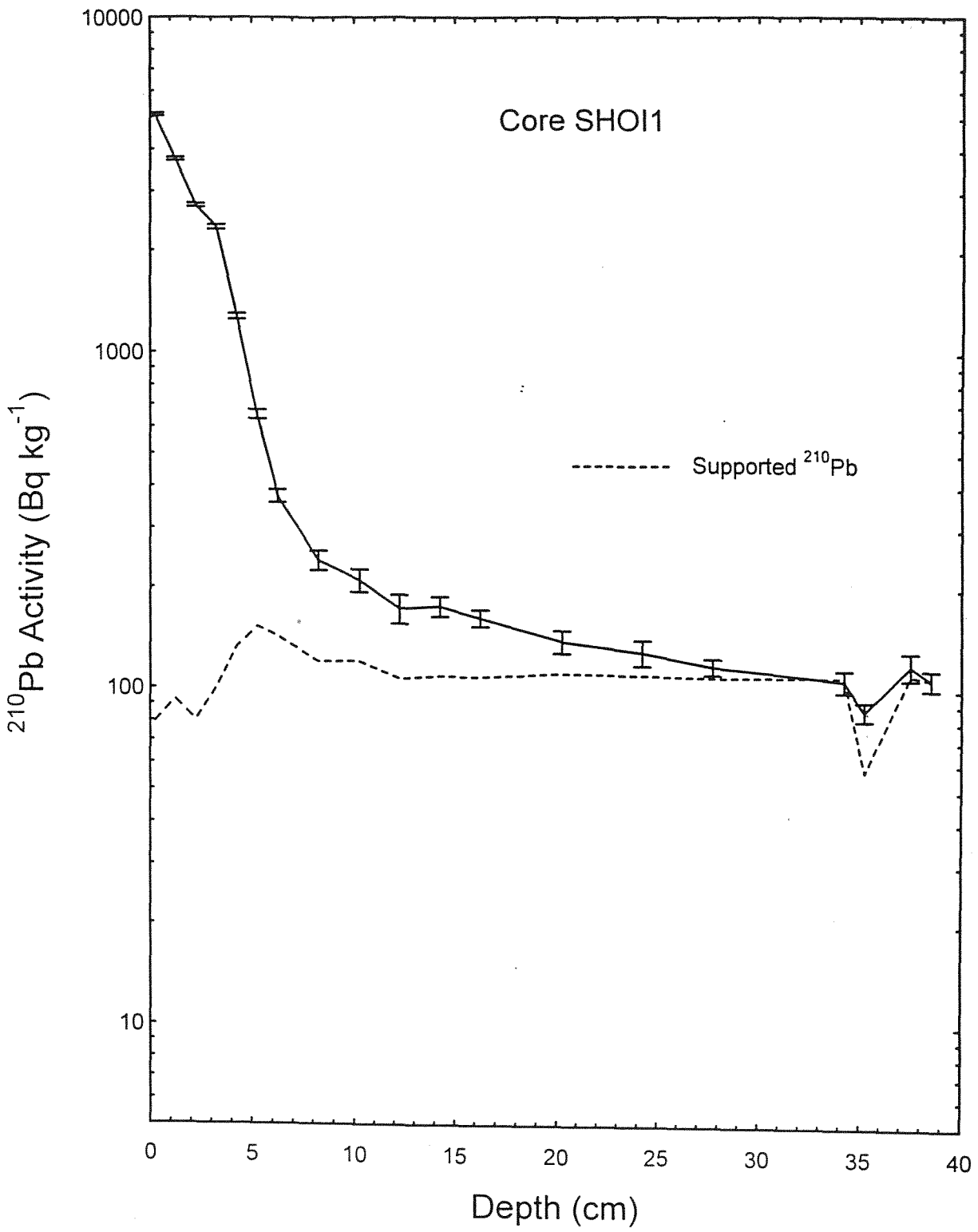**Figure 1(a)   Lake Bolshoie: total ^{210}Pb activity versus depth**

