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Middle and Late Pleistocene environmental changes recorded in the Latvian part of the Baltic Sea basin

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ABSTRACT

This thesis outlines the Middle and Late Pleistocene environmental changes as they are recorded in the stratigraphy in western Latvia in the Ziemupe-Jurkalne area and in the northern part of Gulf of Riga (Gulf of Livonia). Latvia is located in the exaration–accumulation zone of the Fennoscandian ice sheets, which affected the interglacial sediments, so they have been preserved mainly in buried valleys and in bedrock depressions.

Pleistocene sediment sequences have been analysed by means of lithological and biostratigraphical methods with an emphasis on pollen analysis. The presence of marine Pleistocene deposits accumulated in the Holsteinian and Eemian Seas has been established by an analysis of the foraminifera and diatom composition recorded in the interglacial sediments. New continuous Holsteinian and Eemian sediment cores have been characterised and compared with previously investigated sites in the same area, and put into a regional context. Holsteinian and Eemian interglacial marine sediment sequences, as well as Elsterian, Saalian and Weichselian late and early glacial deposits have been identified.

The results of the biostratigraphical investigations indicate a very early transgression of the Holsteinian Sea already at the end of the Late Elsterian Glaciation, while true marine conditions occurred in the Eemian Interglacial in the early temperate substage before the climatic optimum. The sediment sequences, including the Eemian Interglacial, contain marine foraminifera and diatoms characteristic of the Eemian Sea. The identified foraminifera and diatom taxa reflect shallow brackish-freshwater conditions during the post-temperate sub-stage of both interglacials.

Pollen records from the Holsteinian sites show a succession of three main vegetation types in the coastal zone. Nine regional pollen assemblage zones are distinguished and they represent a periglacial vegetation (PAZ I), a temperate climate vegetation complex dominated by pollen of coniferous trees (PAZ II-VI), and an open landscape vegetation (PAZ VII-IX).

The Eemian interglacial pollen succession (regional PAZ E1-E8) in the study area began with a dominance of *Betula* (E1), which was gradually replaced by *Pinus* (E2). The maximum distribution of broad-leaved forest started with the spread of *Ulmus* and *Quercus* (E3), followed by *Tilia* (E5) and *Carpinus* (E6). *Picea* and *Pinus* (E7), dominated after the climatic optimum and were followed by *Betula* (E8). The presence of *Hedera* and *Brasenia* indicates a favourable climate with oceanic influence.

During the Eemian Interglacial, broad-leaved forests were widespread in the coastal area. In contrast, coniferous forests had a wider distribution and diversity during the Holsteinian Interglacial. The pollen diagrams from Latvian Holsteinian sites are more similar to those from north-western Europe than the Eemian ones, suggesting a greater difference in the coastal vegetation in the last Interglacial. Both interglacials are ending with a *Betula-Pinus* zone, rich in Ericales and with an admixture of broad-leaved tree pollen, whose presence "*in situ*" is still under question.

The results prove that western Latvia is a key area to the study of Pleistocene stratigraphy, since the north-easternmost extension of the Holsteinian Sea as far as we know has been identified in this area. New Eemian marine sites widen the knowledge of the Eemian Baltic Sea in the south-eastern Baltic area.

Keywords: Pleistocene, stratigraphy, Holsteinian Interglacial, Eemian Interglacial, stadials, interstadials, marine sediments, foraminifera, diatoms, pollen, vegetation history, Ziemupe-Jurkalne area, western Latvia, Gulf of Riga.

1 INTRODUCTION

Geological mapping that was carried out in Latvia in the 1980s resulted in a large amount of valuable and important geological data. The author of the present study did bio- and lithostratigraphical analyses on a considerable number of samples (Table 1) for 25 years at the Central Laboratory of the State Geological Survey of Latvia. All information obtained was not used nor interpreted in detail for the reports of the Geological Survey, because of their practical interest in applied geology. The data and the interpretation of the results looked interesting and important enough for the author to continue and broaden the studies. It was decided that a reinvestigation and reinterpretation, as well as analyses of additional samples with the required methods were to be carried out.

The present study covers the Ziemupe-Jurkalne area in western Latvia, and the north-eastern part of the Gulf of Riga (Fig. 1A,B) These two areas were chosen for two reasons: 1) the large amount of geological material available there, and 2) their complex geological structure and history. The study is based on investigations of Pleistocene marine and associated fresh-water sediments, as well as glacial deposits obtained from boreholes cored in western Latvia for the geological mapping at a scale of 1:50 000 by the Geological Survey of Latvia, (map sheets 0-34-115 and 0-34-116, Tracevski *et al.* 1989) and sequences from outcrops in the Akmenrags-Jurkalne area, as well as material from the mapping at a scale of 1:200 000 in the Gulf of Riga during the period 1984 - 1992.

Numerous boreholes were drilled in the Pavilosta area in Western Kurzeme (Fig. 1C), and 127mm diameter cores were obtained with 80-95% sediment recovery. Nine of them were chosen for detailed litho- and biostratigraphical studies and environmental reconstruction. Field descriptions of the cores and subsampling for different analyses (granulometrical, mineralogical, palaeontological and palynological) were carried out. Most of the sediments were analysed provisionally for the construction of geological maps. Later, in 1993 - 1997, the collected samples were reinvestigated and reanalysed, and additional samples were analysed specifically for this study.

During the geological mapping at a scale of 1:200 000 in the northern part of the Gulf of Riga (1990 - 1992) Quaternary deposits were studied with seismic reflection profiling (Seredenko *et al.* 1997), which helped to identify deposits of the Eemian Sea and the Weichselian Glaciation (Stiebrins 1992). Sampling was carried out on cores 20, 21 and 25 south-west of the Kihnu Island (Fig. 1B), and the Pleistocene deposits originating from the Eemian Interglacial and Weichselian Glaciation have been studied palynologically (Kalnina 1993, 1996a, 1997a, b, c, d; Kalnina & Juskevics 1998a, b, c). Palynological and lithological investigations of Pleistocene deposits were carried out on both till beds and intertill strata. The analyses were carried out at the Geological Survey of Latvia (Kalnina 1993, 1997a,d; Juskevics & Talpas 1997) and were part of an interdisciplinary European research project "Environmental History of the Baltic region" (European/ PACT, Nordic/Baltic Program). The reinterpretation of analytical data from the previous geological mapping and additional laboratory analyses were done at the Laboratory of Quaternary Environment, Department of Geology, University of Latvia. Studies of literature, correlation and conclusions were carried out at the Department of Quaternary Research, Stockholm University. All available data were collected and selected to reconstruct the sedimentary and palaeoenvironmental conditions. Lithostratigraphical data were supplemented by biostratigraphical evidence *i.e.*, foraminifera, diatom and pollen data. Some sediment was barren of diatom and foraminifera, and then the results of the pollen analyses were of great importance (Kalnina 1996a), especially since the study area is located close to the mainland.

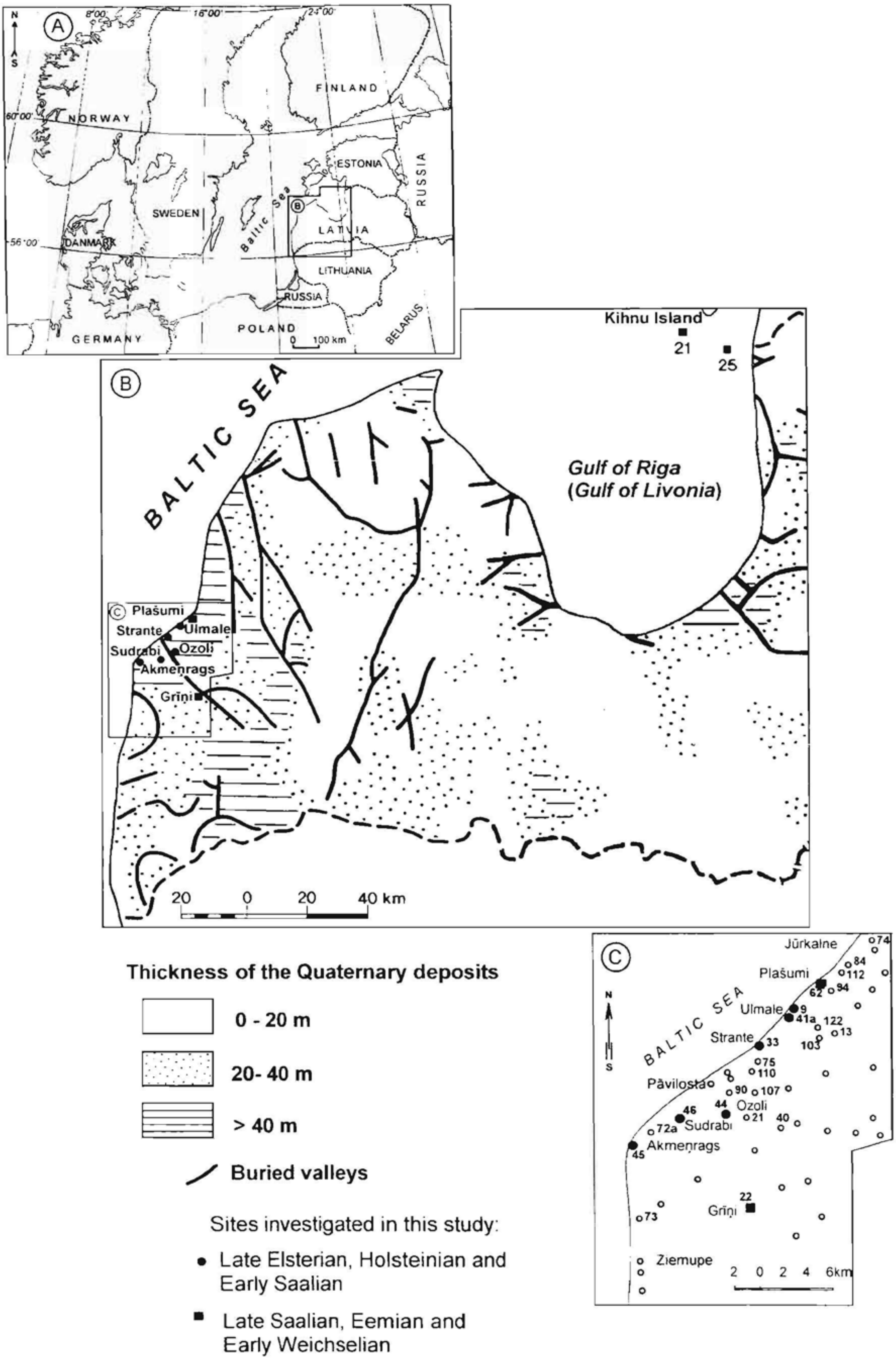


Fig. 1. A – Location of study area in the Baltic Sea region; B – Location of sites studied in the Gulf of Riga and on the Latvian coast with the thickness of Quaternary deposits and location of buried valleys; C – Location of the key sites in the Ziemupe-Jurkalne area.

Table 1. The analyses carried out and used in this study. Analyses made by other researchers have been marked as explained below.

Site	Location	Analyses							
		Lithostratigraphical				Biostratigraphical			
		Grain size	Lithology (Dreimanis method, size fraction 0.5-1 mm)	Roundness of hornblendes (size fraction 0.1-0.25 mm)	Mineralogy (size fraction 0.05-0.1 mm)	Pollen	Diatoms	Forams	Loss on ignition
Akmenrags -45	W coast of Latvia	30	5	5		224	12**	10#	
Strante-33	-" -	29	5	5		220	18**	20	20
Ulmale-41	-" -	40	6	6		276			40
Ozoli-44	-" -	21	6	6	13	116	23**		
Sudrabi-46	-" -	28	7	7		75*	16**	37#	
Plasumi-62	-" -	32	3	3		237	10**	15	
Grini-22	-" -	11				76	9**		
Gulf of Riga-21	Gulf of Riga	51	6	6		185	15**	8***	
Gulf of Riga-25	-" -	20	5	5		99			12
Sum of analyses		**262**	**43**	**43**	**13**	**1508**	**103**	**90**	**72**

* O. Kondratiene, I. Jakubovska and L. Kovalenko (Seglins 1987)
** M. Sakson (in Seglins 1987, Tracevskis *et al.* 1989, Juskevics &Talpas 1997, and pers. comm. of data)
*** foraminifera analysis K. Schoning
# foraminifera analysis V. Mihailov (Seglins 1987)

The importance of this investigation is related to a wide international interest in the history of shallow epicontinental and shelf seas, including the Baltic Sea, which play an extremely important role in the global climate system. Their often high-resolution Quaternary sediment records represent an important archive for studies of environmental changes.

The aim of the study is the reconstruction of palaeoenvironment and palaeoecology during the Pleistocene by means of data recorded in the sediments of the Latvian part of the Baltic Sea basin. Emphasis is placed on the composition of pollen spectra, correlation of data on the local and regional level, and the reconstruction of palaeoenvironment for the Holsteinian and Eemian Seas. The task was to study pollen incorporated in the marine sediments for reconstruction of the vegetation history on the mainland and the climate at the time of the deposition of these sediments. The results are based on a large number of analyses carried out in the geological mapping in scale 1:50 000. The area of investigation covers the Grini - Akmenrags - Strante - Jurkalne area on the mainland along the western Latvian coast (Fig. 1) and two sites in the north-eastern part of the Gulf of Riga. Stratigraphical interpretation is based upon the Pleistocene sediment sequences in the Baltic Sea basin.

The main tasks are:

- to study the composition and distribution of aquatic (marine and lacustrine) and glacial Middle and Late Pleistocene sediments,
- to analyse the pollen composition in Pleistocene sediments,
- to study vegetation composition and succession in the course of interglacials, interstadials and glacials in Latvia, and the differences between Holsteinian and Eemian pollen spectra in aquatic sediments,

- to characterise interstadial pollen floras in the sediments representing the late glacial phases preceding the interglacial and the early glacial cycles,
- to compare vegetation history as reflected by pollen spectra on a local and on a regional scale,
- to reconstruct the palaeoenvironment and palaeoecology of the Holsteinian and Eemian seas as reflected by diatoms and foraminifera,
- to interpret the stratigraphy of the sediment sequences in the Baltic Sea basin along the Latvian coast, mainly based on pollen analysis and completed by other biostratigraphical parameters (forams, diatoms),
- to correlate the sequences studied on a regional scale within the Baltic States and with other sites in north-western Europe as a whole.

2 GEOLOGICAL BACKGROUND

The area that is known as Latvia today was not only bordered by the Baltic Sea in the Holocene, but records of marine sediments between glacial deposits in western Latvia and the Gulf of Riga show that Latvia also bordered on earlier stages of the Baltic Sea during the Holsteinian and Eemian Interglacials (Fig. 1B).

Latvia probably experienced four glaciations separated by three interglacials during the Pleistocene (Danilans *et al.* 1964a). Lacustrine and marine sediments rich in organic remains are considered to have been accumulated at least in the same thickness and had similar distribution as the Holocene ones during previous interglacials, both in the Baltic Sea basin and on land. Most of the interglacial deposits, however, were eroded by glaciers and therefore have been preserved only in buried valleys and other depressions. Regional stratigraphical terms used in this investigation are shown in Table 2.

The present is the key to the past, but the implications of this statement are limited, since sedimentary conditions that were unique in the geological past have no analogues today, or if present do not function in the same way. Recognition of ancient environments involves much hypothetical thinking, which must be based in an understanding of modern sedimentary processes and their relationship to environment; each sequence having its own uniqueness.

In the last ten years there has been an increasing international interest to re-construct and model changes in the environment, climate and sea level, and the extension of the ocean in the Pleistocene. Depositional records from shallow sea basins, for instance the Baltic Sea proper and the Gulf of Riga, are not as complete as those from the deep-sea. Shallow sea basin sequences are interrupted by unconformities caused by sea level changes (*e.g.* emergence and erosion). However, these sequences have very high resolution, and they are thus suitable for well-resolved investigations of palaeoenvironmental change and terrestrial-marine correlation (Scourse *et al.* 1998). Sedimentation rates in such settings can be of greater magnitude (in meters per 10^3 yrs.) than those in deep-seas, thus reducing the mixing caused by bioturbation.

Marine interglacial sediments of Holsteinian age have been found in the south-western areas of the ancient Baltic Sea basin in a few sites (Eggstedt, Dockenhuden, Wedel, Hummelsbüttel, Granzin in Fig. 2), as well as in the coastal areas of the Sambian peninsula and Curonian spit. More sites of Eemian Interglacial age have been identified than Holsteinian ones. They are located along the entire Baltic Sea depression, including Denmark, northern Germany, northern Poland, western Latvia, the Gulf of Riga, northern Estonia, the St. Petersburg region in Russia, southern and south-western Finland and Sweden (Fig. 3).

In western Latvia there are accumulations of marine interglacial sediments at a depth of 60 - 70 m in the Baltic bedrock depression. In spite of significant glaciotectonic deformations in this area during the Saalian (Kurzeme) and Weichselian (Latvija) Glaciations, the depression contains sediment sequences that reflect almost the entire Holsteinian Interglacial cycle, as well as parts of the Eemian Interglacial, and different Early Weichselian interstadials at some sites. This is the only north-eastern area where Holsteinian marine sediments have been found so far and also one of the few Eemian marine sites in the south-eastern Baltic Sea region.

Table 2. Regional stratigraphical terms used and discussed in the text. Interglacials are given in bold.

Division of the Quaternary	Western Europe, North Germany (Lippstreu 1995)	Eastern Baltic Region (Raukas & Gaigalas 1993)	Latvia (Latvijas stratigrafijas komisija 1994)	Western Kurzeme (Kalnina *et al.* 2000)	
Holocene	Holocene				
Late Pleistocene	Weichselian Glaciation	Nemunas Glaciation	Latvija Glaciation	Latvija Glaciation	Latvija Formation
	Eemian Interglacial	**Merkine Interglacial**	**Felicianova Interglacial**	**Felicianova Interglacial**	**Felicianova Formation**
Midddle Pleistocene	Saalian Complex	Ugandi Glaciation	Kurzeme Glaciation	Kurzeme Glaciation	Kurzeme F. Jurkalne F.
	Holsteinian Interglacial	**Butenai Interglacial**	**Pulvernieki Interglacial**	**Akmenrags interglacial**	**Akmenrags formation**
	Elsterian Glaciation	Dainava Glaciation	Letiza Glaciation	Letiza Glaciation	Sudrabi member Letiza Formation
	Cromerian complex	**Turgeliai Interglacial**	**Zidini Interglacial**		
Early Pleistocene	Menapian Glaciation	Dzukija Glaciation	Latgale Glaciation		

3 PREVIOUS INVESTIGATIONS

The history of the Baltic Sea basin and the surrounding areas before the last glacial stage, the Weichselian (Latvija), has been the subject of numerous studies in the adjacent countries. In the southern coastal North Sea districts, and to a certain extent also in the Baltic basin, there are firmly established sediment accumulations from two previous interglacial marine stages, the Holsteinian Sea (Elster / Saale; Letiza / Kurzeme Interglacial) and the Eemian Sea (Saale / Weichselian; Kurzeme / Latvija Interglacial).

3.1 Survey of investigations of marine Holsteinian Interglacial deposits

3.1.1 North-western Europe

The oldest marine Quaternary deposits were identified during the first decades of 20th century and A. Penck (1922) coined the term Holstein Sea.

More intensive investigations of Holsteinian marine sediments started in the 1960s, when the Tornskov site in Denmark was studied (Andersen 1963). Approximately at the same time Holsteinian marine sediments were identified at the south-eastern part of the Baltic Sea basin. Kondratiene (1966) studied marine Pleistocene deposits in the Sambian peninsula. Konshin and Savvaitov (1969) reported on marine Pleistocene deposits at western Kurzeme in Latvia. These marine sediments were correlated with the Holsteinian Sea (Danilans 1973).

Marine deposits of the Holsteinian Interglacial, which preceded the Saalian complex (Litt & Turner 1993) are known and have been investigated in Western Europe by Woldstedt (1950), in the Netherlands by Zagwijn (1973) and Paepe *et al.* (1981), in Denmark (Andersen, 1963; Feyling-Hanssen & Knudsen 1980; Knudsen 1986, 1988, 1993a, 1993b, 1994) and Northern Germany (Erd 1970, 1973; Müller 1974a, Knudsen 1988 and Müller *et al.* 1995). A wide distribution of the Holsteinian marine deposits is firmly established in Western Europe. The Holsteinian Sea is the oldest marine stage known to have penetrated into the Baltic basin in the Quaternary period (Nilsson 1983).

Around the mouth of the Elbe River, and in the main part of Schleswig-Holstein, the Holsteinian Sea formed a deep bay into the land (Ludvig & Schwab 1995) and the marine transgression penetrated also into the Baltic Sea basin. The presence of marine Holsteinian deposits in a number of boreholes in the Neuwerk area, Northwest Germany, was originally described by using pollen stratigraphy (Linke 1970). Recent ESR (Electron Spin Resonance) dates from the same deposits correlate them with other Holsteinian sediments in the Hamburg area (Linke *et al.* 1985), and supported a correlation of the Holsteinian Interglacial with oxygen isotope stage 7 (Shackleton & Opdyke 1973).

The Holsteinian type area of Hamburg-Dockenhuden in north-western Schleswig-Holstein have been investigated by Hallik (1960), Menke (1970), Grube *et al.* (1986), Linke & Hallik (1993), Benda (1993), Ehlers (1993), Stephan (1993) and Knudsen (1993a, b) (Fig. 2).

Hitherto no marine Holsteinian deposits have been found in Poland (Mojski 1985, Ehlers 1996). North of Poland, in the Kaliningrad District (Russia), and also in western Lithuania, marine Holsteinian deposits occur in the coastal area and have been investigated by Cheremisinova (1970), Kondratiene (1965, 1967, 1996), Kondratiene & Yerukhin (1974) and Gudelis (Kondratiene & Gudelis 1983). The most north-eastern location of deposits suggested to have been accumulated in the Holsteinian Sea within the Baltic Sea basin can found in the coastal area of western Latvia (Konshin *et al.* 1970, 1971; Danilans 1973, 1976; Seglins 1987; Cerina 1993; Kalnina 1993; Kalnina *et al.* 2000;). No Holsteinian marine deposits have so far been found in the northern area of the Baltic basin, possibly because of erosion in subsequent glaciations.

Marine Holsteinian deposits have been encountered also in the coastal areas of the Netherlands (Paepe *et al.* 1981) and Great Britain (West 1970) and have been identified in borings far out in the North Sea basin (Laban 1995; Ekman 1998 a,b; Kristensen *et al.* 1998b).

In Schleswig-Holstein, in north-western Germany the oldest Quaternary deposits are considered to consist of Elsterian till and synchronous glaciofluvial sediments. These Elsterian glacial deposits are covered by the "Lauenburg Clay", which is barren of fossils, apart from some, probably reworked, marine balanid shells. Most of the clay is laminated and as meltwater sediment, deposited in ice-dammed lake during the deglaciation of the Elsterian ice sheet (Ehlers 1983; Ehlers *et al.* 1984). These clays, called "potklei" (Peelo Formation), were investigated by Zagwijn (1973) who found that they contain Mesozoic reworked palynomorphs but also primary pollen from late glacial herbaceous and shrub vegetation.

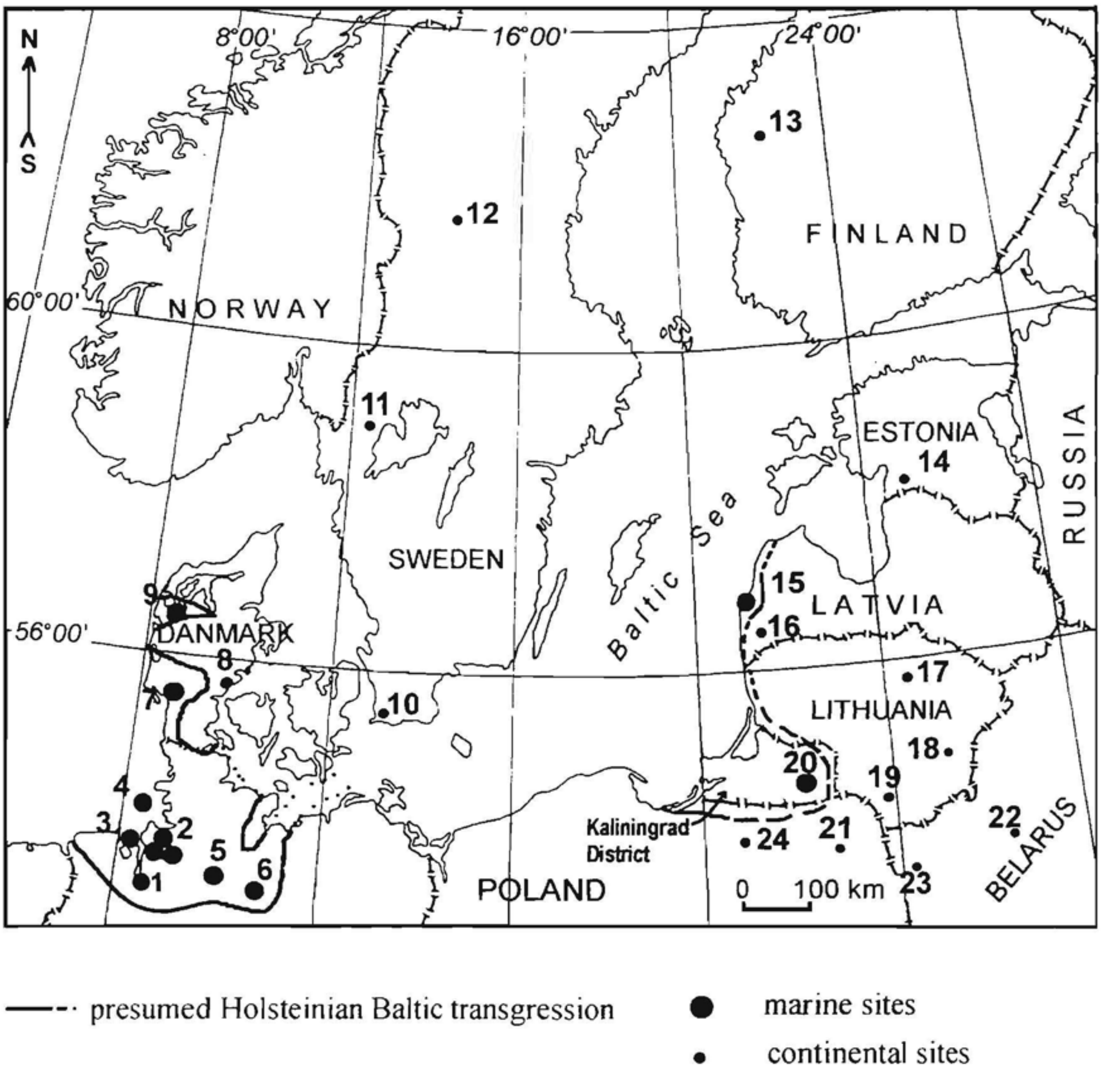


Fig. 2. The Holsteinian marine and continental palynologically investigated sites mentioned in the text. Presumed Holsteinian transgression in Western Europe modified after Donner (1995).
1-Eggstedt, 2-Hamburg area (Dockenhuden. Wedel. Hummelsbüttel), 3-Wacken, 4-Cuxhaven area, 5-Granzin, 6-Pritzwalk, 7-Tornskov, 8-Vejlby, 9-Kås Hoved, 10-Hyby, 11-Snickarekullen, 12-Öje, 13-Lappajärvi, 14-Karuküla. 15-Akmenrags area (Akmenrags. Ulmale. Strante. Ozoli. Sudrabi), 16-Pulvernieki. 17-Butenai, 18-Pailge, 19-Gailunai, 20-Uvarovo, 21-Koczarki. 22-Seilovichi, 23-Zydowszczyna, 24-Kryzewo.

The "Lauenburg Clay" is overlain first by freshwater clay, and then followed by marine clayey and sandy sediments (*e.g.* "Mytilus clay", "Cardium clay"), that contain foraminifera and a mollusc fauna typical for the Holsteinian Sea.

Deposits of the Holsteinian Sea have been found in the Jutland peninsula, Denmark in Tornskov, Kås Hoved, Inder Bjergum, Renbaek, and Rugard sites. Knudsen (1988), and Knudsen and Penney (1987) have investigated the foraminiferal and ostracod faunas of the Holsteinian Sea in more detail. The foraminiferal assemblages in Jutland indicate boreal, mainly sublittoral conditions and a relatively open access route to the North Sea. In general they are similar to those of south-western Denmark and northern Germany. The Holsteinian ostracod faunas were investigated by Penney, who found that the ostracod fauna of Denmark is analogous to those recorded in Northern Germany, and also similar to those reported in Mid-Pleistocene deposits in Great Britain (Knudsen & Penney 1987).

The mollusc fauna of the Holsteinian Sea was poor in taxa, and resembled the fauna of the present North Sea and the Baltic Sea: *e.g. Ostrea edulis* (one of the most warmth demanding), *Mytilus edulis*, *Arctica* (=*Cyprina*) *islandica*, *Macoma baltica*, *Cerastoderma* (=*Cardium*) *edule*, and *Littorina littorea*. The oldest Holsteinian Sea deposits include *Portlandia arctica* and *Hiatella* (=*Saxicava*), suggesting that the marine Holsteinian transgression started already during the Elsterian Late Glacial. During the thermal maximum, temperature conditions were probably almost the same as they are in the present-day North Sea (Gibbard *et al.* 1991).

Andersen (1963), who correlated the regional pollen zones H1-H5 in Tornskov to the Holsteinian Interglacial, established a detailed pollen stratigraphy of marine Pleistocene deposits. In the last three decades the Holsteinian marine sediments have been palynologically investigated in detail (Zagwijn 1973; Erd 1973; Kondratiene & Yerukhin 1974; Linke & Hallik 1993; Kondratiene 1996; Kalnina 1998, Kalnina *et al.* 2000) and in many cases pollen data proved to be very important for estimating the relative age and sedimentation conditions of the marine deposits.

3.1.2 South-eastern part of the Baltic Sea basin

Geological investigations and mapping have been carried out in the coastal areas around the Baltic Sea (Fig. 2). Holsteinian marine deposits have been found in an area from the Sambian peninsula (Kaliningrad District, Russia), to western Lithuania and the western coastal part of Latvia.

Kaliningrad area and western Lithuania

In the Sambian peninsula and in western Lithuania, marine Holsteinian deposits occur in the coastal area and have been investigated by Cheremisinova (1970), Kondratiene (1966, 1967, 1996), Kondratiene & Yerukhin (1974) and Gudelis (Kondratiene & Gudelis 1983). Marine deposits that are rich in diatoms, which resemble the flora of the Holsteinian Sea deposits covered by glacial formations have been found. The diatom complex that has been identified in sandy layers at the base of the interglacial sequence reflects the start of the ingression of saline water into the large cold lakes in Late Elsterian. The diatom taxa from the upper part of the interglacial sediment sequence reflect the increase of salinity and depth of the basin. According to the results obtained Cheremisinova (1970) point to a direct connection between the Baltic Sea basin and the North Sea in the second part of the Holsteinian Interglacial.

A large number of pollen analyses showed that the interglacial sequence belongs to the Holsteinian. Most of the pollen spectra show a composition reflecting a vegetation existing during the middle part of the Holsteinian Interglacial, correlated with zone B 3 and B4 of the Butenai Interglacial (Kondratiene 1966) and comparable with that from Tornskov in Denmark and Granzin in north-western Germany (Fig. 2).

There are a number of pollen diagrams from sites in western Lithuania, *e.g.* Laukzeme, Gwildzaj, Zadeikai-27, Stancaiciai and Skomantai, but the stratigraphy is problematic (Kondratiene 1996) and the marine conditions have not been proven with certainty.

Coastal area of Latvia

In western Kurzeme (Figs 1, 2) the lithology of tills was first described by Dreimanis (1936). He considered a lower grey till bed had been deposited during the penultimate Saalian/Kurzeme Glaciation, but he did not discuss the intertill sediments exposed along the bluffs of the Baltic Sea coast, since he did not notice any organic deposits in them.

The continental interglacial sediment sequences were studied already in the first half of 20th century in Latvia (Dreimanis 1949), but marine ones have been found much later. Test drillings in the coastal area of western Kurzeme established at the end of the 1960s the existence of marine Pleistocene sediments in Latvia. Konshin and Savvaitov (1969) presented the first results of the investigations of marine Pleistocene deposits at the third Scientific conference in Minsk. Afterwards new results have been discussed. Detailed descriptions of intertill marine sediments in western Latvia and some characteristics of intertill sediments were given by Konshin *et al.* (1971). Veinbergs and Savvaitov (1970) presented a study on structural peculiarities of the upper part of the marine intertill strata in the Jurkalne-Ulmale area. The particularities of the formation of interglacial deposits were discussed and a first map of the distribution of marine Pleistocene deposits was drawn by Konshin *et al.* (1970).

Charamisinava´s diatom studies showed the existence of a marine genesis of interglacial deposits at the stratotype key site Ulmale 9, (Charamisinova 1971). She explained the changing composition of the diatom flora in the different layers of the marine deposits and most diatoms as being benthic neritic and oceanic forms that occurred in seas with normal salinity, but she proposed an Eemian age of the sediments.

Since 1969 intertill sediments in western Latvia have been interpreted and discussed as being of marine origin by many researchers (Konshin *et al.* 1970; Veinbergs & Savvaitov 1970; Charamisinava 1971; Konshin *et al.* 1971; Danilans 1973; Meirons & Straume 1979; Meirons 1986a,b; Seglins 1987). Konshin *et al.* (1971, 49 p.) selected the Ulmale area as the key section of marine intertill deposits in western Latvia from the stratigraphical point of view and pointed out that "Spore-pollen diagram of the marine intermorainic deposits of the Ulmale section is comparable with the spectra of Holstein marine deposits in western Europe and with those of Likhvian lacustrine and peat deposits in the Russian Plain."

The marine intertill sediment sequence of the Ulmale-9 section was analysed by means of pollen, and the pollen diagram shows, from the bottom and upwards, a regular succession of six pollen complexes (Konshin *et al.* 1971; Danilans 1973, Fig. II). The succession indicates definite regular changes in the vegetation, which have arisen under the influence of climatic changes when these marine intertill deposits accumulated. The general vegetation history was characterised first by the spread of *Pinus-Betula* forests, followed by *Picea-Carpinus* and *Picea-Pinus* forests with *Alnus* and *Abies*. Kalnina *et al.* (2000) compared the pollen diagram of the marine intertill sediments of the Ulmale section with the spectra of Holsteinian marine deposits of western Europe, particularly with the Granzin section in Germany studied by Erd (1969) and with Likhvian lacustrine sediments in Russia (Grichuk 1961). In the end of 1960s 13 sections were studied palynologically in the coastal area of Latvia in addition to the Ulmale-9 section. The pollen spectra identified in these sections (Ovisi, Liepene, Ventspils, Ernini, Zuras, Jurkalne, Alsunga, Cirava, Dzintari and Ulmale outcrop) mostly reflect the late temperate part of the Interglacial and have been correlated with regional pollen zones IV, V or/and VI (Konsin *et al.* 1971).

Danilans (1973) assigned the term Ulmale formation to the marine intertill sediments and correlated them with the Pulvernieki (Holsteinian, Likhvinian) terrestrial interglacial deposits, pointing out that the upper part of these sequences belong to the beginning of the Kurzeme (Saalian) Glaciation. On the basis of palynological investigations, Danilans (1976) distinguished two subunits in the Ulmale formation: the Ulmale beds and the overlying Staldzene beds. In 1983 Kondratiene made an overview of the marine Pleistocene deposits in the south-eastern Baltic region and showed that the pollen sequence in the Ulmale section corresponds to the Holsteinian Interglacial (Kondratiene & Gudelis 1983). Meirons (1986b) discussed the age of these sediments and considered them as being deposited in the Holsteinian Sea, and applied the term "Jurkalne" to the inter-glacial sediments overlying the Staldzene beds (Meirons 1986b, 1992).

Seglins (1987) raised the stratigraphical rank of the Ulmale formation to a group and divided it into two formations. He investigated the sedimentary sequences in several new cores (Akmenrags, Sudrabi, Ozoli) using lithological and paleobotanical analyses, and assigned the name "Akmenrags formation" to the marine interglacial Ulmale beds. The underlying sediments, formed under cold climatic conditions, were named the "Sudrabi beds". By using samples from new test drillings, Kalnina (1993, 1998, 1999, 2000) presented new pollen diagrams (Akmenrags, Ozoli, Strante, Ulmale 41a) of the marine Holsteinian deposits in western Kurzeme. The studies of plant macro remains were carried out by Cerina (1993), who demonstrated the presence of a Holsteinian Interglacial flora.

A lot of unpublished geological data and unsolved stratigraphical problems from the Ziemupe-Jurkalne area inspired the author and her co-workers to make an inventory and to reinterpret the material from a new point of view (Kalnina *et al.* 2000).

3.2 Survey of investigations of marine Eemian Interglacial deposits in the Baltic Sea region

The Eemian Interglacial has been correlated with the deep-sea oxygen isotope ($^{18}O/^{16}O$) substage 5e, (Mangerud 1989). Its thermal maximum is dated between 128 000 and 125 000 BP (Shackleton & Opdyke 1973: Martinson *et al.* 1987).

The Eemian Interglacial was named after the river Eem in the Netherlands (Harting 1875), where the stratotype of the Eemian Interglacial is located. Information about the Eemian Baltic Sea, appeared already at the 19th century, but was used internationally only after 1908, when Madsen, Nordmann and Hartz published their systematic study of the Cyprina Clays in Denmark, northern Germany and the Netherlands (Madsen *et al.* 1908). They found that the transported masses when studied in detail exhibit a regular and constant succession of beds which shows an upward passage from freshwater through brackish into marine deposits, and is so well characterised by its peculiar assemblages of fossils that it is readily identifiable wherever it occurs.

3.2.1 Sediment sequences in the Eemian Baltic Sea

The first investigations, which were made in the beginning of the 20th century, gave some understanding of the character and sedimentary environment of the marine Eemian sediments. It was already stated by Wright that: "All the localities, where the Eemian deposits occur as reworked/ relocated masses incorporated in till are all located in eastern Denmark and northern Germany. To the west and south of this area they are undisturbed and in their original position" (Wright 1914; Fig. 42, p. 126). Earlier studies were performed on the interglacial sediments at Ristinge Klint in Denmark in the south-western Baltic Sea (Fig. 3), where the presence of a continuous early Eemian sediment succession that had gradually changed from a freshwater environment to marine conditions was found (Madsen *et al.* 1908). After almost one hundred years, this site has recently been reinvestigated (Kristensen *et al.* 2000). Today Eemian marine deposits in the Baltic Sea basin are known from numerous sites extending from Denmark (Knudsen 1984, 1986, 1994), Poland, Latvia and Estonia, to north-western Russia, Finland and Sweden. In contrast to the Holsteinian Sea, there is evidence that suggests that the Eemian Sea had a wider extension in the Baltic basin.

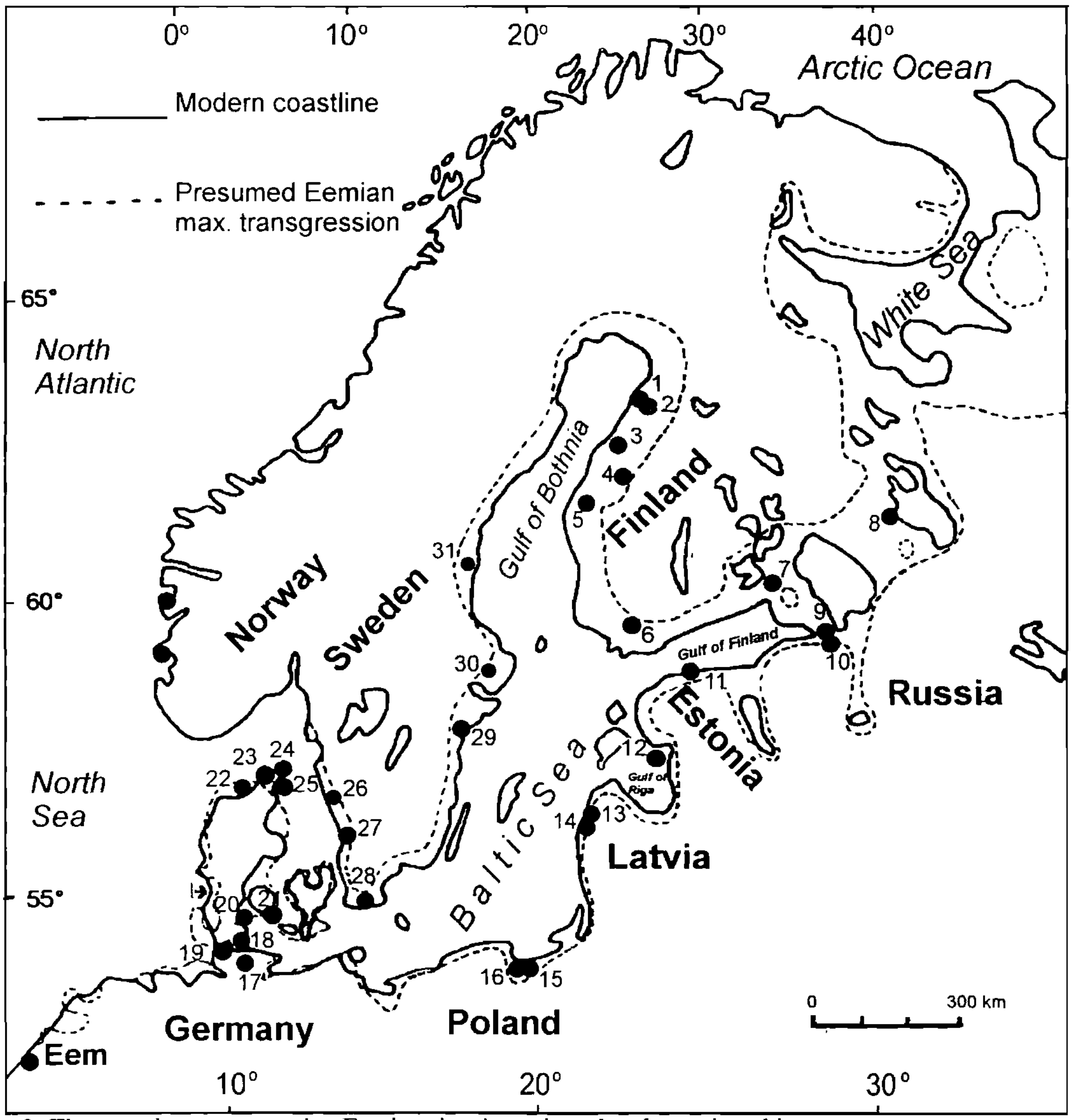


Fig. 3. The most important marine Eemian sites investigated and mentioned in text.
1 - Mertuanoja, 2 - Ollala, 3 - Evijärvi, 4 - Alajärvi, 5 - Norinkylä, 6 - Somero, 7 - Rouhiala, 8 - Vasilyevskij Bor, 9 - Mga, 10 - Ribatskoje, 11 - Prangli, 12 – Gulf of Riga-21, 13 - Plasumi, 14 - Grini, 15 - Nowiny, 16 - Tychnowy, 17 - Schnittlohe, 18 - Offenbüttel, 19 - Husum, 20 - Stensigmose, 21 - Ristinge Klint, 22 - Nörre Lyngby, 23 - Skærumhede, 24 - Skagen, 25 - Apholm, 26 – Holmagärde, 27 - Margareteberg, 28 - Hyby, 29 - Nyköping, 30 - Skulla, 31 - Dellen.

In the areas south of the present Baltic Sea the palaeoenvironment of the Eemian Baltic Sea has been studied mainly by means of faunal remains comprising only marine species. Since the fauna includes several thermophilous, lusitanian species (Nilsson 1983, Knudsen 1991, 1994) it is assumed that the south-western part of the Eemian Baltic Sea was warmer than the present North Sea.