Figure 1(b)   Lake Bolshoie: unsupported ^{210}Pb activity versus depth
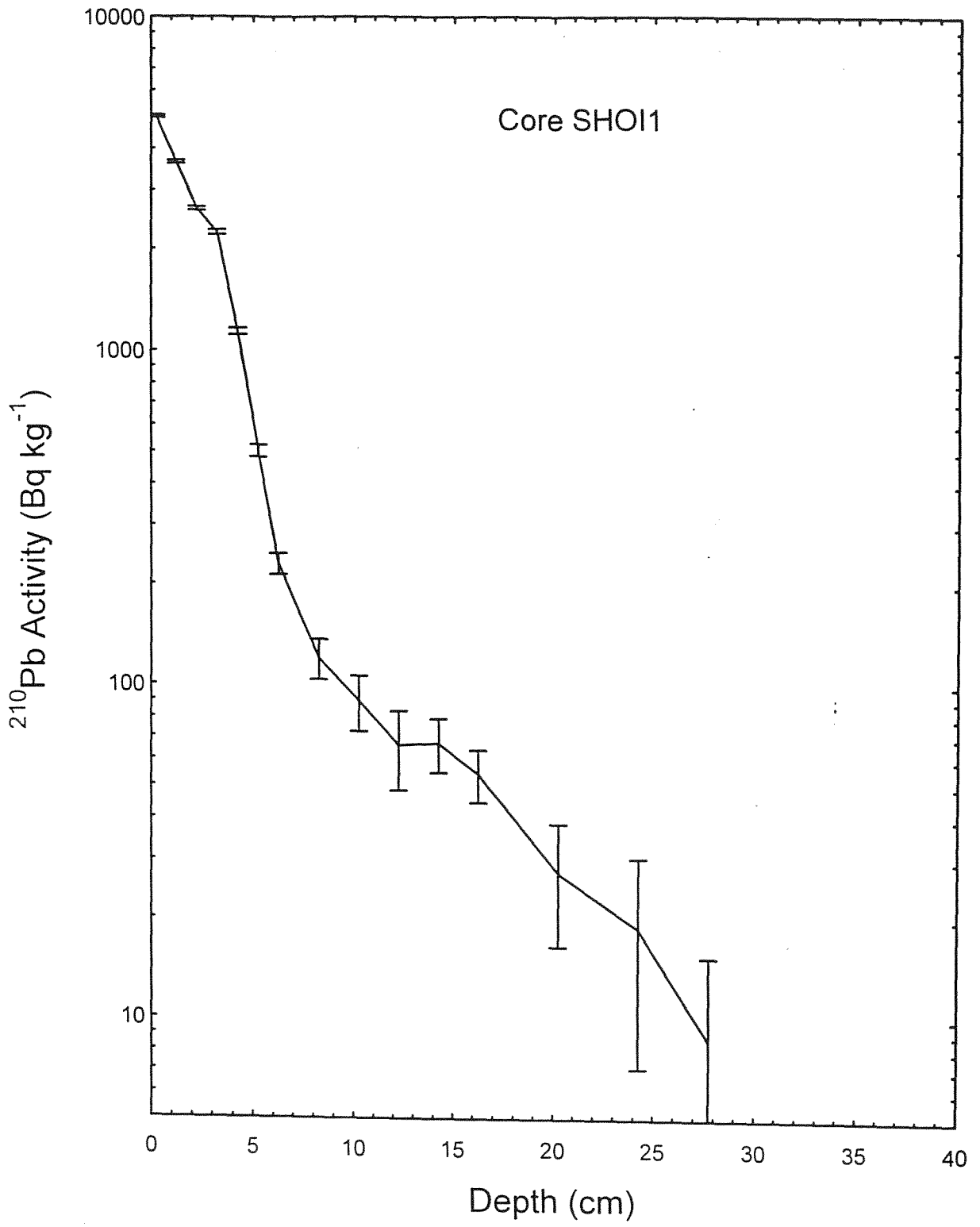
Figure 2   Lake Bolshoie: ^{137}Cs & ^{241}Am activity versus depth
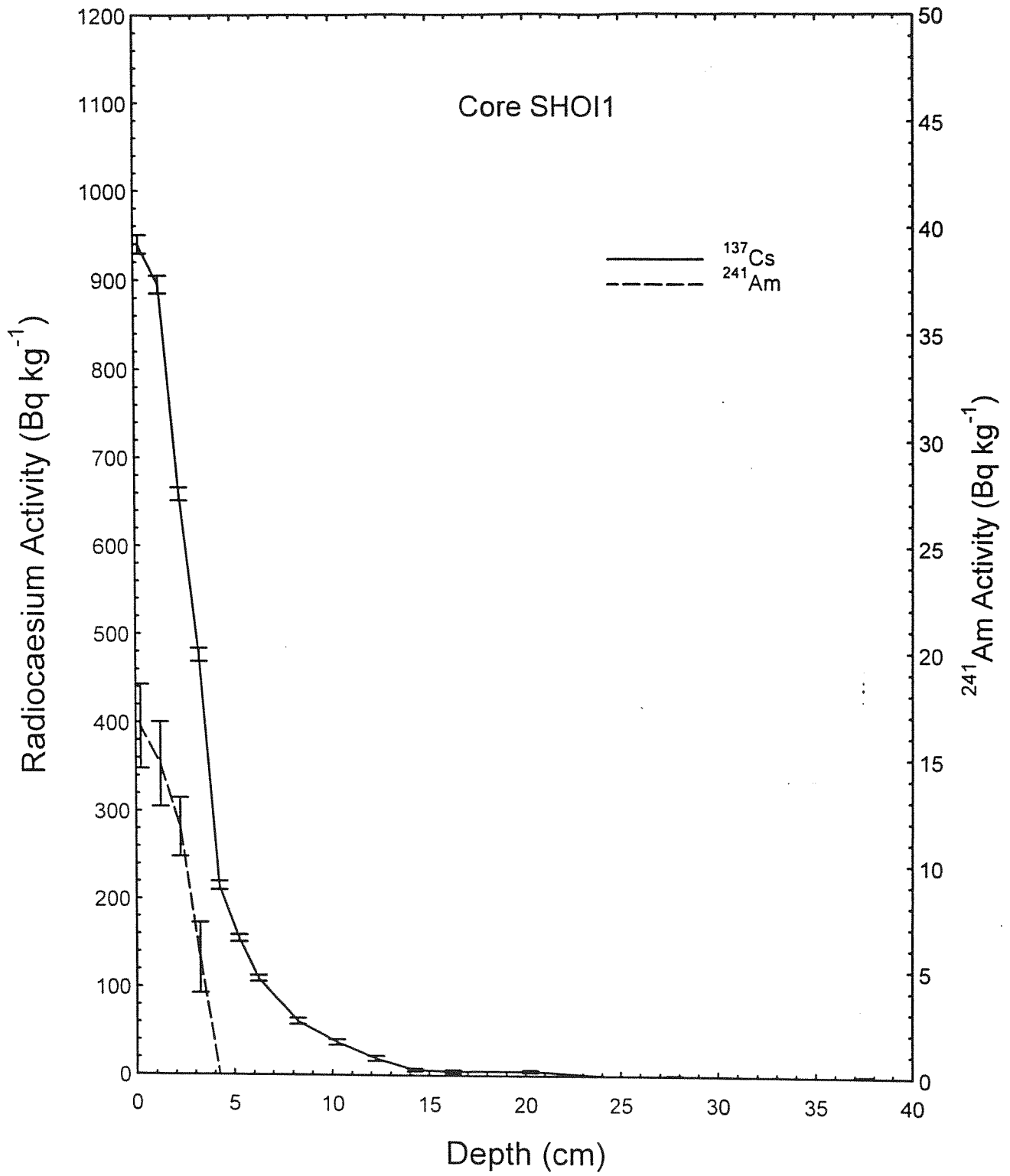