Kosack and Lange (1985) describe Eemian strata from Offenbüttel and Schnittlohe in Schleswig-Holstein, northern Germany, and Tynni (in Menke 1985) have investigated Eemian diatom assemblages in brackish-marine sediments from Husum, Schleswig-Holstein. The stratigraphy demonstrated that there existed a connection between the Eemian North Sea and the Eemian Baltic Sea.

A rich Eemian marine diatom flora has been identified at Kady, Elblag Heights near Gdansk Bay, Poland and marine Eemian deposits also occur in the Lower Vistula river valley (Mojski 1985). Makowska (1982) identifies two transgressions of the Eemian Sea - Tychnowy and Sztum in northern Poland by means of diatom analysis.

A marine Eemian diatom flora was also identified in sediments at a depth of 60-70 m below present sea level on the Estonian island of Prangli (Fig. 3), in the southern part of the Gulf of Finland, and first presented by Cheremisinova (1961) and later by Liivrand (1984, 1987, 1991). Liivrand (1987) proposes the Prangli site as the stratotype locality of the marine Eemian Baltic Sea deposits for the eastern part of the Baltic basin.

Sediments containing marine diatoms related to the north-eastern part of the Eemian Baltic Sea were first found in the Karelian Isthmus (Brander 1937) and in the Saint Petersburg District, where the stratigraphical position and distribution of Mga Interglacial Sea and its main paleogeographical features were studied (Znamenskaya 1959; Lavrova & Grichuk 1960; Lavrova 1961; Znamenskaya & Cheremisinova 1962; Malahovskij *et al.* 1989; Krasnov *et al.* 1995;

Since then, sediments containing diatom species interpreted as having been deposited in the Eemian Baltic Sea have been identified in Finland (Niemelä & Tynni 1979), but they have in fact often been redeposited (Somero, Ostrobothnia, Donner & Gardemeister 1971; Niemelä & Tynni 1979; Gibbard *et al.* 1989). The Eemian interglacial environment has been reconstructed at Mertuanoja (western Finland) on the basis of pollen, diatom and dinoflagellate analyses (Eriksson *et al.* 1999). In general, sediments with less abundant, mostly reworked and relocated Eemian Baltic Sea diatoms have been reported from the northern and north-western parts of the present Baltic Sea. In Sweden they have been found at Bollnäs, Dellen, Nyköping, Skulla (Halden 1915; Miller & Persson 1973; Robertsson & Garc□a Ambrosiani 1992; Robertsson *et al.* 1997). The sequence from Margreteberg, south-western Sweden, (Miller, in Påsse *et al.* 1988), which was tentatively correlated with the later part of the Eemian Interglacial, contains redeposited marine diatoms. The same is the case in the Hyby sequence from the Alnarp Valley, southern Sweden, where reworked marine diatom species and thermophilous pollen occur in silt and sand layers between Saalian and Weichselian tills (Miller 1977, 1981). Marine Eemian sediments were also identified from Holmagärde (Påsse 1992).

3.2.2 Marine Eemian interglacial deposits in Latvia

Marine Pleistocene deposits have been investigated to a considerably less extent as compared to the more than one hundred year long history of investigations of the continental Pleistocene sequences in Latvia. Investigations of Pleistocene deposits started already in the second half of the 19th century with studies by Professor K. Grewingk at Tartu University. Redeposited marine Pleistocene fossils (*Portlandia arctica*) were first investigated by Dreimanis (1936) and Zans (1936). Zans drew a map showing the probable extent of the Portlandia Sea in the Baltic basin (Zans, 1936, Fig.1, p. 247).

Information about the Quaternary deposits in the Gulf of Riga was first obtained in the early 1960s using seismoacoustic profiling. *Portlandia arctica* and foraminifera were found in the sediment core at the Kolka site carried out in 1953 (Ulst *et al.* 1963). The Geological Survey of Latvia carried out geological mapping in the Gulf of Riga 1984 - 1992. At that time deposits of the Eemian Sea and the Weichselian Glaciation were found southwest of Kihnu Island, close to an area where Estonian geologists had identified analogous probably redeposited deposits previously (Liivrand 1976; Raukas 1978).

The Gulf of Riga is situated in an area that was affected by the Fennoscandian Weichselian ice-sheet, and where intensive erosion processes took place. The oldest Quaternary deposits are preserved only in depressions of the Pre-Quaternary surface and in buried valleys.

Detailed studies of marine Pleistocene deposits made it possible to find marine Eemian sediment sequences at Grini and Plasumi, in the Ziemupe-Jurkalne area (Kalnina & Juskevics 1998a, Kalnina *et al.* 2000), which were earlier known only to include marine Holsteinian sequences (Figs 1, 3). Some researchers′ opinion of the Eemian age of marine sediments in this area inspired the author to look more carefully at sediment sequences whose stratigraphical position was unclear or doubtful. Reinvestigation of sequences and reinterpretation of data show that the marine sediment sequences of the Grini and Plasumi sites were deposited during the Eemian Interglacial.

Today, two main areas are known with marine Eemian deposits in Latvia: 1) the Baltic Sea basin in the western Kurzeme area and 2) the northern part of the Gulf of Riga (Fig.1).

3.2.3 Problems of the reconstruction of the Eemian Sea history and palaeoecology

New data obtained of the Eemian Baltic Sea and the Eemian North Sea, and, as well as the wide application of new research methods and available correlations, give a clearer understanding of the marine history during the Eemian Interglacial. Based on regional correlations to other European terrestrial and North Atlantic marine proxy records were used by a combination of sea level changes, changes in the hydrologic cycle and changing oceanic circulation patterns. The latter two may have been triggered by the opening and closure of the Baltic Sea-White Sea connection, the initial build-up of continental ice sheets, and the first major impacts of meltwater induced freshwater in key areas for thermohaline circulation (Björk *et al.* 2000).

The complicated evolution of the Baltic Eemian Sea, is the reason why different points of view exist on its history. At the beginning of the Saalian Late Glacial the oceanic waters entered into the Baltic depression already before the Eemian transgression. During the Eemian Interglacial (5e), the eustatic ocean level was a few metres higher than it is at present (Bloom *et al.* 1974).

It is further assumed that the Eemian North Sea had an open connection to the Atlantic Ocean through the English Channel (Gibbard *et al.* 1991). The marine diatom species found in the Eemian deposits in the eastern part of the Baltic basin imply that the salinity of the water approached that of the ocean during the Eemian interglacial and that it was more saline than the postglacial Baltic Sea (Cheremisinova 1961; Niemelä & Tynni 1979; Forsström *et al.* 1988; Eriksson 1993; Grönlund 1991).

As suggested by Finnish researchers (Niemelä & Tynni 1979; Grönlund 1988, 1991; Forsström *et al.* 1988, Nenonen 1995) the Baltic Eemian Sea was connected to the North Sea and to the Arctic Ocean via the White Sea during the Eemian. This is supported by findings of Arctic Ocean cryophilic diatoms and Atlantic Ocean thermophilic diatoms, which are common in the Eemian deposits of Ostrobothnia (Zans 1936; Niemelä & Tynni 1979; Grönlund 1991; Liivrand 1991). In all likelihood, the connection between the White Sea and the Baltic basin opened early because cryophilic marine diatoms and molluscs are present in the basal marine clays (Grönlund 1991, Funder *et al.* in print).

The occurrence of molluscs that thrive in cold water, *e.g. Portlandia* (*Yoldia*) *arctica*, among species favouring warm water, has led to the distinction of a separate Portlandia Sea phase of the Eemian Interglacial. During this phase the sea extended from the Atlantic Ocean through the Baltic to the White Sea (Funder *et al.* in print). The chronological position of this phase has been questioned, and it has been correlated with either the initial or final stage of the Eemian Baltic Sea, even with the beginning of the last glaciation. Grönlund (1991) has described a freshwater stage before the marine Eemian transgression. For a long time there were two alternative viewpoints about the extension of the Eemian Sea (Fig. 4):

1 - Lavrova (1961), Grichuk (in Gerasimov & Velichko 1982), Forsström *et al.* (1988) and Grönlund (1991) suggest that a connection existed between the Eemian Sea in the west from the North Sea through Skagerrack, Kattegat and the Danish Straits, or through Central Sweden, and to the White Sea basin through a system of shallow straits including the Ladoga Lake and the Onega Lake basins.

2 - An alternative model suggests approximately the same configuration of the Eemian Baltic Sea as the present Baltic Sea with a connection only with the North Sea. The transgressive waters of the Eemian Sea only occasionally flooded small areas of the estuaries of the Vistula, Narva and Neva River (Gerasimov & Velichko 1982).

In the Leningrad and Karelian Isthmus area there are sections that are very important for answering the question about a possible connection between the Baltic Eemian Sea and the White Sea basins (Krasnov *et al.* 1995; Funder *et al.* in print). These sections, however, are scattered and located in the marginal zone of the Baltic Shield, where tectonic activities have been frequent. Therefore they are not suitable for paleogeographical reconstruction of the Eemian Interglacial.

Several authors suggest that during the transgression the extension of the Eemian Sea closely coincided with the Litorina Sea limit and, therefore, could only have been connected with the western ocean via the Skagerrack, the Kattegat and the Danish Sounds. Transgressive waters would have inundated the Lake Ladoga depression, small areas at the Vistula and the Narva River mouths, and the ancient Neva River valley (Blagovolin *et al.* 1982). Resolving the question concerning the connection of the Baltic Eemian Sea with the White Sea basin is of principal importance. If no such connection existed, the hydrological regime in the eastern part of the Eemian Sea would have been very similar to the Holocene (Flandrian) transgression. If the connection with the White Sea basin did exist - the situation must have been fundamentally different from that in the Holocene.

A number of diatom records indicate that the Baltic Eemian Interglacial sediments were deposited first in a freshwater basin, then in the Eemian Baltic Sea, and finally again in a freshwater basin (Grönlund 1991; Eriksson *et al.* 1999). The presence of dinoflagellates in deposits of western Finland demonstrates that the Eemian Baltic Sea was connected to the Atlantic Ocean when at its maximum extent (Eriksson *et al.* 1999).

Some authors have used the term "last interglacial" (Zans 1936; Raukas 1991; Kukla *et al.* 1997) with a much broader

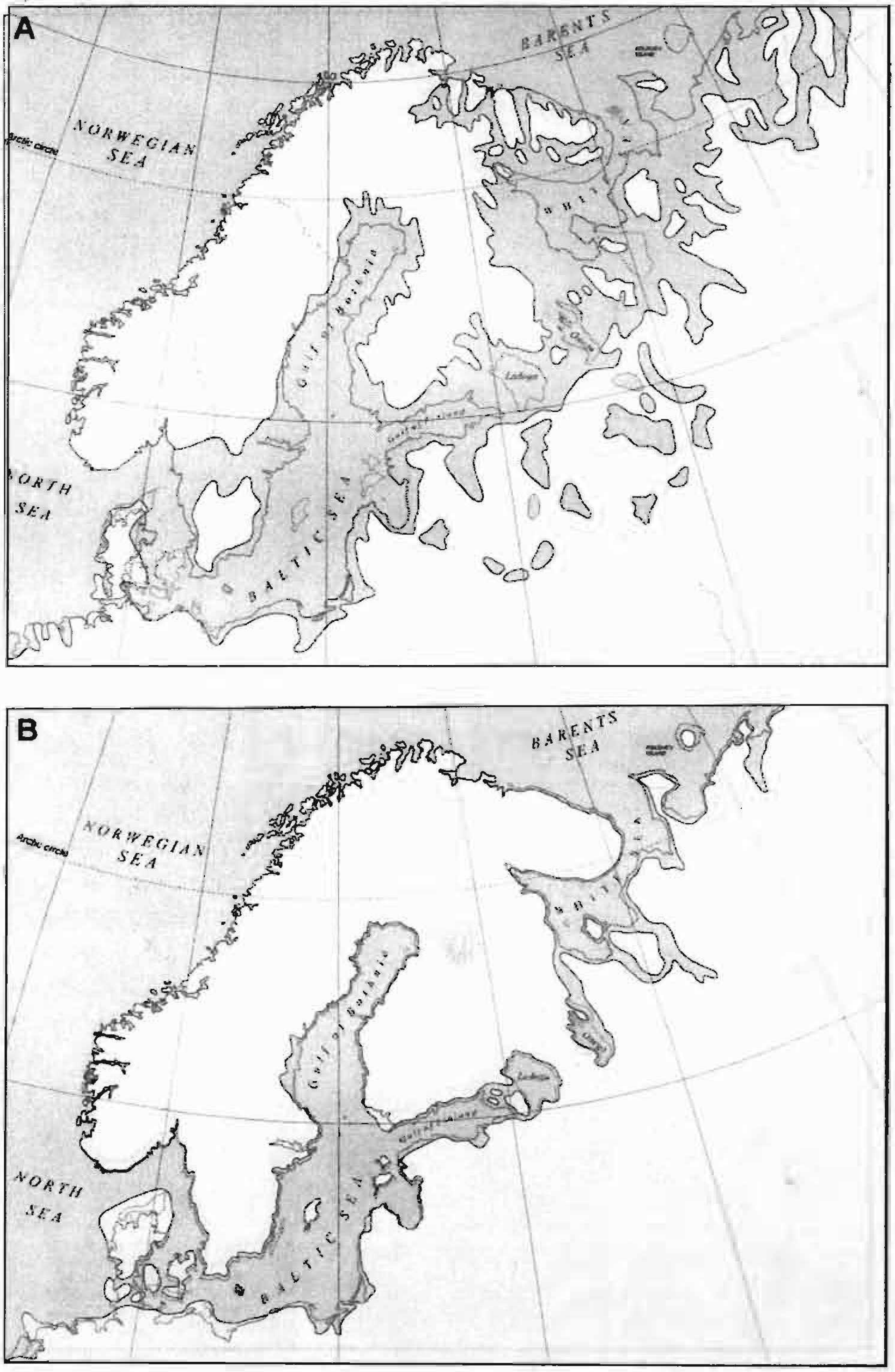


Fig.4. Maps of two different viewpoints about the Baltic Eemian Sea distribution (Molodkov & Raukas 1998). Eemian/Boreal shorelines (dotted) and submerged areas: A – after Grichuk (1982) with corrections after Knudsen (1994); B – after Blagovolin *et al.* (1982).

meaning than only "Eem" or "Eemian", which can raise some misunderstandings and confusion in the correlation. The term "last interglacial" might cover a much longer interval than isotopic stage 5e, probably even the entire 5 or 5e-5c. It has been suggested that the Baltic Sea was considerably larger when it had a connection to the White Sea during the Eemian than today (Zans 1936; Raukas 1991, Krasnov *et al.* 1995; Kukla *et al.* 1997). However, the nature, timing and duration of this connection remain unclear, because it is not known whether this was a single or multiple event (Kristensen *et al.* 2000).

4 MATERIALS AND METHODS

4.1 Character of materials and sequence of investigation

The materials on which the present study is based have mainly been obtained from test drillings at geological mappings. First a visual description was done in the field, and subsequently the sub-sampling was made. Separate samples were taken for litho-stratigraphical and biostratigraphical analyses. The number of samples and the interval between samples chosen depend on character of the sediment and the type of analysis.

The Quaternary deposits in the Gulf of Riga were first studied with seismic reflection profiling (Seredenko *et al.* 1997) to find a suitable place for test drillings and core sampling. The deposits were subdivided into three seismo-stratigraphic sequences based on the recordings of reflected seismo-acoustic signals. The lowermost seismic sequence was locally developed, and occurs as infillings of valleys and trenches in the Pre-Quaternary sedimentary bedrock surface. This sequence consisted of various layers of both the Middle and the Upper Pleistocene age. The test drillings were performed with the vibro-coring equipment KMO- 2.

Several questions arose during the geological mapping, *e.g.* at Plasumi and Grini. The stratigraphical position of the sediment sequences was unclear. The lack of data created uncertainity about the environmental changes that were recorded in the marine sediments and in those underlying and overlying them.

These problems required new data, additional studies and improvement of study methods. In north-western Europe, studies focused on marine environments and climate changes are based on detailed (team work) investigations of foraminifera, ostracod, macrofauna, diatom and pollen assemblages, as well as on stable isotope studies, high-resolution reflection seismic profiles, and discussions of the combined results of biostratigraphical correlation, optically stimulated luminescence (OSL) dating and amino acid ratio determinations.

This study is based on investigations and analytical data from the earlier geological mappings, new data obtained as a result of additional laboratory analyses and on the reinterpretation of data. Lithostratigraphical data, which will be used to clarify and modify the environmental and stratigraphic interpretation of the pre-Latvijan (pre-Weichselian, Table 1) deposits in the Grīni - Akmenrags - Strante - Jurkalne area (Fig. 1C) and in the Gulf of Riga will be presented (Figs 1B,C and 3). The age of the marine sediments could not be determined with absolute dating methods, but was concluded from palynological and other biostratigraphical data. Therefore, the main focus will be on the results of biostratigraphical data, particularly from palynological investigations and their correlation with surrounding areas.

The sediment cores from test drillings were first examined visually and described in the field (Strante-33, Ulmale-41, Riga Gulf-21, Riga Gulf-25), and afterwards they were split, and representative samples were taken to granulometric, lithological and micropaleontological analyses. Sampling was performed with the aim to get all possible information from the sediments of the same layer and depth interval. Although, samples for different analyses were subsampled separately, the corresponding depth interval and characteristics of deposits were taken into account. Interval of subsampling for lithological analyses varied from 0.2 to 1.0 m and more, depending on the homogeneity of the sediment layer. Till and coarse sand was sampled more rarely than fine sand, silt and clay. Subsampling for pollen analysis was performed at intervals of 3 - 5 cm from sediment rich in organic material, to 15 - 20 cm of sand and tills. Sample weight was taken according to the technique necessary for getting qualified data. Subsequently, lithological and palynological investigations were done by the author at the Central Laboratory of the Geological Survey of Latvia (until 1995) and the Laboratory of Quaternary Environment at the Geological Department, University of Latvia.

The analytical investigations included determinations of grain size, mineralogical composition and physical-mechanical properties, analysis of pollen and spores, diatoms and foraminifera. Only those analytical methods that were carried out by the author will be discussed further. An exception is diatom analysis, which has primarily been carried out and interpreted by M. Sakson (pers. comm.) and E. Cheremisinova (1970, 1971), and will be summarised in the present study.

4.2 Lithological methods

Grain size analysis: Analyses were carried out by sieving and using the pipette method. The following particle size boundaries have been used: boulder/pebbles: 100 mm, pebbles/gravel: 10 mm, gravel/sand: 2 mm, sand/silt: 0.05 mm, silt/clay: 0.01 mm, in order to compare the results with previous Latvian analytical data.

Grain-size analysis was carried out:

1) for coarse-grained parts (> 0.05 mm) – by sieving. The samples were washed through a 0.05 mm sieve and dried at 105° C, and then sieved through 5 - 9 sieves, obtaining the following fractions (in mm): > 10.0, 10.0-5.0, 5.0-2.0, 2.0-1.0, 1.0-0.5, 0.5-0.25, 0.25-0.14, 0.14-0.1, 0.1-0.05;

2) for finer parts of sediments (< 0.05 mm) grain-size fractions of 0.05-0.01, 0.01-0.005, 0.005-0.001 and < 0.001 mm were determined with the pipette method.

Mineralogical analysis: Mineralogical analyses were carried out on selected fractions (mainly 0.1 - 0.05 mm) of sediment. The minerals were first separated with bromoform (density 2.9 g/cm^{-3}) in light and heavy fractions. The weight percentages of heavy minerals, of the total, were also determined.

The following light minerals were determined at each analysed level: quartz, feldspars, muscovite, chlorite, glauconite, carbonates by using an immersion solution of bromnaphtaline with a refraction index (R.I.) 1.551 under microscope. 400 grains of light minerals were identified.

Heavy minerals were identified by using immersion in bromnaphtaline with R.I. 1.63. The following groups of allogenic minerals were determined: ore minerals, leucoxene, amphibole, pyroxene, zircon, garnet, tourmaline, epidote, apatite, rutile, staurolite, monazite, sphene and also authigenic minerals: pyrite, siderite, hematite, galena, anatase, leucoxene. 500 grains were determined at each analysed level.

Roundness of hornblende: The method of using the abundance of rounded hornblende grains for stratigraphic differentiation of tills was introduced by Ulst and Maiore (1964) and since then it has been used by Quaternary geologists in Latvia. Heavy minerals (0.1 - 0.25 mm) were separated by bromoform, hornblendes were identified and the roundness of the grains was determined. In the tills, four morphological types of hornblende grains can be found: short angular (IV), short rounded (III), long angular (II) and long rounded (I) grains (Fig. 5). According to Ulst and Maiore (1964) the average sum of rounded hornblende grains are approximately 17 - 22% in Latvija (Weichselian) till, 24 - 36% in Kurzeme (Saalian) till, and 10 - 15% in Letiza (Elsterian) till.

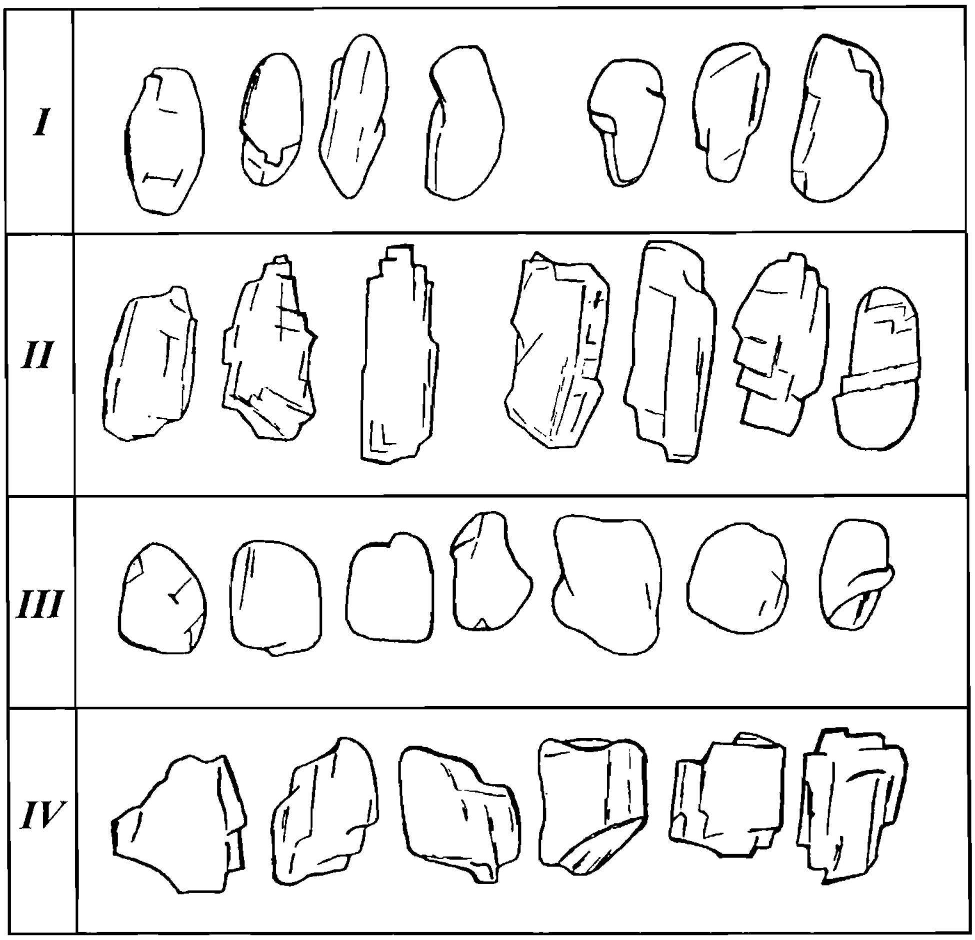


Fig. 5. Types of roundness degree of hornblendes (Ulst & Maiore 1964).
I – long rounded grains, II – long angular grains, III – short rounded grains, IV – short angular grains.

Lithological composition of the grain size fraction 1.0-0.5 mm (Dreimanis method): The lithological composition of 0.5 - 1 mm sand particles was investigated in accordance with the Dreimanis method (1939). Latvian geologists have named this method in honour of Professor A. Dreimanis who developed it, and it is commonly used for investigation of tills in Latvia. Dreimanis (1939, 1947) reported that recognisable differences between tills of different age could be found in the grain size fraction 1.0-0.5 mm.

The following rock and mineral fragments are determined: limestone, dolostone, quartz, sandstone, feldspar and dark minerals. The ratio of limestone to dolostone is most commonly used for lithological differentiation of tills from the last three glaciations.

Organic matter and loss on ignition analysis: Organic matter and loss on ignition were determined by ignition of dry samples (dried at 105 °C) at 1000 °C for 2 hours to constant weight.

4.3 Biostratigraphical methods

4.3.1 Pollen analysis

Pollen analysis is one of the most widespread methods in research of aquatic sediments, to solve questions regarding stratigraphy and palaeoecology. In this study, where aquatic sediments are not rich in other macro- and microfossils, and interruption in the sedimentation occurs comparatively often, pollen analysis is extremely important. The rapid changes in granulometric and lithological composition can only give an idea about hiatuses, but rapid changes in pollen composition, preservation and low absolute content of palynomorphs, can more precisely point out hiatuses in the sediment record.

Estimation of the relative age of marine Pleistocene deposits is mainly based on pollen analysis and therefore the methodology of pollen analysis will be described in more detail.

Palynology is the study of organic-walled microfossils, which include pollen, spores, dinoflagellates, acritarchs, tasmanites and chitinozoa (MacDonald 1990). Quaternary palynology is concerned predominantly with the palaeoecological analysis of fossil pollen and spores. The application of palynological methods for the investigation of Quaternary deposits is one of the most widely used techniques in Quaternary palaeoecology (Birks & Birks 1980).

Pollen is the male part of flowers, and the smallest unit in the pollination process. Plants produce pollen for their reproduction. Pollen is spread to the surrounding environment and becomes fossilised and preserved in the deposits and may indicate a relationship between plants, or groups of plants, and climate conditions, at the time when these deposits were formed.

Fossil pollen and spores (palynomorphs) can be found in a wide variety of sediments, including aquatic Pleistocene deposits. Palynological analysis is useful for a better understanding of vegetation history in the adjacent coastal area and the climatic conditions at the time of formation of the deposits. Therefore, pollen analysis is very important not only for continental deposits, but also for marine deposits. For example, for the estimation of the relative age of marine sediments from the Prangli site in Estonia pollen analysis was applied (Liivrand 1991), because the pollen flora reflected all the phases of the vegetation history characteristic of the Eemian Interglacial.

Coring, test drillings, sampling and subsampling: Palynological investigations were carried out on samples from seven test drillings: Nos. 33, 41a, 44, 45, 46, 62 and 22 (for their location, see Fig.1C) in Kurzeme in western Latvia and Nos. 21 and 25 in the Gulf of Riga (Fig. 1B). In all palynologically investigated sites 127 mm diameter cores were obtained with 80 - 95% sediment recovery.

For a better understanding of the environmental changes recorded in the deposits of the Gulf of Riga, the most suitable sampling sites for palynological investigations were selected on the basis of echo-sounding data by the Marine Group of the Geological Survey of Latvia. Boreholes Nos. 21 and 25 were chosen, because they represent the most complete stratigraphical sequences in the Gulf of Riga (Fig. 1B).

Beside the lithological investigations, also palynological investigations of the Pleistocene deposits were also carried out on samples from till beds and intermorainic strata in the Ziemupe-Jurkalne area and in the Gulf of Riga. The aim was to study pollen incorporated in the marine sediments for a reconstruction of the vegetation history on the mainland and the climate at the time of the deposition of these sediments.

Each of the subsamples for pollen analysis consisted of a 5 - 10 cm thick slice of the sediment core. The interval of subsampling depended on the character of the sediment, so it was sparser in sand and till, 20 - 30 cm.

Sample preparation and comparison of preparation methods: Fossil pollen was concentrated by means of chemical and mechanical treatments, in order to dissolve and eliminate minerogenic and non-palynomorphic organogenic material in the samples. The samples that contained carbonates were treated with 10 % HCl. All samples were boiled with 10 % KOH for 5 minutes. Coarse mineral particles were removed by decantation. The preparation and concentration principally followed Grichuk's separation method (Grichuk & Zaklinskaya 1948; Petrova *et al.* 1986), using KJ+ CdJ_2 heavy liquid (density 2.22). Then the organic fraction was treated with the standard acetolysis technique (Erdtman 1960).

Eleven samples of clay and silt from various boreholes were first concentrated by two different standard methods of concentration: Grichuk and Zaklinskaya (1948), and Assarsson and Granlund (1924) and Faegri & Iversen (1975) and then by acetolysis. The obtained results were very similar (Table 3). These experimental results indicate that pollen analysis of samples treated according to both these methods are comparable.

Table 3. Comparison of the experimental results by using two different pollen concentration methods. Percentages of the main arboreal pollen are presented.

Sample	*Picea*, %		*Pinus*, %		*Betula*, %		*Alnus*, %		*Corylus*, %	
	A	B	A	B	A	B	A	B	A	B
989/10	3.6	3.8	50,7	51.0	20.6	20.4	22.1	21.6	2.4	1.9
989/20	1.2	1.6	26.1	26.4	39.4	39.3	27.7	27.4	3.6	3.2
989/50	11.7	12.0	47.1	47.2	6.8	6.8	22.1	22.3	4.1	4.4
989/63	0.6	1.0	45.6	45.9	13.0	12.8	25.8	25.5	8.0	8.1
B-9	2.2	2.5	56.5	56.9	22.5	22.4	16.0	16.1	1.4	1.3
B-15	4.3	4.6	67.8	68.2	14.9	14.9	9.3	9.2	1.9	1.5
21/50	37.8	38.0	51.1	51.7	1.8	2.0	3.6	3.3	2.6	2.4
21/42	3.8	3.8	22.6	22.5	12.5	12.3	32.1	32.0	14.7	14.3
21/24	2.3	2.5	80.1	80.3	9.4	9.0	7.6	7.8	0.6	0.6
25/31a	1.2	1.8	71.2	71.1	22.8	22.6	1.2	1.0	-	-
25/80	0.9	1.3	93.4	93.5	4.8	4.7	0.9	0.3	-	0.1

A - Samples treated according to Grichuk's method (heavy liquid KJ + CdJ2).
B - Samples treated according to Assarsson and Granlund's (1924) method (using HF).

Counting and identification of pollen and spores: Quantitative and qualitative pollen analyses were carried out by using light microscopes Polam-17 and MBS-15 of X400 - 900 magnification. Glycerine was used as embedding medium for slide preparation. Usually 300 - 400 arboreal pollen grains were counted per sample, but in sandy sediments only 100 - 150 arboreal pollen grains could be identified.

The identification of pollen and spores was made by comparison with the available pollen and spore reference material and descriptions in Grichuk and Zaklinskaya (1948), Erdtman (1954, 1960), Andersen (1964, 1970), Moe (1974), and Moore & Webb (1978).

Simultaneously with the identification of the pollen and spores, their degree of preservation was noted. Palynomorphs were best preserved in silty and clayey sediments, but were commonly torn and corroded in sand. Sand usually also contained less pollen and spores and sometimes almost none at all, for instance in the 52 - 56 m interval in the Ulmale section. In the Strante interval of 39.0 - 60.0 m most *Pinus* and *Picea* pollen, and *Sphagnum* spores were torn to a high degree and/or corroded. Therefore, these parts of the pollen diagrams with low pollen frequency and/or corroded pollen may not be reliable for a reconstruction of the vegetation composition. The pre-Quaternary palynomorphs have also been identified.

The calculation of absolute abundance (frequency) of palynomorphs per 1g dry sediment was done following Davis (1965) and Dabrowski (1975).

Construction and zoning of pollen diagrams: For the construction of pollen diagrams and for plotting the data, the computer programs TILIA 2.00. (Grimm 1991) and TILIA Graph were used. The percentage diagrams were prepared using the basic sum (100%) of all terrestrial pollen. Other plants (x) and spores (x) are calculated as a percentage of terrestrial pollen sum + x. The diagrams presented have been subdivided into pollen assemblage zones (PAZs), the drawing of which was done with the computer program TILIA Graph 1.25.

A pollen zone is a biostratigraphical unit, which is a body of deposit defined or characterised by its pollen content. In the present study pollen assemblage zones have been distinguished. The characterisation of pollen assemblage zones of marine sediments are based on general considerations, where various factors are taken into account, but the position of pollen spectra is the main but not the only criterion. The boundaries of the pollen assemblage zone are based on changes in the composition of pollen, reflecting the vegetation on the adjacent land. Boundaries of pollen assemblage zones are defined by the lowest and/or highest occurrences of more than one taxon, and are defined by marker changes in relative abundance of taxa.

In accordance with these rules pollen diagrams have been subdivided in pollen assemblage zones (PAZ). The first step is to subdivide the local pollen assemblage zones, which were named after prevailing pollen taxa or/and the first letters of the site studied. The second step is to correlate the local PAZ with regional PAZ.

In a marine environment, pollen assemblage zones may have more transitional boundaries as a result of the presence of pollen from both local and more distant sources (Björck *et al.* 2000).

4.3.2 Foraminifera analyses

Previous data on foraminifera were available only for some sediment cores, because of the low content of foraminifera in the marine sediments studied by Konshin *et al.* (1970) and Seglins (1987). Therefore, the author of this study chose to investigate the cores from the Plasumi and Grini sites.

For the foraminiferal analysis samples were treated in the laboratory in the way described by Feyling-Hanssen (1983). The samples (100 g dry weight) were washed through sieves with mesh sizes of 1.0, 0.1 and 0.063 mm. The foraminifera in the 0.1-1.0 mm fraction were concentrated by flotation in an ethylene bromide/absolute alcohol solution with the specific gravity of 1.75 g/cm^3. The analysed deposits were poor in foraminifera and therefore all specimens in each sample had to be counted. The concentration and relative frequencies of selected foraminifera species are shown in diagrams (Figs 31, 38) and tables (Table 5, 8) to provide the basis for the palaeo-ecological interpretations.

The foraminifera species were divided into three climatic tolerance groups (arctic, transitional and boreal). The transitional group contains species that can be found both in cold boreal and in sub-arctic assemblages. An additional fourth group (indifferent) consists of cosmopolitan species and species with uncertain environmental preferences. To make the palaeoecological interpretation more certain, the arctic *Elphidium excavatum* (Terquem) form *clavata* Cushman, 1930 and boreal *E. excavatum* f. *boreale* (Nuzhdina) were counted separately. For identification the following literature was used: Gudina (1965, 1966, 1976) and Knudsen (1978, 1984, 1985a, 1986, 1988, 1991, 1994). The ecological interpretation is based on Gudina and Evzerov (1973), Knudsen (1978, 1984, 1986, 1987, 1988, 1993a,b), Klingberg (in Påsse *et al.* 1988) and Lykke-Andersen and

Knudsen (1991).

Foraminiferal analysis of sediments from the Gulf of Riga was carried out by K. Schoning (pers. comm.). Data from earlier foraminifera studies by Mihailov (in Seglins 1987) has also been used for interpretations and palaeoenvironmental studies.

4.3.3 Diatom analysis

In this study diatom data and their interpretation have been taken from two researchers: E. Cheremisinova and M. Sakson. The first researcher to describe diatom data from sediments in the study area was the Byelorussian diatomist E. Cheremisinova (1961, 1970, 1971). She presented the diatom composition of the sediment layers investigated, pointed on dominating taxa and their palaeoenvironment, as well as mentioned relict diatom taxa and supplied a correlation with western Europe. However, the method of diatom analysis is not described, although the interpretation of data from the Kaliningrad district and Ulmale area are logical and clear and it was possible to use them in this study for reconstruction and correlation.

Diatom analysis was carried out by M. Sakson in the Ziemupe-Jurkalne area at the end of the 1980's and beginning of the 1990's. Most of this data is not yet published. It was, however, used by Seglins in his dissertation (1987) and in a report of geological mapping (Tracevski *et al.* 1989). Part of the data has been used in this study with the kind permission by M. Sakson. Diatom analytical studies of the deposits in core-21 from the northern part of Gulf of Riga have been carried out in connection with the interdisciplinary research project PACT Nordic / Baltic Program: Environmental History of the Baltic region.

The samples were prepared for diatom analysis in accordance with Battarbee (1986).

Diatom valves were counted by traversing the slide at X1000 magnification under oil immersion. About 200 - 400 diatom valves were counted per slide whenever possible. The abundance of each taxon was calculated as a percentage of the total count in each sample and the taxa were grouped according to their salinity requirements and main habitat.

The diatom flora is classified by salinity preference as polyhalobous (salinity in the habitat 35- 17 ‰), mesohalobous (salinity in the habitat 35 - 0.2 ‰) and oligohalobous (freshwater indifferent) species (Sakson & Miller 1993).

5 FACTORS INFLUENCING THE FORMATION OF MARINE POLLEN SPECTRA

Pollen analysis has been widely applied in studies of marine Holocene sediments. Erdtman (1921) presented tree pollen spectra in marine sediments from the provinces of Halland and Västergötland in south-western Sweden. Since then pollen analysis has been used to correlate marine deposits without molluscs. Pollen analysis has been widely applied in biostratigraphical and palaeogeographical studies of marine Pleistocene sediments (Andersen 1963, Mangerud 1972; Mangerud *et al.* 1981; Anderson *et al.* 1991a, b; Liivrand 1991; Ekman 1998 a,b; Kalnina 1996c, 1997a; Kalnina & Juskevics 1998a; Kristensen *et al.* 2000).

Pollen transport in sea areas is complicated. About 98.5 % of the pollen rain is first transported there by air (Kabailiene 1969) and then further transported by water. The fact that several large and small rivers enter the Baltic Sea, especially in the Gulf of Riga must be taken into account. In the coastal areas the principal factor controlling pollen deposition is probably water transport.

Much of the pollen assemblages are, however, likely to consist of pollen from vegetation on nearby land. At a site with a large catchment area the pollen flora in the sediments will contain a large proportion of regional rather than local pollen (Moore & Webb 1978, Glaister & Gibbard 1998). Pollen transported from more southerly regions can have some effect on the relative proportions of pollen, and new pollen taxa that are not characteristic for the investigated region may appear. It is not impossible that pollen may also be transported for long distances from northerly regions.

There is a direct relationship between the amount of pollen that falls out on a unit of sea surface in a certain time period, the direction, force and duration of the prevailing winds at the time of maximum blooming of various plants, the distance from windward coast, and the vegetation composition in the adjacent coastal area (Savukyniene & Lukosevicius 1992). The pollen productivity and physical parameters of the grain, *e.g.* weight and size, are also important to note. The distance to the coast is of secondary importance. Some adverse weather conditions, *e.g.* mist and rain, decrease the pollen amount in the air.

Savukyniene found that the maximum amount of herbaceous pollen is found at a distance of 5-10 km from the coast (Savukyniene & Lukosevicius 1992). Among tree and shrub pollen, pine pollen is dominating, which can be explained by good ability of these pollen grains to be transported by air and the high pollen productivity of pine (Erdtman 1937). Among other trees, birch and alder pollen occur in large amounts in the spring at a distance of 5 - 10 km from the coast, because of their high productivity and good ability to be long distance transported by air.

Pollen transport and deposition by water is partly related to hydrodynamics, the size of the water basins and the size and specific weight of the pollen grains. The highest variety and concentration of pollen in water is observed in the surface layer: approximately 940 grains per litre (Savukyniene & Lukosevicius 1992). This can be explained by continuous entry of pollen from the air and by morphological properties of pollen grains and their ability to float for a long time. The amount and variety of the pollen decrease rapidly with increasing water depth. In calm water heavy pollen grains are sedimented quickly, but smaller ones stay floating.

The interpretation of pollen data from sediments in large water bodies depends on many factors that can influence pollen sedimentation. The interpretation of pollen data is usually based on our knowledge of the relationship between the plant communities and the pollen and spore spectra on the mainland in adjacent areas. In marine sediments it is very difficult to determine how many times pollen have been redeposited and where the source of redeposition is to be found. The author of this study was guided by the experience of other researchers (see below).

The zone boundaries are based on changes in the composition of pollen, reflecting the vegetation on adjacent land. The boundaries of pollen zones in diagrams of continental sediments have also been considered. It can be erroneous to zone pollen diagrams without additional information on the lithology of sediments. The differences and similarities between corresponding pollen zones from mainland and in marine sediments depend on the varieties of sedimentation. Correlation of zones can only be based on the similarities of zones. How are they reflected in the pollen composition of marine sediments? How much pollen is redeposited? Is the pollen sedimentation influenced by bioturbation? Results and discussions in the following publications from the eastern Baltic region are used: *e.g.* Danilans (1973), Danilans *et al.* (1964 a, b), Kondratiene (1965, 1967, 1986, 1996), Seglins (1987), Liivrand (1976, 1987, 1990, 1991), Grichuk (1989), Raukas and Gaigalas (1993), Raukas *et al.* 1995, Krasnov and Zarina (1986), Pleshivceva (1998a, b), as well as from north-western Europe: Andersen (1963, 1964, 1970, 1975), Nilsson (1965, 1983), Havinga (1967), Miller (1977, 1981), Berglund and Lagerlund (1981), Donner (1983, 1991), Behre and Lade (1986), Behre (1989), Ehlers (1983, 1996), Robertsson (1988), Robertsson *et al.* (1997), Litt (1994), Grüger (1989, 1995, 1996), Eriksson (1993), Field *et al.* (1994), and Kristensen *et al.* (2000).

6 DESCRIPTION OF SITES AND RESULTS

6.1. Holstenian Interglacial

The idea about the presence of marine interglacial deposits in the coastal area of western Latvia appears already in 1960s, when amber grains were found in sandy-gravely sediments under blue-grey till in the surroundings of Liepaja Lake (Gavrilova & Straume 1963). Although the first marine intertill Pleistocene sediments were established later (Veinbergs & Savvaitov 1970; Konshin *et al.* 1971) north of this area. The 50-70 m thick marine interglacial sediment strata occupied a wide depression in the Devonian bedrock in the coastal area between Ziemupe and Ovisi (Konsin *et al.* 1971, Fig.1).

In the present paper, all the areas of proposed distribution of marine interglacial deposits are not discussed, but only the southern part – the Ziemupe-Jurkalne area, where there is strong evidence for distinguishing sediments as marine and which contains more records that reflect the conditions of their formation (Figs 1c, 6). The northern part of the marine sediment distribution area *e.g.* Jurkalne-Ovisi, as well as the coastal area in southern Liepaja need additional investigation.

Marine deposits fill up buried valleys and depressions in the sub-Quaternary surface and are usually represented by bluish and greenish grey, seldom brown or almost black, horizontally laminated clay and clayey silt (Meirons & Murniece 1982). Outside buried valleys they are represented by layers of grey and bluish grey sandy silt or silty sand. The upper part of the marine interglacial strata is usually represented by sand, while the lower part is represented by clay and silt.

The area around Ulmale is the stratotype area of marine Holsteinian (Akmenrags) Interglacial deposits in Latvia (Konshin *et al.* 1971). The test drilling core Ulmale-9 contains a representative sequence of Holsteinian marine and freshwater sediments. From a stratigraphical point of view the Ulmale-9 site was established as a key section of marine Holsteinian sediments by Konshin, Savvaitov and Straume already 30 years ago (Konsin *et al.* 1971).