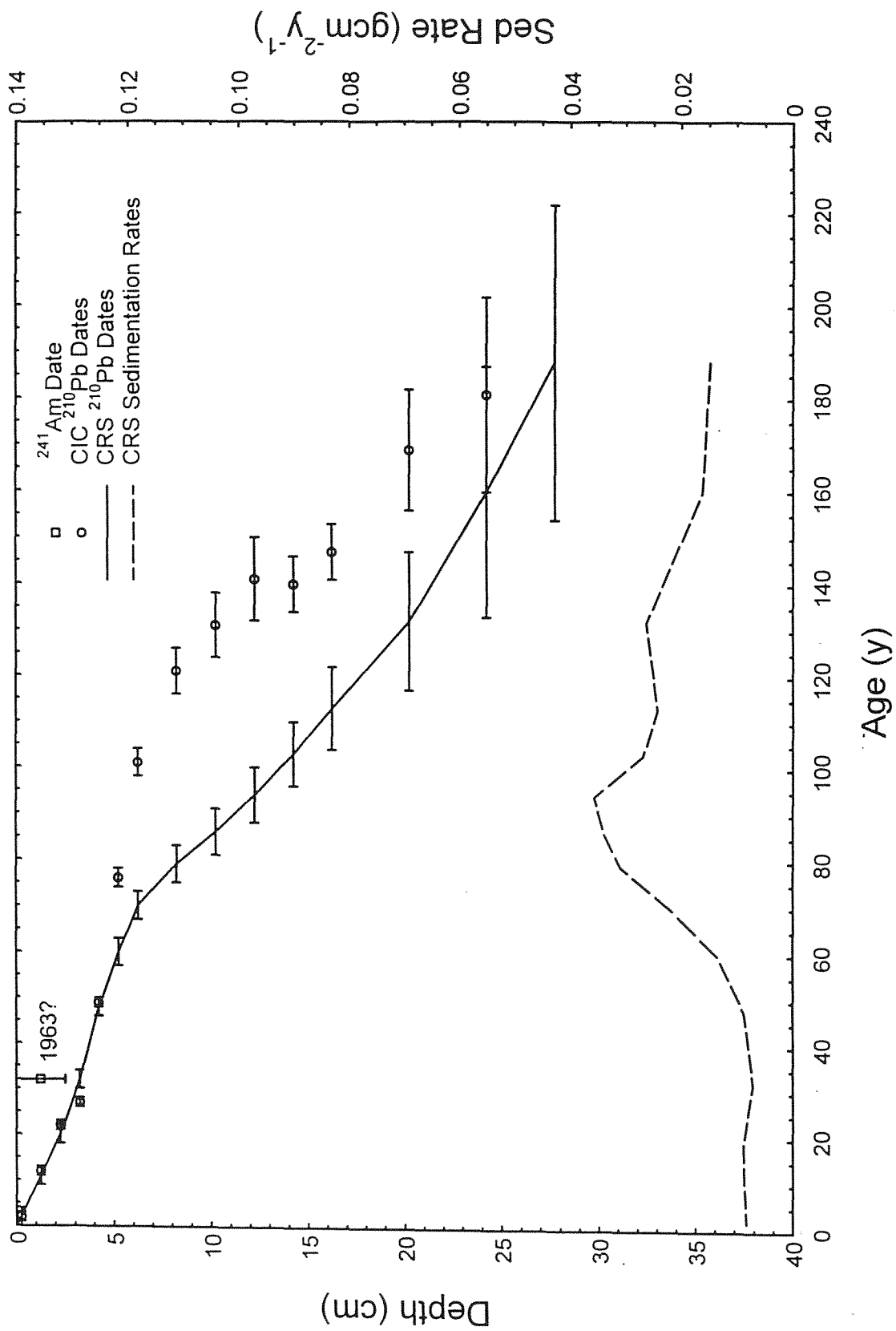
Figure 3 Lake Bolshoie: core SHOI1: depth versus age