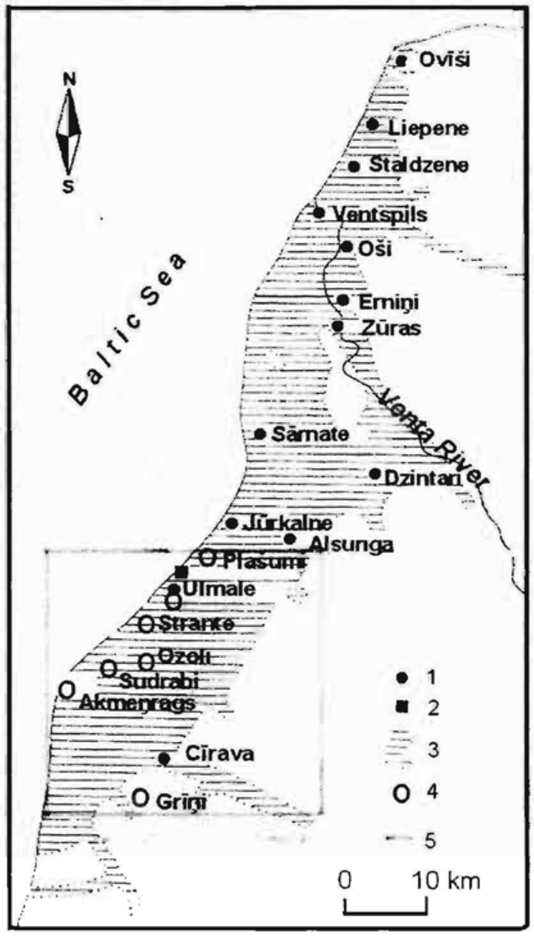


Fig. 6. Distribution area of marine intertill deposits and the location of palynologically investigated marine sequences by means of pollen according to Konshin *et al.* (1971). The cores investigated in the present study are added.
1- palynologically investigated cores; 2 – outcrop; 3 – distribution area of marine intertill deposits according to Konshin *et al.* (1971); 4 – cores palynologically investigated in Seglins 1987, Tracevskis *et al.* 1989, Kalnina *et al.* 2000 and the present study; 5 – boundary of the area of the present study.

The test drilling Ulmale-1 was done at geological fieldwork in 1979, but for technical reasons the drilling was stopped at the depth of 58.5 m below surface, and the

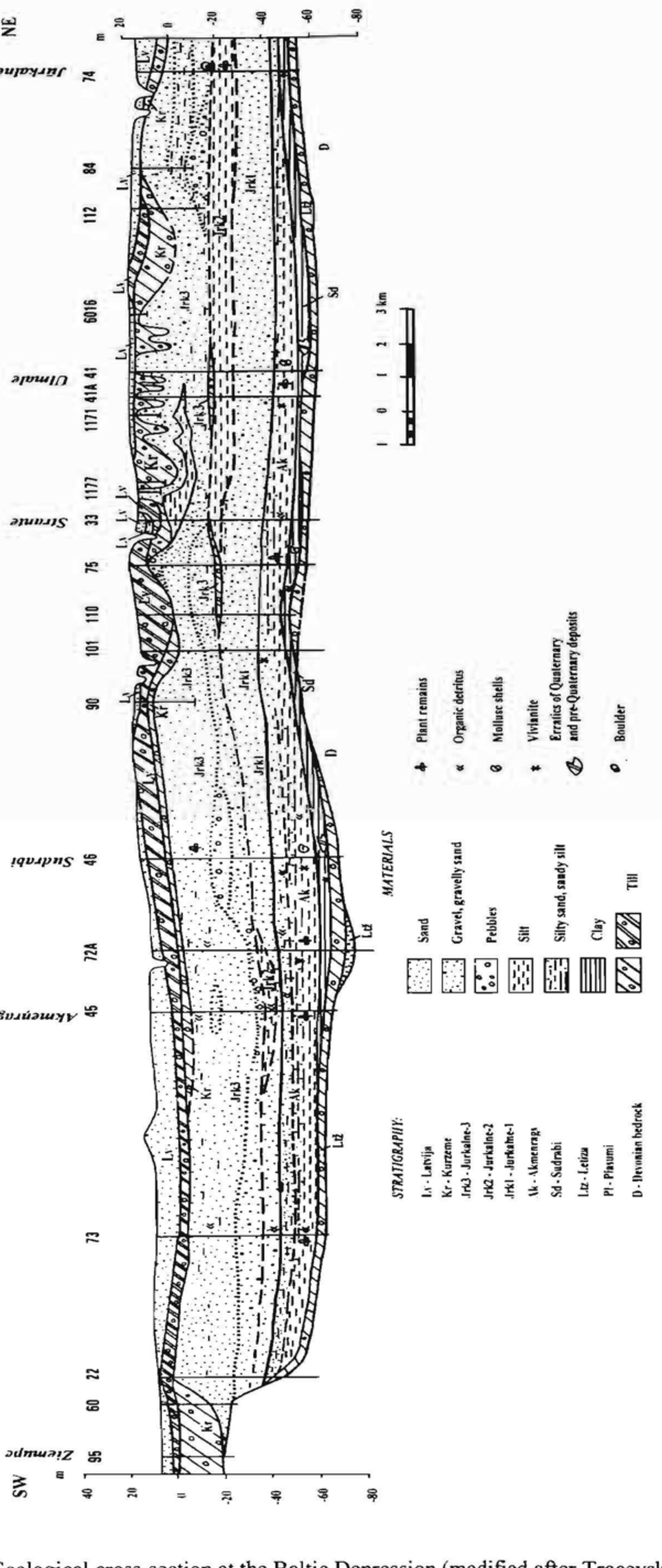


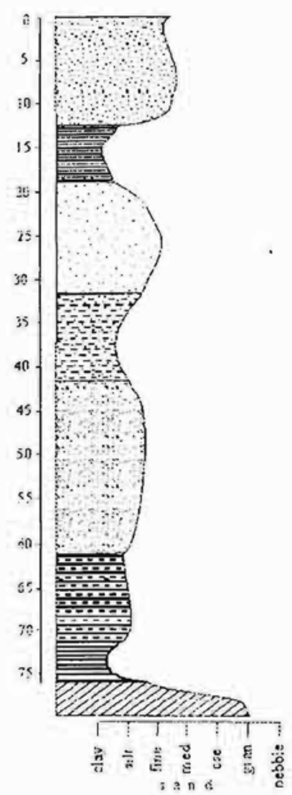
Fig. 7. Geological cross-section at the Baltic Depression (modified after Tracevskis et al. 1989; Kalnina et al. 2000). Depth above and below present sea level.

lowest part of the interglacial sediments was missed. This coring contains a sediment sequence similar to Ulmale-9, but some differences were found in the lithological composition, and also, the thickness of some sediment units was different. In many places the grey till of the Kurzeme (Saalian) Formation, containing lenses, interlayers, and erratics of light grey silt, covers marine and lacustrine sediments in the stratotype area of Ulmale. Some inclusions in the till contain plant remains, megaspores, pollen and spores, foraminifera and mollusc shells. In this area the Pleistocene sediments are glaciotectonically deformed and in some sections the intertill sediment sequence is only covered by glacial deposits of the Latvija (Weichselian) Formation (Fig. 7).

Although the test drilling Ulmale-9 contains a very representative sediment sequence of Holsteinian Interglacial and was established as the key (stratotype) section of marine Holsteinian sediments, its description and the results of investigation were published in Russian and Byelorusian (Konshin & Savvaitov 1969; Konshin *et al.* 1970; Charamisinava 1971; Danilans 1973). Only general information about this site has appeared in English in the last ten years (Dreimanis & Zelcs 1995; Kalnina *et al.* 2000). Information from the Ulmale-9 site has been used in discussions and reconstructions of palaeoenvironment of the area. Since the stratotype site has only been described in Russian, this previously published data and drawings will be translated, modified and presented here from the point of view of the present study.

6.1.1 Ulmale site - core No. 9, the stratotype site

56° 56'02" N Lat., 21° 16'42"E Long.
13.3 m a.s.l.



Depth below surface (m)	Description
0 - 12.2	sand, various coarseness with occasional gravel and pebbles, yellowish
12.2-19.3	silt, thin laminated, light grey
19.3-31.4	sand, various coarseness, yellowish and light grey
31.4-41.5	silt, with laminae of clayey silt and sand, light grey to bluish grey
41.5-63.1	sand, fine, light yellow and light grey
63.1-71.7	silt, laminated, bluish grey and grey
71.7-76.3	clay, with laminae of light silt, reddish brown
76.3-78.0	diamicton, reddish brown
deeper 78.0	Devonian sandstone

Fig.8. Log and lithological description of the sediment sequence from the key site at Ulmale-9.

Lithology

The site Ulmale-9 has been established as a stratotype section according to comprehensive studies of a 78.0 m long Quaternary sediment sequence, underlain by Devonian sandstone (Konshin & Savvaitov 1969; Konshin *et al.* 1970; Danilans 1973). At the base of this sediment sequence there is a reddish till at the depth interval 78.0-76.3 m, which upwards is replaced by brownish reddish clay with interlayers of silt. A bluish-grey and grey laminated silt occurs at the depth interval 71.7-63.1 m, and is upwards overlain by a 21.6 m thick layer of fine sand yellow, light yellow and light grey in colour. The partly laminated silt layer at the depth interval 31.4-41.5 m varied in colour from light grey to bluish-grey and is covered with yellow and light grey sand of various coarsity. The very uppermost silt layer occurs at the depth interval 19.3-12.2 m and is overlain by yellow sand of varying coarsity with an admixture of pebbles. According to Danilans (1973) this sand layer was deposited in the Baltic Ice Lake as a result of active coastal formation processes, including the possibility that the lowermost part of this layer could be of older marine origin.

Foraminifera

16 samples from Ulmale-9 have been investigated for foraminifera, and 13 of them did not contain foraminifera. Most foraminifera are in the lower part of the sediment sequence. The sample from the bluish-grey laminated silt at the depth of 70.5 m contains 2854 specimens of foraminifera. The taxon *Elphidium subclavatum* Gudina dominates among them and is represented by 2420 specimens (Danilans 1973). Sediments higher up are almost barren of foraminifera, for instance, in the sample from the depth of 15 m only two shells have been found.

Diatoms

Diatom analysis of the Ulmale-9 core was done by Charamisinava (1971). She found that the abundance of diatoms varies in different parts of the sequence. Three diatom complexes were distinguished.

1st diatom complex. The clay in the lowest part of the sequence (> 69.5 m) contains only a few diatoms, a mixture of cold relicts, freshwater-brackish, brackish and marine taxa. The neritic Coscinodiscus *lacustris* var. *septentrionalis* Grun., *C. perforatus* (Ehr.) A. Cl., *Chaetoceros* spp and the littoral taxa *Actinocyclus ehrenbergii* Ralfs and *Hyalodiscus scoticus* (Kütz.) Grun. are present.

2nd diatom complex. The bluish-grey silt in the interval of 69.5-61.1 m contains mainly marine deep water and oceanic diatom taxa. *Coscinodiscus perforatus*, *Actinoptychus undulatus* (Bail.) Ralfs and *Chaetoceros* spp dominate, but the silicoflagellate *Distephanus speculum* (Ehr.) Haeckel is also abundant. In some samples the brackish *Thalassiosira baltica* (Grun.) Östr. and *Coscinodiscus lacustris* var. *septentrionalis* dominate.

3rd diatom complex. Sand and silt in the interval of 61.1-31.5 m contain a few diatoms, represented by marine, brackish and also by freshwater taxa, *e.g. Cymatopleura elliptica* (Breb.) W. Sm., *Navicula scutelloides* W. Sm., *Coscinodiscus lacustris* var. *septentrionalis, C. curvatulus* var. *minor* (Ehr.) Grun., *Hyalodiscus scoticus*, *Grammatophora* spp and *Rhabdonema arcuatum* (Lyngb.) Kütz.

Pollen flora

For the 59.5 m long sediment sequence of clay, silt and sand at the depth interval of 71.7-12.2 m pollen analysis has been done by M. Neimane (Fig. 2, in Konshin *et al.* 1971). Six pollen complexes (I-VI) have been distinguished in the pollen diagram, but according to the author of the present study the diagram can be reinterpreted and compared to the pollen diagrams from the Ziemupe-Jurkalne area (Fig. 9). Pollen complexes I - V distinguished by Konshin *et al.* (1971) correlate with pollen assemblage zones (PAZ I-V) distinguished by Kalnina *et al.*, 2000 in the core Ulmale-41a. These complexes can be considered as alternatives to the pollen assemblage zones. A problem arises with Neimane's pollen complex VI, which according to the pollen data and geological position in the Ziemupe-Jurkalne area compares with PAZ VIII (Kalnina *et al.* 2000).

Below the description of the pollen complexes of the diagram from Ulmale-9 (Konshin *et al.* 1971 Fig. II) is given as reinterpreted by the present author (Fig. 9):

I pollen complex =PAZ I - NAP-*Pinus-Betula*, (71.5-70.1 m, clay with silt interlayers)

The spectra are characterised by abundant herb pollen, with dominance of *Artemisia*, and presence of *Betula*. The high percentage of *Pinus* pollen and some occurrence of *Alnus*, *Carpinus, Quercus* and *Corylus* pollen obviously indicate redeposition.

II pollen complex = PAZ II - *Betula-Pinus*, (70.1-69.35 m, laminated silt)

Decrease in the values of herb pollen and increase of *Betula* pollen. Decrease or almost disappearance of redeposited broad-leaved tree pollen.

III pollen complex = PAZ III - *Alnus-Corylus-Carpinus-Picea*, (69.35-68.15 m, laminated silt)

A rapid increase and reaching maximum values of *Alnus, Corylus, Carpinus*, a weakly expressed maximum of Quercetum mixtum. Gradual increase of *Picea*, but a considerable decrease of *Pinus* and *Betula* pollen.

IV pollen complex = PAZ IV - *Pinus-Picea-Abies*, (68.15-66.85 m, laminated silt)

An increase in *Pinus* and *Picea,* and decrease in *Alnus*, *Carpinus* and *Corylus* pollen, presence of *Abies* (0.5-1.8 %).

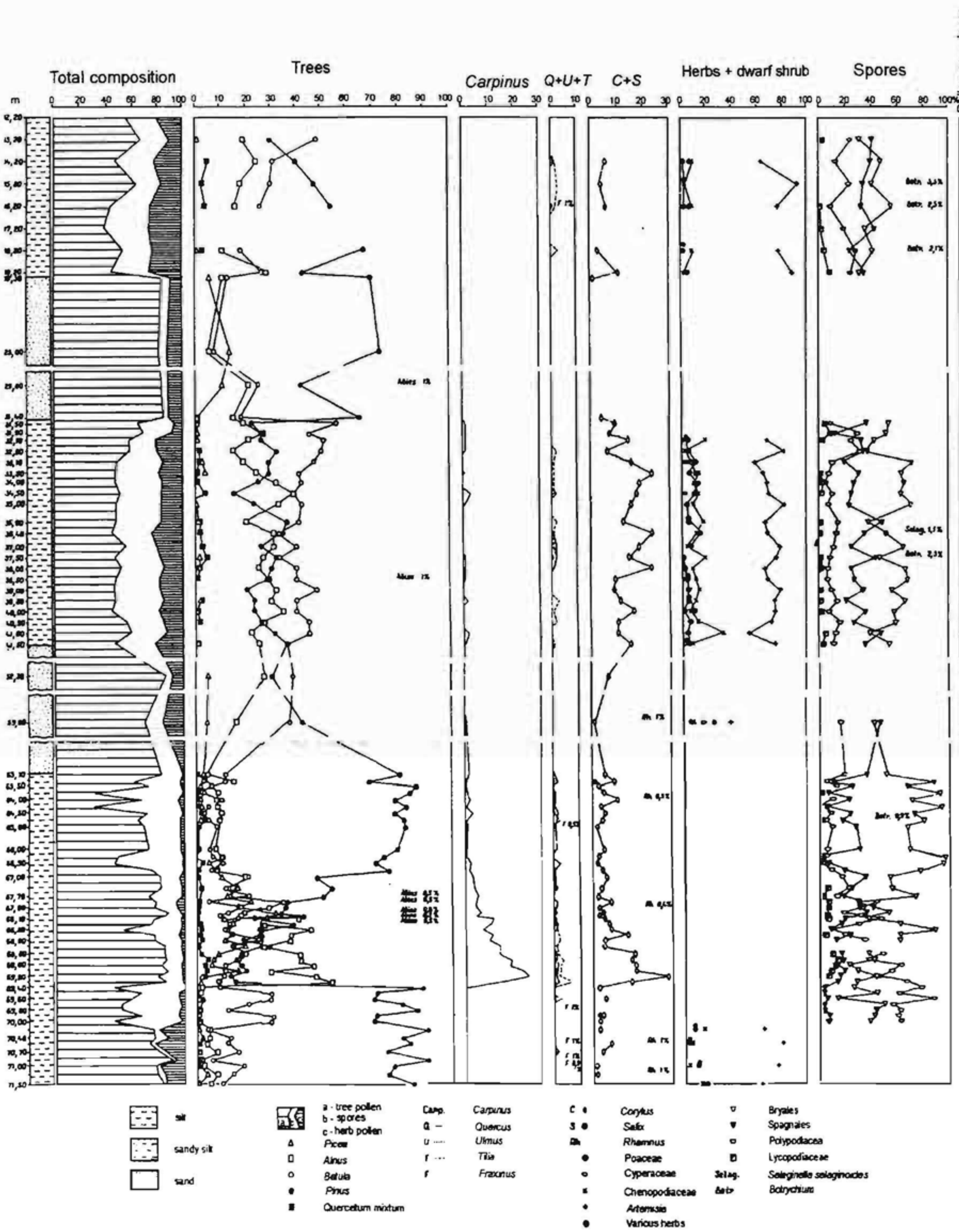


Fig. 9. Pollen diagram of marine intertill deposits from the core Ulmale-9 with PAZ according to M. Neimane in Konshin *et al.* (1971) and zonation in the present study.

V pollen complex = PAZ V- *Pinus*, (66.85-63.1 m, laminated silt)
The dominance of *Pinus* and low percentage of other pollen is characteristic and so is the comparatively low abundance of palynomorphs. The upper boundary of the zone is placed approximately at 63 m because of low pollen concentration.

The depth interval 63.1-41.5 m of sand is poor in pollen and no pollen assemblage zone can be distinguished, though Neimane induces this interval in the lower part of the pollen complex VI.

PAZ VIII is the middle 1/3 of the complex VI (Konshin *et al.* 1971) (see Fig. 9 in the present study)- *Betula*-NAP-*Pinus*-*Alnus*-*Corylus*, (41.5-31.5 m, silt).

The dominance of *Betula* and lower values of *Pinus*, *Alnus* and *Corylus* pollen, as well as sporadic presence of broad-leaved tree pollen characterise this silt interval. Comparatively high values of herb pollen, with dominance of *Artemisia*, have been noted. The depth interval 31.5-19.0 m, represented by sand, is poor in pollen and no pollen assemblage zone can be distinguished here. The uppermost part of complex VI at 19.3-12.2 m is probably representing regional **PAZ IX** (not separated in Konshin *et al.* 1971) - NAP-*Betula*. A rapid increase in herb pollen, dominated by *Artemisia*, and comparatively high values of *Betula* and *Pinus* have been noted. Redeposited pollen of broad-leaved trees, *Corylus* and *Alnus*, are present.

Two new test drillings, Ulmale-41a and 41b, were made close (100 and 150 m respectively) to the stratotype site Ulmale-9. The sediment sequence from the test drilling core Ulmale-41a was studied in detail.

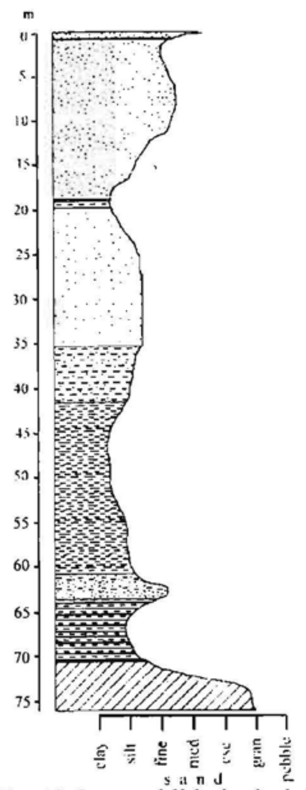
A marine genesis of the interglacial deposits had already been established in diatom studies of the stratotype site Ulmale-9 by Charamisinava (1971). Almost 20 years later the new sediment core Ulmale-41 was studied by Sakson (in manuscript) and a similar diatom composition was also found. Data from foraminiferal analyses show that sediments in the lowest part of the section are very rich in foraminifera, something that indicates that there were marine conditions already in the final phase of the late-glacial part of the Late Elsterian.

Table 4. Comparison of the diatom flora, foraminifera fauna and pollen assemblage zones from the stratotype site Ulmale-9.

Depth m (below surface)	Diatom flora (Charamisinava 1971)	Foraminifera (Danilans 1973)	Pollen assemblage zones (Konshin *et al.* 1971, modified and completed by Kalnina)
12.2-31.5		15.0 m, 2 foraminifera	12.2-19.3 m, IX - NAP, *Betula*
			19.30-31.5 m, poor in pollen
31.5-61.1	diatoms rare, marine, brackish and freshwater		31.5-41.5 m, VIII - *Betula*, NAP, *Pinus*, *Alnus*, *Corylus*
			41.5-63.1 m, poor in pollen
61.1-69.5	dominance of marine and oceanic deep-water species	63.5 m, 67 foraminifera	63.1-68.15 m, V- *Pinus*
			66.85-68.15 m, IV - *Pinus*, *Picea*, *Abies*
			68.15-69.35 m, III- *Alnus*, *Corylus*, *Carpinus*, *Picea*
>69.5	diatoms rare, from different ecological groups: cold water relicts, freshwater-brackish, brackish, as well as marine deep water and littoral species	70.5 m, 2854 foraminifera, dominance of *Elphidium subclavatum* Gudina	69.35-70.1 m, II - *Betula*, *Pinus*
			70.1-71.1 m, I - NAP, *Pinus*, *Betula*

6.1.2 Ulmale site - core No. 41a

56° 56'02" N Lat., 21° 16'42"E Long.
13.3 m a.s.l.



Depth below surface (m)	Description
0 - 1.7	sand, fine
1.7 - 18.3	sand, fine with rare gravel and pebbles
18.3 - 20.0	clay, silty, brownish grey
20.0 - 35.1	sand, fine, very fine, brownish grey
35.1 - 35.3	diamicton, calcareous, grey with gravel and pebbles
35.3 - 43.6	silt, with laminae of clayey silt and sand, grey
43.6 - 61.0	silt, with clayey silt lenses, grey
61.0 - 63.8	sand, silty, grey
63.8 - 70.9	clay, silty, with plant remnants, dark grey
70.9 - 76.2	diamicton, clayey, reddish brown

Fig. 10. Log and lithological description of the sediment sequence from the core Ulmale-41a.

Lithology

A reddish brown to brown, very dense, calcareous diamicton, which is interpreted as Letiza (Elsterian) till (Kalnina *et al.* 2000), with sandy or silty clay dominating in its matrix, as well as high gravel and pebble content, is the lowermost stratigraphic unit (Fig. 10). The till is rich in carbonates: 50 - 58% in the 0.5-1.0 mm fraction (Fig. 11), with the limestone/dolostone ratio 1.5.

Data from hornblende roundness analysis clearly indicate that the till contains predominantly angular hornblendes, only 5-7% are rounded, which is characteristic for the Elsterian (Letiza) till (Ulst & Majore 1964).

The Letiza till is overlain by the Sudrabi beds that comprise laminated clays, which become silty with increasing organic content towards the top (Fig.10). A silty clay of the Akmenrags formation, which is rich in disseminated organic material, with plant remains, ostracodes, foraminifera, diatoms and fragments of marine mollusc shells, overlies the dense clay of the Sudrabi bed. A presence of blue grains (0.5-3 mm in diameter) of vivianite, pyrite concretions, limonite crusts along with plant remains, occasional grains (about 0.5 mm) of amber and some insect remains has been noted.

The 2.8 m thick grey silty sand strata overlay the silty clay at the depth of 63.8 m, but at the depth 61 m they are replaced by grey silt with clayey silt lenses. The thickness of the lenses varies from 1-2 cm to 10-15 cm and they contain more organic matter than the silt. Upward besides clayey silt laminae also sandy laminae occur. The content of organic matter varies, but in general it decreases up the core (Fig. 11).

A 20 cm thick grey diamicton layer occurs at the level of 35.3 m, which is the boundary between laminated silt and brownish grey fine sand. It has the high limestone content (24-32%) and near-absence of dolostone (0.1-0.7%) in the size fraction 0.5-1.0 mm, and the high content of the rounded hornblendes (32-38%) indicates that diamicton lithologically is similar to the Kurzeme till. Fine brownish grey sand strata overlying the diamicton upwards gradually become very fine. At the upper boundary of this layer a 1.7 m thick brownish grey silty clay layer (depth 20 m) divides the lower fine sand layer from upper the fine sand layer with occasional gravel and pebbles.

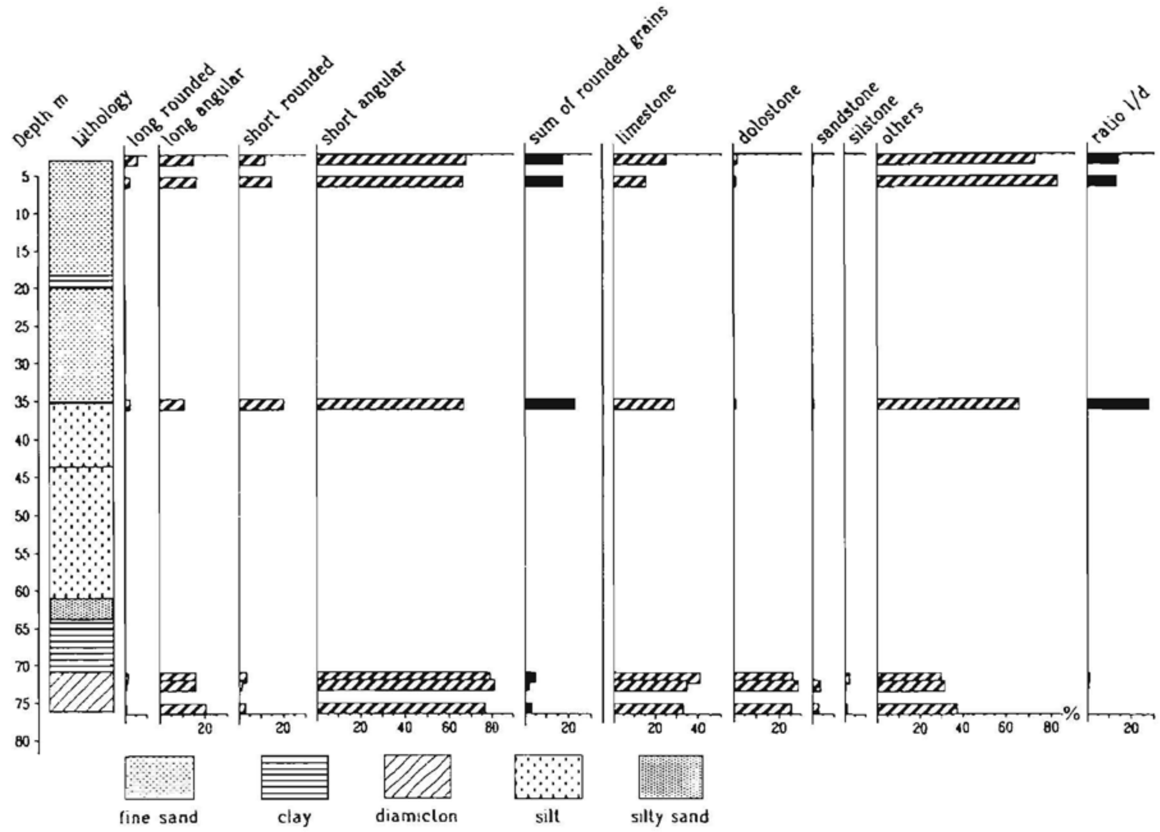


Fig. 11. Roundness of hornblendes (size fraction 0.1-0.25 mm) and lithological composition (size fraction 0.5-1.0 mm) in the sediments of the core Ulmale-41a.

Pollen analysis

Sediments, represented by clay, silt and sand from the depth interval 71-5 m in the core Ulmale-41a, have been palynologically investigated. Nine pollen assemblage zones (PAZ) have been distinguished in the pollen diagram (Fig. 12a,b, 13a,b).

PAZ I – *Betula sect. Albae-Betula nana* type-NAP: depth interval 70.8-69.0 m,(dense, slightly varved clay)

PAZ I from the lowest part of the pollen diagram presents pollen spectra from sediments directly overlaying the Letiza (Elsterian) till. The absolute frequency of palynomorphs is about 100 grains per 1 g dry sediment. Tree pollen is present at about 60%, but it must be taken into account that *Pinus* pollen, which constitutes the greatest part of the AP have probably been transported a long distance (Fig. 12a). *Betula* is the second component in the AP composition, and it is mainly represented by *Betula nana* type. Only in the top of the zone, tree type *Betula* increases significantly. *Alnus* and *Salix* pollen have continuous curves, but their values are low (2-5%). Pollen and spores of periglacial plants, *e.g. Ephedra, Hippophaë, Selaginella selaginoides, Helianthemum, Dryas octopetala, Lycopodium alpinum* are present (Fig. 12b). Herbaceous pollen is abundant in the lower half of the zone, where it is represented by high values of *Artemisia*. Redeposied palynomorphs, *e.g. Taxodium, Sequoia, Ilex, Ostrya, Eucomnia, Rhus, Nyssa, Pterocarya, Tsuga,* and *Cyathes,* are relatively significant and reach 10% in some samples.

Changes in *Betula* types in PAZ I, allow a division into two subzones – PAZ Ia – *Betula nana type-Artemisia* and PAZ Ib – *Betula-Betula nana* type.

PAZ II – *Pinus*, depth interval 69.0-68.5 m (the very upper part of the varved clay)

Pinus pollen dominates. *Alnus, Picea* and *Corylus* increase upwards in this zone. The total values of herb pollen vary (2-12%) and they are represented mainly by *Artemisia.* It is possible that the uppermost part of the zone is missing, because on the boundary between the varved clay and the clayey silt layer, thin laminae (0.5-1.5 cm) appear and coarse sand and very pronounced pollen changes occur above the laminae (Fig. 12b)

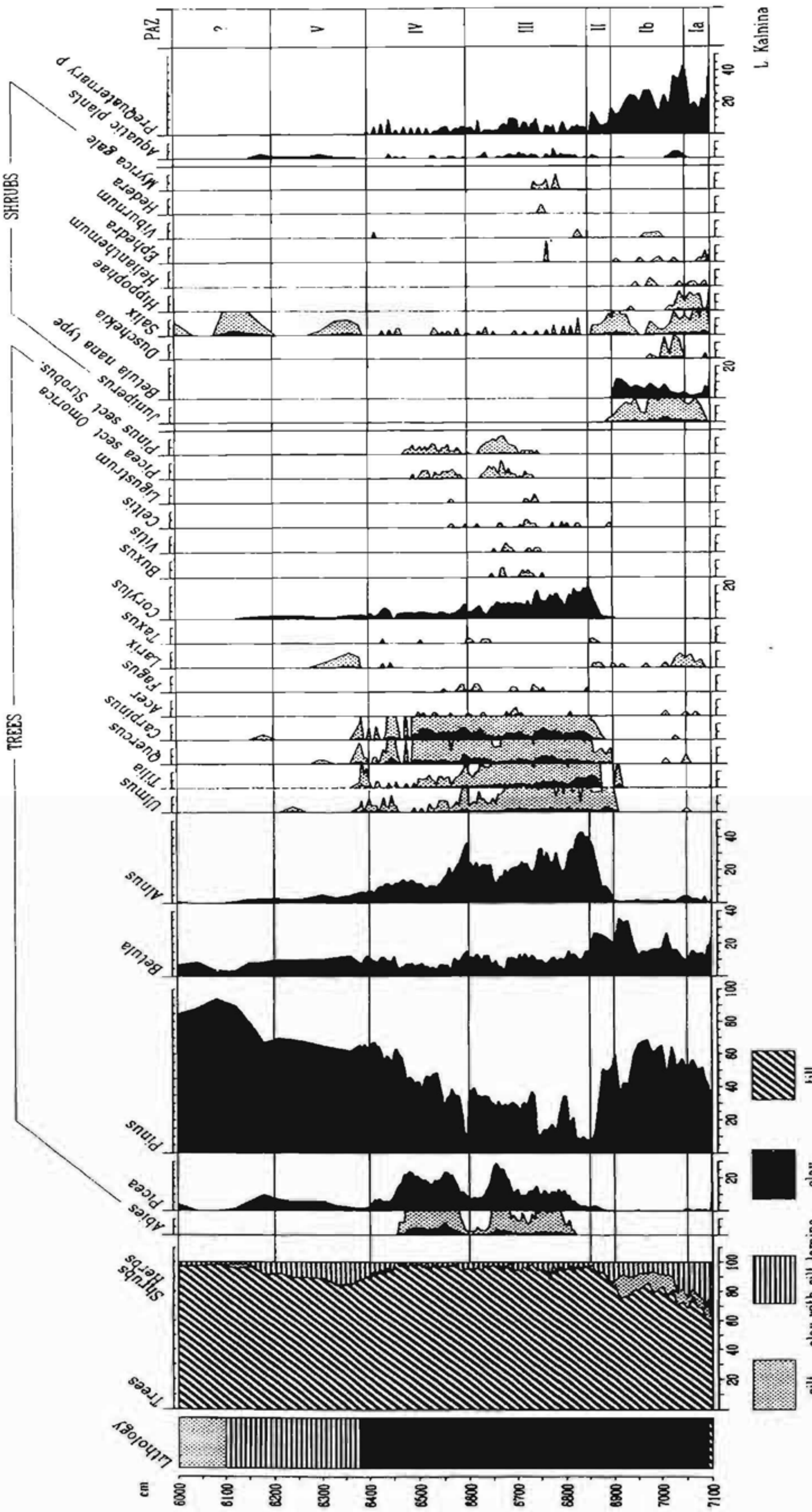


Fig. 12a. Pollen diagram from the Late Elsterian and Holsteinian deposits in the core Ulmale-41a. Dotted areas represent permille values.

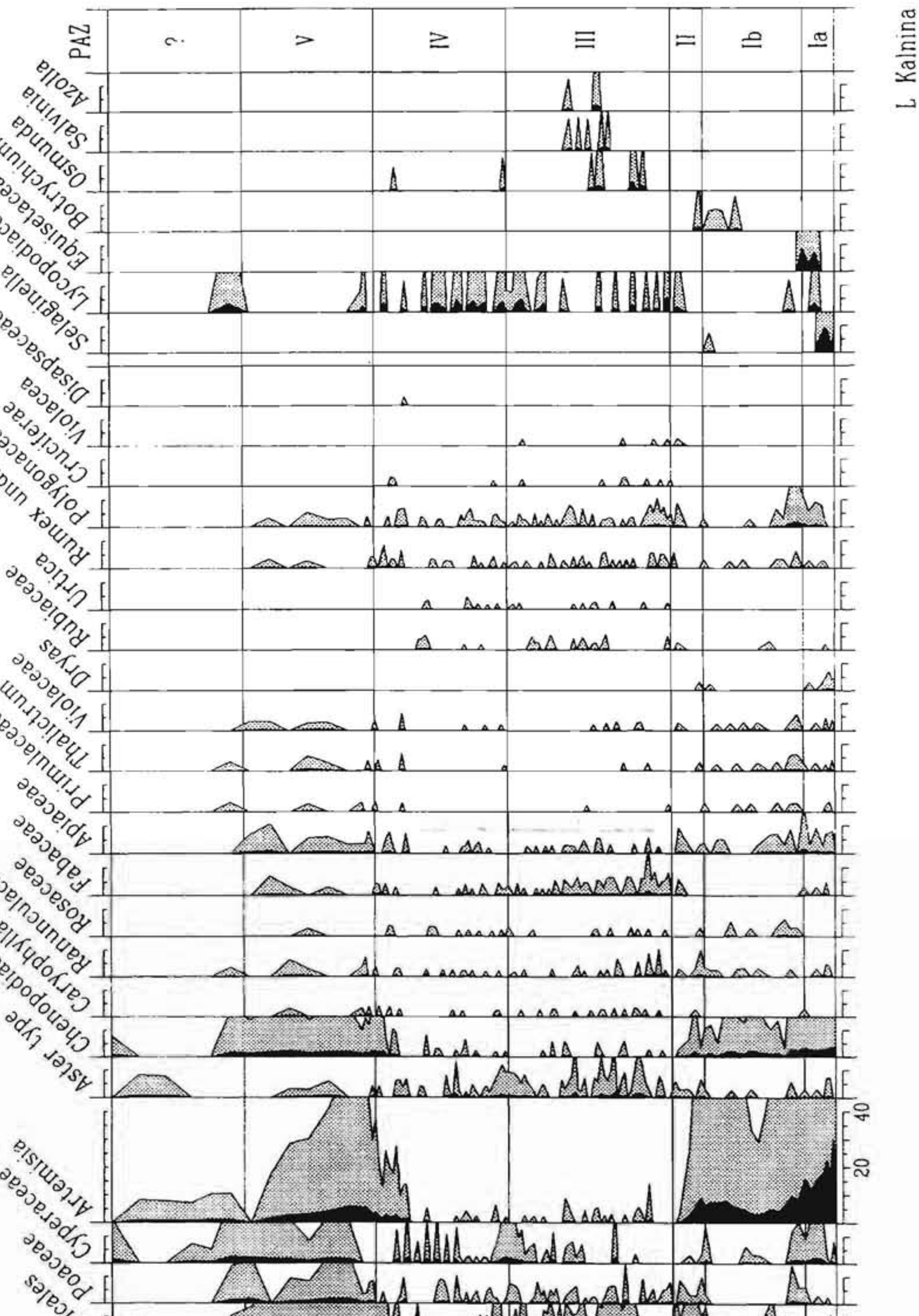


Fig. 12b. Herb pollen and spores diagram from the Late Elsterian and Holsteinian deposits in the core Ulmale-41a.

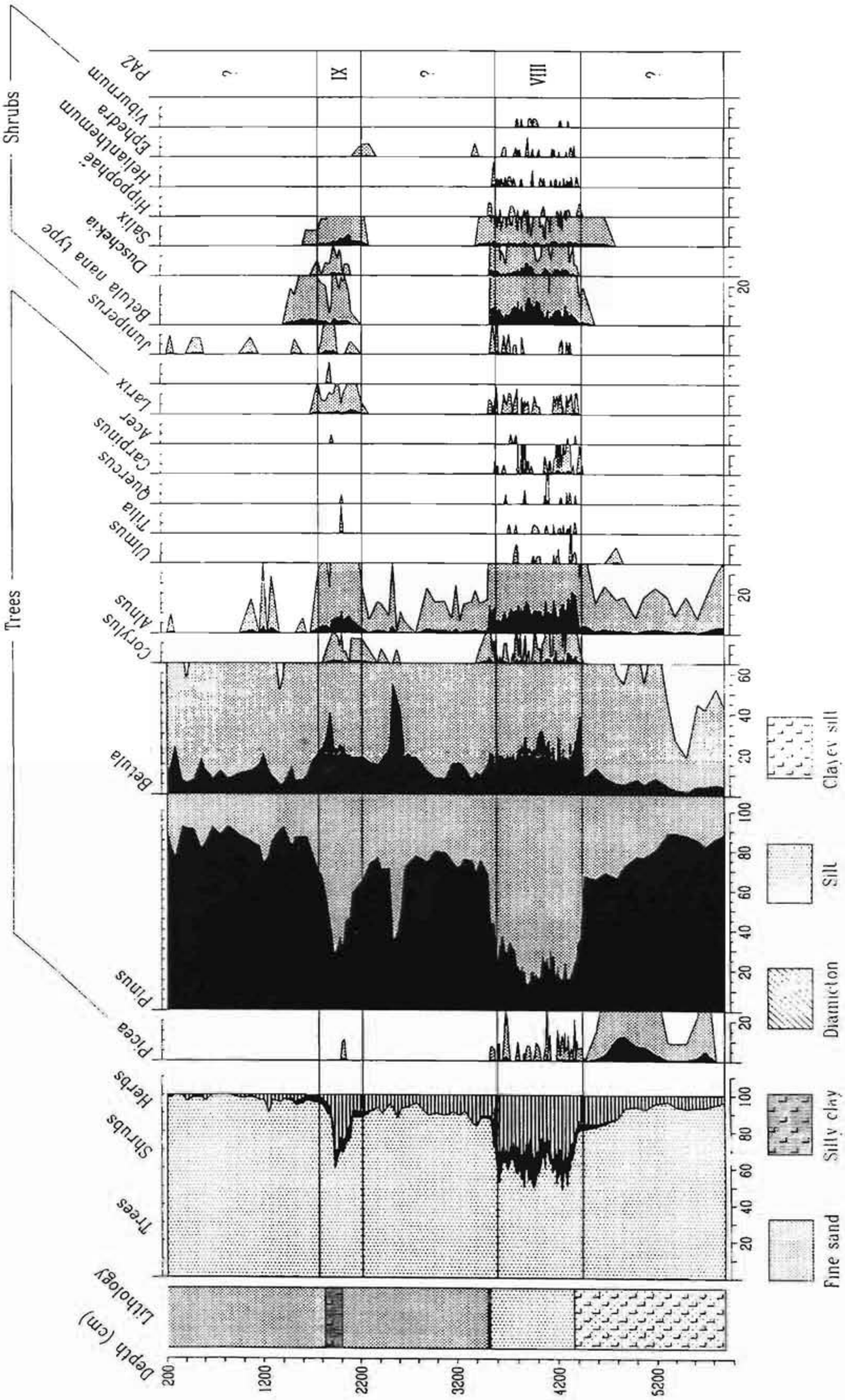


Fig. 13a. Pollen diagram from the Jurkalne (Early Saalian) Formation deposits in the core Ulmale-41a.

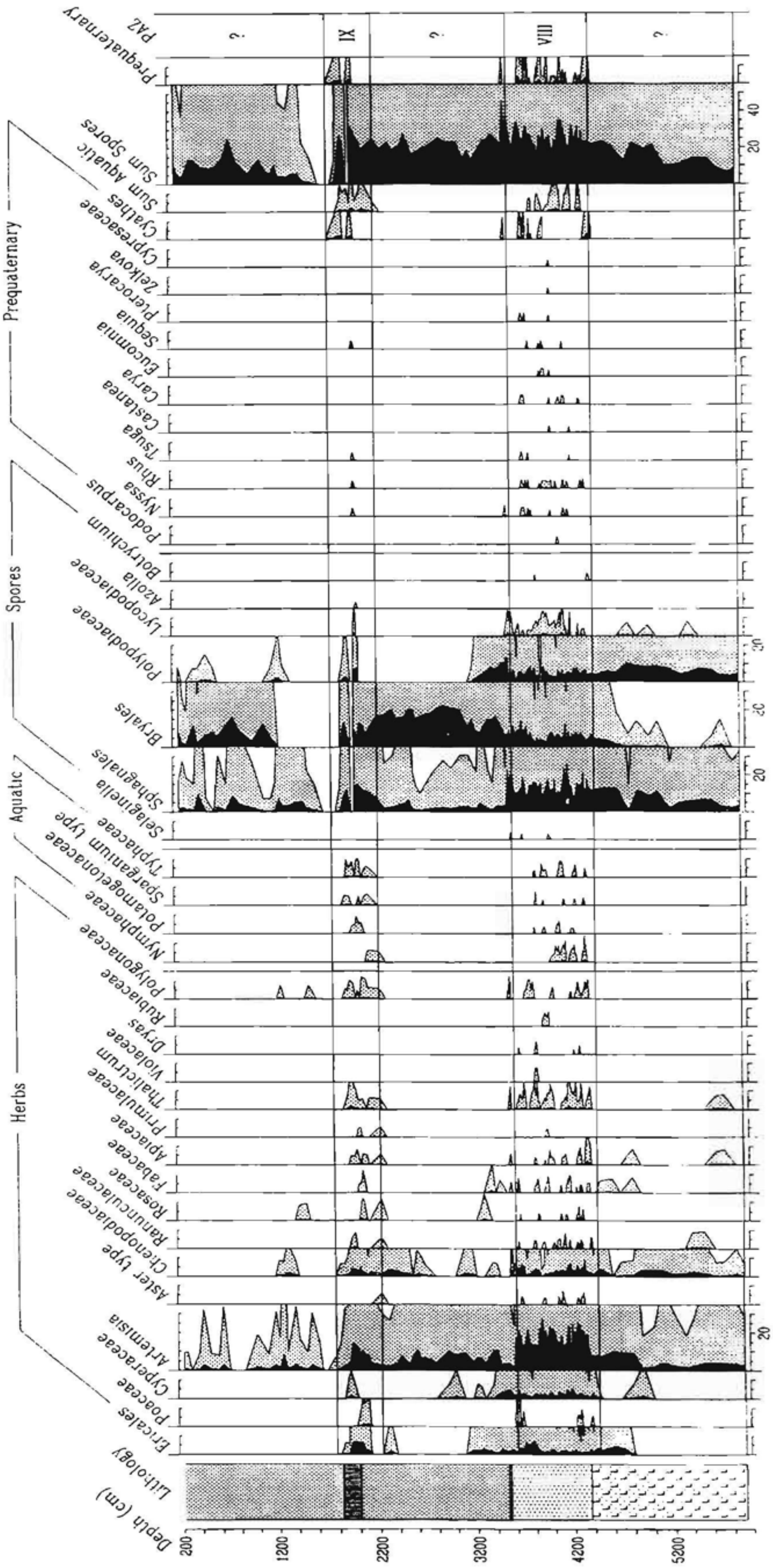


Fig. 13b. Herb pollen and spores diagram from the Jurkalne Formation (Early Saalian) deposits in the core Ulmale-41a. Legend see Fig. 13a.

PAZ III - *Alnus*-Q mixtum-*Picea-Corylus-Carpinus*, depth interval 68.5-66.0 m, (silt rich in organic matter)
Pinus and *Betula* pollen values decrease, but *Alnus, Ulmus, Tilia, Quercus* and *Corylus* reach their highest values. *Alnus* pollen dominates and reaches about 40% of the total pollen sum. *Picea* gradually rises and reaches the first peak in the upper part of zone III, and pollen of *Picea* sect. *Omorica* and *Pinus* sect. *Strobus* are present there. *Abies* pollen forms a continuous curve and has small peaks simultaneously with culmination of *Picea*. Pre-Quaternary pollen are represented by Tertiary extinct taxa, but also *Cyathes* type spores are present. The pollen spectra of this PAZ reflect the early temperate substage of the Interglacial.
PAZ IV – *Picea-Abies-Pinus*, depth interval 66.0-64.0 m (silt and clayey silt)
Pollen of broadleaved trees decreases, while *Pinus* inceases in relative value. *Picea* has its second peak and *Abies* reaches its maximum. *Alnus* pollen is still present with c. 20%, and *Carpinus* values vary 3-7%. Herb pollen values are low (1-2%). Like in the upper part of the previous zone, pollen of *Picea* sect. *Omorica* and *Pinus* sect. *Strobus* are present in PAZ IV.
PAZ V – *Pinus*, depth interval 64.0-62.0 m, (fine sand in the lower part and medium sand with plant remains and organic matter in the upper part of the zone)
The upper boundary is marked where the absolute amount of palynomorphs decreases to 10 grains per 1 g dry sediments, and *Pinus* pollen dominates. Some of the pollen grains are corroded and torn.

The sandy interval (62.0-44.5 m) is poor in organic matter and pollen, among which *Pinus* dominate. Pollen spectra in this interval do not reflect vegetation development in adjacent land areas, but consist of redeposited pollen. The regional PAZ VI and PAZ VII are missing in this sequence.

PAZ VIII – *Betula nana* type-*Alnus-Duschekia*-NAP, depth interval 44.5-36 m (silt)
The silt is relatively rich in palynomorphs: up to 400-450 grains per 1 g of sediment. The pollen and spores are well preserved. NAP is abundant and reaches 25-30%, and the AP decreases to 40-50%. About equal percentages of *Pinus* and *Betula* pollen are present in the AP. *Betula* is represented by both tree and *Betula nana* type pollen (Fig. 13a). *Alnus* and *Duschekia* are abundant and increase in percentage, and also *Salix* forms a continuous curve. A few pollen grains of *Ephedra, Helianthemum* and *Hippophaë* have been noted in this zone. *Artemisia* dominates among the NAP, Cyperaceae, Ericales and Chenopodiaceae pollen percentages vary 3-12% (Fig.13b). *Sphagnum* dominates among spores. *Selaginella selaginoides, Lycopodium alpinum, L. clavatum, L. selago* and *L. appressum* are present.

The upper boundary of PAZ VIII coincides with the thin diamicton layer at 35.5 m depth.

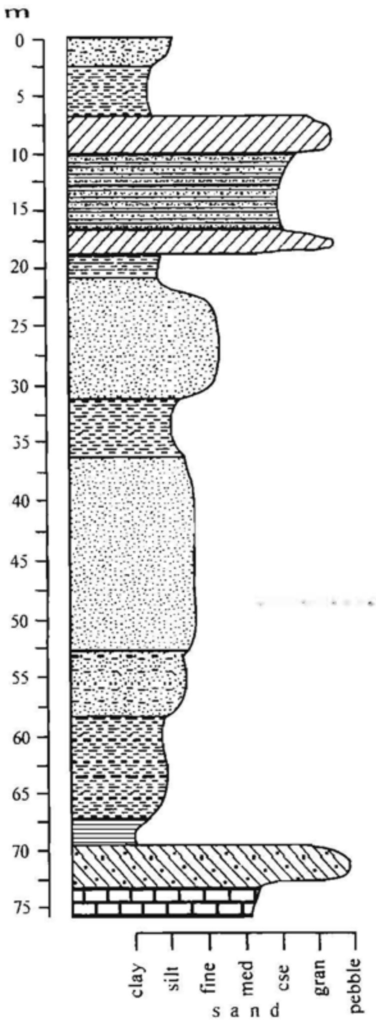
The sandy interval (22.2-35.5 m) between PAZs VIII and IX is marked with "?" and is characterised by a very low frequency of palynomorphs and poor preservation of those few that were encountered. *Pinus* pollen dominates, but others vary in abundance from one site to another. The above characteristics suggest redeposition of pollen and long distance transport and/or redeposition also of *Pinus* pollen.
PAZ IX – NAP-*Betula*, depth interval 22.2-17.7 m (silty clay)
The pollen and spore abundance and composition are similar to that of PAZ VIII, but *Pinus* pollen has higher values than *Betula* (Fig. 13a). *Artemisia* reaches nearly 20% (Fig. 13 b).
The uppermost part (depth 17.7 to 0 m) above PAZ IX - No zones have been distinguished in this part of the pollen diagram because of too low absolute pollen frequency in the sandy sediment.

6.1.3 Strante site - core No. 33

56° 54'40" N Lat., 21° 14'10"E Long.

9.7 m a.s.l.

The Strante site is located about 3 km south-west from the Ulmale stratotype site. The test drilling was performed at the geological mapping in 1987 with the aim of getting more information about the vertical and horizontal distribution, as well as changes in composition, of the marine sediments.



Depth below surface (m)	Description
0 - 3.0	sand, silty
3.0 - 7.1	silt, grey, clayey
7.1 - 9.8	diamicton, clayey, grey
9.8 - 16.8	clay, with occasional pebble and gravel, rare sandy lens, dark grey
16.8 - 18.2	diamicton, grey
18.2 - 20.5	clay and silt varved, grey
20.5 - 31.0	sand, fine, brownish grey
31.0 - 36.5	silt, varved, grey
36.5 - 53.0	sand, fine, grey with some coarser sandy interlayers
53.0 - 58.0	sand, silty, grey
58.0 - 67.0	silt, dark grey with organic remnants
67.0 - 70.0	clay, dark grey, with some silty interlayers
70.0 - 73.3	diamicton, reddish brown
> 73.3 m	Devonian sandstone

Fig. 14. Log and lithological description of the sediment sequence in the core Strante-33.

Lithology

The lowermost part of the Quaternary sequence is represented by reddish brown to brown very dense calcareous diamicton, with sandy or silty clay dominance in its matrix and high gravel and pebble content. The diamicton is rich in carbonates: an average of 54-60% in the 0.5-1.0 mm fraction (Fig. 15), with the limestone/dolostone ratio 1.6. Hornblende grains, 0.1-0.25 mm fraction, are very angular, only 8-11% of the grains are rounded (Fig. 15). All mentioned characteristics correspond to Letiza till and prove that the described layer belongs to this till.

Overlying dark grey clay with silty interlayers in the depth interval 70.0-67.0 m contains foraminifera, ostracodes and mollusc shells. Silty interlayers prevail in the upper part of this interval, but at a depth of 67 m dark grey silt with plant remains and thin (0.5-1 cm) interlayer (lamina) of coarse sand (at 67.0-58.0 m) and some gravel occur. The dark grey silt with plant remains continues upwards, and blue vivianite and small amber grains, and weakly expressed lamination occur.

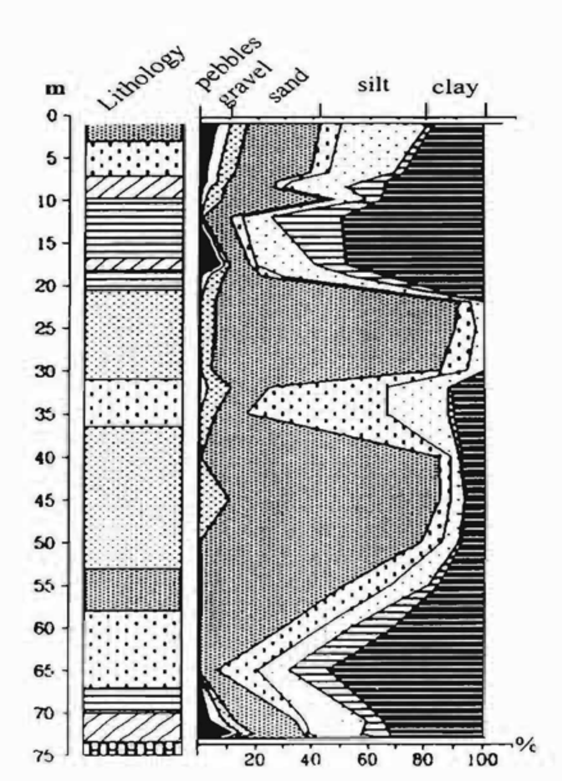


Fig. 15a. Grain size composition of the sediment sequence in the core Strante-33. Legend see Fig. 15b.

The depth interval 58.0-53.0 m is represented by silty grey sand, which upwards has been replaced by grey fine sand with some coarser sandy interlayers, but at the depth of 36.5 m it has been overlain with grey varved silt. At a depth of 31 m this silt has been overlain by a 9.5 m thick brownish grey fine sand layer. In the depth interval at 20.5-18.2 m grey varved clay and silt occur, which have been covered by grey clayey diamicton with occasional pebbles, which are dominated by limestone, presence of Precambrian igneous and metamorphic rocks and very few dolostones.

In the grain size fraction 0.5-1 mm limestone percentages are 23-55 and dolostone 0-3%. The limestone/dolostone ratio is about 13-16, and roundness of hornblende grains in the 0.1-0.25 mm fraction varies form 19 to 28%. Among them short rounded grains prevail (Fig. 15). Clay with occasional pebble and gravel, as well as dark grey sandy lenses occur between the diamicton layers in the depth interval 16.8-9.8 m. The characteristics of the upper diamicton is similar to the lower ones, but it is more clayey.

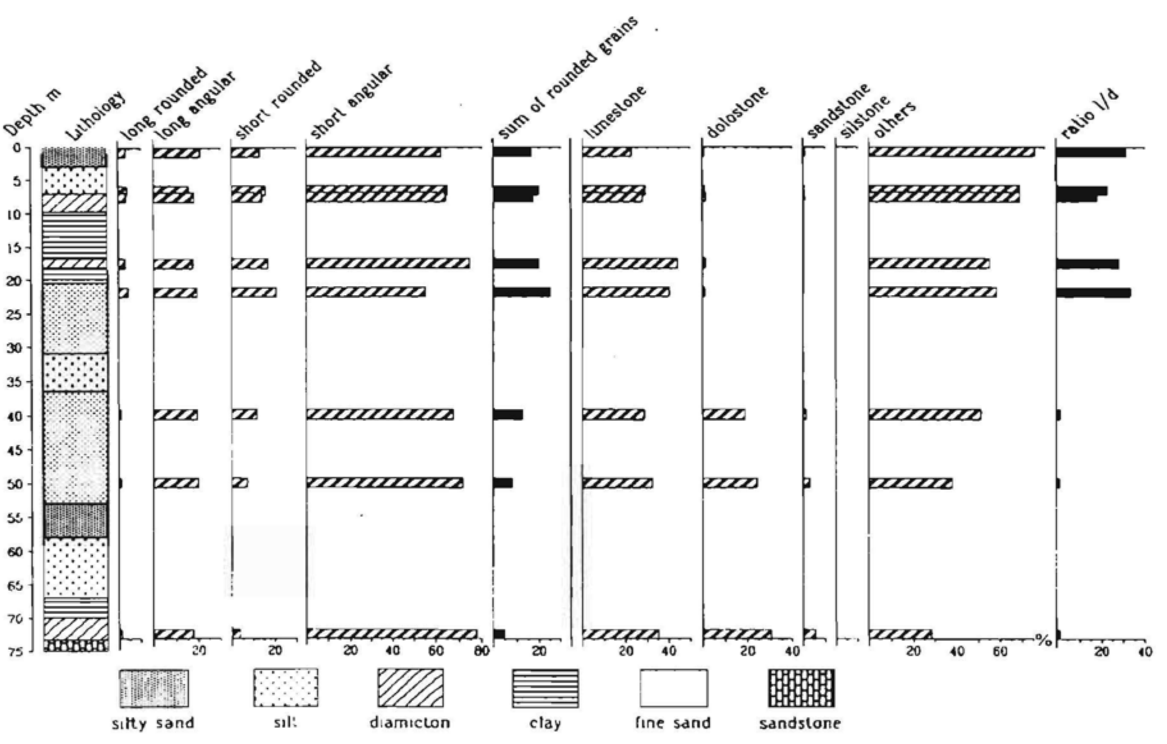


Fig. 15b. Limestone-dolostone ratio (fraction 0.5-1.0 mm) and roundness of hornblendes (fraction 0.1-0.25 mm) in the sediment sequence of the core Strante-33.

Foraminifera analysis

Twenty samples of silt, clay and silty sand in the interval 70-53 m were analysed. The sediment sequence analysed is not rich in foraminifera, both number and diversity, except depth interval 65.7-66 m of dark silt with organic remnants. The interval 58–53 m, does not contain any foraminifera and the clay from the lowest samples at the depth of 70-69 m is also almost barren of foraminfera. Twelve samples from the interval 68.5 to 63.5 m contain foraminifera, but the abundance of foraminifera is very different. It varies from 2-10 at 65-63.5 m to 1185 at 65.7 m and again decrease in the lowest interval at 67.5-68.5 m to 10 per 100 g dry weight (Table 5), where the presence of redeposited (deformed and broken shells) foraminifera has been noted.

Three foraminiferal assemblage zones FAZ ST1 to FAZ ST3 have been distinguished:

FAZ ST1 - *Cassidulina reniforme, Bucella frigida, B. hannai arctica* and *Elphidium albiumbilicatum.* The association of species reflects some marine water transgression in the basin just after the retreat of the ice sheet (Hald *et al.* 1994).

FAZ ST2 - *Elphidium excavatum* f. *clavata* and *E. granatum.* The amount of foraminifera increases significantly in comparison with the previous zone, though diversity is low (8 species). The appearance of lusitianian species, *e.g. Bulimina marginata* and *Elphidium granatum,* indicates ameliorated temperature, and slightly higher salinity. In spite of low diversity, however, the high abundance of dominating species indicate real marine conditions.

Table 5. Composition of foraminifera in the sediment sequence of the Strante-33 core.

Foraminifera / **Depth m**	63.5	64.0	64.5	65.0	65.5	65.7	66.0	66.5	67.0	67.5	68.0	68.5
Lithology	Dark grey silt with organic remnants									Dark grey clay		
Bucella frigida (Cushman, 1922)		1							3	1	2	1
Bucella hannai artica Voloshinova	2								5	4	3	3
Bulimina marginata (d'Orbigny, 1826)					5	38	42	23				
Cassidulina reniforme Nørvang, 1945		1								2	1	1
Elphidium albiumbilicatum (Weiss, 1954)	1	2	3	4	2	3	25	22	31	1	3	
Elphidium excavatum (Terquem) f. *clavata* Cushman, 1930	1		1		12	798	316	48				
Elphidium granatum Gudina				1	11	311	286	4				
Elphidium incertum Williamson, 1858				2	5	8	13		1			
Haynesina orbiculare (Brady, 1881)		1		1	11	25	4	1				
Polymorphinidae sp.				1	2							
Protelphidium depressulum Walker et Jacob				1			1					
Protelphidium parvum Gudina		1			1							
Protelphidium sp.						2	2					
Redeposited									3	1	1	11
Sum of foraminifera per 100 g dry sediments	2	6	4	10	49	1185	689	98	43	9	10	16
FAZ	FAZ ST3				FAZ ST2				FAZ ST1			

FAZ ST3 - *Elphidium albiumbilicatum.* This FAZ is distinguished by a low number of foraminifera. *Elphidium albiumbilicatum* has been found in almost all samples, where foraminifera has been noted, but in this zone it became the dominant species, although with a low frequency. The decrease in foraminifera indicates a regressing sea.

Diatoms

The results of diatom analysis of the Strante-33 core show that the abundance of diatoms varies in the different parts of the sequence. Three diatom assemblage zones were distinguished.

DAZ ST1 - *Actinocyclus ehrenbergii-Hyalodiscus scoticus* (67-69.5 m, clay). The dark clay with silty interlayers in the lowest part of the sequence contains only a few diatoms, cold relicts with some freshwater-brackish, brackish and marine diatoms. The littoral taxa *Actinocyclus ehrenbergii* and *Hyalodiscus scoticus* dominate. The neritic *Coscinodiscus lacustris* var. *septentrionalis* and *Chaetoceros* spp are present.

DAZ ST2 - *Coscinodiscus perforatus-Actinoptychus undulatus-Chaetoceros* spp (67-58 m, silt). The dark-grey silt with organic remains in the interval is abundant in marine deep water and oceanic diatoms.

Coscinodiscus perforatus, *Actinoptychus undulatus* and *Chaetoceros* spp dominate and *Diploneis domblittensis* Grunow Cl., *D. didyma* (Ehr.) Cleve, *Stephanodiscus astraea*, *Opephora martyi* Herib. *Thalassiosira baltica* (Grun.) Östr. and *Coscinodiscus lacustris* var. *septentrionalis* are quite abundant.

DAZ ST3 - *Actinoptychus undulatus-Coscinodiscus lacustris* var. *septentrionalis* (58-53 m, silty sand). This zone contains a few diatoms, represented by marine, brackish and also by freshwater taxa, *e.g.* *Aulacoseira granulata* (Ehr.) Ralfs, *Stephanodiscus astraea*, *Navicula scutelloides* W. Smith, *Coscinodiscus lacustris* var. *septentrionalis*, *C. curvatulus* var. *minor* (Ehr.) Grunow, *Hyalodiscus scoticus*, and *Grammatophora* spp. The presence of relict species *e.g.* *Cyclotella comta* var. *pliocaenica* Krasske, *C.* cf. *baikalensis* Skvortzov and *Melosira praegranulata* Jousé was noted.

No diatom was found upwards in the sandy sediments (58-53 m).

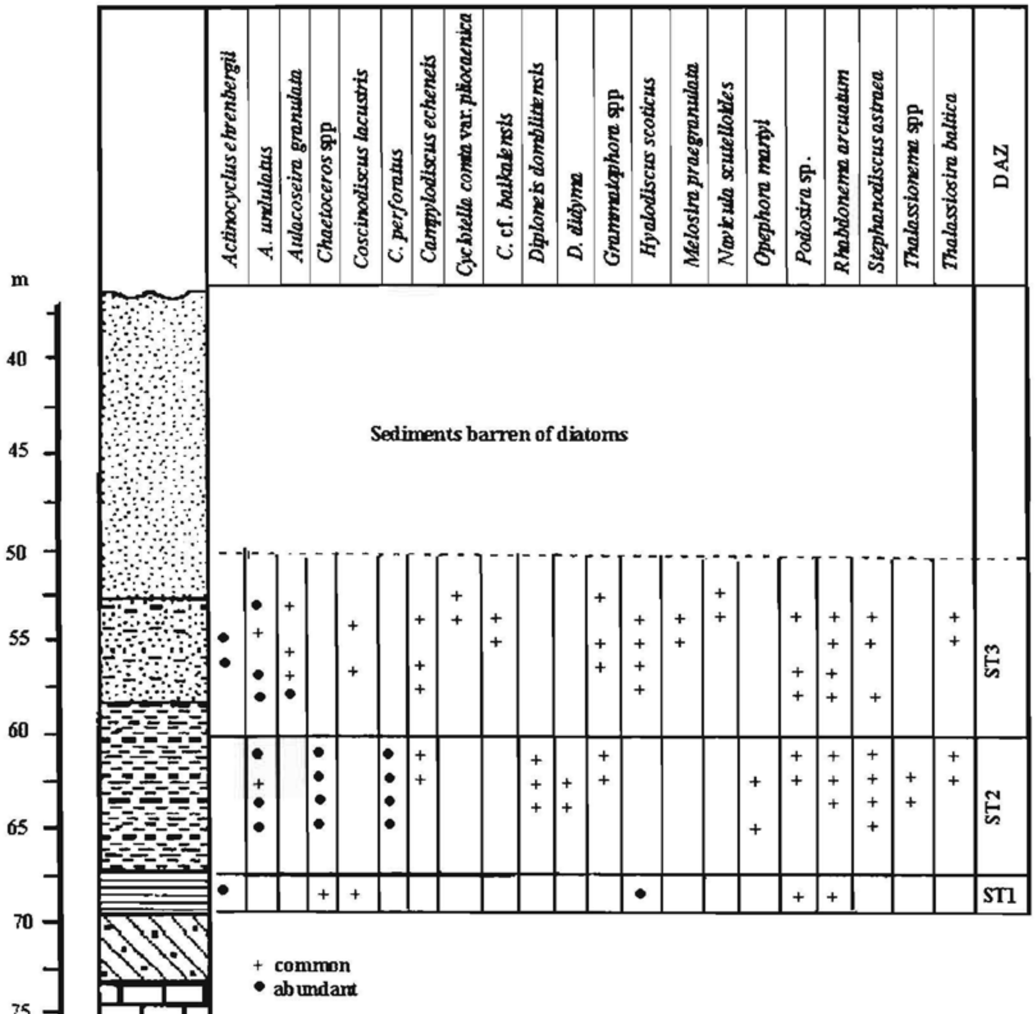


Fig. 16. Distribution and relative frequency of the main diatoms in the core Strante-33 (analysis made by M. Sakson). Depth below surface. Legend see Fig. 14.

Pollen analysis

Nine pollen assemblage zones (PAZ I-IX) both local and regional have been distinguished in the pollen diagram in the test drilling Strante-33 (Figs 17a, b, c, d).

PAZ I – NAP-*Betula nana-Duschekia*, depth interval 70.0-66.2 m, (dense clay, which continue upwards as varved clay and silt)

This interval is comparatively rich in pollen and the absolute content of palynomorphs reaches about 100 grains per 1 g dry sediment. PAZ I is characterised by high values of *Betula*, represented mainly by *Betula nana* type, and abundance of herb pollen, dominated by *Artemisia*. It is also rich in Cyperaceae and Chenopodiaceae pollen, pioneer plants being present, *e.g. Dryas*, *Hippophaë*, *Helianthemum* and *Selaginella*. *Pinus* pollen is also abundant, but they have probably been transported a long distance. Redeposited pre-Quaternary palynomorphs (Tertiary, Mesozoic and Devonian) have been noted to adjoin to the redeposited pollen of *Pinus*, *Picea* and broad-leaved trees. The pollen spectra show some differences in composition in the lower and upper part of the zone, something that allows the division of the PAZ into the subzones Ia and Ib. The pollen spectra of the PAZ Ib are richer in broad-leaved tree pollen, which must have been redeposited. It is surprising that their preservation is good, in contrast to the *Pinus* pollen, which aside from well preserved pollen is also represented by torned and crumpled grains.

A sharp boundary appears in the pollen composition at the level 66.2 m in the pollen diagram, while there is no substantial change in the stratigraphy. A thin (1-2 cm) interlayer of coarse sand appears at that level, which suggests a *hiatus* in the sedimentation and the regional PAZ II does not seem to be present in the diagram.

PAZ III – *Alnus- Corylus-Abies*-Quercetum mixtum, depth interval 66.2-65.0 m, (silt rich in organic material)

Pinus and *Betula* sharply decrease, while *Alnus*, *Ulmus*, *Tilia*, *Quercus*, *Carpinus* and *Corylus* pollen values reach their maxima. A simultaneous culmination of pollen of all mentioned genera may indicate that only the second half of PAZ III is represented. The lowermost part of PAZ III may have been eroded. The pollen spectra in PAZ III reflect early temperate substage conditions.

PAZ IV – *Abies-Picea-Carpinus-Alnus*, depth interval 65.0-62.2m, (silt)

Coniferous pollen significantly increases and *Picea* and *Abies* reach their maximum values. *Picea* sect. *Omorica* and *Pinus* sect. *Strobus* pollen has been noted in this interval. *Carpinus* is still high, while *Ulmus*, *Tilia*, *Quercus* and *Corylus* decrease. The upper boundary of zone IV has been placed on the level where *Abies* pollen disappears, but *Picea* and *Alnus* decrease markedly.

PAZ V – *Pinus*, depth interval 62.2-56.0 m, (silty sand in lower part and sand in upper part)

Absolute values of pollen are 10 grains per 1 g dry sediment at the top of the zone. *Pinus* dominates among tree pollen. The contribution of other pollen types is comparatively low.

The upper boundary of PAZ V is distinct because of low absolute values of palynomorphs and because the pollen is mainly represented by *Pinus*, but overlying sediments are represented by medium coarse sand with low content of organic matter. It is suggested that the pollen spectra in the depth interval 56.0-39.0 m probably do not reflect vegetation on the adjacent land areas.

PAZ VI and **VII** are not represented in this sediment sequence.

PAZ VIII – *Betula nana-Duschekia*-NAP, depth interval 39-31 m (silt and silty sand).

The lower boundary of PAZ VIII is marked where there is an increase in absolute frequency of palynomorphs and a significant change in the pollen composition occurs (Kalnina *et al.* 2000). *Pinus* decreases markedly, while *Betula*, mainly represented by *Betula nana* type, increases. Pollen and spores of pioneer plant vegetation appears, *e.g. Duschekia*, *Artemisia*, *Dryas* and *Salix*, but in the same sample pollen of broad-leaved trees and *Corylus* pollen occurs.

The upper boundary of PAZ VIII is put where a sandy layer with low organic content begins and a similar pollen composition to the one below PAZ VIII appears.

PAZ IX – *Pinus-Alnus*-Ericales, depth interval 16.9-9.8 m (silty clay interbedded between till layers)

Absolute values of palynomorphs reach 100 grains per 1 g dry sediment. Among tree pollen *Pinus*, *Betula* and *Alnus* prevail. *Picea* and *Salix* show continuous curves in this zone. The presence of *Betula nana* type, *Duschekia*, *Ephedra*, *Hippophaë* and *Helianthemum* has been noted. Herb pollen values are high, mostly represented by *Artemisia*, but also Chenopodiaceae, Cyperaceae, Ericales and Varia herb pollen values reach 5-10%. The QM pollen and pre-Quaternary palynomorphs are probably redeposited. The pollen composition in PAZ IX reflects interstadial conditions.

The uppermost interval (9.8-3.0 m) in the diagram reflects arctic to subarctic conditions during the Weichselian (Latvija) Glacial.

The pollen diagram from the Strante site reflects a long sequence with sediment formation beginning in the Late Elsterian (Sudrabi layers) and with interruptions continued through the Holsteinian (Akmenrags) Interglacial and the Saalian (Kurzeme) glacial. The Eemian sediments, as well as part of the Weichselian (Latvija) glacial deposits, have been eroded.

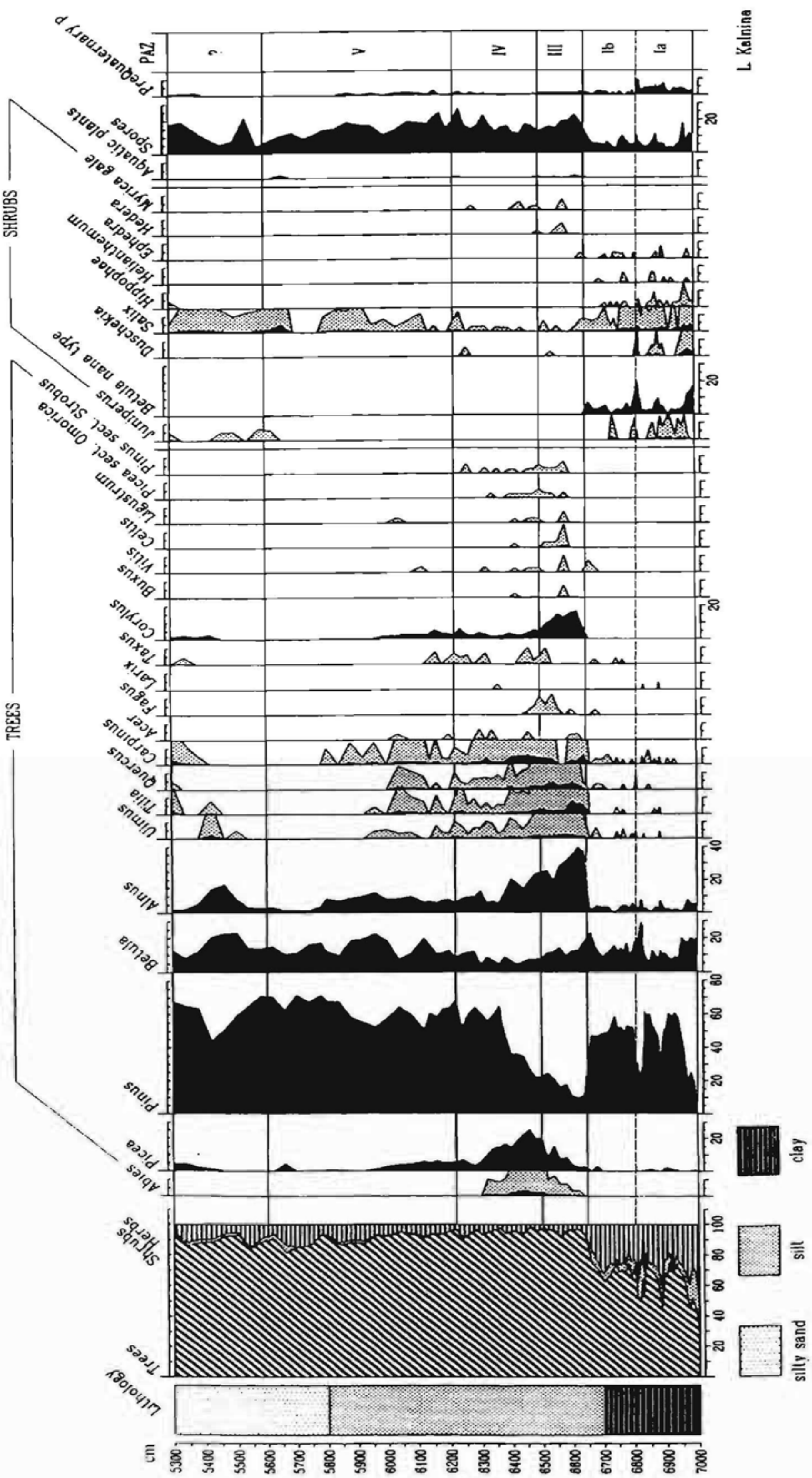


Fig. 17a. Pollen diagram from the Late Elsterian and Holsteinian deposits in the core Strante-33.

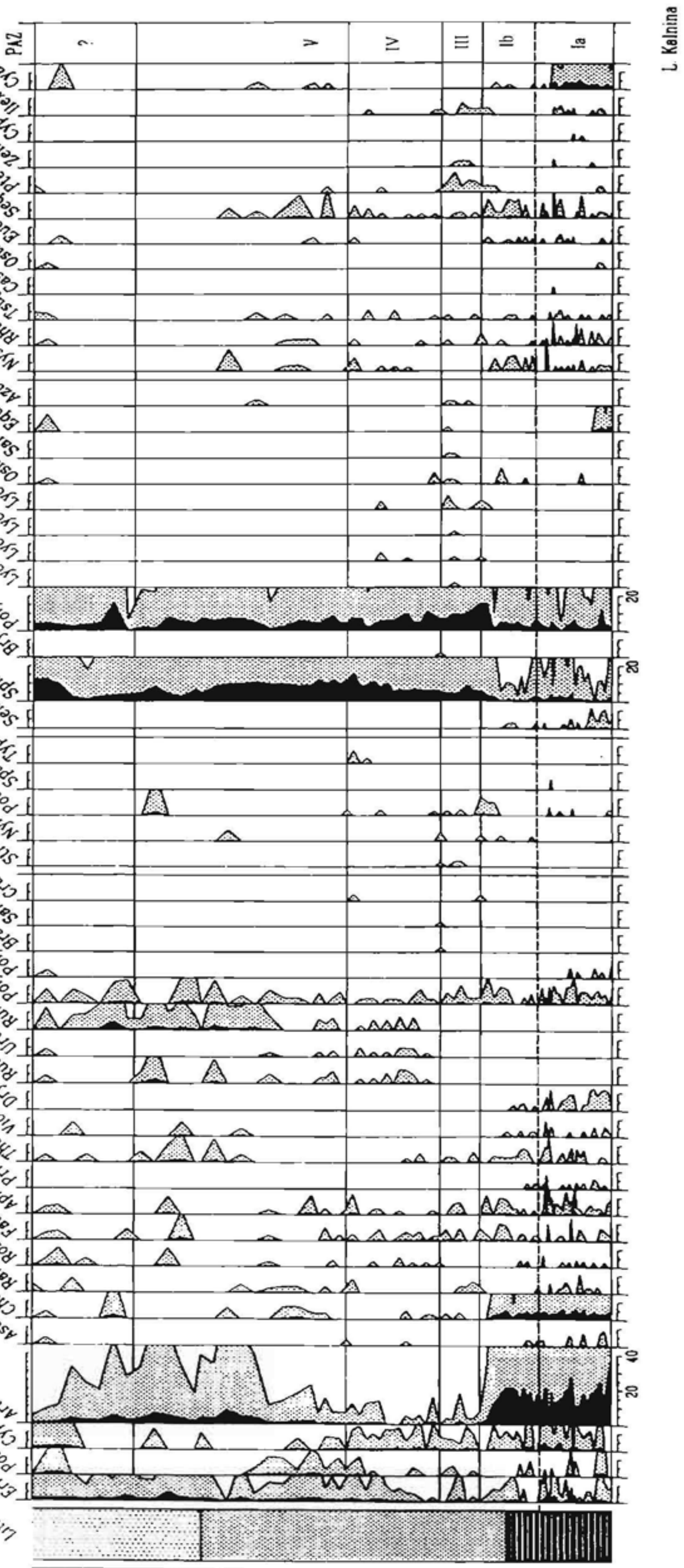


Fig. 17b. Herb, aquatic plant and exotic tree pollen and spores diagram from the Late Elsterian and Holsteinian deposits in the core Strante-33. Legend see Fig. 17a.

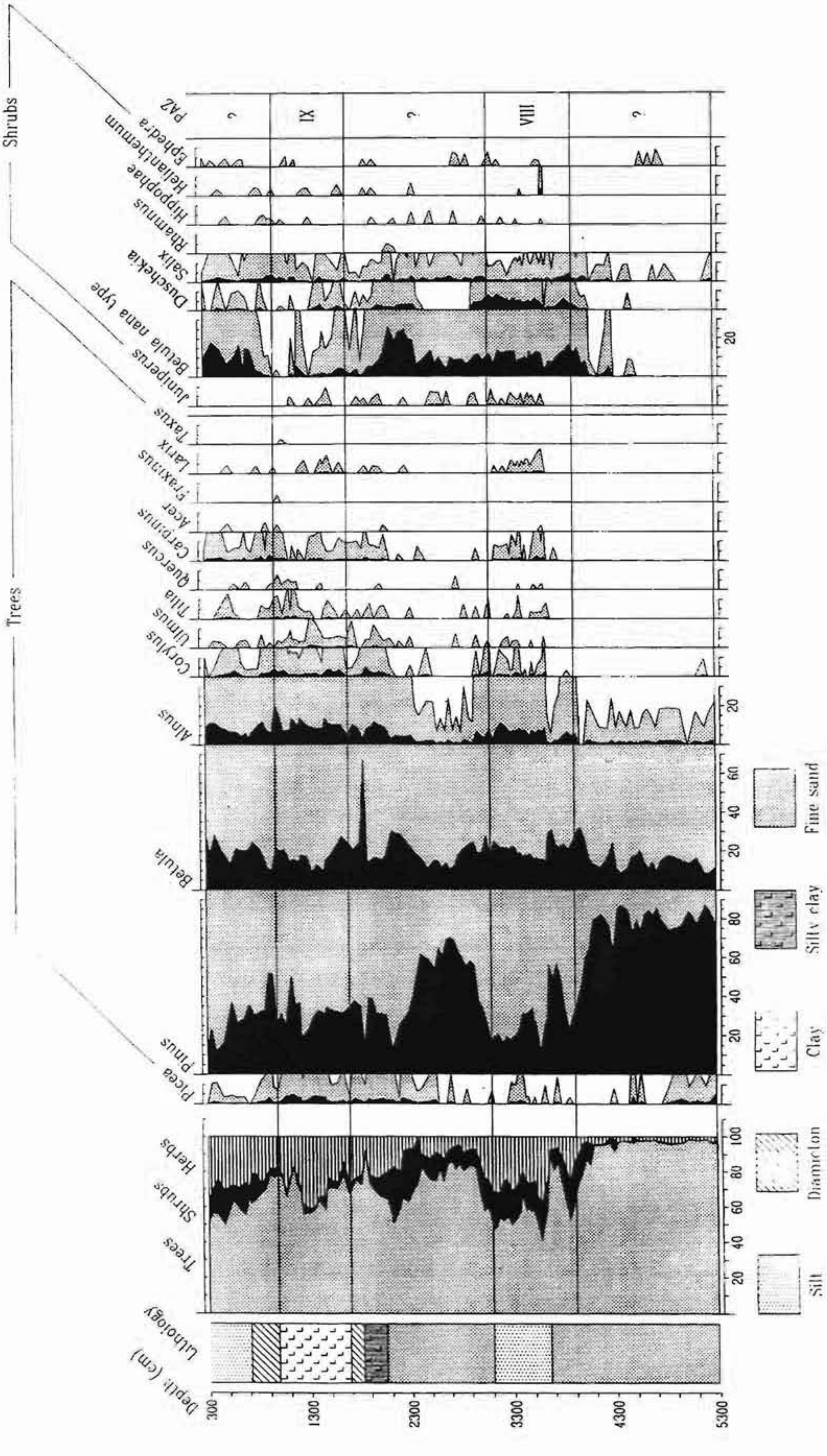


Fig. 17c. Pollen diagram from the Early Saalian (Jurkalne Formation) deposits in the core Strante-33.

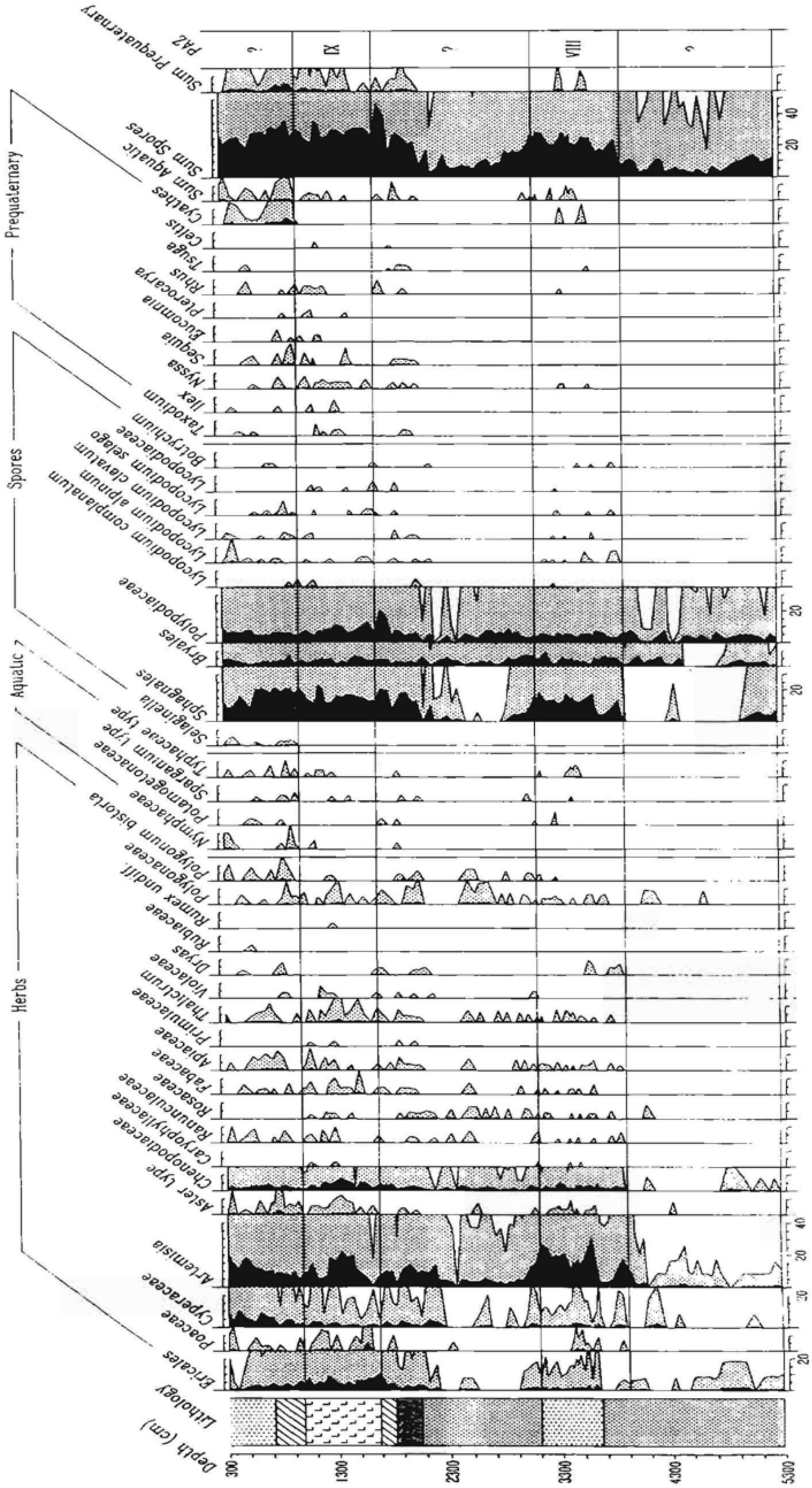


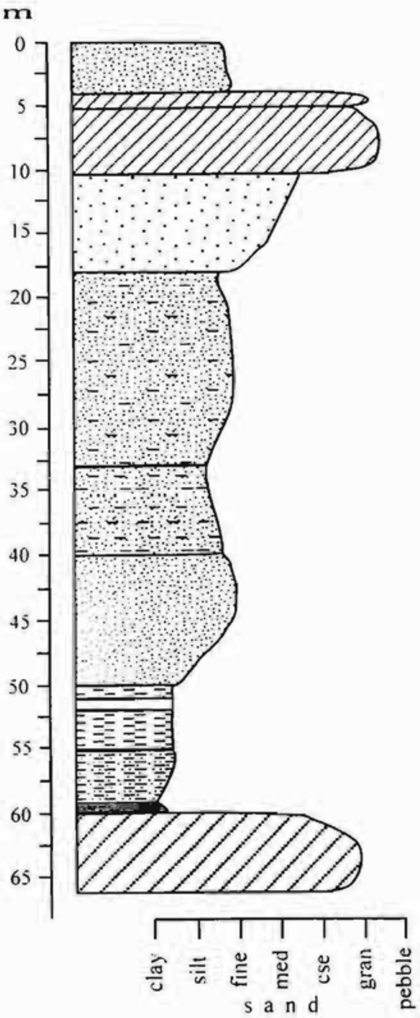
Fig. 17d. Herb pollen and spores diagram from the Early Saalian (Jurkalne Formation) deposits in the core Strante-33. Legend see Fig. 17c.