Figure 3 Lake Bolshoie: core SHOI1: depth versus age

TECHNICAL ANNEX 4

SUMMARY OF LECTURES IN ENVIRONMENTAL PALAEOLIMNOLOGY, MOSCOW, JULY 4-6TH, 1995

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Lecture 1: Introduction to Environmental Change: past, present, and future damage. Health hazards, resource impoverishment, aesthetics. Historical perspective, natural factors, human impact, extent and severity, conspicuous events, imperceptible change, early warnings, baseline conditions and variability, underlying trends and cycles, directions, rates of change, causes and effects, future predictions and dynamic modelling. Lake acidification example.

Lecture 2: Introduction to Environmental Palaeolimnology: Limnology, study of lakes (lentic or standing waters), and streams and rivers (lotic or running waters). Saline lake systems (athalassic waters). Palaeolimnology, history and evolution of lakes, sediment records. Palaeo-lakes, pre-Quaternary times, existing lakes, hold water permanently or intermittently. Material sources, transfers and sinks. Sources of sediment include lake, catchment, and atmosphere. **Lake:** chemical precipitates e.g. calcite, gypsum, organic matter, biochemical residues (pigments), microfossils (diatoms, chrysophytes, pollen and spores, cladocerans, chironomid head capsules, ostracods, macrofossils (seeds, molluscs). **Catchment:** mineral material (clay, silt and sand sizes), organic matter (FPOM, pollen and spores, dissolved humic acids); solutes (cations, anions). **Atmosphere:** volcanic ash, Saharan dust, soil erosion, pollen, spores, charcoal, radionuclides (e.g. ^{210}Pb), pollutants (fly ash, metals, PAH/PCBs, radionuclides). Ontogeny, filling-in, hydrosere, leaching, paludification, water-level change, natural variability. Human impact, Neolithic, erosion, nutrients, recent change, industrialisation, eutrophication, acidification, salinity changes and salinisation, soil erosion, air pollution.

Lecture 3: Lake sediments and sediment coring: Occurrence and distribution of sediments, factors controlling sediment deposition and methods of describing sediments. Selecting suitable core locations. Use of gravity corers, rod operated corers, gas operated corers and box corers. Freezer corers and laminated sediments. Sediment sampling problems including good recovery of material and sediment variability.

Lecture 4: Sediment dating: Historical events, rate of change. Radiometric (e.g. ^{210}Pb) or non-radiometric (e.g. varves), age range, geographical range (within lake, within region, or global, resolution (precision, accumulation rate, mixing depth of sediment), accuracy. ^{210}Pb, half-life = 22.26 years; ^{14}C, half-life = 5730 years. Fallout isotopes from nuclear explosions (atomic weapons testing, Chernobyl) e.g. ^{137}Cs, ^{241}Am. Sediment markers that require calibration, atmospheric sources, e.g. pollen dating (*Ambrosia* (ragweed) *Castanea* (chestnut) decline in New England. Carbonaceous particles from power stations, post-1940 increase, maximum in 1980s. Catchment or lake sources, e.g. clay layers related to soil disturbance, water-level change, flood events, landslides etc. Zurichsee, Jarlasjon. Varves, annually

Upper Mid-west of the USA, Northern Great Plains, ecotone. Salinity transfer function, Devil's Lake, North Dakota. CASPIA project.

Lecture 11: Lake Baikal: Characteristics, British involvement in Baikal research. The use of palaeolimnology to evaluate recent environmental changes. Endemic diatoms and atmospheric contamination. Initial results of sediment core analysis. Consideration of atmospheric contamination of mountain lakes within the Baikal region.

Lecture 12: Mountain lakes - the AL:PE project: Remote mountain lakes as indicators of air pollution and climate change. European Union project, multi-disciplinary, multi-national project co-ordinated by research groups in Oslo and London. Compares remote, sensitive, mountain lakes throughout Europe at sites with differing air quality using chemical, biological (diatoms, invertebrates, fish) and palaeolimnological techniques. Quality control systems are used to standardise methods between laboratories. Sites are located in Norway, Scotland, Ireland, Spain, Portugal, France, Italy, Austria, Slovenia, Slovakia, Poland and Russia. Conclusions so far are: (i) sensitive sites in areas of low sulphur deposition are not acidified; (ii) sensitive sites in areas of high sulphur deposition are acidified; (iii) nitrate levels increase towards the centre of Europe and contribute to lake acidification; (iv) even the most remote sites show some recent contamination from atmospheric pollutants such as PCBs, trace metals and fly-ash; (v) however, there has been no apparent biological change at these sites, and these are therefore most suitable for studies of climate variability and change. Russian sites are in the Kola Peninsula, and studied by the Kola Science Centre.