6.1.4 Ozoli site - core No. 44

56° 51'27" N Lat., 21° 12'09"E Long.
9.7 m a.s.l.

The Ozoli site is located to the east of the test drillings at Akmenrags and Sudrabi, close to the Saka railway station (Fig.1C). The 66.5 m long sequence of Quaternary sediments are underlain by Upper Devonian Amata Formation sandstones.

Inter-diamicton sediments were found in the depth interval 59.8-11.0 m. The first studies of this site were done by Seglins (1987) with interpretation of lithological, pollen and diatom data.



Depth below deposit surface (m)	Description
0 - 4.0	sand, fine
4.0 - 5.5	diamicton, yellow brown
5.5 - 11.0	diamicton, bluish grey
11.0 - 18.0	sand, middle coarsed, grey
18.0 - 33.0	sand, fine, very fine, with occasional silt laminae and plant remnants
33.0 - 40.0	layer with laminas of clayey silt and silty sand, rare plant remnants
40.0 - 50.0	sand, fine, grey, with plant remnants
50.0 - 50.8	silt, dark, clayey, with plant remnants
50.8 - 51.8	gyttja
51.8 - 55.4	silt, dark, with plant remnants
55.4 - 59.3	silt with thin (0.3-0.1 cm) fine sand lamina
59.3 - 59.8	clay, varved, dense, with organic remains (mollusc shells, ostracodes)
59.8 - 66.5	diamicton, clayey, dark violet greyish brown, dense
From 66.5 m	Devonian sandstone

Fig. 18. Log and lithological description of the sediment sequence from the core Ozoli-44.

Lithology

The Quaternary sediment sequence lies directly on the Devonian sandstone at the core Ozoli-44. The lowermost diamicton is very dense and massive, with calcareous clay dominating in its matrix (Figs 18, 19). About 50% of the gravel and occasional pebbles are represented by sedimentary rocks, with limestones in domination, although dolostones are abundant. The diamicton is rich in carbonates, which reaches 55-58% in the 0.5-1.0 mm size fraction. The limestone/dolostone ratio is about 1.5, which is characteristic of Letiza (Elsterian) till in the study area (Fig. 20a). Sandstone and siltstone grains are also present in about 5% of the sediments. The uppermost diamicton has a matrix that consists of silt and sand. It is richer in pebbles and gravel than the lower one (Fig. 19).

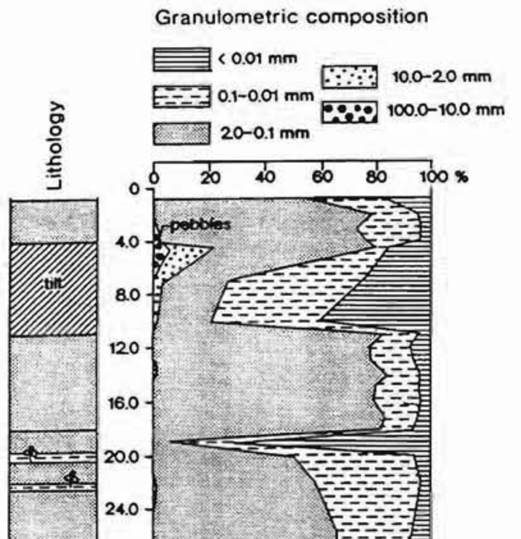


Fig. 19. Grain size composition of the sediment sequence from the core Ozoli-44. The lithology is described in Fig. 18.

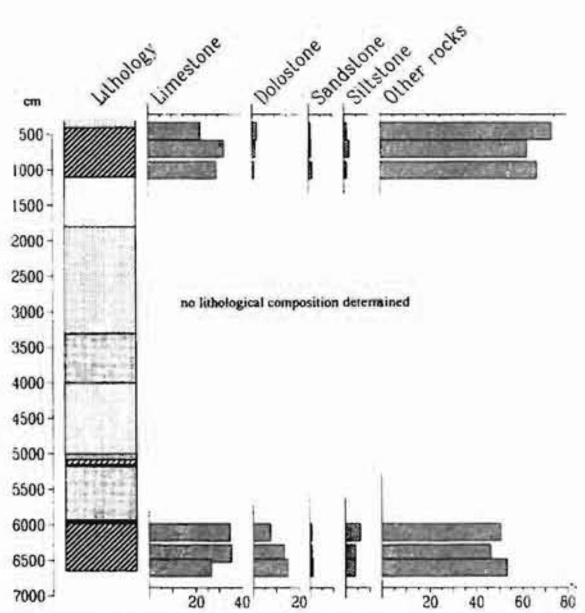


Fig. 20a. Lithological composition of deposits (size fraction 0.5-1.0 mm) from the core Ozoli-44. For legend see Fig. 21.

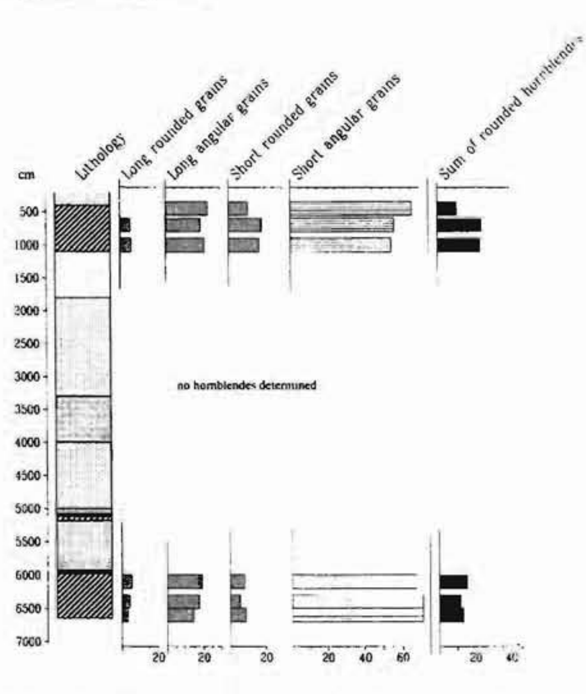


Fig. 20b. Roundness of the hornblende grains (size fraction 0.1-0.25 m) of the deposits from core Ozoli-44. For legend see Fig. 21.

In the grain size fraction 0.5-1.0 mm of the uppermost diamicton the percentage of limestone is 28-35% and dolostone 1-3%, but limestone/dolostone ratio is about 25, which is characteristic of Kurzeme (Saalian) till. This data is also supported by the roundness of hornblendes, which is between 11 to 14% for Elsterian till and 25% for uppermost diamicton. This can be correlated with Saalian till (Fig. 20b).

The mineral composition of grain size fraction 0.05-0.1 mm shows composition that is similar for both till layers and also for the intertill sediments (Fig. 21). Quartz dominates among light minerals, feldspar reaches 11-15%, but micas and carbonates have low percentages. Exceptions can be found in the uppermost sample at the point of contact between diamicton and sand, where carbonates reach 35%. The composition of heavy minerals is also similar, although some differences can be mentioned: the lowermost till contains a slightly higher percentage of ore minerals and apatite, while in the uppermost till pyroxene is higher. Garnet is more abundant in the sandy layers.

The results of the lithological and mineralogical analyses allow us to determine Letiza (Elsterian) till with certainty, while the uppermost till is determined as Kurzeme (Saalian), but some indicators (roundness of hornblendes, mineralogical composition) might indicate Weichselian till.

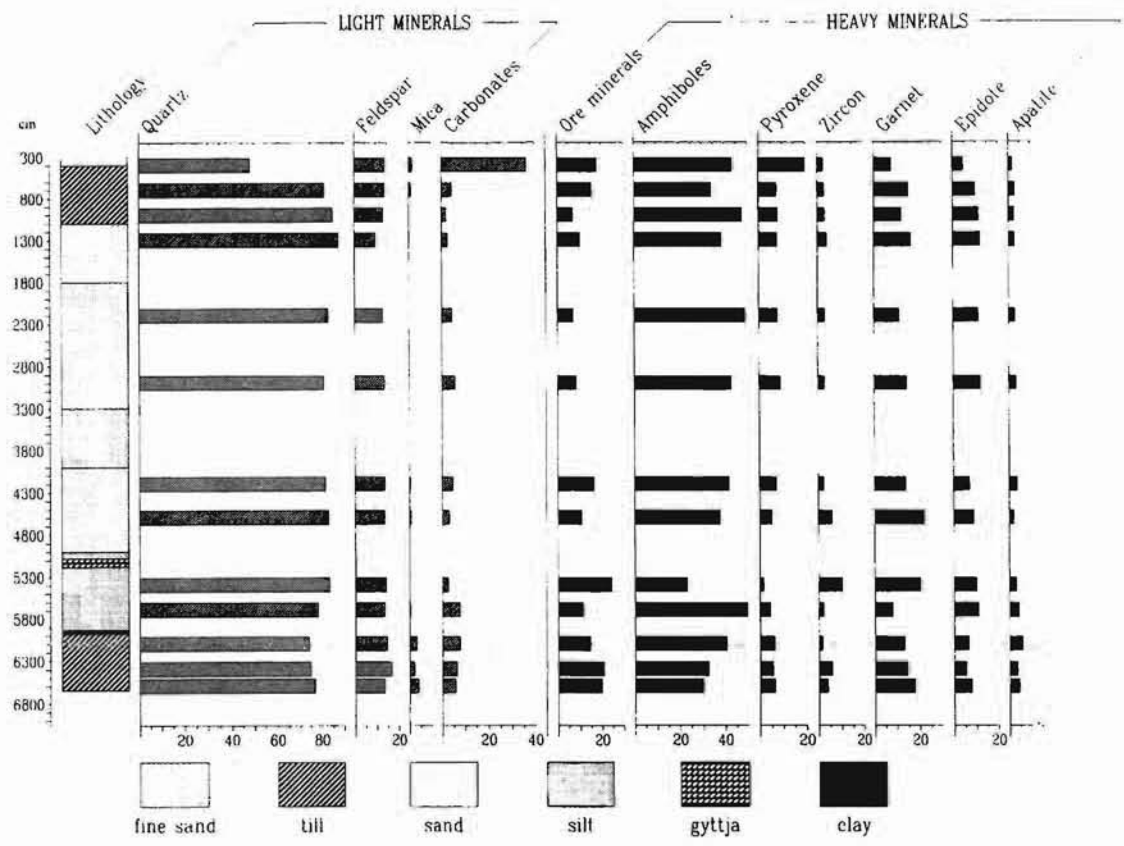


Fig. 21. Mineral composition of deposits from the core Ozoli-44.

Diatom studies

The diatom study of M. Sakson (in Seglins, 1987) suggests that the sediments in the lowest part of the intertill interval were probably formed in a basin under late-glacial conditions (high sedimentation rate, low transparency) since no diatoms were noticed. Upwards in the sequence, three diatom complexes were identified, reflecting the sedimentation conditions.

The 1st diatom assemblage zone is represented by *Rhabdonema arcuatum* (Lyngbye) Kütz., *Actinoptychus undulatus, Paralia sulcata, Chaetoceros mitra* (Bail.) Cl., *Hyalodiscus* sp., *Grammatophora arctica, Cocconeis pediculus, Navicula scutelloides* and *Opephora martyi* indicating coastal marine conditions.

The 2nd diatom assemblage zone is poor in diatom species. Plankton species, both from slightly brackish and freshwater are present: e.g. *Fragilaria inflata, Opephora martyi, Aulacoseira (Melosira) islandica* and *Navicula scutelloides,* indicating sedimentation conditions from the time, when the bay was turning into a freshwater basin.

The 3rd diatom assemblage zone is represented by a few brackish and numerous freshwater diatoms: *Fragilaria inflata, F. construens, Opephora martyi, Navicula scutelloides, Stephanodiscus astraea, Aulacoseira islandica, A. granulata,* pointing to eutrophic freshwater conditions in the basin.

M. Sakson identified a large number of diatoms belonging to various *Cyclotella* species, among them the *Cyclotella comta* var. *lichvinensis* Jousé and *C. temperei* Herib. et Perag. species, which became extinct in the end of the Middle Pleistocene (Khursevich 1996, Seiriene & Sinkunas 1995). Significant is also the presence of rare diatom species, Pliocene relicts, which today can only be found in some water basins: *Aulacoseira granulata* f. *curvata* (Grun) Hust., *A. italica* f. *curvata* (Panyt.) Hust., *Cyclotella iris* Brun et Herib., *C. vorticosa* A.

Berg, *Stepanodiscus niagarae*. Seiriene (Šeiriene & Šinkunas 1995) and Khursevich (1996) are of the opinion that such a composition of diatom assemblages clearly indicates a Holsteinian (Likhvian) age.

Pollen analysis

Pollen analysis in the sediment sequence at the core Ozoli-44 was done for intertill sediments represented by clay, silt with sand lamina, gyttja, silt with plant remains and fine silt. The sediment interval 59.8-50.8 m is rich in pollen and demonstrates a continuous vegetation history represented by seven PAZs (Figs 22a, b, 23a,b).

PAZ Ia – *Betula nana* type-*Juniperus*-NAP (59.8-59.3 m, clay)

The varved, dense clay with mollusc shells and ostracodes is rich in pollen and spores of the pioneer vegetation. Herb pollen constitutes at least or more than 40%. Tree pollen is represented by *Pinus* and *Betula*, but the presence of *Pinus* is the result of long distance transport. Shrubs are including *Juniperus, Betula nana* type and *Salix*. Cyperaceae, *Artemisia* and Chenopodiaceae dominate among herbs and *Dryas* can be found. The described pollen assemblage indicates periglacial vegetation at the adjacent areas of the Ozoli site.

PAZ Ib – *Betula-Pinus-Alnus* (59.3-58.5 m, silt with sand laminae)

This zone is characterised by decrease and absence of periglacial plant pollen and increase of tree pollen, however, herb pollen still reaches 20%. The pollen spectra indicate a Preboreal type of vegetation occurring in the beginning of an interglacial.

PAZ II – *Pinus-Alnus* (58.5-58.2 m, silt) Tree pollen gradually increase and *Pinus* dominates, while *Betula* decreases, but *Alnus* reaches almost 15%. Other tree pollen occurs sporadically.

PAZ III – *Alnus-Picea-Carpinus*-QM-*Taxus* (58.2-57.5 m, silt)

Pinus decreases considerably, but *Alnus, Picea* and *Carpinus* increase. Broad-leaved trees and *Corylus* pollen reach their maxima. *Taxus* traces a continuous curve, although the values are low. Presence of *Hedera* and *Myrica* pollen has been noted.

PAZ IV – *Picea-Carpinus-Abies* (57.5-56.5 m, silt)

Picea, Carpinus and *Alnus* pollen dominate. *Abies* appears and reaches its maximum. Gradually *Pinus* begins to increase and at the end of the zone its values become significant. QM pollen decreases and some small maxima of *Buxus* might be distinguished.

PAZ V - *Pinus* (56.5-55.5 m, silt and fine sand)

Pinus dominates, but *Picea* and *Alnus* gradually decrease. *Betula* values are low and presence of other tree pollen is occasional.

PAZ VI – *Pinus-Betula*-NAP (55.5- 50.3 m, fine sand, gyttja, silt)

Betula increases and replaces *Picea* and *Alnus*. Some broad-leaved tree pollen occurs. The values of herb pollen increase, mainly represented by Ericales, Poaceae, Cyperaceae, *Artemisia* and Chenopodiaceae. The absolute frequency of palynomorphs increases (to 1000 grains per 1 g) in the gyttja layer (50.8-51.8 m), and the general pollen composition is, however, the same as in the entire zone, although some more QM pollen appears (Kalnina *et al.* 2000).

PAZ VII - *Pinus-Larix-Betula nana* type (50.3-49.0 m, fine sand with plant remains) *Pinus* dominates and increases, reaching 60%. *Larix* appears and traces a continuous curve. Pioneer and light demanding plant pollen increases, *e.g. Juniperus, Betula nana* type, *Artemisia*, Chenopodiaceae and *Dryas* (Figs 23a, b). Pollen spectra indicate periglacial vegetation at the beginning of a glaciation.

The pollen sequence in the core Ozoli-44 reflects vegetation history from the late glacial through the entire Holsteinian Interglacial back to the periglacial conditions during the early Saalian glacial period.

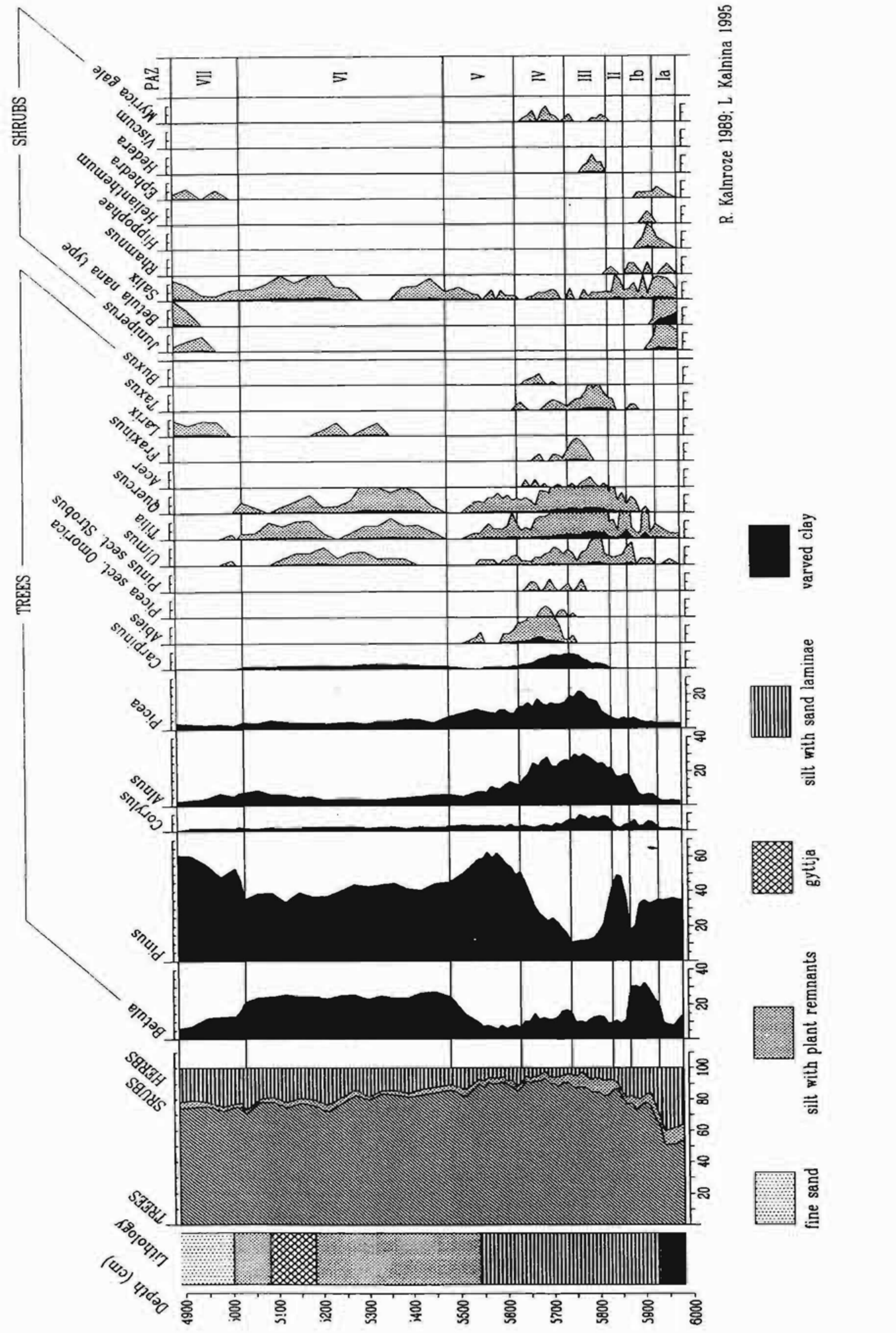


Fig. 22a. Pollen diagram from the Late Elsterian and Holsteinian deposits in the core Ozoli -44.

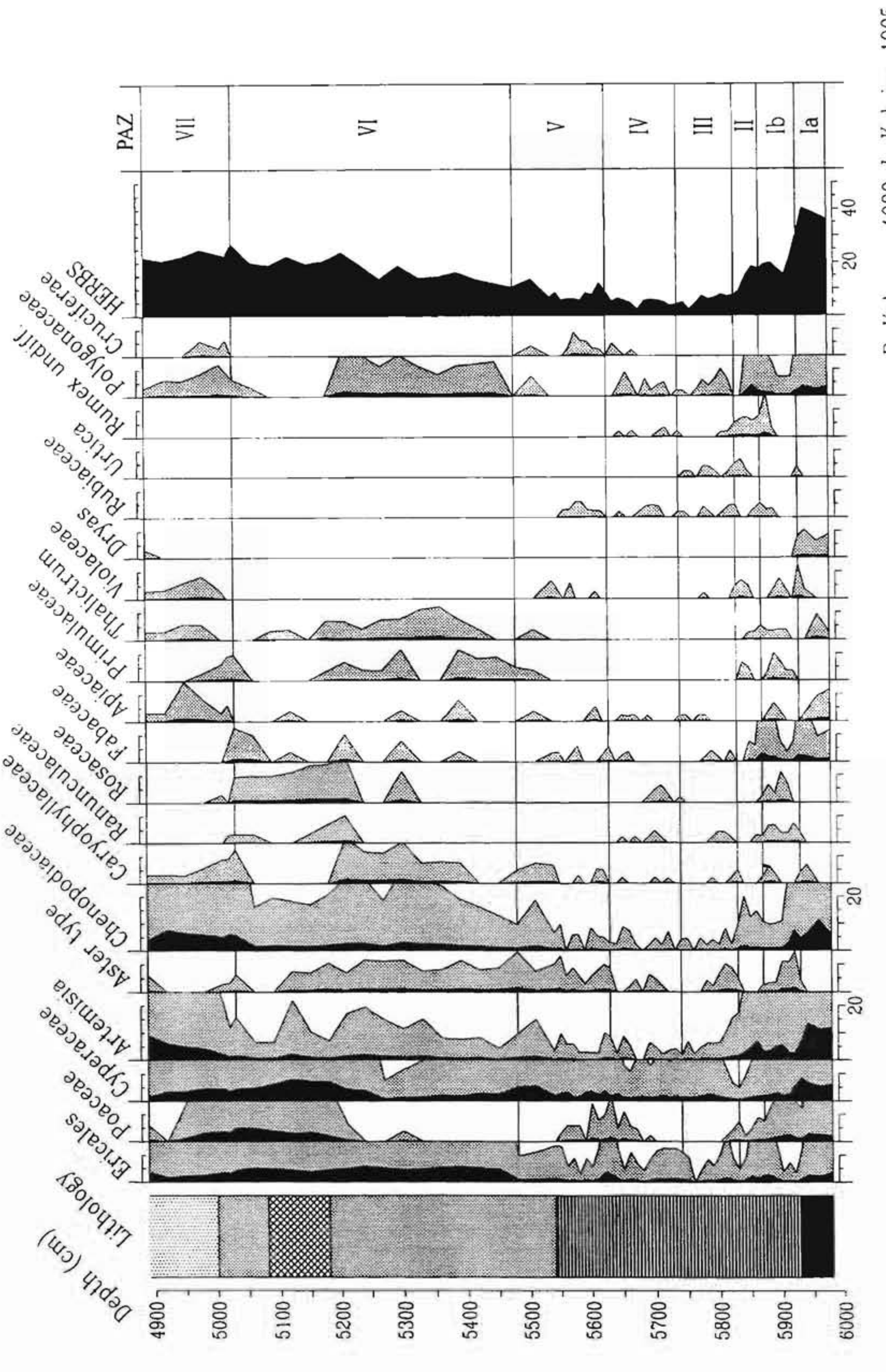


Fig. 22b. Herb pollen diagram from the Late Elsterian and Holsteinian deposits in the core Ozoli-44. Legend see Fig. 22a.

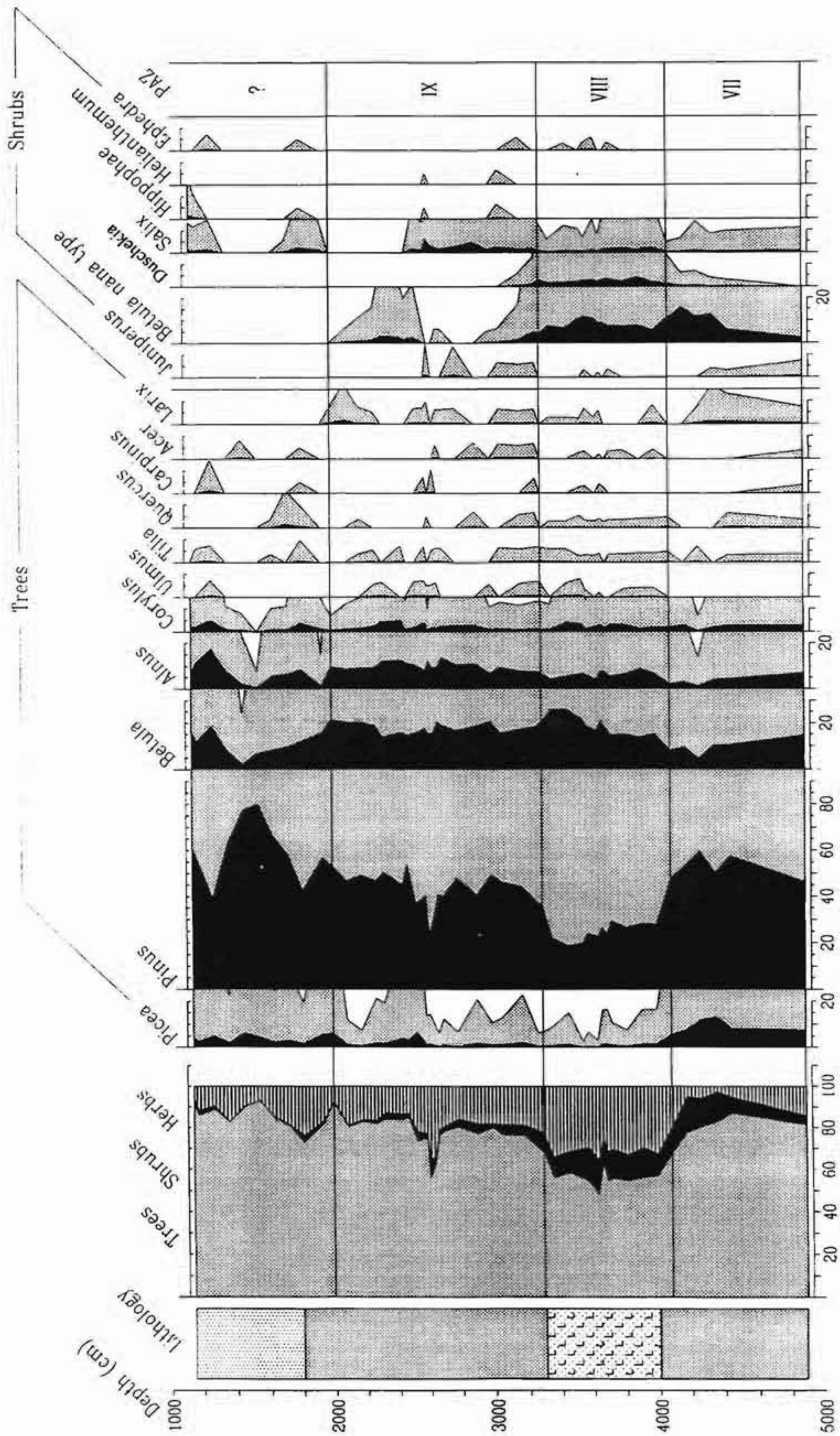


Fig. 23a. Pollen diagram of the Early Saalian (Jurkalne Formation) deposits in the core Ozoli – 44.

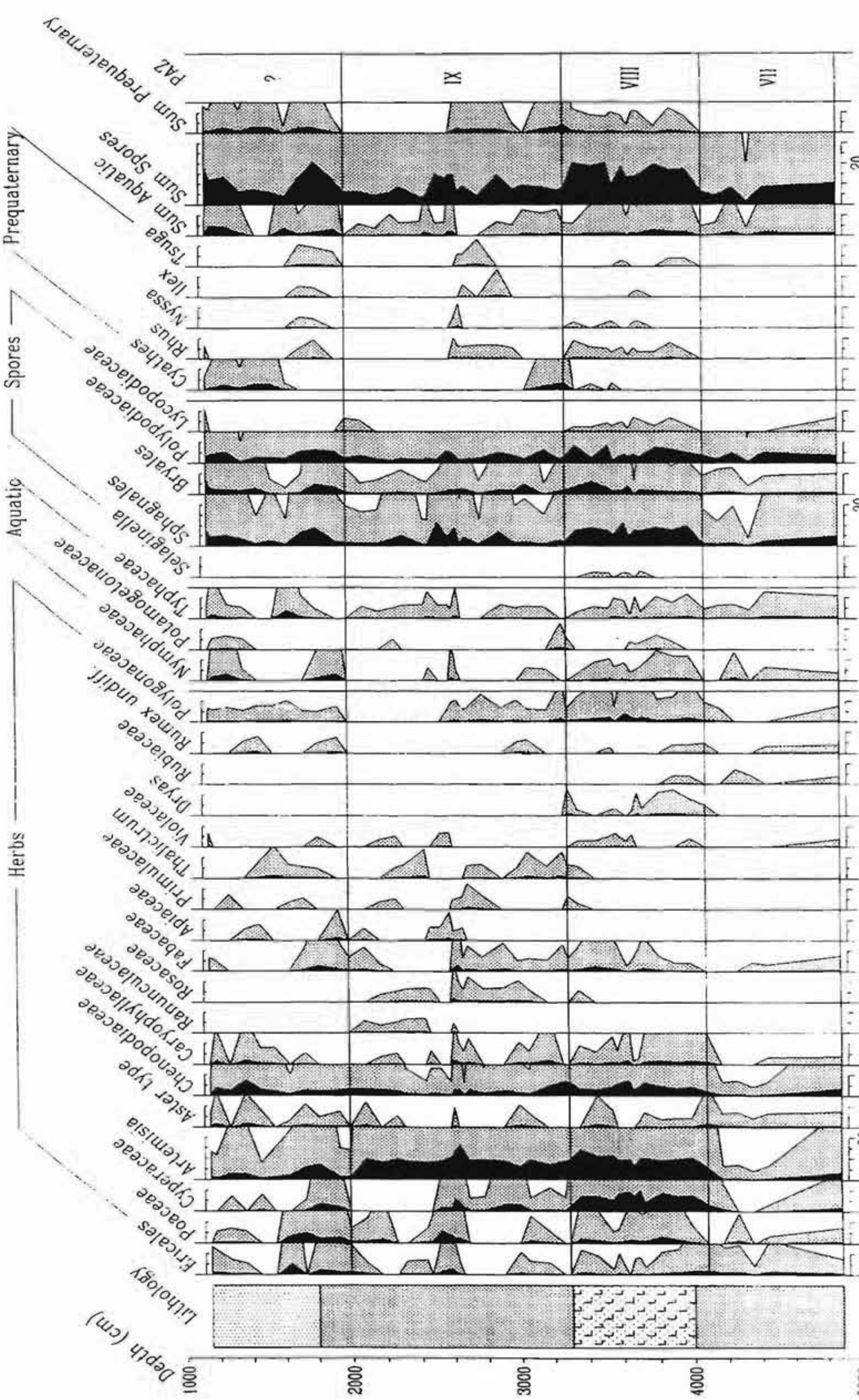


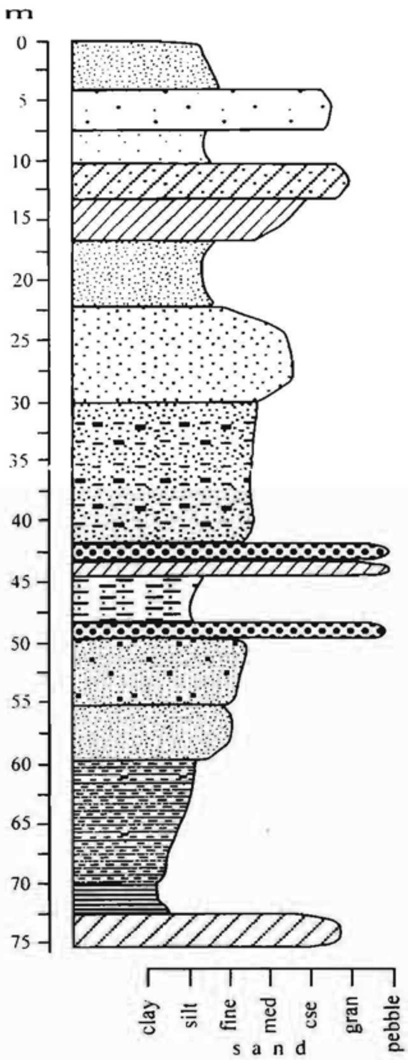
Fig. 23b. Herb pollen diagram of the Early Saalian (Jurkalne Formation) deposits in the core Ozoli – 44. Legend see Fig. 23a.

6.1.5 Akmenrags site - core No. 45

56° 49'55" N Lat., 21° 03'37"E Long.
6.0 m a.s.l.

One of the most complete sediment sequences was found in the test drilling Akmenrags-45, which was carried out in 1985, on the Litorina Sea Plain, 250 m east of the Akmenrags lighthouse.

A 75.2 m deep Quaternary sediment sequence was studied from Akmenrags-45 (Fig. 24) and the methods applied include grain size (Fig.25), roundness of hornblende (Fig. 25a) and pollen analysis (Figs 26, 26a). The foraminiferal analysis indicates that the sediment sequence is barren of foraminifera. Diatoms were represented by oligohalobous and halophobous taxa which are characteristic for eutrophic basins (Seglins 1987).

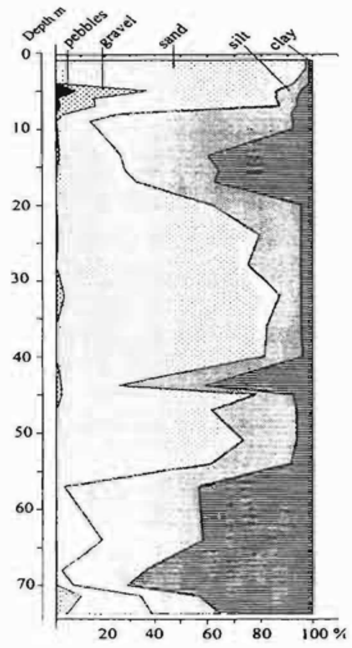


Depth below surface (m)	Description
0 - 4.0	sand, fine light grey
4.0 - 7.5	sand with rare pebbles, light
7.5 - 10.5	sand, fine with rare gravel
10.5 - 13.0	diamicton, sandy, brownish grey
13.0 - 16.7	diamicton, clayey, dark bluish grey
16.7 - 23.5	sand very fine, grey
23.5 - 30.5	sand, middle coarse and coarse
30.5 - 43.0	sand, fine and middle coarsity with silt lenses and rare gravel
43.0 - 43.6	pebbles
43.6 - 44.0	diamicton, clayey, dark bluish grey
44.0 - 48.0	silt, sandy
48.0 - 49.3	conglomerate
49.3 - 55.3	sand, fine with rare gravel
55.3 - 59.0	sand, very fine
64.0 - 70.8	clay, with silt laminae, grey
70.8 - 73.0	clay, reddish brown
73.0 - 75.2	diamicton, clayey, reddish brown
from 75.2 m	Devonian siltstone

Fig. 24. Log and lithological description of the sediment sequence from the core Akmenrags-45.

Lithology

The lowermost Quaternary sediment layer overlying the Devonian siltstone is a very dense calcareous reddish brown diamicton with clay dominating in its matrix (Figs 24, 25a). Gravel and pebbles are abundant and dominate with sedimentary rocks, mainly limestones and dolostones. In the diamicton layers at the 44-43.6 m and 16.7-10.5 m levels, clay particles are less abundant, but sand increases in the matrix. The roundness of the hornblende grains for the lower diamicton displays the characteristic features of Letiza (Elsterian) till: the sum of rounded hornblendes 7 to 13% (Fig. 25b), while results of upper two diamicton layers show similar values (20-25%), which are close to the lower limit of the hornblende roundness of the Saalian till and upper limit of the Weichselian till in the study area.



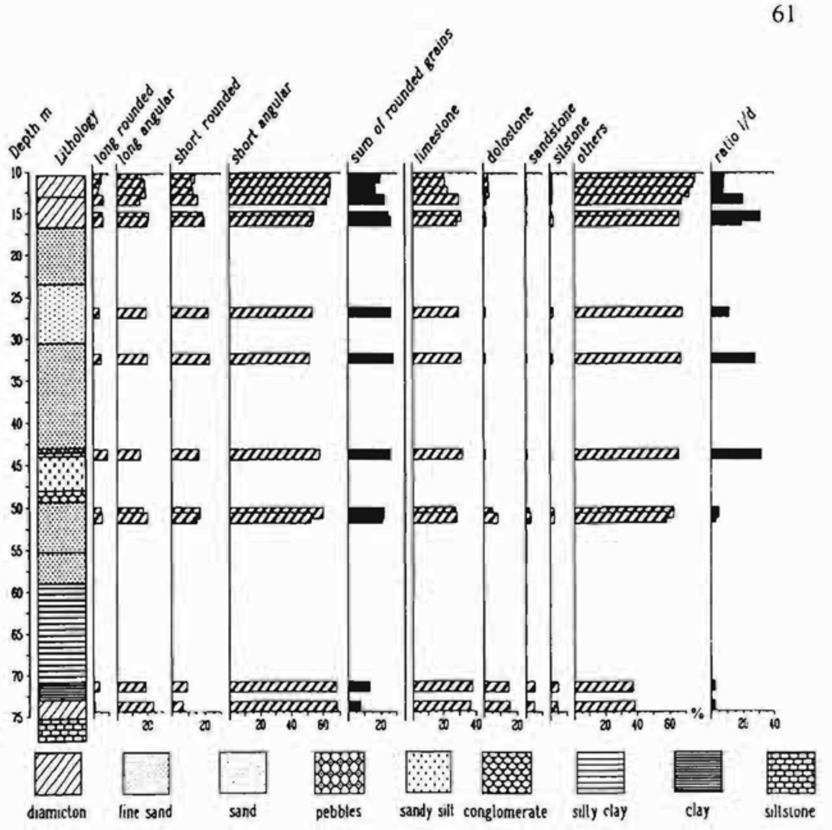


Fig. 25a. Grain size composition (%) of the sediment sequence (excluding grain size fractions larger than 100 mm) in the core Akmenrags-45.

Fig. 25b. Roundness of hornblendes (%), lithological composition (%) and limestone /dolostone (l/d) ratio (size fraction 0.5-1.0 mm) in the core Akmenrags-45.

Pollen flora

Sandy-silty sediments from the depth interval 72.4-17.0 were investigated palynologically (Figs 26, 26a). Seven pollen assemblage zones (PAZ) I-VII were established, which reflect a complete cycle of vegetation development during an interglacial, as well as stadials and interstadials.

PAZ I – *Pinus*–NAP, depth interval 70.6-69.2 m, (clay and clay with silt laminae)

The absolute content of palynomorphs varies from 4 to 130 grains per 1 g dry sediment. Tree pollen prevails (91%) in the general composition of pollen spectra. Herbs compose c. 9% of the total pollen content of which *Artemisia* reaches 7%. Pine pollen dominates in the composition of tree species, birch pollen is represented with up to 22%. *Betula nana* type pollen is present in most of the samples from this sediment interval. *Alnus* participates in pollen composition in low values (1-11%). *Duschekia* pollen is present. Pollen of broad-leaved trees occurs sporadically and they are obviously redeposited. *Picea* pollen is found at a level of 1- 6%, but they are poorly preserved – much pollen are destroyed and mineralised, suggesting redeposition. Some pollen grains of *Salix* and *Ephedra* have been noted.

In general the pollen composition of PAZ I indicates cool climatic conditions at the end of the late-glacial.

PAZ II – *Pinus-Picea*, depth interval 69.2-68.0 m, (laminated silt and clay)

The pollen composition in this zone is characterised by a decrease in tree pollen values and increase in spores, among which Polypodiaceae and Sphagnales dominate, but spores of *Osmunda claytoniana* type are also present. *Pinus* is still predominant, but gradually its values decrease in the upper part. Birch pollen makes up about 20% and is only from tree species. The values of *Picea* and *Alnus* pollen increase. The rational limit of broad-leaved tree pollen and *Corylus* occurs in this zone. Herb pollen decrease slightly and they are represented by *Artemisia* and Chenopodiaceae, but in the upper part of the zone Ericales pollen values increase. Such a development in vegetation, suggested by the pollen composition, reflects warmer climatic conditions, which favours development of coniferous forests and overgrowing of the water basins.

PAZ III – *Picea-Abies-Alnus-Tilia-Corylus-Carpinus*, depth interval 68.0-65.0 m, (silt and clay rich in organic content)

The pollen spectra reflect a vegetation composition at a climatic maximum, but due to changes in the dominant tree pollen composition, three local subzones a, b and c can be distinguished.

PAZ IIIa - *Picea-Abies-Alnus,* depth interval 68.0-67.0 m

The absolute pollen content increases to 1000 palynomorphs per 1 g dry sediment. The climate conditions are favourable for development of spruce forest, which has a maximal distribution. The presence of the *Picea* sect. *Omorica* is noted. *Abies* pollen represented by two species: *Abies alba* and *Abies* sp. reach their highest values (5%) in the sequence analysed. Also *Carpinus* pollen reaches the highest values (7.1%). *Pinus* values vary from 20 to 50 % including pollen of *Pinus* sect. *Strobus*. Pollen values of broad-leaved trees and *Corylus* gradually increase. Herbaceous pollen is mainly represented by Ericales and Varia.

Spores of *Osmunda claytoniana* and *O. regalis* type are found and spores of *Lycopodium clavatum* and *Lycopodium annotinum* are also present in almost all samples.

PAZ IIIb - *Alnus-Tilia-Corylus*, depth interval 67.0-65.7 m

The changes occur in tree pollen composition. Maximum values reached are: *Alnus* (30%), *Corylus* (13%) and *Tilia* (15%). *Picea* and *Pinus* values decrease considerably, and *Abies* disappears. The main part of alder pollen probably represents *Alnus glutinosa*.

PAZ IIIc - *Picea-Alnus-Carpinus*, depth interval 65.7-65 m

Values of coniferous pollen increase, and *Pinus* sect. *Strobus* and *Picea* sect. *Omorica* appear again. *Carpinus* pollen is present during the whole PAZ III, but in subzone IIIc it reaches its maximum values.

PAZ IV- *Abies-Picea-Pinus*, depth interval 65-64 m, (silt with clay interlayers)

Pollen of coniferous trees dominate, among them *Picea* and *Abies* reaching their second maximum, but decreasing at the end of the zone, while *Pinus* values continue to increase.

PAZ V- *Pinus*, depth interval 64-59.5 m, (sand and sandy and clayey silt interlayers)

Pinus pollen dominates. *Betula, Alnus*, *Picea* and other tree pollen show fluctuating curves. Values of herb pollen, *e.g.* Ericales, Chenopodiaceae and *Artemisia,* and aquatic plants, increase.

PAZ VI - *Betula-Alnus-Pinus*-Ericales, depth interval 59.5-55 m, (sand, silt and clay interlayers)

The absolute pollen abundance fluctuates from 100 to 1000 grains per 1 g dry sediment. Pollen values of *Pinus* decrease, while *Alnus* increases considerably and some *Larix* pollen are present. Broad-leaved trees and *Corylus* values increase and form almost continuous curves. NAP values increase and fluctuate from 10 to 25%. Among them Ericales increases significantly and reach 15%. Cyperaceae, *Artemisia* and Chenopodiaceae values also increase. Light demanding pioneer plants, *e.g. Dryas* and *Hippophaë,* are present.

The boundary between PAZ VI and PAZ VII marks the upper boundary of interglacial pollen spectra at the level where the absolute pollen values decrease to 20 grains per 1 g dry sediment (Kalnina *et al.* 2000). Among tree pollen *Pinus* sharply increases and dominates.

PAZ VII - NAP-*Pinus-Betula nana* type, depth interval 55.0-50.5 m, (sand with silt interlayers)

Tree pollen is mainly represented by *Pinus*. The herb pollen increases, although, their numbers vary sharply. Subarctic flora representatives, *e.g. Selaginella selaginoides* and *Lycopodium alpinum,* are present.

PAZ VIII - *Betula* sect. *Albae, B. nana* type-*Duschekia*-NAP, depth interval 48.0-44.0 m, (sandy silt with silt and clay interlayers)

Betula pollen values increase, and it is represented mainly by tree species, although, Betula *nana* type is present in the lower part of zone too. *Alnus* and *Duschekia* pollen values also increase. Values of herb pollen vary, but generally show an increase in Cyperaceae and Varia pollen.

The intervals between PAZ VIII and IX are characterised by a low number of pollen and by poor preservation (torn, mineralised and corroded). Dominance of *Pinus* pollen, absence or low values of other pollen types and their variation in frequency indicates redeposition.

PAZ IX - *Pinus-Betula-Alnus*-NAP, depth interval 30.0-25.0 m, (silty sand)

The absolute values of palynomorphs increase significantly in comparison with underlying sandy strata and reach 40-50 grains per 1 g dry sediment. The pollen of *Pinus* still dominate, but values of *Picea, Betula, B. nana* type, *Alnus* and *Corylus* pollen increase. A few pollen of Ulmus, *Tilia* and *Quercus* have been noted. In spite of incompatibility of pollen spectra, almost all pollen grains are well preserved.

The samples from the depth interval 15-25 m (fine sand) have also been analysed palynologically, but the results show that this sandy interval is very poor in pollen and spores.

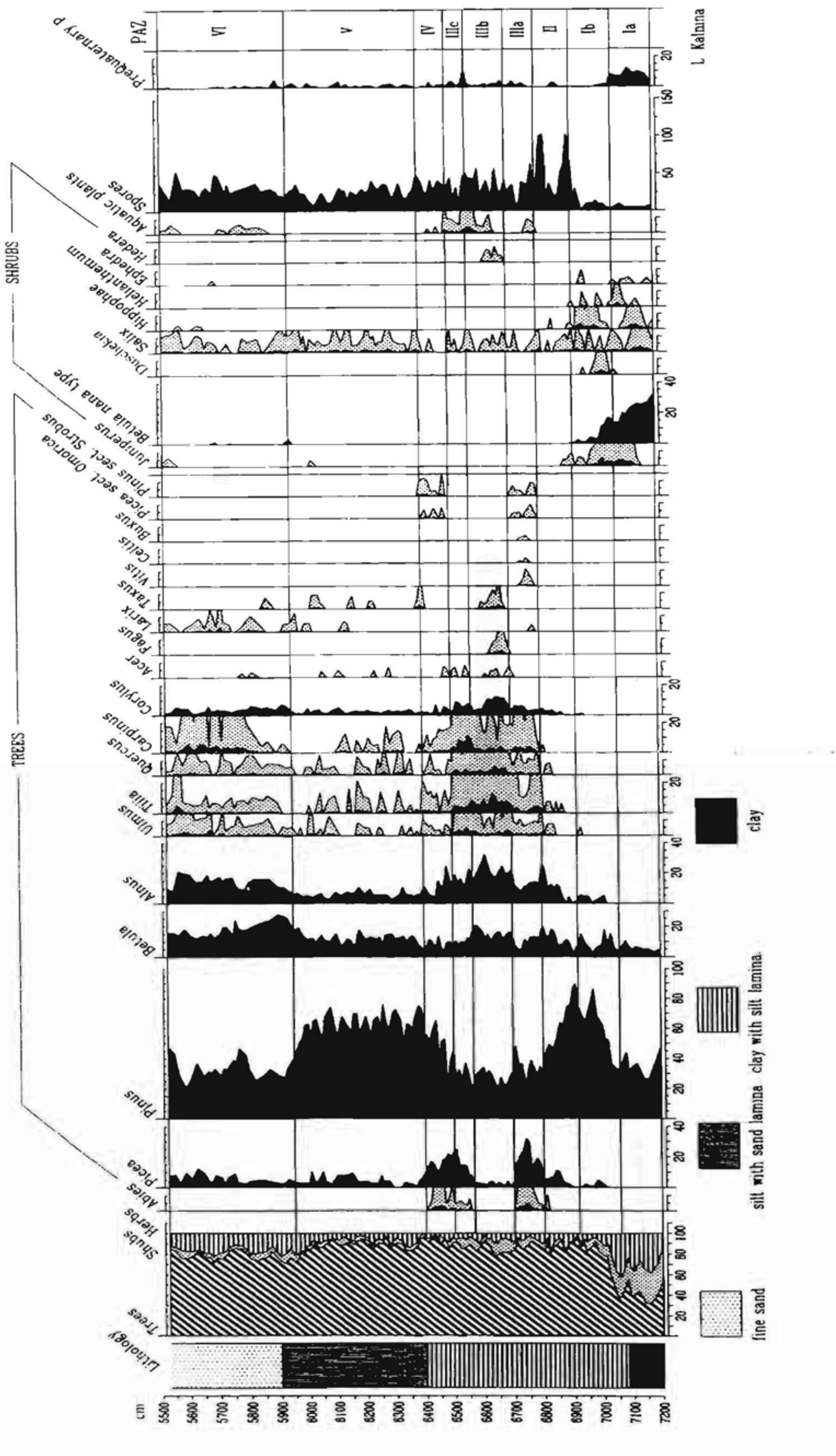


Fig. 26a. Pollen diagram of the Pleistocene deposits in the core Akmenrags-45.

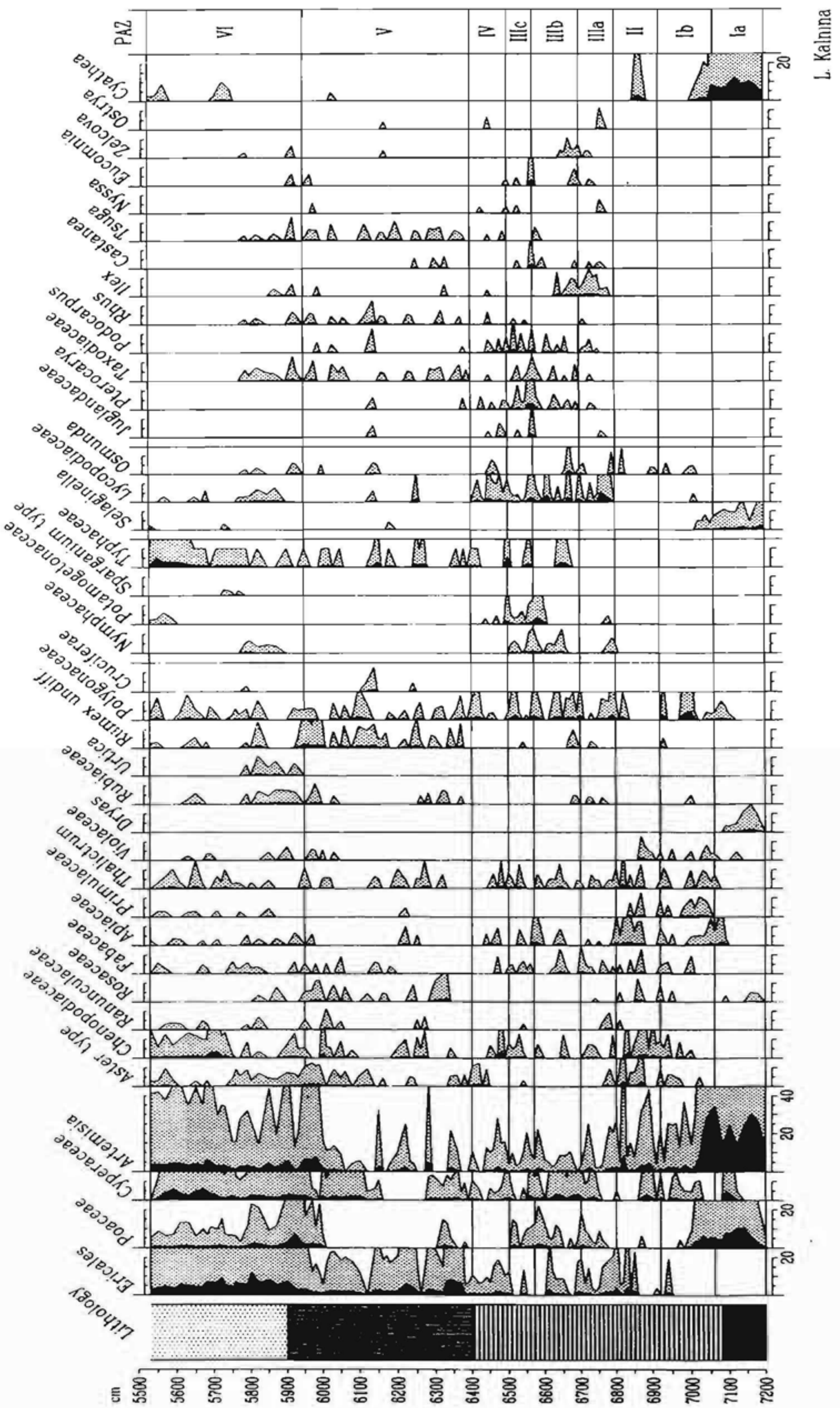


Fig. 26b. Diagram illustrating herb and exotic tree pollen and spores from the Late Elsterian and Holsteinian deposits in the core Akmenrags-45. Legend see Fig. 26a.

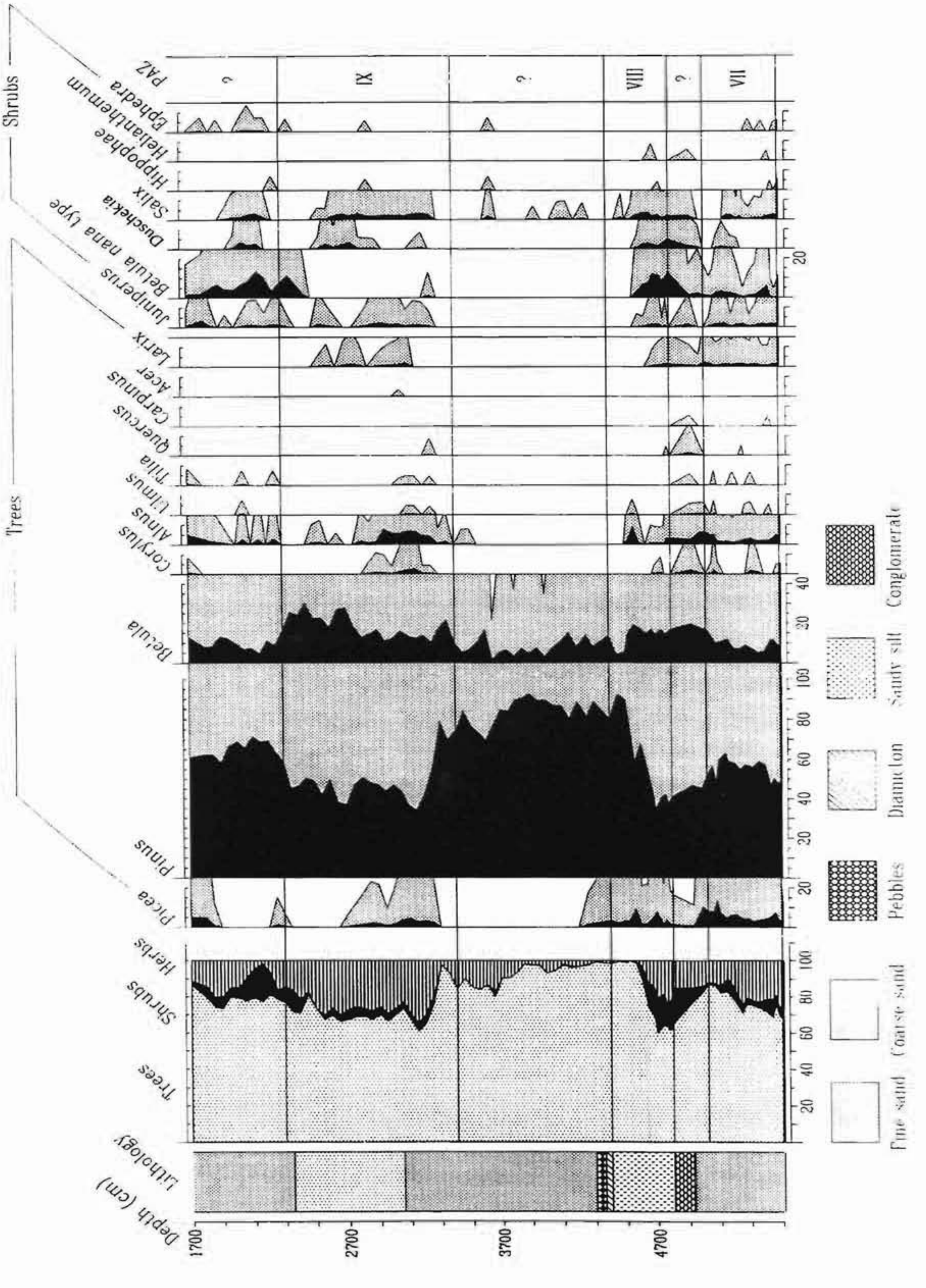


Fig. 27a. Pollen diagram of the Early Saalian deposits from the core Akmenrags-45.

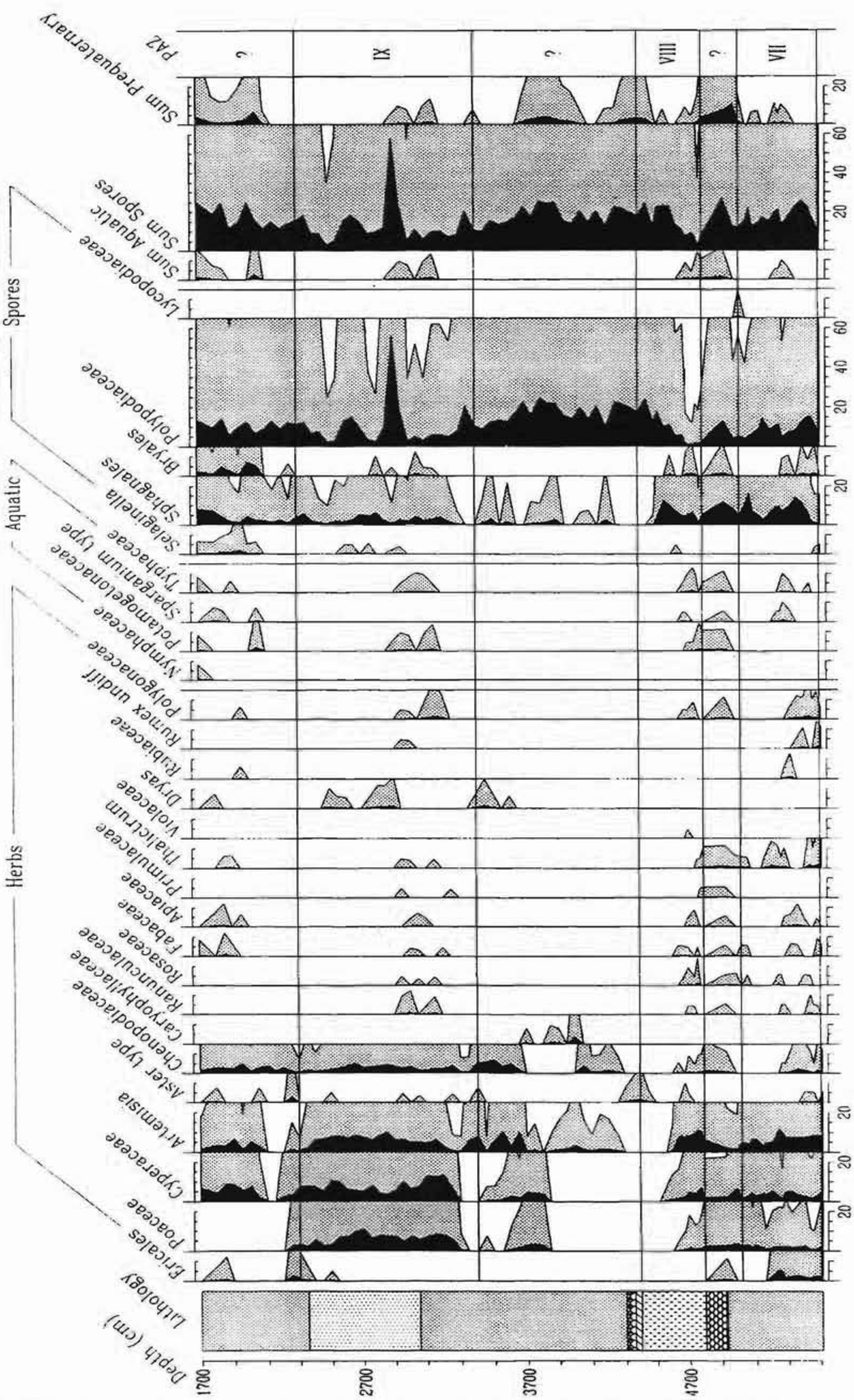
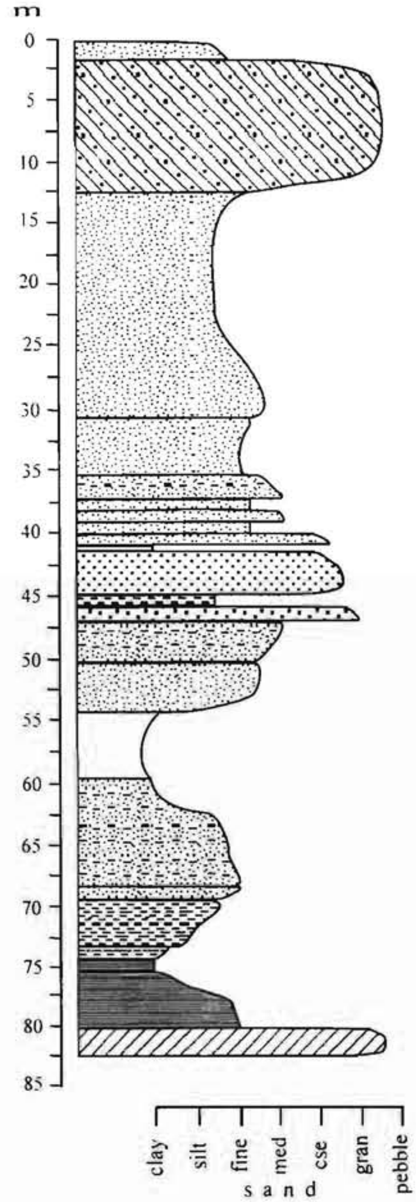


Fig. 27b. Diagram illustrating herb and aquatic plant pollen and spores from the Early Saalian deposits in the core Akmenrags-45. Legend see Fig. 27a.

6.1.6 Sudrabi site - core No. 46

56° 50'56" N Lat., 21° 07'52"E Long.
12.5 m a.s.l.
A representative sediment sequence was found in the test drilling Sudrabi–46, carried out in 1985, between the village Saka and the Cape Akmenrags.



Depth below deposit surface (m)	Description
0.0-1.5	sand, fine, light grey
1.5-13.1	till, bluish grey, pebbly
13.1-31.5	sand, fine, grey, medium coarse in the lower part
31.5-34.0	sand, with plant remains in interval 33.0-33.5 m
34.0-35.0	sand, with gravel and pebbles, with silty sand lens
35.0-35.4	sand, with silt 1.5 cm thick laminae containing plant remains
35.4-36.0	sand, middle coarsity and coarse, cross-bedded
36.0-40.5	sand, in interval 39.4-39.5 with silt lenses containing plant remains
40.5-42.5	sand, coarse, with some gravel
42.5-42.7	peaty gyttja
42.7-45.0	sand, coarse, with some gravel
45.0-45.25	silt, sandy, with fine sand laminae 0.5-0.7 mm
45.25-46.2	gravel with sand admixture
46.2-49.0	sand, with 1 cm thick sandy silt interlayers
49.0-54.0	sand, fine and medium coarsed
54.0-59.5	gyttja
59.5-68.0	sand, silty, light grey with bluish grey silt interlayers 2-4 cm
68.0-69.7	sand, fine with silt interlayers 0.1-2.0 cm containing plant remains
69.7-73.8	silt, dark bluish with laminae and lenses of fine sand and plant remains
73.8-74.8	clay, silty, greenish grey with vivianite, expressed laminae in lower part
74.8-75.7	clay, light brow, weakly laminated, contains plant remains
75.7-80.5	clay, greyish brown, dense, with lenses of reddish brown till, gravel and pebbles
80.5-82.5	till, clayey, reddish brown with carbonate rocks
	Devonian siltstone

Fig. 28. Log and lithological description of the sediment sequence in core Sudrabi-46.

Lithology
The lowermost sediment layer in the core is reddish till with gravel and pebbles of carbonate rocks. This till is replaced by the dense greyish clay with inclusions of the till at the depth 80.5 m (Fig. 28). Roundness of hornblendes is low in the till and reaches 8-10% (Fig. 30), which is characteristic of the Letiza (Elsterian) till.

The next layer (75.7-74.8 m) consists of light greyish clay with weakly expressed fine laminations in the lower part. It becomes better expressed in the upper part of the interval, marked by organic remains. Some inclusions of till are present near the base of the clay. Upwards, at the depth interval 74.8-73.8 m, there is greenish-grey clay with inclusions of vivianite and interlayers that are rich in organic remains.

This clay layer is overlain by dark bluish-grey silt (73.8-69.7 m), which has greenish fine sand interlayers at its base, thin laminae with inclusions of organic remains. At the depth interval 71.4-69.7 m, the silt layer has interlayers and lenses of fine sand and organic remains. This stratum is overlain by sand layers of various coarseness (68-13.1 m) and with gyttja (54-59.5 m) and peaty gyttja (42.5-42.7 m) interlayers.

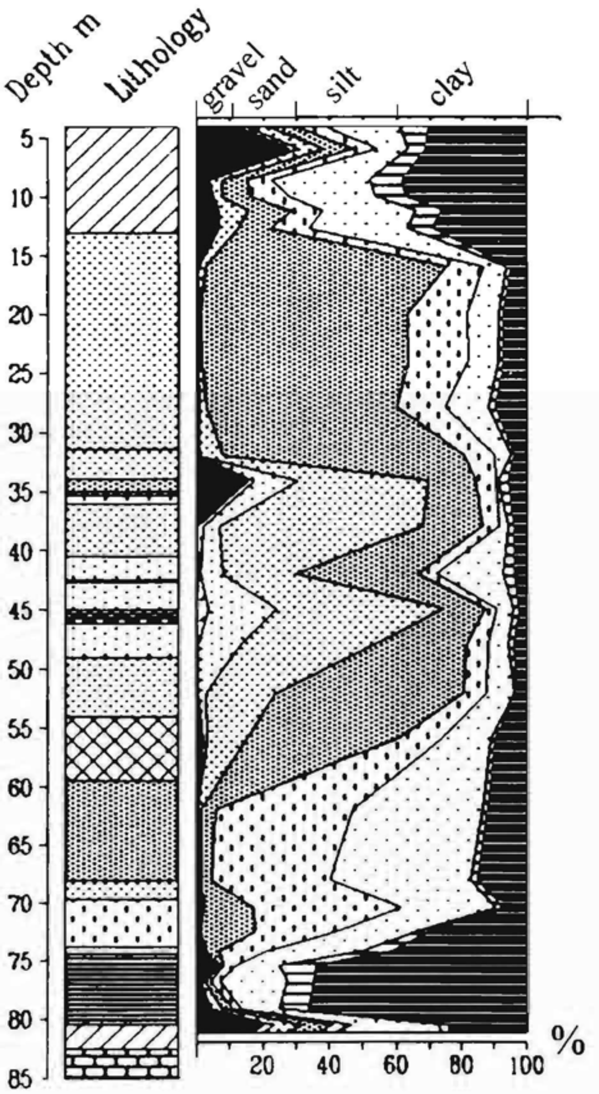


Fig. 29. Grain size composition in the sediment sequence of the core Sudrabi-46. Legend see Fig. 30.

A bluish-grey pebbly till occurs almost at the top (depth interval 13.1-1.5 m) of the sediment sequence. This is a calcareous fine-textured diamicton with a matrix consisting of clayey silt to sandy silt. The gravel fraction (2-10 cm) is dominated by limestone (81-85%), but dolostone is rare in the till, and the limestone/dolostone ratio is high (about 20), which is typical for the Kurzeme till in this area (Figs 29, 30). The hornblende grains in the 0.1-0.25 mm fraction are rounded 20-28% (Fig. 30), which is typical for the Kurzeme till of the Baltic States (Ulst & Maiore 1964).

Foraminifera

The sediment sequence of the Sudrabi site was studied by means of foraminifera (V. Mihailov in Seglins 1987) in 40 samples in the depth interval 80.0-12.0 m, but at the depth 76.0-72.0 m only 5 of them contain foraminifera. Clay at 74.7 m was richest in foraminifera (Tracevski *et.al* 1989). *Elphidium granatum* Gudina predominates (300 shells) and *E. excavatum* (470). Other foraminifera identified are present in lower amounts, *e.g. Elphidium albiumbilicatum* (8), *E. clavatum* (80), *E. inertum* (5), *Protelphidium orbicularis* (45), *Bucella* sp. ind., *Guttulina* sp. ind., *Polymorphinidae* Gen. et. sp. ind. and *Recurvoides turbinatus* Brady are found only as single shells (Fig. 31). The fauna indicates that the clay in the depth interval 75.5-74.0 m was formed under marine interglacial conditions, but in the depth interval 73.0-71.4 m the composition reflects a regression of the sea (Mihailov in Seglins 1987).

Diatom studies

Diatom studies of the Sudrabi site sediment sequence (Sakson in Seglins 1987) show that marine littoral species predominate in the lower part, *e.g. Rhabdonema arcuatum, Actinoptychus undulatus, Paralia sulcata, Chaetoceros mitra* (Bail) Cl., *C.* sp., Hyalodiscus sp., *Grammatophora arctica, Cocconeis pediculus, Opephora martyi* and *Amphora ovalis*.

Besides marine also brackish and freshwater diatoms occur upwards in the sequence, *e.g. Fragilaria inflata, Melosira islandica, Navicula scutelloides* and *Nitzschia navicularis*.

The extinct diatom taxa *Cyclotella comta* var *lichvinensis* Jouse and *C. temperei* Herib. et Perag. occur, as well as pliocene relict species: e.g. *Melosira granulata* f. *curvata* (Grun) Hust., *M. italica* f. *curvata* (Pant) Hust. and *Cyclotella iris* Brun et Herib.

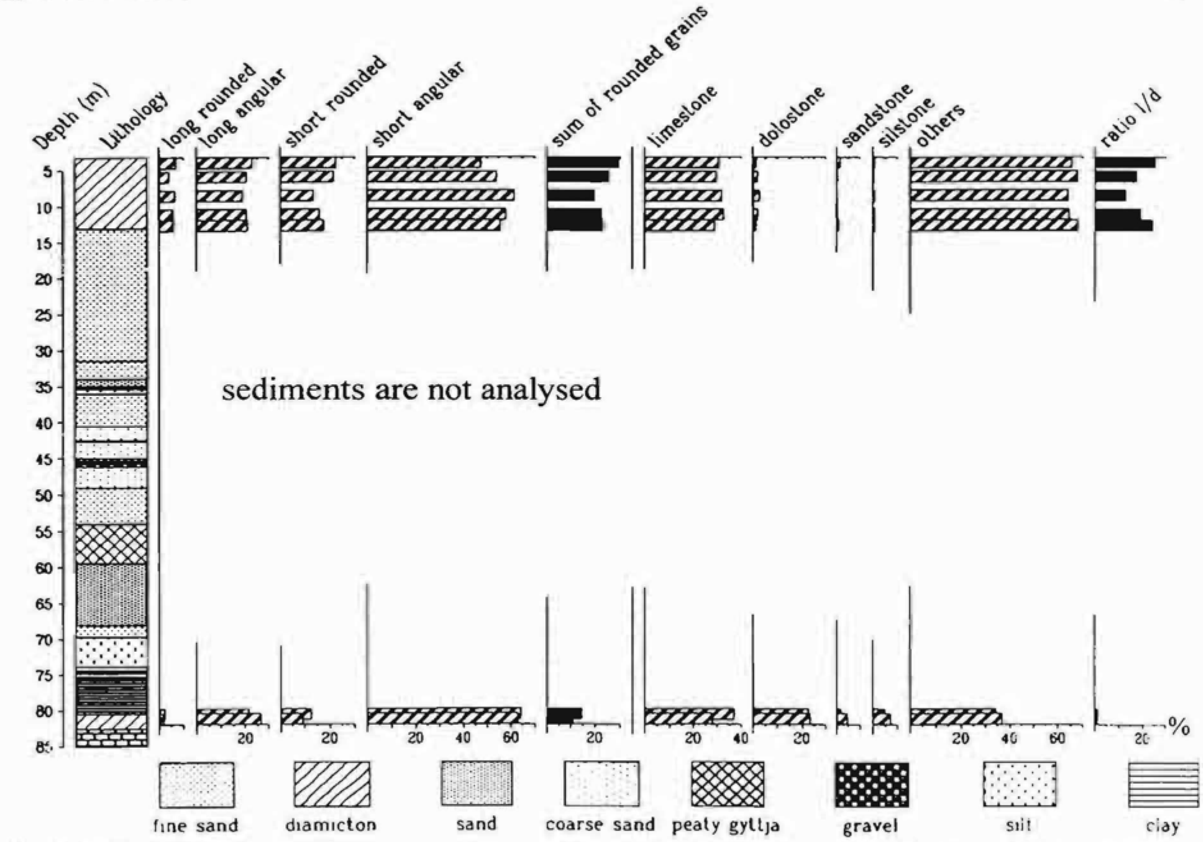


Fig. 30. Lithological composition (size fraction 0.5-1.0 mm) and roundness of horblende grains (size fraction 0.1-0.25 mm) in the sediment sequence of the core Sudrabi-46.

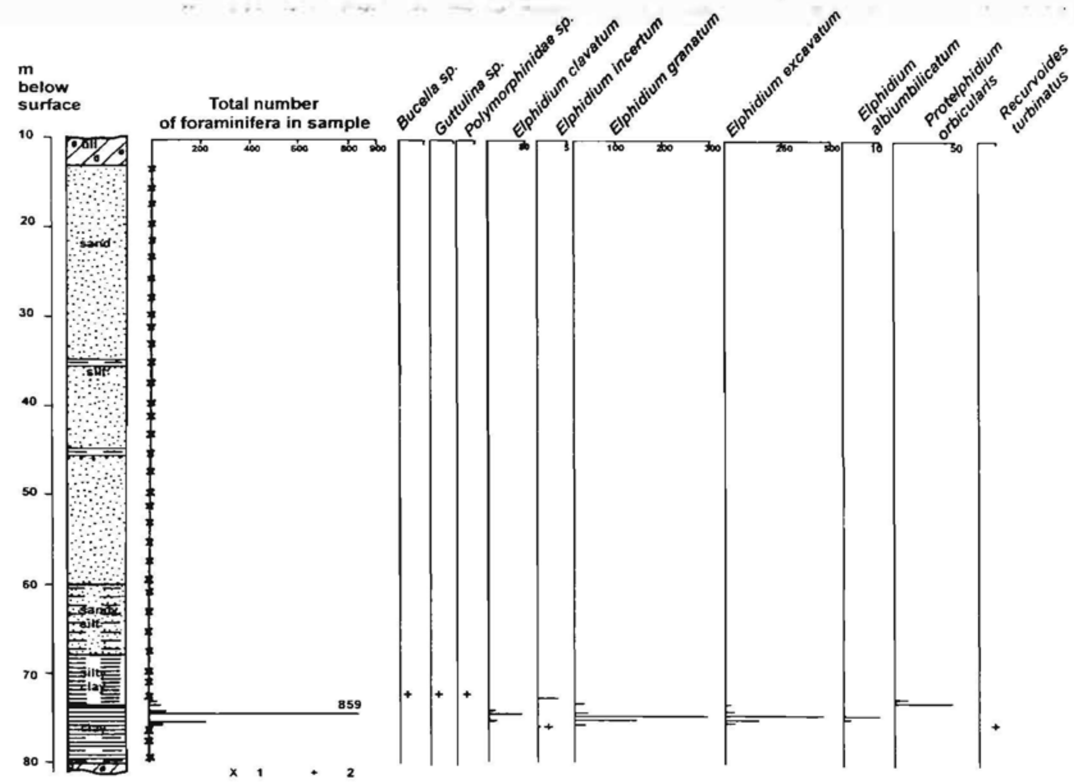


Fig. 31. Foraminifera composition in the sediment sequence from the core Sudrabi-46 (after Seglins 1987. analysed by V. Mihailov). 1- no foraminifera found; 2- single foraminifera identified.

Pollen studies

Different palynologists (O. Kondratiene, I. Jakubovska and L. Kovalenko) have carried out pollen analyses of the intertill sediment sequence (80.5-13.1 m) of the Sudrabi site. The pollen diagrams were divided in seven local pollen assemblage zones (Seglins 1987). The pollen composition of the sediment sequence of laminated and dense clays, from the lower part of the Sudrabi site section (80.4-74.8 m) is characteristic of open landscape vegetation, and Seglins (1987) suggests the name "Sudrabi layers" for these clays accumulated under periglacial conditions. The pollen complexes II-VII are comparable with those from Ulmale-9. Kondratiene noted the presence of a lot of pre-Quaternary pollen and spores (Seglins 1987).

6.1.7 Summary of results

Lithological studies

The Quaternary deposits in the study area were analysed by means of lithological parameters of glacial and interglacial, as well as interstadial formations. These data constitute the basis for establishing the stratigraphical position of the sediment sequence, as well as to find out the palaeoenvironmental records of the sedimentation conditions.

The oldest diamicton: Letiza till (Ltz)

A brownish grey diamicton has been found overlying the Devonian bedrock. The lithological characteristics of this diamicton are that of Letiza till (Springis *et al.* 1964; Konshin 1964; Danilans 1970). The till bed in this region is comparatively thin, only up to 2-4 m, a reddish brown to brown very dense calcareous diamicton, with sandy or silty clay dominating in its matrix and with high gravel and pebble content. The till is rich in carbonates: an average of 58% in the 0.5-1.0 mm fraction (Figs 11, 20), with the limestone/dolostone ratio 1.5. Hornblende grains, 0.1-0.25 mm fraction, are very angular, only 10% occur as rounded grains (Figs 11, 15).

Sudrabi member (Sd)

The Sudrabi beds, dense and weakly laminated clays, have been found 70-50 m below the present sea level (Fig. 7) and 80.5-67 m below surface (Figs 14, 28). They are underlain by the oldest diamicton identified as the Letiza till, and are overlain conformably by the Akmenrags formation. Their thickness is relatively uniform, ranging from 1.5 to 6 m, commonly about 3 m. The Sudrabi beds comprise laminated clays, becoming silty towards the top. Because of the increasing organic content, their colour gradually changes from reddish brown at the base to greyish brown in the middle and grey at the top. Lumps, up to 0.6 m thick, of the underlying Letiza till occur in the lower part, with impact structures in the laminated clays underneath them. Small clasts, ranging from coarse sand to pebbles, are present higher up. Charamisinava (1971) also reported sand lying underneath the clay, but our test drillings did not encounter it. Beside plant remains, fragments of mollusc shells, particularly *Portlandia arctica,* and also ostracods and foraminifera in the upper part (Konshin *et al.* 1970; Seglins 1987), and diatoms (Charamisinava 1971), are present.

According to Charamisinava (1971) most of the marine diatoms that are present in the lower part of the clay, were also found in the underlying till, which means that they may have been redeposited from older deposits, but most of the taxa identified in the upper part of the Sudrabi clays were not, however, noticed in the underlying till, and they may be indigenous in the clay, suggesting its deposition in a marine environment.

Akmenrags formation (Ak)

The Akmenrags formation (Seglins 1987) occurs through an area of over 200 square km (Fig. 1c), with its top at a depth of 55-40 m below the present sea level (Figs 10, 14, 18, 24). Its thickness increases from zero about 4-7 km inland from the Baltic Sea coast to more than 13 m in test drillings near the coast between Akmenrags and Ulmale

(Fig. 16). The Akmenrags formation overlies the Sudrabi member concordantly with transitional contacts. Laminated grey, slightly greenish, sandy silts dominate. The sand content increases towards the top, where the greenish colour changes to light grey, occasionally black when moist.

The Akmenrags formation is rich in disseminated organic material, particularly plant remains, but also ostracods, foraminifera, diatoms and fragments of marine mollusc shells (Konshin *et al.* 1970). It also contains blue grains (0.5-3 mm diameter) of vivianite, pyrite concretions, limonite crusts along with plant remains, occasional grains (about 0.5 mm) of amber and some insect remains.

According to Charamisinava (1971) and Sakson (Seglins 1987) a great variety of marine and brackish water diatoms are present in the sediments of the Akmenrags formation, definitely suggesting a marine environment. Konshin *et al.* (1970) report, besides the marine species, also several brackish water and freshwater diatoms, suggesting considerable input of freshwater into the marine environment. The presence of freshwater ostracod *Cytherissa lacustris* in the middle part of the Akmenrags sediments (Konshin *et al.* 1970, p. 43) and the reduction in the amount of marine diatoms indicate a dominant freshwater phase at that time. A water depth of more than 20 m is suggested by comparing several of the foraminifera species with those present in the Holocene sediments in the Kattegat (Nordberg 1989).

The contact of the Akmenrags formation with the overlying Jurkalne formation appears to be concordant, except for a buried valley east of the Jurkalne.

Jurkalne formation (Jrk)

The Jurkalne formation was identified in 50 test drillings and at the Baltic Sea bluffs through an area of more than 600 sq. km (Fig. 1). Its thickness increases from zero about 12-15 km inland of the Baltic Sea coast, to almost 60 m at the coast in the Ulmale area (Fig. 7).

The upper part of the Jurkalne sediments and the overlying Kurzeme till have been glaciotectonically deformed (Fig. 7). In the coastal abrasion plain the upper parts of both the strongly deformed units have been partly eroded, exposing the Jurkalne sediments in sea shore bluffs, stream cuts and on a surface underneath a thin cover of the Baltic Ice Lake sediments. Because of the glaciotectonic deformations, the elevation of the Jurkalne formation and Kurzeme till contact varies for at least 20 metres (Kalnina *et al.* 2000).

The most common sediment of the Jurkalne formation is fine to medium grained sand interbedded with thin layers or lenses of coarser, even gravelly sand. Less common are silt beds, containing plant remains, but one of them, in the middle, is up to 10 m thick. Thin beds (0.2-1 m) of clay are encountered in some depressions.

The Jurkalne formation may be subdivided into two main continuous subunits or members: Jrk1 and Jrk3 sediments (Kalnina *et al.* 2000). They are separated by the Jrk2 silt bed in the Strante - Jurkalne area (Fig. 7, Table 6).

The lower member, Jrk1, is about 10-25 m thick fine and silty sand layer (Fig.7). Deformation structures were noted at the contact with the overlying diamicton south of Strante. In the sand layers the carbonate content is low, about 8% in the 0.5-1 mm grade, with an average limestone/dolostone ratio of 7.6 (Figs. 11, 15).

The upper member, Jrk3, is up to 30 m thick and sandy, but coarser grained, with 0.25-1.0 mm particle size fraction dominating. Gravel content is commonly up to 15%, but it *increases* to 25-35% along the lower boundary. Silt lenses are rare and thin. Pebbles, cobbles and boulders are present in some test drillings along this boundary. In seven test drillings in the Strante-Ulmale area, a 0.2-3 m thick till-like greenish grey, sandy clay to clayey sand diamicton was encountered. Lithologically the diamicton resembles the Kurzeme till (Fig. 20): its limestone/dolostone ratio averages 22.5, ranging from 4 to 46, and the percentage of rounded hornblende grains is 22, ranging from 13 to 38. Texturally this diamicton is either more clayey or more sandy than the typical Kurzeme till of the same area (Kalnina *et al.* 2000).

In contrast to the lower subunit, the carbonate content in Jrk3 is high, averaging 34% in the 0.5-1 mm fraction, and the limestone/dolostone ratio is also high: average 23 (Fig. 25). The organic content is low, and therefore yellowish and brownish colours dominate.

Marine diatoms were encountered by Charamisinava (1971) in the Jurkalne sediments, but in low abundance, and they may have been incorporated from reworked and underlying Akmenrags sediments. According to M. Sakson (in Seglins 1987) brackish water diatoms are present in the lower part of the Jurkalne sediments, followed higher up by eutrophic freshwater species.

Kurzeme till (Kr)

The Kurzeme till (Kr) is a bluish grey to grey calcareous fine textured diamicton, with a matrix consisting of clayey to sandy silt (Fig.4 and Dreimanis 1936, Table II). Its gravel fraction (2-10 cm) in sections exposed along the Baltic Sea Bluffs (Fig. 7) is dominated by limestone, up to 86% (Dreimanis 1936; Konshin 1964), with Precambrian igneous and metamorphic clasts in second place (19-35 %); dolostone is rare (0-1%). In the 0.5-1 mm fraction the limestone percentages is 23-55 and dolostone 0-3%. The resulting high limestone/dolostone ratio, about 20 (Fig. 15) is typical for the Kurzeme till along the Baltic Sea coast in western Latvia (Dreimanis 1936; Konshin 1964; Bitinas *et al.* 1998). Commonly more than 20% of hornblende grains in the 0.1-0.25 mm fraction are rounded (Fig. 15); this is typical for the Kurzeme till of the south-eastern Baltic region (Ulst & Maiore 1964).

The Kurzeme till and the underlying Jurkalne formation sediments have been glaciotectonically deformed (Fig. 3; Dreimanis 1936) in meso- to megascale, mainly by being folded. The deformations are exposed along the bluffs of the Baltic Sea, particularly between Strante and Jurkalne (Dreimanis 1936, Fig. 12). Most deformations are large-scale folds, striking north-east – south-west. The deforming stress came from the north-west.

Pollen stratigraphy

Pollen diagrams from the sediment sequences analysed by means of pollen in the Ziemupe-Jurkalne area (Ulmale-9, 41a, Akmenrags-45, Ozoli-44, Strante-33, and Sudrabi-46) provide a relatively complete sequence and characteristics of the vegetation succession at the time of the accumulation of the investigated deposits. Pollen analysis performed on the sediment sequence from the Sudrabi-46 show that the data obtained are very important, particularly from its lower part, and this section is established as stratotype site for the Saalian Late Glacial clay beds rich in foraminifera and ostracods (Seglins 1987). The sediment sequence at the Akmenrags site contains pollen spectra that reflect the complete vegetation cycle during the Holsteinian Interglacial and has been chosen as a stratotype site (Seglins 1987, Kalnina 1993, 2000, 2001, Kalnina *et al.* 2000)

By comparing and correlating the pollen diagrams, nine regional pollen assemblage zones (PAZ I-IX) have been distinguished. The characteristic pollen spectra of these zones and the thickness of the sediments of each zone as found in the four cores are listed in Table 6.

All nine pollen assemblage zones were encountered in the Ozoli and Akmenrags sections (Figs 22, 27). In the other sections the accumulation of sediments has apparently been interrupted, as indicated by the sudden changes in the grain size and lithological composition and pollen assemblages. The pollen curves suggest interruptions in sedimentation, probably by erosion, particularly in PAZs II, V, and VI.

At Strante (Fig. 17) and Ulmale (Fig. 13) the sands overlying PAZ V contain very few pollen, mostly *Pinus* and those that are present are torn and corroded, and have been reworked. Sediments representing the pollen assemblage zones VI - VII may have been present here, but were probably destroyed and reworked by water currents. At Strante (Fig.17b) and Ulmale (Fig. 13b) only PAZs VIII and IX were identified, separated by intervals poor in pollen.

Sudrabi layer (Sd)

The amount of palynomorphs from the deposits of the Sudrabi layer varies from 10 to 200 grains per 1 g of dry sediment, most commonly about 100. The pollen spectra from this sediment sequence represent PAZI.

PAZ I - Arboreal pollen dominates: 60-70% of the total pollen sum, but the greater part of them, *i.e.* tree pollen, are result of redeposition or long distance windblown, particularly *Pinus* pollen. NAP is present with *Artemisia* (7-40%) and Chenopodiaceae (up to 21%). *Betula* usually varies from 10-20%, though in the Ulmale section it reaches 50%. *Alnus* pollen percentage values vary from 2 - 20%. Most of the birch pollen is from *Betula nana* type and *B. humilis*. *Duschekia* pollen is present (up to 10%) in the lower part of the Sudrabi beds. *Salix* pollen is commonly 1-5%, except for the lower part of the Strante section, where it occurs with up to 10%. Pollen of *Larix* appears sporadically. *Picea* sect. *Eupicea* pollen was also recorded. *Quercus* and *Corylus* pollen is either torn or mineralised. Periglacial plant pollen and spores, *e.g.* *Ephedra, Hippophaë, Selaginella selaginoides, Helianthemum, Dryas octopetala, Lycopodium alpinum,* are present. The amount of spores ranges from 5% at Strante to 20% at Ulmale. Pre-Quaternary palynomorphs are represented by for example *Taxodium, Sequoia, Ilex, Ostrya, Eucomnia, Rhus, Nyssa, Pterocarya, Tsuga* and *Cyathes*.

In general the pollen composition of PAZI represents a light demanding pioneer vegetation with a change from arctic tundra-steppe vegetation to subarctic tundra-forest tundra with some boreal elements towards the top of the zone. Changes in the relationship of pollen values inside the zone, reflect climate fluctuations during the deglaciation and allow the division in **a** and **b** part in some sections. The boundary between **a** and **b** is marked by the increase in the pollen values of *Betula nana* type, *Dryas* and *Artemisia* and decrease in the absolute amount of palynomorphs (~10 grains per g). This probably reflects a short climatic deterioration represented only by a few samples in the interval of ~ 10-20 cm in some sections (Strante-33 and Ulmale-41a).

Table 6. Characteristic pollen spectra and sediment thickness of the pollen assemblage zones I-IX in the cores from Strante-33, Ulmale-41a, Ozoli-44 and Akmenrags-45.

(Age) and formation or member	PAZ	Characteristic pollen spectra	Thickness of sediments			
			33-Strante	41a- Ulmale	45-Akmenrags	44-Ozoli
(Saalian interstadials?) Jurkalne - 3	IX	*Pinus, Selaginella selaginoides, Artemisia*	? (10.0 m) 10.5 m ? (10.5 m)	?(19.0 m) 1.0 m	? (30.0 m) 2.0 m? (16.0 m)	19.0 m
Jurkalne - 2	VIII	*Betula nana, Duschekia, Artemisia, Dryas*	5.0 m	19.0 m	3.0 m	10.5 m
(Early Saalian) Jurkalne - 1	VII	*Pinus*	? (24m)	? (11m)	4.5 m	10.3 m
(Holsteinian) Akmenrags	VI	*Pinus, Betula, Alnus*, Ericales	-	-	3.5 m	5.2 m
	V	*Pinus*	1.0 m	3.0 m	4.5 m	1.6 m
	IV	Maxima of *Abies, Picea;* presence of *Picea* sect. *Omorica, Pinus* sect. *Strobus*	3.5 m	2.0 m	1.6 m	1.1 m
	III	Maxima of Quercetum mixtum and *Alnus*, presence of *Pinus* sect. *Strobus*, *Picea* sect. *Omorica, Osmunda*	2.5 m	2.5 m	2.0 m	1.0 m
	II	*Pinus*	-	0.7 m	1.0 m	0.4 m
(Late Elsterian) Sudrabi	Ib	*Pinus, Betula, Betula nana*	2.0 m	2.1 m	2.0 m	0.8 m
	Ia	*Betula nana* type, *Artemisia, Dryas*, pre-Quaternary palynomorphs	1.5 m	0.4 m	2.0 m	0.6 m

Akmenrags formation (Ak)

Five pollen assemblage zones (II-VI) were distinguished in the Akmenrags formation. Pollen grains are well preserved in the clayey sediments. The sediments representing PAZ II comprise 0.9 m in the Akmenrags section, 0.5 m in the Ulmale section, 0.4 m in the Ozoli section and they were too thin in the Strante section to be differentiated.

PAZ II - Arboreal pollen dominates, but in some sections spores are very abundant, for instance in the Akmenrags section. *Pinus* dominates among the AP at the bottom, but it decreases upward. *Betula* is represented only by tree-like species. *Picea* and *Alnus* pollen are present, and increase gradually. Pollen of broad-leaved deciduous trees and *Corylus* form continuous curves. *Abies* and *Carpinus* pollen appear near the top of PAZ II. NAP is 5-15%, represented mainly by *Artemisia*, Chenopodiaceae, and Ericales.

The upper boundary of PAZ II is drawn where the abundance of pollen increases up to 500 grains per 1 g sediment, and where considerable increase is noticeable in the pollen percentages of *Alnus* (30%), Quercetum mixtum (10%) and *Corylus* (20%).

PAZ III - The sediments of this zone are particularly rich in organic material, and palynomorphs reach up to 800 grains per 1 g dry sediment. Arboreal pollen constitutes up to 85%, and NAP less than 5% of the total pollen sum.

The abundance of *Picea* pollen increases rapidly, and in some sections it reaches a maximum (47% in the Strante section). *Picea* sect. *Omorica* pollen was found occasionally. *Abies* (*Abies alba* and *Abies* sp.) reaches a maximum (5%), *Carpinus* occurs up to 10%. *Pinus* is less abundant, 20-30%; occasional *Pinus* sect. *Strobus* pollen was noted. *Alnus* culminates at 40%, *Corylus* at 15-20%, and Quercetum mixtum at 17%. *Tilia* dominates among the broad-leaved deciduous trees: 15%, including *Tilia platyphyllos* and *Tilia tomentosa*. The pollen maxima of thermophilous trees listed above are particularly strongly developed in the Strante section (65.5-63.0 m) and in the Akmenrags section (68.0-65.0m). Still, there are also some differences among the sections investigated. Thus, the broad-leaved deciduous tree pollen values culminate in the Strante and Ulmale sections before the *Picea* and *Abies* pollen maxima. In the Akmenrags, however, the QM pollen maximum divides the *Picea* and *Abies* maxima in two parts. This is probably a local phenomenon.

The NAP is represented mainly by "Varia" (undifferentiated herbaceous pollen). Spores are relatively abundant, mainly Polypodiaceae and *Sphagnum*. A few spores of ferns, *Osmunda claytoniana* and *O. regalis* type were present (not shown in the diagrams), as well as *Lycopodium clavatum* and *L. annotinum*.

The upper boundary of the PAZ III is marked at the level where the pollen percentages values of *Alnus, Corylus* and QM mixtum decrease, and those of coniferous taxa increase.

PAZ IV - The absolute amount of palynomorphs from the sediment is still high: 300-400 grains per 1 g dry sediment, but with a tendency to decrease. The proportions of AP, NAP and spores remain the same as in PAZ III. Marked changes occur among the tree pollen values. The role of coniferous trees becomes more prominent, particularly pine (up to 70%). *Pinus* sect. *Strobus* and *Picea* sect. *Omorica* pollen is present. *Abies* pollen values are up to 3%. The pollen percentages of *Alnus* (about 10%), *Corylus* (about 5%) and broad-leaved trees (about 2%) decrease markedly.

The upper boundary of PAZ IV is marked by a decrease of *Picea* and the appearance or increase of *Artemisia* pollen. The percentages of *Sphagnum* spores also increase in most sections.

PAZ V - The abundance of palynomorphs decreases to about 20 grains per 1 g dry sediment, except for Akmenrags, where it is still about 40. The AP remains dominant, but the percentages values of NAP, particularly Ericales and *Artemisia*, and the *Sphagnum* spores increase. *Pinus* is the dominant forest tree. *Picea* decreases, and *Abies* disappears. Even the percentages of *Betula* and *Alnus* decrease, and the presence of broadleaved deciduous trees is sporadic. *Larix* pollen occurs in some sections.

The upper boundary of PAZ V, which also coincides with the upper sedimentological boundary of the interglacial silty Akmenrags formation, is determined by a decrease in the amount of palynomorphs to less than 10 grains per 1 g sediment, again with exception of the Akmenrags section, and the absolute dominance of *Pinus* pollen (about 85%), while the frequency of other pollen and spores is low.

PAZ VI - is represented in the Akmenrags and Ozoli sections. The amount of palynomorphs increases slightly, but the percentages of trees decrease, while NAP percentages increase, particularly Ericales and Cyperaceae. Among tree pollen *Pinus* decreases considerably, while *Betula* and *Alnus* pollen increases in abundance. Subarctic flora elements, e.g. *Dryas* occur simultaneously with some pollen of broad-leaved trees. The latter ones may have been redeposited from older sediments, similarly to the pre-Quaternary pollen that are also present. Spores, particularly *Sphagnum*, are abundant.

Jurkalne formation (Jrk)
At Akmenrags (Fig.15) and the test drilling at Ozoli (Fig.12), the Jurkalne formation is represented by pollen assemblage PAZs VII to IX, but at Strante (Fig. 8) and Ulmale (Fig. 6) by the PAZs VIII and IX (even with a question mark, because of the probable reworking of the pollen). The differences in pollen spectra, preservation level of pollen and sediment granulometric composition permit us to separate the Jurkalne-1 (PAZs VII), from Jurkalne-2 (PAZ VIII) and from Jurkalne-3 (PAZ IX).

PAZ VII - In the Akmenrags section (Fig.15b) most of the sediments belonging to this zone are sandy layers, where pollen is poorly preserved and low in content. *Pinus* dominates (60-80%) among the arboreal pollen, with a presence of *Betula*, (10-20%), *Picea* (10%) and some broad-leaved deciduous trees. NAP occurs up to 10%, represented mainly by *Artemisia* and Cyperaceae. Spores compose 20%. This pollen spectrum is not very reliable for palaeoclimatic and palaeoecologic interpretations. The presence of pollen of both thermophilous and periglacial plants suggests that some of them are redeposited. Pollen spectra with high *Pinus* percentages are present also in the 55.5–39 m interval of the Strante section (Fig. 17b) and 60-44 m of the Ulmale section (Fig.13b). The absolute frequency of pollen is, however, so low (less than 25 grains per 1 g dry sediment at Ulmale and Strante), and, with the exception of the very high frequency of *Pinus* pollen, other pollen are so poorly represented that zonal assignments for this interval can not not be justified in these two sections.

PAZ VIII – Silts, at the interval of 39-31m in Strante and 44-36 m of Ulmale, are relatively rich in palynomorphs: up to 450 grains per 1 g of sediment. The pollen and spores are well preserved. NAP is abundant (25-30%), also spores (20-30%), but AP decreases to 40-50%. About equal percentages of *Pinus* and *Betula* pollen are present among the AP, but *Betula nana* type and *B. humilis* dominate among birches. *Alnus* and *Duschekia* are also relatively abundant (20-25%), and *Salix* forms a continuous curve.

Artemisia dominates among NAP, Cyperaceae pollen corresponds to 15-20%, Ericales and Chenopodiaceae to 3-12%. *Sphagnum* dominates among spores. *Selaginella selaginoides*, *Lycopodium alpinum*, *L.clavatum*, *L. selago* and *L. appressum* are present. Redeposited Tertiary pollen, and pollen of *Picea* and broadleaved deciduous trees occur in small, insignificant quantities.

In the Akmenrags section (Fig. 27) the sediments are sandy and contain more arboreal pollen (60-80%), particularly *Pinus*, than in the above two sections, suggesting a presence of more redeposited or long distance transported pollen. The abundance of NAP here is low, less than 10%.

At Ulmale the upper boundary of the PAZ VIII coincides with the thin diamicton layer at 35.5 m (Fig. 13) that occurs at the base of Jrk3. At Strante this diamicton layer is located some 15 m higher (Fig. 8). Except for the directly underlying 1.5 m of silts, sand dominates here at the interval of 31.5 to 20.5 m. As is often the case, in sand pollen is poorly preserved and has low values, but the pollen and spore spectrum in the silts at 19-20.5 m interval is similar to that underneath the sand.

The interval between PAZs VIII and IX - This interval, with questionmark in Figs 13 and 17, is characterised by a very low frequency of palynomorphs and poor preservation of those that were encountered: they were torn and/or corroded. *Pinus* pollen dominantes, but others vary in quantity from one site to another. All the above characteristics suggest redeposition.

PAZ IX - This zone is best represented in the Strante section (Fig. 17) at the interval 17.5-10.0 m, above the thin diamicton layer. The pollen and spore abundance and composition are similar to that of PAZ VIII, but with some differences: *Betula* pollen dominates among the arboreal species, and *Alnus* is considerably more abundant than *Duschekia*. Ericales and Polypodiaceae are more abundant than in PAZ VIII. Though *Picea, Carpinus* and Quercetum mixtum form continuous low quantity curves, so does the Tertiary redeposited pollen, suggesting that all of them be redeposited. In the Ulmale section (Fig.13b), the stratigraphically equivalent part is at 35-5 m. Most of it is sand with low palynomorph frequency and poorly preserved pollen and spores. An exception is a silty interbed at 20-18 m. Its pollen and spore spectrum is very similar to that of PAZ IX from the Strante section described above.

Upper part above PAZ IX - No zones have been distinguished in the upper parts of the pollen diagrams (Figs 13b, 17b) because of the following reasons. First, in the Akmenrags and Ulmale sections the absolute pollen frequency is too low. Second, in the Strante section, the upper 10 m consist of deposits of the last glaciation, a till layer overlain by glacio-lacustrine sediments not discussed in this paper.

Summary

The palynological investigations suggest three main pollen complexes, which reflect three different vegetation types on the adjacent land at the time of the formation of the sediment sequences investigated:

1) A periglacial vegetation with relatively high frequencies of *Betula nana* type and herbaceous pollen, including a dominance of *Artemisia* and Chenopodiaceae and presence of pioneer plants, *e.g. Selaginella selaginoides*, *Dryas* and *Hippophaë,* and redeposited Devonian and Tertiary spores and pollen.

2) The PAZs II - VI, represent a temperate climate vegetation complex. It is dominated by pollen of coniferous trees, with the following characteristics: an early appearance and significant values of spruce (*Picea*), a simultaneous appearance of thermophilous deciduous trees, presence of *Abies*, *Picea* sect. *Omorica, Pinus* sect. *Strobus, Osmunda claytoniana* and *Ligustrum.*

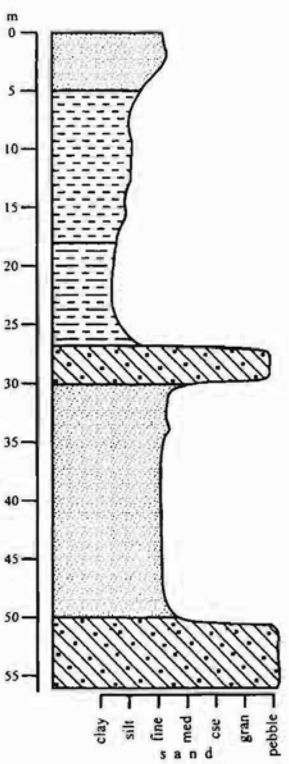
3) The pollen spectra from PAZs VIII and IX suggest an open landscape vegetation on the adjacent area.

6.2 Eemian and Weichselian sites

In the Gulf of Riga, the first Eemian site was found at a geological mapping in 1990. Two separate sites, Grini and Plašumi (Fig. 1B, C) occur on the west coast of Latvia. Initially these two sites were not interpreted as Emian, because a limited number of analyses were done among others pollen analysis, and no certain lithostratigraphical position could be established. These sites have been reinvestigated by the author, and the palaeogeographical and palaeoecological conditions during the formation of the sediment have been determined.

6.2.1 Test drilling cores from the Baltic basin at the Latvian coast

Grini site - core No. 22
56° 48' 15" N Lat., 21° 10'20"E Long., 11.7 m a.s.l.



Depth below surface (m)	Description
0 - 5.0	sand, fine, with silty interlayers
5.0 - 18.0	silt, greenish grey with silty sand and clay laminae, plant remains
18.0 - 26.8	clay, silty with sand interlayers, brownish grey
26.8 - 30.0	diamicton, clayey, grey
30.0 - 50.0	sand, fine with silt interlayers
50.0 - 56.0	diamicton, violet reddish brown, compact

Fig. 32. Log and general description of the sediment sequence in the core Grini-22.

The Grini site is located south-east of Akmenrags, close to the boundary of the distribution area of the Akmenrags (Holsteinian) interglacial deposits (Fig. 2). Coring at Grini (Fig. 32) was carried out during the geological mapping (Tracevski *et al.* 1989) with a core recovery of c. 90%.

A 56.0 m long core with Quaternary deposits was sampled, but initially only some of the samples were analysed. The age of the deposits was not defined and the entire sediment sequence overlying the upper diamicton, interpreted as Kurzeme (Saalian) till because of its grey colour (Fig. 32, 33), was considered to be of Late Latvijan (Weichselian) age. Doubts about such an interpretation stimulated a reinvestigation of the sediment sequence of silt and clay (26.8-5.0 m) overlying the Kurzeme (Saalian) till, with special attention to the depth interval 26.8-18.8 m, which consists of a silty clay layer with high content of organic matter. This organic bearing clay was also found in test drilling No.113 (Fig. 33) located south-east of the Grini site at the same depth. The clay is underlain by two different till beds, which were identified as belonging to the Kurzeme (Saalian) and Letiza (Elsterian) glaciations (Kalnina *et al.*, 2000). The clay was not noted in the borings made towards the sea and in the deeper part of the Baltic Depression (Nos. 87, 45, Fig. 33). The marine origin of the clay was established by diatom analysis in connection with geological mapping and also a few foraminifera were found in the clay.

Lithology

Reddish brown very compact, massive and calcareous diamicton with silty clay in the matrix directly overlaying the Pre-Quaternary rock has been found in the lowermost part of the core Grini-22. Gravel and pebble content is comparatively high, and mostly represented by limestone, in contrast to Precambrian clasts, which are rare. The limestone/dolostone ratio is 1.6 and roundness of hornblende grains in the size fraction 0.1-0.25 mm is 8-9%. At a depth of 50.0 m the diamicton is overlain by 20 m fine sand with silt interlayers (Fig. 32).

A grey clayey calcareous diamicton covers sand strata at the depth 30.0 m. It is finely textured and the matrix consists of clay to clayey silt. A brownish grey silty clay with 1-3 cm sand interlayers has been found at the depth 26.8-18.0 m overlying the diamicton. The clay is rich in organic remains. Upwards in the sediment sequence (depth 18.0-5.0 m) the clay is replaced by greenish grey silt with silty sand, clay laminae, and plant remains.

The uppermost part of the sediments in this core is represented by sand with silty interlayers and is poor in organic content.

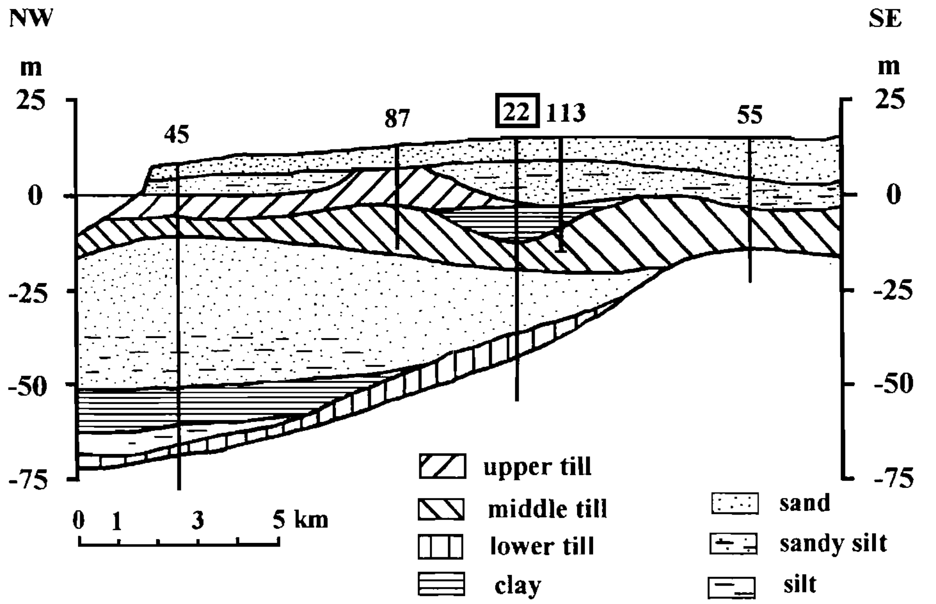


Fig. 33. Geological cross-section at the Grini site (after Kalnina & Juskevics 1998a)

Diatom analysis

(Sakson pers. communication)

The sediments analysed were poor in diatoms, which were noted only in a few samples. On the basis of the positive results from the 26-23.5 m interval of the brownish grey clay with silt and sand interlayers, two diatom assemblage zones GR-D1 and GR-D2 were established:

GR-D1: The depth interval 26-24.5 m is dominated by the freshwater taxa *Cocconeis disculus* and *Diploneis domblittensis*. Diatom frustules of the indifferent, fresh to slightly brackish water genera *Pinnularia* and *Epithemia,* and some marine littoral species, *e.g. Hyalodiscus scoticus,* also occur.

GR-D2: The composition of the diatom assemblage of the interval of 24.5-23.5 m provides evidence of marine conditions. Littoral taxa predominate: *Paralia sulcata, Hyalodiscus scoticus, Actinocyclus Ehrenbergii* and *Grammatophora oceanica.* The warmth demanding relict species *Navicula abrupta* and *Coscinodiscus antiquus* are also present.

Samples from the intervals 26.8-26.0 m and 22.0-18.0 m (silt, clay) were barren of diatoms.

Pollen analysis

The fine grained sediments of the interval 26.3-5.3 m were studied palynologically in the Grini core. Eight local pollen assemblage zones (GR1-GR8) were distinguished in the interglacial sediments and five (LT1-5) in the glacigenic sediments (Fig. 34a, 34b).

PAZ GR1 - *Betula*-NAP, depth interval 26.5-25.7 m, (silty clay)

The dominance of *Betula* tree pollen and the abundance of *Pinus*, presence of herbs (up to 12%), as well as pre-Quaternary palynomorphs are characteristics of this zone. *Betula nana* type and *Artemisia* occur up to 5%. *Juniperus* and single pollen grains of *Dryas*, *Helianthemum* and *Ephedra* and spores of *Selaginella* have been noted at the very beginning of this zone, but upwards they disappear. This composition of the pollen flora suggests a late-glacial tundra succeded by forest. It is supposed that birch trees were present in isolated stands, surrounded by shrubs and graminids, gradually changing to birch forest with an admixture of pine.

The upper boundary of PAZ GR1 is drawn at the level where there is a sharp decrease of *Betula* and an increase of *Pinus*.

PAZ GR2 - *Pinus*, depth interval 25.7-24.5 m, (sandy clay)

The dominant arboreal pollen is *Pinus*, which at the beginning of the zone reaches about 80%, but upwards gradually decreases, while *Betula* pollen values are low (8%). *Alnus*, *Quercus* and *Corylus* pollen appear in the middle of this zone and their values gradually increase upwards. Ericales and *Aster*-type pollen becomes most dominant of the NAP taxa, which otherwise decrease. The pollen flora suggests an ameliorating climate.

PAZ GR3 - *Alnus-Quercus-Corylus*, depth interval 24.5-23.6 m, (silty clay)

In this zone there is a substantial increase in pollen of thermophilous taxa (*Ulmus*, *Tilia*, *Fraxinus*). *Quercus* pollen reaches its highest values, while *Corylus* has a tendency to decrease after the first peak in the previous zone. The vegetation type in the adjacent land area was dominated by mixed oak forest.

PAZ GR4 – *Ulmus-Fraxinus*, depth interval 23.6-23.0 m, (silty clay)

In comparison with the previous zone a slight decrease of *Quercus* pollen can be observed, while *Ulmus* increases and culminates. The frequency of *Pinus*, *Betula* and *Alnus* is stable as in the previous zone. Generally the forest vegetation is stable; only *Quercus* was probably partly replaced by *Ulmus*.

PAZ GR5 – *Tilia-Taxus-Corylus*, depth interval 23.0-22.0 m, (silty clay)

The composition of the pollen spectra in this zone demonstrates decrease in *Ulmus* and *Quercus* and increase in *Corylus*, *Carpinus* and *Tilia*. *Osmunda* spores are noted. *Taxus* pollen appears in this zone.

Pollen of thermophilous herbs, *e.g.* *Hedera* and *Brasenia* are noted.

PAZ GR6 – *Carpinus-Tilia-Alnus*, depth interval 22.0-21.25 m, (silty clay)

Pollen maxima of *Tilia* and *Carpinus* and a decrease in *Corylus* characterise this zone, which appears to represent a continuous growth of QM forest in adjacent areas.

PAZ GR7 - *Picea*, depth interval 21.25-20.4 m, (silty clay)

Pollen of thermophilous tree taxa decreases considerably, while the *Picea* pollen frequency increases. This indicates a climatic deterioration, with slightly decreasing temperature and lower precipitation. The pollen concentration, however, shows that the apparent drop in occurrence of thermophilous taxa is largely caused by an increase of *Picea* pollen, and that the thermophilous taxa are still present in the vegetation, at least during the first half of the zone. Non-arboreal pollen shows higher values and the main components are Cyperaceae, Chenopodiaceaė and Ericaceae, which suggests open areas in the coastal zone.

PAZ GR8 - *Pinus*-NAP, depth interval 20.4-18.25 m, (silty clay, clay, sandy clay)

Picea pollen values decrease significantly throughout this zone and are replaced by *Pinus* as the dominant component. This zone represents a significant climate deterioration and increasing podsolisation in adjacent areas. Among non-arboreal pollen taxa, Poaceae and Cyperaceae become dominant, but pollen values of *Artemisia* also increases towards the end of this zone.

The upper boundary of PAZ GR8 has been drawn at the level where elements of a periglacial flora appear or increase, such as *Betula nana* type, *Dryas* and *Selaginella*. At the same time this limit marks the boundary between the Eemian (Felicianova) Interglacial and Early Weichselian (Latvija) stadial conditions. Pollen data are supported by a decrease in values of organic matter from 1.1% in the sandy clay to 0.1% in the sandy silt, which overlays the sediments accumulated under interglacial conditions.

PAZ LT1 – *Pinus-Betula nana* type-*Salix-Juniperus*, depth interval 18.2-15.5 m (sandy silt)

Significant changes occur in the composition of the pollen spectra in this zone. *Pinus* pollen keeps the dominant position, but a marked increase is noted in shrub pollen, represented by *Betula nana* type, *Salix* and *Juniperus*. NAP increases, *e.g.* Cyperaceae, *Artemisia*, *Thalictrum*, Violaceae and *Dryas*. There is a significant amount of *Selaginella* spores in PAZ LT1, as well as an increase in the Pre-Quaternary palynomorphs, mainly represented by spores of *Cyathes*-type. The pollen composition suggests an open periglacial subarctic landscape represented by the spectra of PAZ LT1.

PAZ LT2 - *Betula-Pinus-Picea*, depth interval 15.5-12.25 m, (sandy silt)

The sandy silt is characterised by a small increase of organic matter (0.6%) and pollen. The absolute pollen frequency rises and reaches 100 grains per 1 g dry sediment. The percentage values of *Picea*, *Betula*, *Alnus* and *Corylus* pollen increase. Single *Larix* pollen grains have been found. *Betula nana* type and other pollen of pioneer plants disappear. The pollen composition of PAZ LT2 suggests a vegetation reflecting interstadial conditions.

PAZ LT3 - *Betula nana type*-NAP, depth interval 12.25-10.5 m, (sandy silt)

The sediments in this zone are characterised by a lower organic matter content (0.2%) and a lower number of palynomorphs per 1 g dry sediments (20-30 grains). Changes in the pollen composition are reflected in rising values for plants representing a periglacial flora, *e.g.* *Betula nana* type, *Selaginella* and *Dryas*. Obviously, stadial conditions dominated during the formation of the sediments containing palynomorphs in PAZ LT3.

PAZ LT4 - *Picea-Larix-Salix*, depth interval 7.1-10.5 m, (sandy silt)

A succession is observed among the tree pollen taxa: *Betula-Pinus-Picea-Larix*, suggesting some improvement of climate. Pollen that represents a periglacial flora decreases. Herbaceous pollen decreases, but the diversity of herbaceous taxa is higher than in the preceeding zone. The pollen composition of PAZ LT4 suggests interstadial conditions.

PAZ LT5 - *Pinus-Betula nana* type-NAP, depth interval 5.3-7.1 m, (sandy silt and clay)

The uppermost sediment layer is poor in pollen, only 10-20 grains per dry sediment. In the flora pollen of *Betula nana* type and *Ephedra* and spores of *Selaginella* reoccur, indicating that PAZ LT5 reflects stadial conditions.

Interpretation of results

Palynological investigations of the fine-grained sediments in the depth interval of 26.3-5.3 m at the Grini site provide evidence for correlation of these deposits with the Eemian and Early Weichselian stages. The pollen flora in PAZ GR1-PAZ GR8 reflects an almost complete pollen sequence that is characteristic for the Eemian Interglacial in Latvia and the eastern Baltic region. The composition of the pollen flora in PAZ LT1, LT3 and LT5 demonstrates the stadial conditions of the Early Weichselian Glaciation, in contrast to PAZ LT2 and LT4, which indicate interstadial conditions during the Early Weichselian.

Comparisons of pollen and diatom data indicate that the real marine conditions began in the middle part of the interglacial, during the expansion of QM (PAZ GR3) on the adjacent mainland (Table 7). A shallow freshwater basin existed at the Grini site in the early part of the interglacial. This is shown by the predominance of littoral diatom species, mainly living in cold freshwater, but there was also some influence of saltwater. Obviously, the basin at Grini continued to be shallow during the marine stages of the Baltic Eemian Sea, which could explain the admixture of fresh and brackish water diatom species in the sediments. It could have been a small embayment of the Baltic Eemian Sea.

In the upper part of the section no diatoms were noted in the deposits representing late temperate and post-temperate conditions, which were established by pollen data from the interval 22.0-18.0 m. The water level in the basin probably decreased, and the depositional environment became terrestrial at the Grini site.

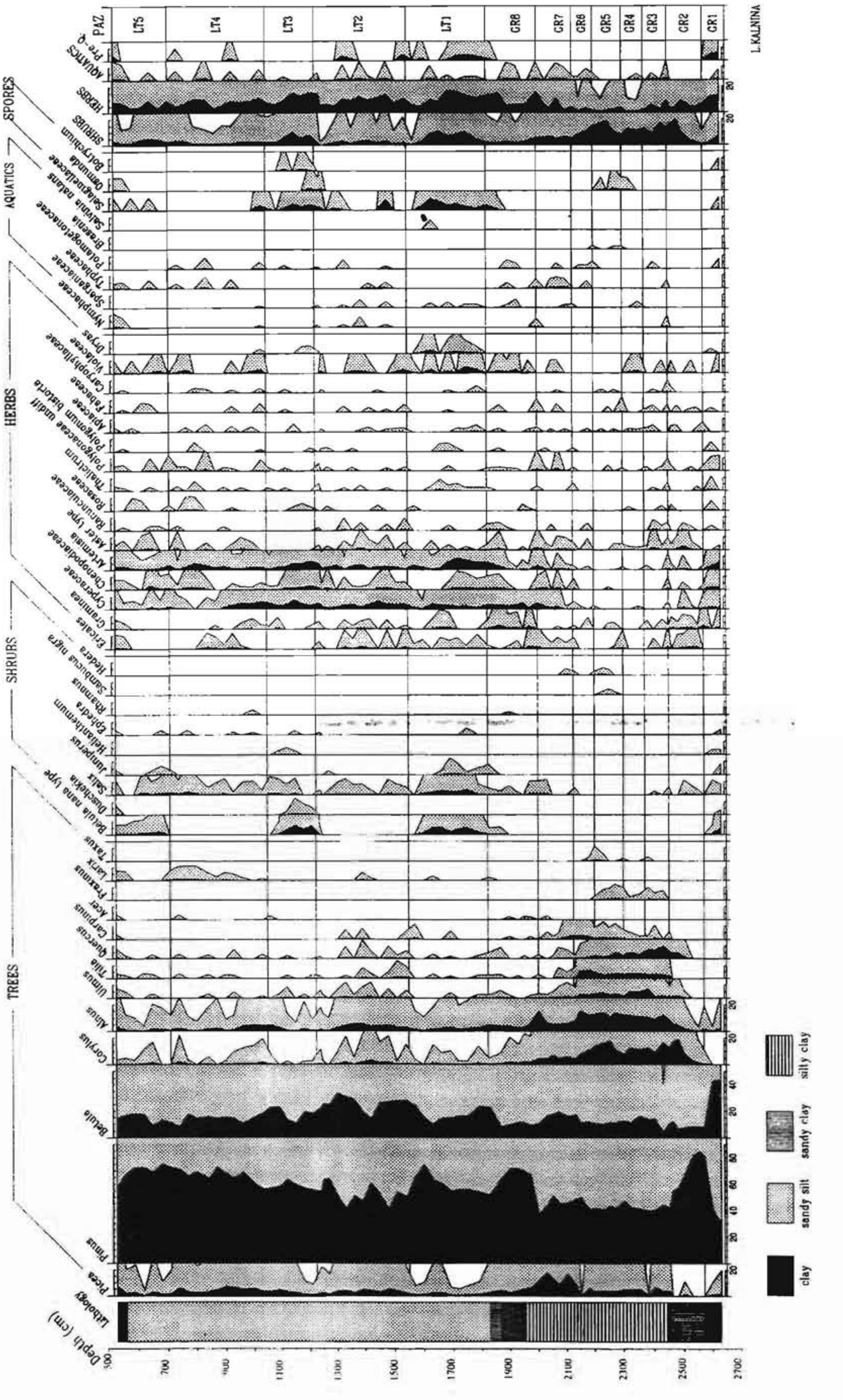


Fig. 34a. Pollen diagram of Pleistocene deposits from the core Grini-22

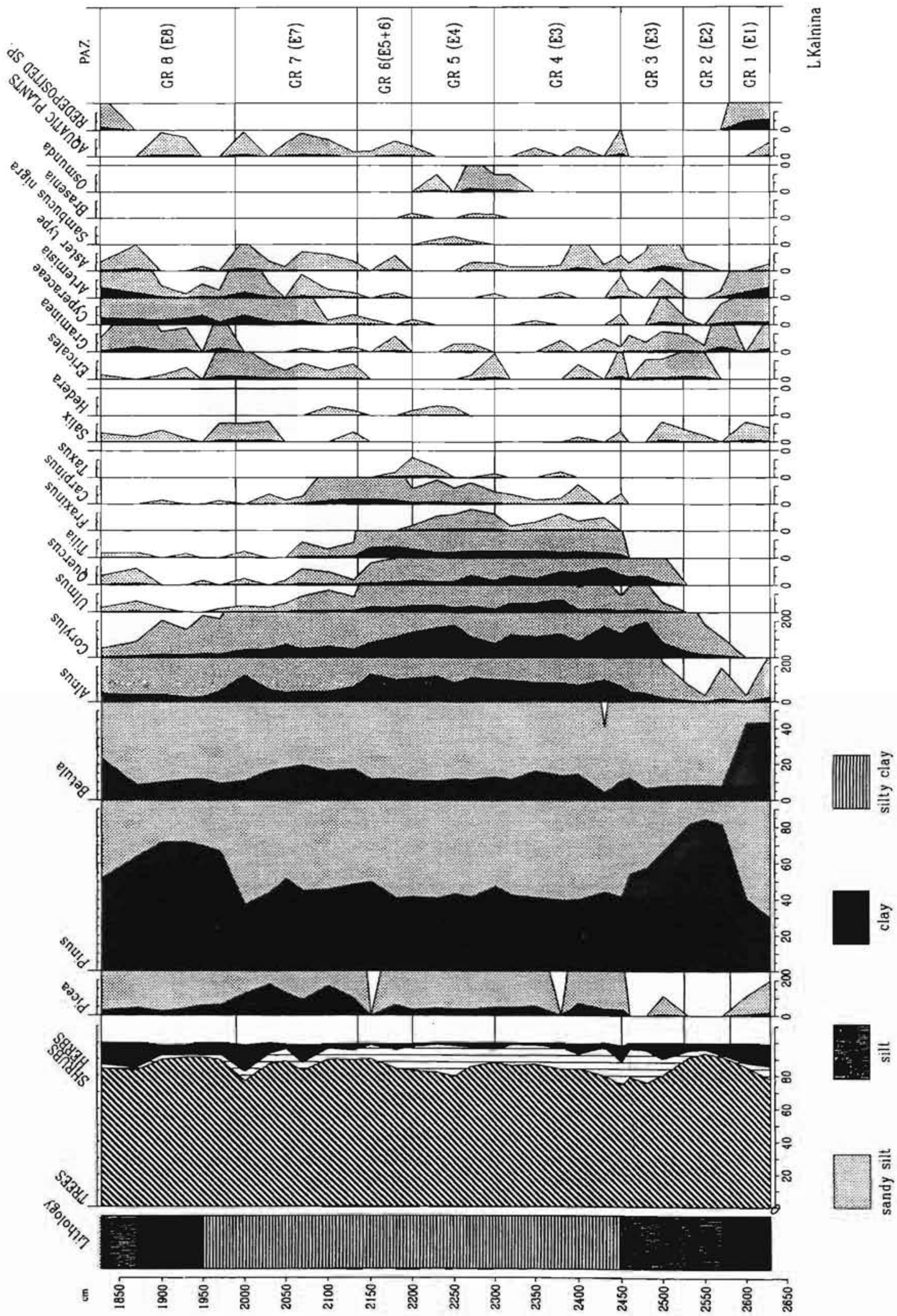


Fig. 34b. Pollen diagram of Eemian interglacial deposits from the core Grini-22

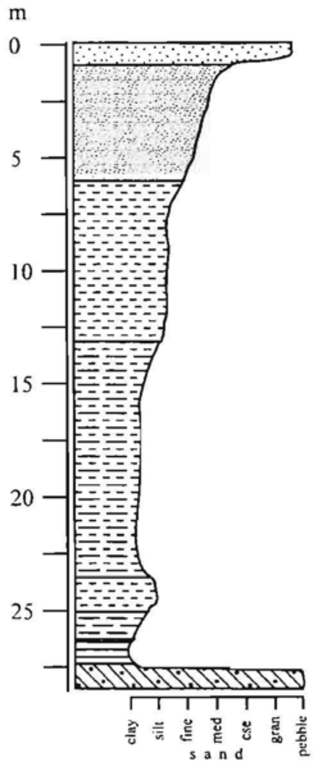
Table 7. Comparison of diatom and pollen zones from the interglacial sediments at the Grini site and characteristics of the environmental conditions. Substages are according to West (1970).

<table>
<tr><th>Depth m below surface</th><th>Diatom zones and dominating taxa</th><th>Pollen assemblage zones (PAZ)</th><th>Environmental conditions</th><th>Substages</th></tr>
<tr><td rowspan="3">22.0-18.0</td><td rowspan="5">barren</td><td>GR8: Pinus-NAP</td><td rowspan="5">no data</td><td>Post temperate</td></tr>
<tr><td>GR7: Picea</td><td rowspan="3">Late temperate</td></tr>
<tr><td>GR6: Carpinus, Tilia, Alnus</td></tr>
<tr><td rowspan="2">23.5-22.0</td><td>GR5: Tilia, Taxus, Corylus</td></tr>
<tr><td>GR4: Ulmus, Fraxinus</td><td rowspan="2">Early temperate</td></tr>
<tr><td>24.5-23.5</td><td>GR-D2: Paralia sulcata, Hyalodiscus scoticus, Actinocyclus Ehrenbergii, Grammatophora oceanica, Navicula abrupta, Coscinodiscus antiquus</td><td>GR3: Alnus, Quercus, Corylus</td><td>littoral, temperate, marine</td></tr>
<tr><td>26.0-24.5</td><td>GR-D1: Cocconeis disculus, Diploneis domblittensis, Pinnularia spp, Epithemia spp., Hyalodiscus scoticus</td><td>GR2: Pinus</td><td>fresh cold-water with some slight influence of brackish and shallow marine</td><td rowspan="2">Pre-temperate</td></tr>
<tr><td>26.8-26.0</td><td>barren</td><td>GR1: Betula-NAP</td><td>no data</td></tr>
</table>

Plašumi site - core No. 62

56° 57'45" N Lat., 21° 19'27"E Long., 13 m a.s.l.

The Plašumi site is located in the north-eastern area of the Baltic basin (Figs 1B, C, 3). The coring was carried out at the geological mapping (Tracevski *et al.* 1989). As a result, a 29.0 m long sediment core a with high degree of recovery (98%) was obtained (Fig. 35). For technical reasons coring was stopped at 29 m, in a clayey diamicton layer with some boulders, mostly represented by crystalline rocks (Fig.36).



Depth below surface (m)	Description
0 - 1.0	sand with some gravel
1.0 – 6.2	sand, fine
6.2 - 13.4	silt, grey with plant remains
13.4 - 24.0	silt, clayey, greenish grey with thin (0.2-0.3 mm) dark grey laminae, containing plant remains and foraminifera
24.0 - 25.6	silt, grey with dispersed organics
	clay, silty, grey
25.6 - 26.8	
26.8 – 27.9	clay, grey, with slightly undulating varves
27.9 – 29.0	diamicton, grey, clayey

Fig. 35. Log and general decription of the sediment sequence in the core Plasumi-62.

A palynological investigation was carried out and the results obtained caused discussions about the age and genesis of the sediments. A Holsteinan age was suggested in the report of the geological mapping (Tracevski *et al.* 1989). However, according the stratigraphic position of this sediment sequence, it was interpreted as a raft. Doubts also appeared about the geological position of the site in the area, where a wide distribution of Holsteinian marine deposits had been shown.

As silt with clay and fine sand interlayers had also been found in the adjoing test-drillings Nos. 63, 94, (Fig. 36) the sediments of the Plašumi site were later reinvestigated and additional analyses were carried out for organic carbon content, lithological composition, granulometry, foraminifera and diatom.

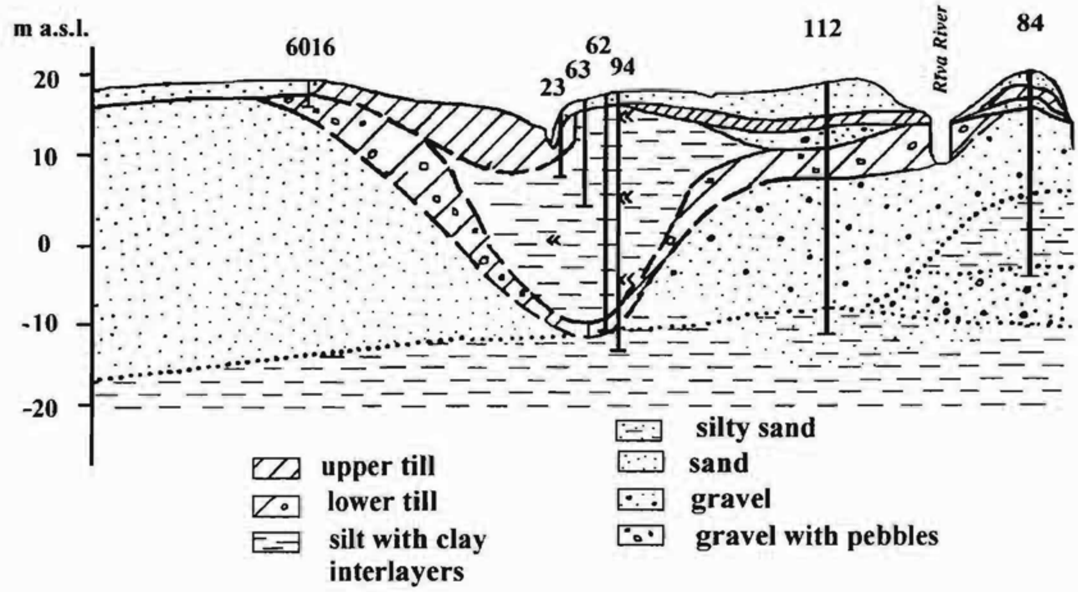


Fig. 36. Geological cross-section of the Plasumi site (after Kalnina & Juskevics 1998a).

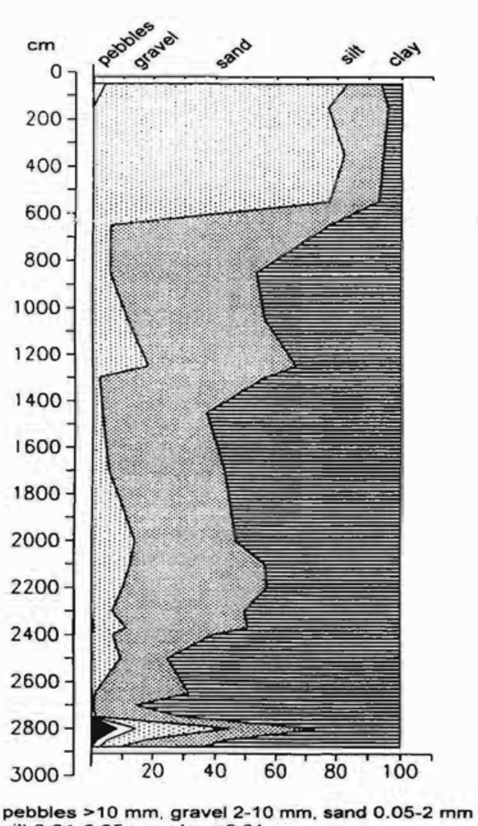


Fig. 37. Grain size composition of the sediments from the core Plasumi. The lithology is decribed in Fig. 35.

Lithology

The lowermost part (29.0-27.0 m) of the sediment sequence is represented by fine textured grey clayey diamicton with a matrix consisting of clay to clayey silt that is rich in plant remains (Fig 35, 37). The diamicton does not abound with gravel and pebbles, mostly represented by limestone, rare crystalline rocks and dolostone. In the size fraction 0.5-1.0 mm, limestone reaches 55-60 %, and in the fraction 0.1-0.25 mm rounded hornblende grains are of 28-36%.

In the depth interval 27.6-26.8 m, grey clay with slightly undulating varves occurs, which upwards is replaced by grey silty clay. In the depth interval 25.6-24.0 m, grey silt that is rich in disperse organic was observed. At the depth 24.0-13.4 m, clayey silt that is rich in organic material occurs and it has 0.3-0.5 cm dark grey laminae containing plant remains and some foraminifera in the lowermost part. Upward the clay becomes more silty, and in the depth 13.4-6.0 m, it is replaced by grey silt with plant remains (Fig. 37). This silt layer is covered by fine sand, which contains some gravel at the top of the sequence (1.0-0 m).

Table 8. Foraminiferal content in samples of Pleistocene deposits from the Plasumi site in the depth interval 13.0-27.5 m. Samples from 6.2 m, 10.5 m and 27.9 m do not contain any foraminifera

Depth (m) **Foraminifera**	13.0	14.5	17.0	20.0	21.0	22.0	23.0	23.7	24.0	25.0	26.5	27.5
Ammonia beccarii (Linné, 1758)			3	5	10	12	11	10	3	3	5	
Bolivina sp.				1	18	13	12	2	1	1		
Buccella frigida (Cushman, 1922)	9		7	2	4							2
Buccella hannai arctica Voloshinova	23	3										5
Bulimina marginata d'Orbigny, 1826	3	1	15	14	17	93	41	83	62	54	35	
Cassidulina laevigata carinata d'Orbigny, 1826	1			3	56	70	31	61	63	9	2	
Cassidulina reniforme Nørvang, 1945	10	26	7									25
Cibicides lobatulus (Walker et Jacob, 1798)	1		6	22	13		1	4		1		
Cibicides rotundatus Stchedrina					1			2	1			
Cibicides sp.	3		1	13	19	41	9	12	11	3	1	
Elphidium albiumbilicatum (Weiss, 1954)	7	11	1									
Elphidium asklundi Brotzen, 1943	1	3										8
Elphidium excavatum f. *boreale* (Nuzhdina)	12	1	23	77	113	119	128	135	60	28	19	1
Elphidium excavatum (Terquem) f. *clavata* Cushman, 1930	15	55	11	3	2						3	54
Elphidium granatum Gudina	1		2								2	1
Elphidium incertum (Williamson 1858)			2	12	25	18	3					
Globigerina sp.	1			4	1	3	2	1			2	
Haynesina nivea				1	2			2				
Haynesina orbiculare (Brady, 1881)	15	2	17	24	49	62	61	58	48	25	14	
Melonis sp.	1			3	6	32	28	21	13	3	2	
Planularia sp.	2		1	1	1	3	2	3	1	1	1	
Protelphidium depressulum Walker et Jacob			1	1			1					
Protelphidium orbiculare Brady	7		7	4	2		3		1			
Protelphidium parvum Gudina	1					1	2				1	
Protelphidium sp.	1			2			3			1	2	
Sangrina subspidencens (Cushman)							2	1	1			
Quinqueloculina boreale							2	3				
Redeposited	13	61	10	11	13	17	14	23	33	45	62	109

Foraminifera analysis

Seventeen samples of silt, silty clays and clays in the interval 27.9-6.2 m were analysed. The upper part of the sedimentary sequence (grey silt with plant remains in the interval 13.4–6.2 m) does not contain any foraminifera and the clay from the lowest sample, at the depth of 27.9 m, is also barren of foraminfera. Twelve samples from the interval 27.5 to 13.0 m are poor to sparse in foraminifera. The number of foraminifera vary from 420 at 23.0 m to 113 at 17.0 m per 100 g dry weight (Table 8).

Four foraminiferal assemblage zones, PL-F1 to PL-F4, have been established and the main characteristics of each zone are summarised below (see also Fig. 38).

Zone PL-F1 (depth interval 28-27 m): Only one sample represents this zone. The number of foraminifera is 195 per 100 g dry sediment, and many of the shells may have been redeposited from older sediments, probably of Holsteinian age. In this zone *Elphidium excavatum* f. *clavata* occurs together with *Cassidulina reniforme, Buccella frigida, B. hannai arctica* and *Elphidium albiumbilicatum.* The association of species reflects the initial occurrence of ice-proximal glaciomarine conditions (Hald *et al.* 1994) just after the retreat of the ice sheet.

Zone PL-F2 (depth interval 27-21.5 m): The diversity of foraminifera increases in comparison with the previous zone and the amount gradually increases upwards. The appearance of lusitanian species, *e.g. Ammonia beccarii, Bulimina marginata* and *Cassidulina laevigata,* points to ameliorated temperature, slightly higher salinity and presumably also deeper water towards the upper half of the zone.

The number of additional species increases, and among them several boreal taxa (*e.g. Bulimina marginata, Cassidulina laevigata, Elphidium excavatum* f. *selseyensis, Melonis* sp. *Haysenina nivea, Sangrina subspidencens* and *Quinqueloculina boreale*) become important members of the assemblage. The comparatively high number of *Haysenina orbiculare* indicates a water depth of approximately 15 m (Klingberg (in Påsse *et al.* 1988, 1997).

The composition of the foraminiferal fauna suggests true marine interglacial conditions. The high number of the shallow cold-water species *Haysenina orbiculare* together with the foraminifera species mentioned are indicative of the Eemian Interglacial (Knudsen 1988, K. Schoning, pers. comm.). The deposits representing this zone have been accumulated in temperate, shallow saline water.

Zone PL-F3 (depth interval 21.5-15.5 m): The abundance of foraminifera decreases, however, their diversity still being the same as in the earlier zones. Presumably the larger number of *Bulimina marginata* and *Cassidulina laevigata* reflects a decrease in water depth (Sejrup & Knudsen 1993). The significant increase in *Cibicides lobatulus* points to a high energy environment and shallow water (K. Schoning pers. comm.).

The changes in the composition of the forminifera fauna indicate shallowing of the waterbody, probably reflecting a regressive phase of the Eemian Sea.

Zone PL-F4 (depth interval 15.5-13 m): The abundance of foraminifera is low and varies from 113 to 152 per 100 g of dry sediment. *Elphidium excavatum* f. *clavata* is dominant and the arctic taxon *Cassidulina reniforme* is the second in abundance. New elements in the fauna are the arctic species *Elphidium albiumbilicatum* and *Bucella hannai arctica.* The content of boreal species is low, and redeposited shells occur. This assemblage reflects a change to arctic conditions in the area and cool water. The significant number of *Haysenina orbiculare* suggests brackish and shallow water conditions during the deposition of the clayey silt (17 to 13 m).

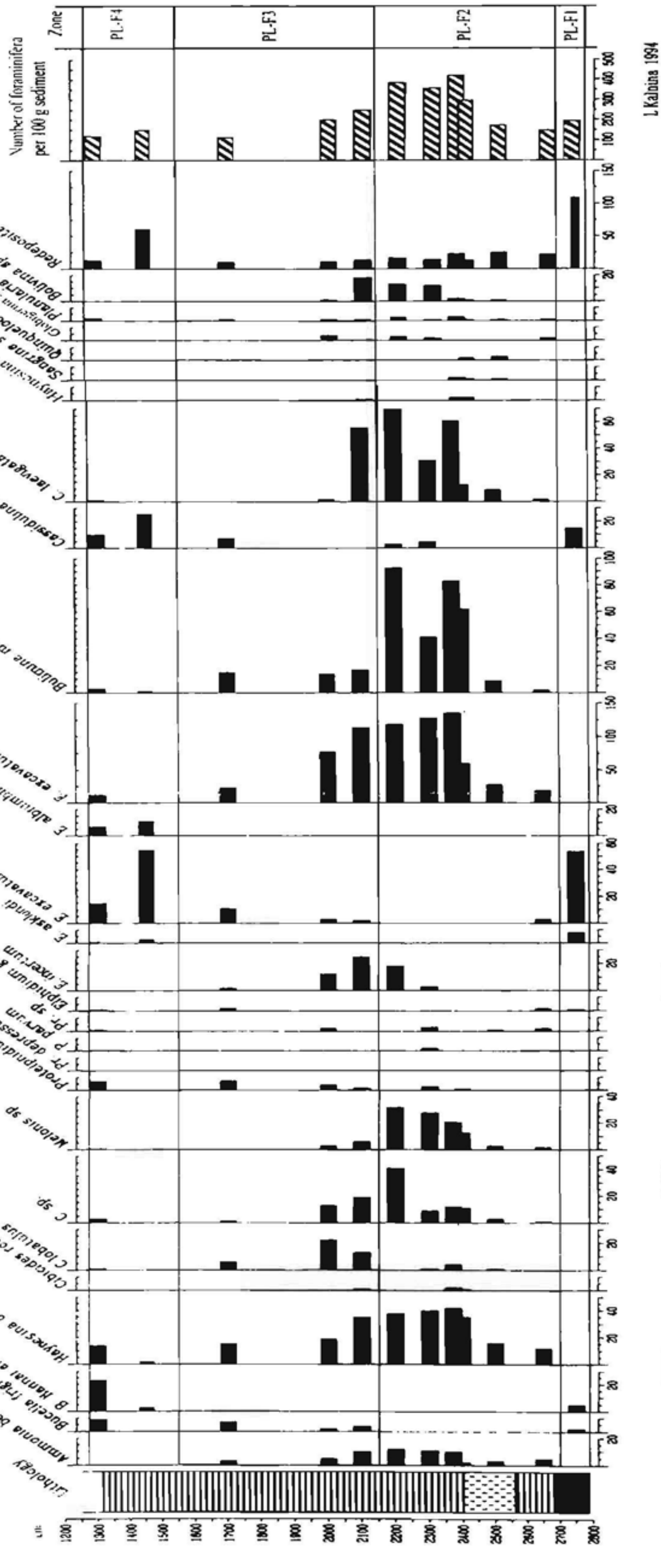


Fig. 38. Foraminifera diagram of the Pleistocene deposits from the Plasumi site.

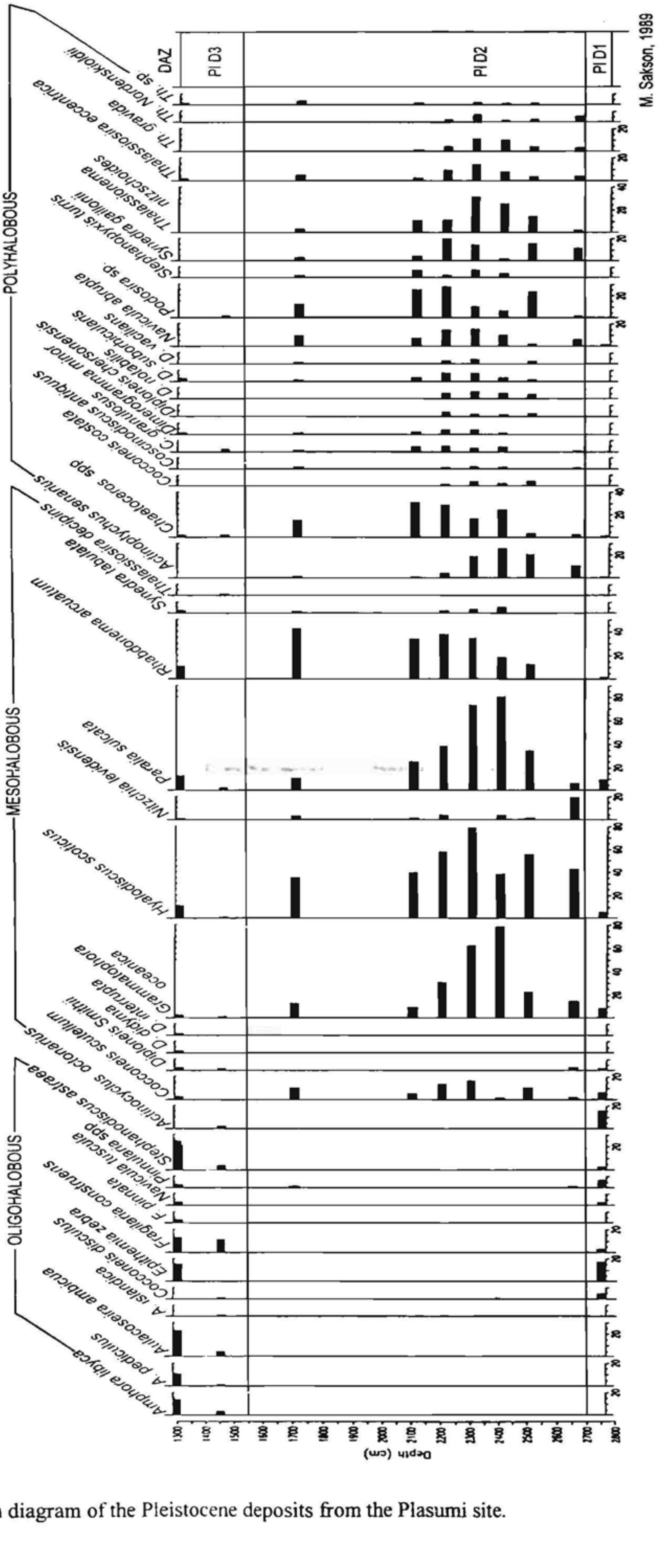


Fig. 39. Diatom diagram of the Pleistocene deposits from the Plasumi site.

Diatom analysis

Diatom analysis was carried out by M. Sakson on 10 samples at the depth interval of 27.9–13.0 m (Fig. 39). The succession of diatom assemblages has been divided into three zones (D1-D3):

Pl D1: clay, depth 27.9-27 m. The total abundance of diatoms is low. The oligohaline (freshwater, salinity 0.5-5 ‰) and mesohaline (salinity 5-18 ‰) species *Epithemia zebra* and *Actinocyclus octinarius* dominate. Freshwater to brackish conditions prevailed during accumulation of the clay containing these diatoms.

Pl D2: silt and clayey greenish grey silt with thin (0.2-0.3 mm) dark grey laminae at the depth of 27-15.5 m is rich in diatoms. Oligohaline taxa disappear, and mesohaline species (*Grammatophora oceanica, Hyalodiscus scoticus, Paralia sulcata, Rhabdonema arcuatum*) increase and dominate the spectra. Also polyhaline (salinity 18-30 ‰) species occur in this zone with high diversity, and *Actinoptychus senarius, Chaetoceros* spp, *Navicula abrupta, Podosira* sp. and *Thalassionema nitzschioides* dominate. Sediments from this interval accumulated under marine conditions.

Pl D3: the abundance of diatoms decreases significantly in the clayey silt at the interval of 15.5-13 m. A few polyhaline species were found, together with some mesohaline diatoms. Again oligohaline species dominate, among them *Aulacoseira ambigua* and *Stephanodiscus astraea*, suggesting almost freshwater conditions during the deposition of the silt in the upper part of the sequence. In the surface water, freshwater plankton dominates, but in the bottom of the shallow basin the water was still brackish.

Pollen analysis

In the sediment sequence of core 62 from the Plašumi site 289, samples have been analysed for their content of pollen. The aim was to clarify environmental changes and the vegetation history of the region.

Fourteen local pollen assemblage zones have been distinguished in the pollen diagram (Figs 40a and 40b.).

PAZ SA- *Betula nana* type-*Juniperus*-NAP, depth interval 27.9-27.0 m, (grey clay with slightly undulating varves)

The spectra contain pollen of light demanding plants, such as *Betula nana* type, *Juniperus*, Chenopodiaceae, *Helianthemum* and spores of *Selaginella*. The sediments are sparse in pollen and organic remains. The pollen spectra identified in this zone suggest late glacial conditions just after glacier retreat.

The sediments in the depth interval 27 to 15.5 m contain pollen and reflect interglacial vegetation. The boundary between the Late Glacial and the Interglacial is drawn at the level where representatives of a subarctic vegetation disappear and trees start to expand as evidence of forest formation.

PAZ E1 – *Betula*, depth interval 27.0-26.1 m (silty clay)

A dominance of *Betula* together with *Pinus* and *Alnus* pollen characterise the zone. A gradual increase in the absolute pollen concentration is observed.

PAZ E2 – *Pinus*, depth interval 26.1-24.2 m (grey silt with dispersed organic remains)

Sharp increase in *Pinus* pollen to 60-70% and continuous presence of *Corylus* and *Alnus* is noted. The pollen spectra reflect a boreal vegetation type.

PAZ E3 – *Ulmus- Quercus-Corylus*, depth interval 24.2-23.4 m (greenish grey clayey silt with plant remains)

Decrease in *Pinus* and increase in *Quercus*, *Corylus* and *Alnus*, together with maximal values of *Ulmus* recorded in the pollen spectra suggests beginning of the climatic optimum.

PAZ E4 – *Quercus-Corylus-Fraxinus*, depth interval 23.4-22.5 m (greenish grey clayey silt)

Pollen spectra in this zone show a maximum of *Quercus* and *Fraxinus*, high values of *Corylus* and *Alnus* and some expansion of *Picea*. Pollen of *Fagus* is present in low numbers, but forms a continuous curve in the diagram. The appearance of thermophilous plant pollen, *e.g. Viscum, Brasenia* and *Vitis*, has been noted, as well as pollen of *Sambucus nigra* in the uppermost part of the zone.

PAZ E5 – *Tilia-Corylus-Picea*, depth interval 22.5-21.6 m (greenish grey clayey silt)

Maximum of *Tilia* and increase of *Picea*, as well as comparatively high (20%) and stable position of the *Alnus* and *Corylus* curves is characteristic for PAZ E5, as well as pollen of *Hedera, Myrica gale, Brasenia, Viscum and Vitis*, and spores of *Osmunda*.

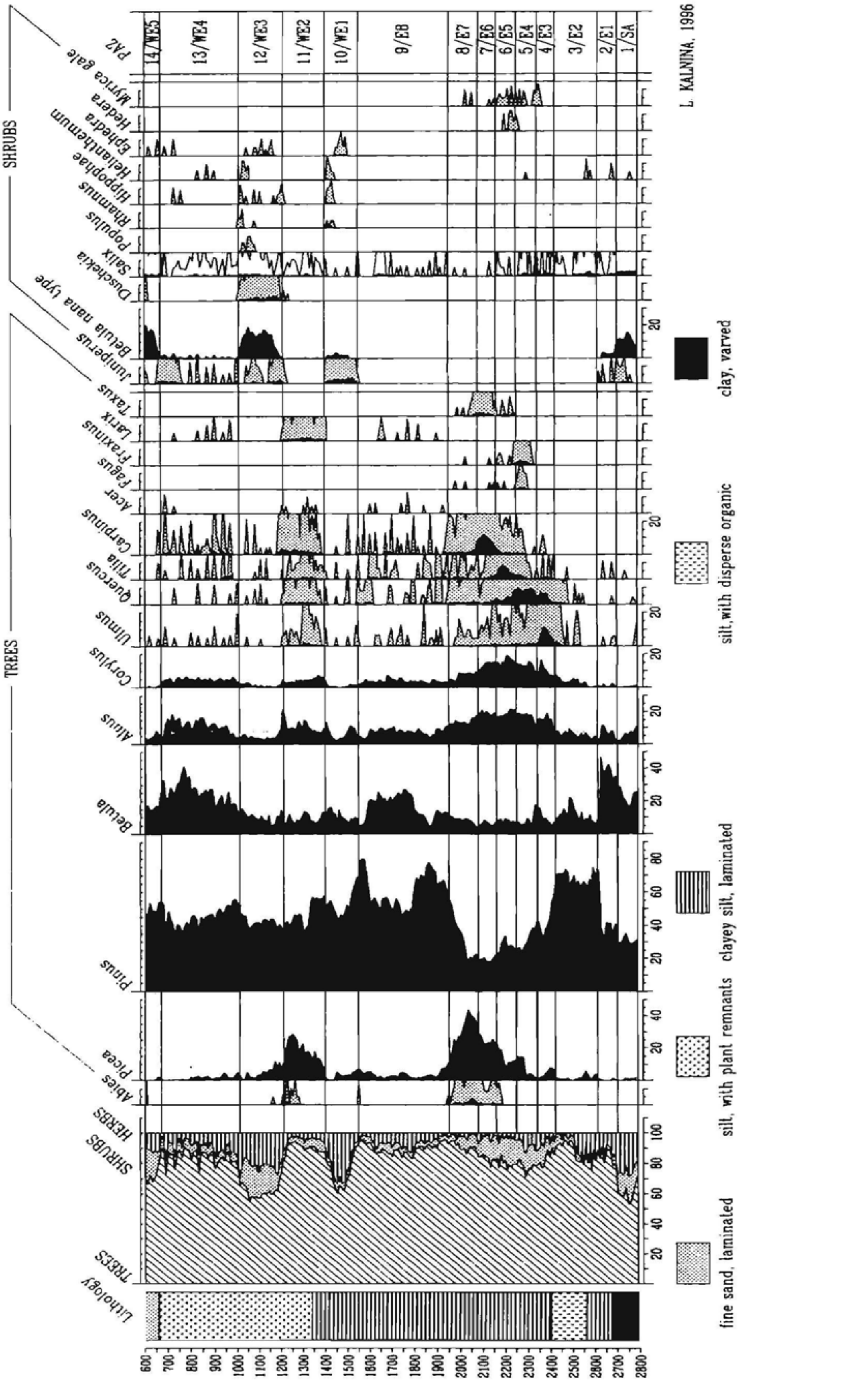


Fig. 40a. Pollen diagram of the Pleistocene deposits from the Plasumi site.

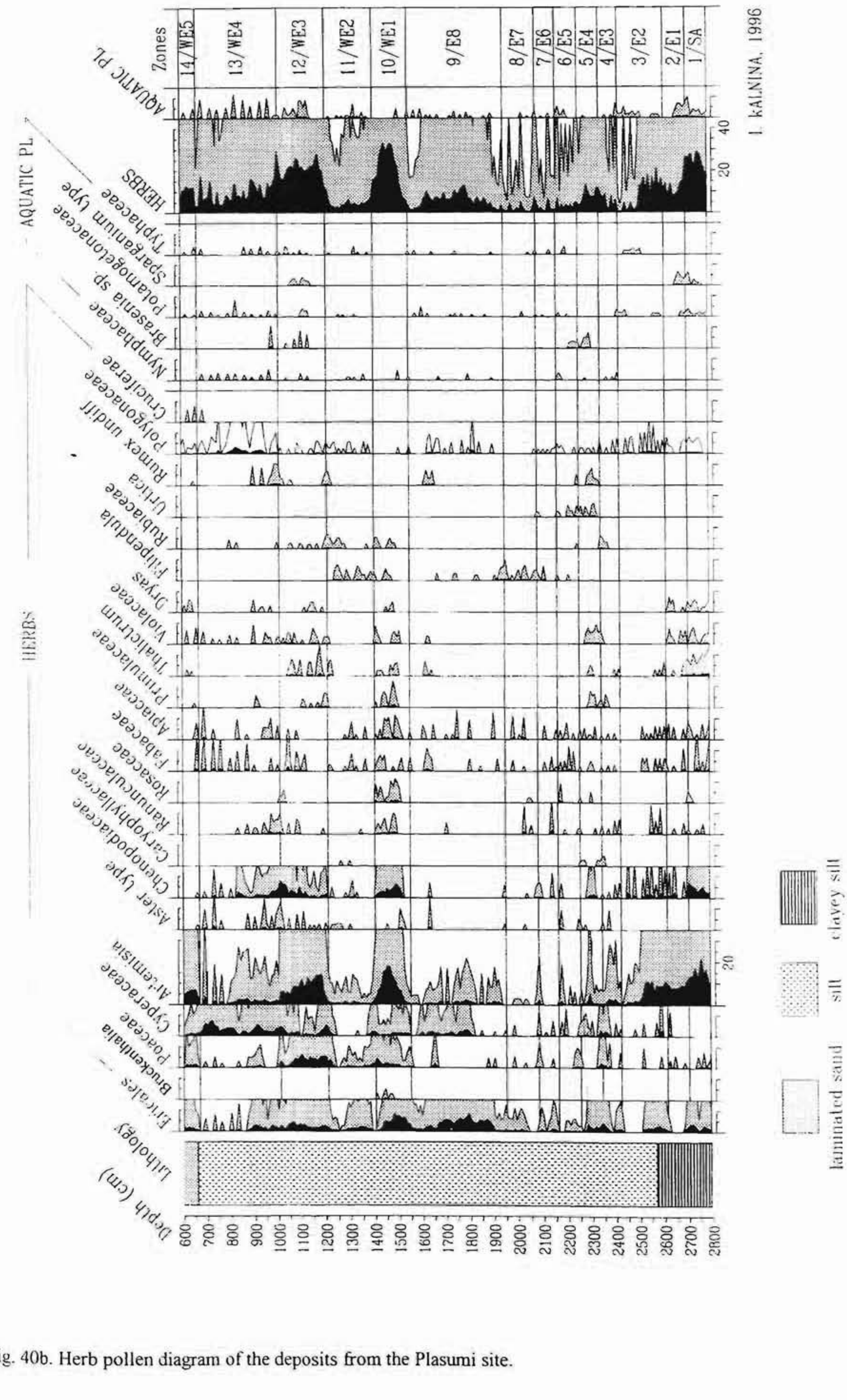


Fig. 40b. Herb pollen diagram of the deposits from the Plasumi site.

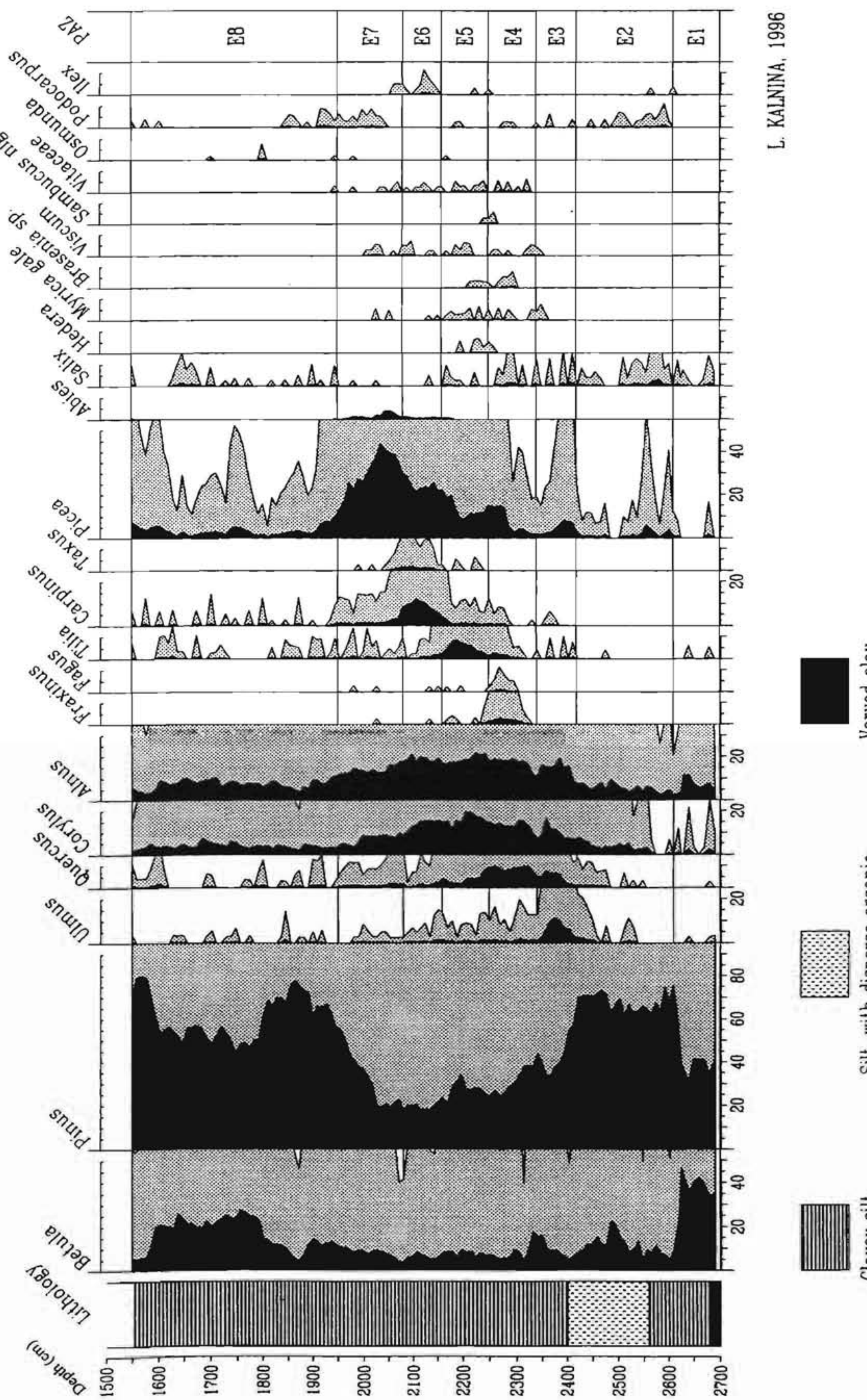


Fig. 41. Pollen diagram of the Eemian interglacial deposits from the Plasumi site.

PAZ E6 – *Carpinus-Taxus-Ilex*, depth interval 21.6-20.8 m (greenish grey clayey silt)
Maxima of *Carpinus*, *Taxus*, *Ilex* are observed in the zone. The proportion of other termophilous tree pollen decreases in comparison with the previous zone, although *Viscum* and *Vitis* pollen is still presented with the same values as in zone E5.

PAZ E7 – *Picea-Abies*, depth interval 20.8-19.5 m (greenish grey clayey silt)
The zone is characterised by maxima of *Picea* and *Abies*, and decrease of broad-leaved trees. Increase of *Pinus* and decrease of *Picea* has been observed at the end of the zone.

PAZ E8 – *Pinus-Betula*, depth interval 19.5-15.5 m (greenish grey clayey silt)
Dominance of *Pinus*, together with *Betula*, low but continuous presence of *Corylus*, *Alnus* and *Picea* is noted. The upper boundary of zone PAZ E8, which is also the boundary between interglacial and early glacial, stadial conditions, is placed at 15.5 m, where the absolute number of palynomorphs sharply decreases and representatives of a periglacial flora appear.

The Weichselian part of the sequence is presented in Fig. 42.

PAZ WE1 – *Artemisia-Ericales-Juniperus*, depth interval 15.5-14.0 m (greenish grey clayey silt)
Total amount of tree pollen decreases and herb pollen increases, mainly represented by *Artemisia*, Ericales and Chenopodiaceae. *Betula nana* type and *Juniperus* also occur. The composition of the pollen spectra reflects a periglacial vegetation.

PAZ WE2 – *Picea-Pinus-Corylus-Larix*, depth interval 14.0-12.1 m (greenish grey clayey silt with plant remains)
The frequency of tree pollen increases again. There is a significantly increase in *Picea* and *Corylus*. Also *Ulmus*, *Tilia*, *Carpinus* and *Larix* pollen appear. This composition of the pollen flora suggests some amelioration of the climate and interstadial conditions.

PAZ WE3 - *Betula nana* type-NAP, depth interval 12.1-10.1 m (grey silt)
Increase in herb pollen, *Betula nana* type, *Duschekia* and *Artemisia*, reflects deterioration of climate and stadial conditions.

PAZ WE4 – *Betula-Alnus-Corylus*, depth interval 10.1-6.7 m (grey silt with plant remains)
Increase in tree pollen, particularly *Betula*, *Alnus* and *Corylus*. The composition of the pollen spectra in this zone suggests interstadial conditions.

PAZ WE5 - *Betula nana* type-NAP, depth interval 6.7-6.0 m (grey silt)
Significant increase of herbs, represented mainly by *Artemisia*, and shrubs, represented by *Betula nana* type, indicates periglacial conditions during the formation of the sediments in the depth interval 6.6-6.0 m.

Interpretation of the results

The pollen composition and range of culmination of the main components reflect that the sediments accumulated during a time span that stretches from the Saalian Late Glacial through the Eemian Interglacial and into the Early Weichselian stadials and interstadials (Table 9).

There are only a few published foraminifera data from the south-eastern region of the Baltic Sea. Therefore the data obtained of the sediment sequence at Plasumi site are mostly compared with results from western Europe, for instance, with the marine shelf sequence from northern Denmark, which covers the climatic shifts from glacial environments, through interglacial and into early glacial conditions (Kristensen *et al.* 1998a). These results are based on a multidisciplinary high-resolution study of lithology, foraminifera, ostracods, macrofauna, diatoms and stable isotopes as well as selected marine glacial-interglacial palaeoenvironmental reconstructions.

Table. 9. Comparison of foraminifera, diatom and pollen zones from the Plašumi site and characteristics of the environmental conditions.

Depth m	Foraminiferal zones	Diatom zones	Pollen zones	Environmental conditions
14.5	Pl F4 brackish and relatively shallow water conditions	Pl D3 almost freshwater conditions in surface water, brackish at the bottom	WE1 *Juniperus*, Ericales, *Artemisia*	periglacial, shallow basin
15.5	Pl F3 shallowing of water, probably during regression of the Eemian Sea			
19.6		Pl D2 marine conditions	E8 *Pinus-Betula*	Regression in the Baltic Eemian Sea basin during the late temperate substage of the Eemian Interglacial
21.1			E7 *Picea, Abies*	
21.4			E6 *Carpinus, Taxus, Ilex*	
21.6				
22.5	Pl F2 true interglacial marine conditions		E5 *Tilia, Corylus, Picea*	Marine conditions during climatic optimum of the Eemian Interglacial
23.5			E4 *Quercus, Corylus, Fraxinus*	
24.6			E3 *Ulmus, Quercus, Alnus, Corylus*	
26.0			E2 *Pinus*	Marine conditions during the early temperate substage of the Eemian Interglacial
27.0			E1 *Betula*	
28.0	Pl F1 arctic-subarctic glaciomarine conditions	Pl D1 Freshwater to brackish conditions, meltwater influence	SA *Betula nana* type, *Juniperus*, NAP	initial occurrence of ice-proximal glaciomarine conditions

6.2.2. Test drilling cores from the Gulf of Riga

The sequences of Quaternary deposits in the Gulf of Riga were cored at the geological mapping in 1990-92, and were studied in detail by numerous methods (Table 1).

Deposits of the Eemian Sea were recorded in the boreholes 20 and 21 (south-west from the Estonian Kihnu Island) (Fig. 42). Here, between the Weichselian till and the Devonian sandstone (in the interval 43.5-34.2 m b. s. l.), clay strata were found. In the lower part (up to 40.6 m depth below sea level) a brownish grey and a brown thin-laminated silty clay with separate clay laminae were found (Figs 42 and 43). Higher up (up to 37.6 m depth, unit e, Fig. 43), the sediments changed to dark grey, sometimes almost black, clays with lighter silty laminae. Frequently thin laminae (some mm thick) with plant remains can be found. The upper part of this unit is formed by grey or blue-grey clays with diffuse varved structure. Similar deposits have been recorded earlier on the Kihnu Island, in south-western Estonia (Raukas 1978), where grey clayey silt with vivianite enclosures, plant remains and mollusc shells were found between Saalian and Weichselian tills at depth of 43 to 27 m.

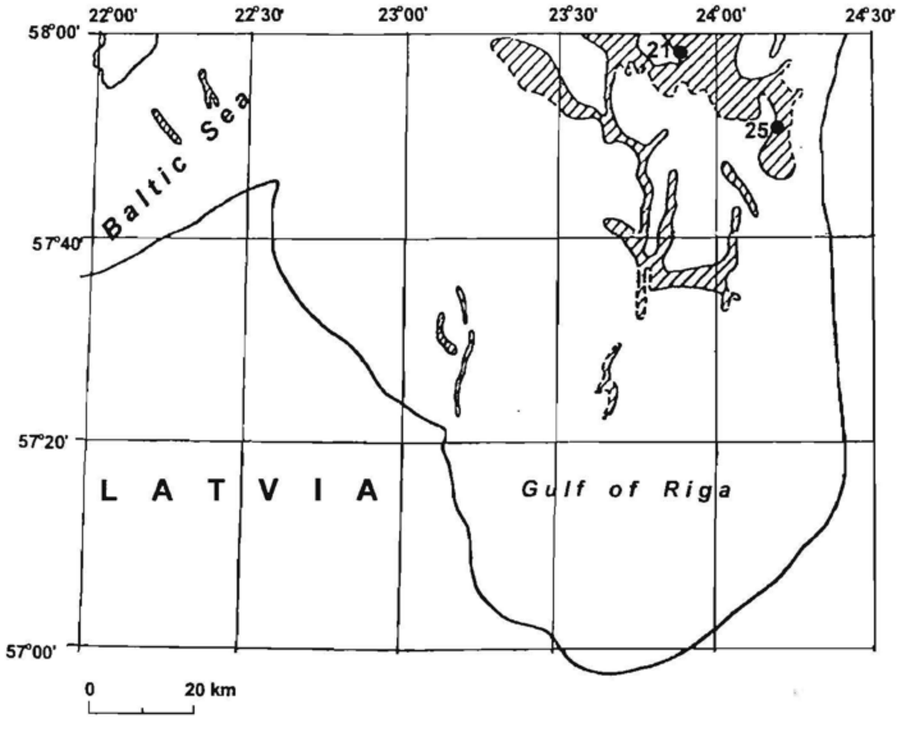
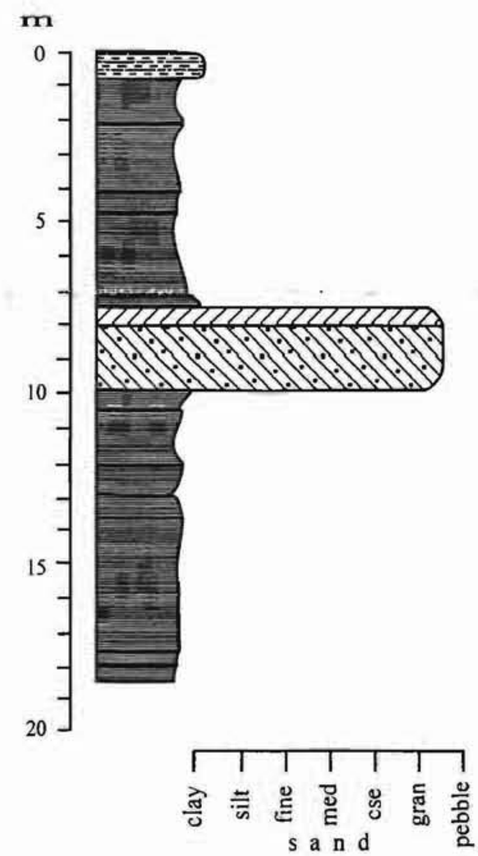


Fig. 42. Distribution of the laminated sand, silt and clay underlying Weichselian till in the Gulf of Riga according to seismoacoustic data (Scheme compiled by V. Juskevics).

The Weichselian glacigenic deposits in the Gulf of Riga are covered by sediments accumulated in the periglacial basin. The glaciogenous sediments form an almost uninterrupted layer directly on the bedrock in the main part of the Gulf. These sediments are in turn covered by limnoglacial clay. Only near the coast, as well as in the vicinity of the Estonian Ruhnu Island, till is exposed on the sea floor. It is partially abraded and covered by a thin (<30 cm) sand, gravel and pebble layer with boulders. In the northern part, the glaciogenous deposits consist of reddish-brown, greyish-brown and also grey diamicton or sandy diamicton. The amount of clay particles (fraction <0.01 mm) usually varies from 18 to 37% (in average 20-30%), and sand - from 27 to 57 %. The density of the diamicton is 1.88-2.08 g/cm^{-3}, the water content 17.0-24.3%. The thickness of the diamicton rarely exceeds 5-8 m in the main part of the Gulf. It increases up to 15-20 m in the bedrock depressions and in buried valleys, as in the accumulative forms along the Kurzeme coast of the Gulf. The laminated sand, silt and clay, which possibly contain Early Weichselian Glaciation and/or Eemian Interglacial records, underlie Weichselian till in the Gulf of Riga only in the small areas (Fig. 43) established by seismoacoustic investigation (Juskevics pers. comm.).

Core No.21
57° 58' 57" N Lat., 23° 52'37" E Long.
Water depth 24.0 m



Depth below sediment surface (m)	Description
0.05 - 0.90	clay, silty, light brown
0.90 - 2.20	clay, brownish-greyish multi-coloured
2.20 - 4.20	clay, brown (more dark 2.8- 3.0 m)
4.20 - 4.80	clay, white
4.80 - 4.90	clay, varved, brown;
4.90 - 7.00	clay, homogenous, brown ;
7.00 - 7.20	clay, brown with some pebbles
7.20 - 7.40	diamicton
7.40 - 10.00	diamicton, sandy
10.00 - 10.70	clay, grey (at 10.40 m shells);
10.70 - 12.00	clay, light grey (at 11.10 m vivianite)
12.00 - 13.00	clay, grey
13.00 - 13.70	clay, multi-coloured
13.70 - 17.70	clay, dense, grey, at interval 17.40-17.50 m multi-coloured
17.70 - 18.00	clay, dense, varved, dark brown
18.00 - 18.30	clay, varved, brown

Fig. 43. Log and description of the sediment sequence in core 21 of the Gulf of Riga.

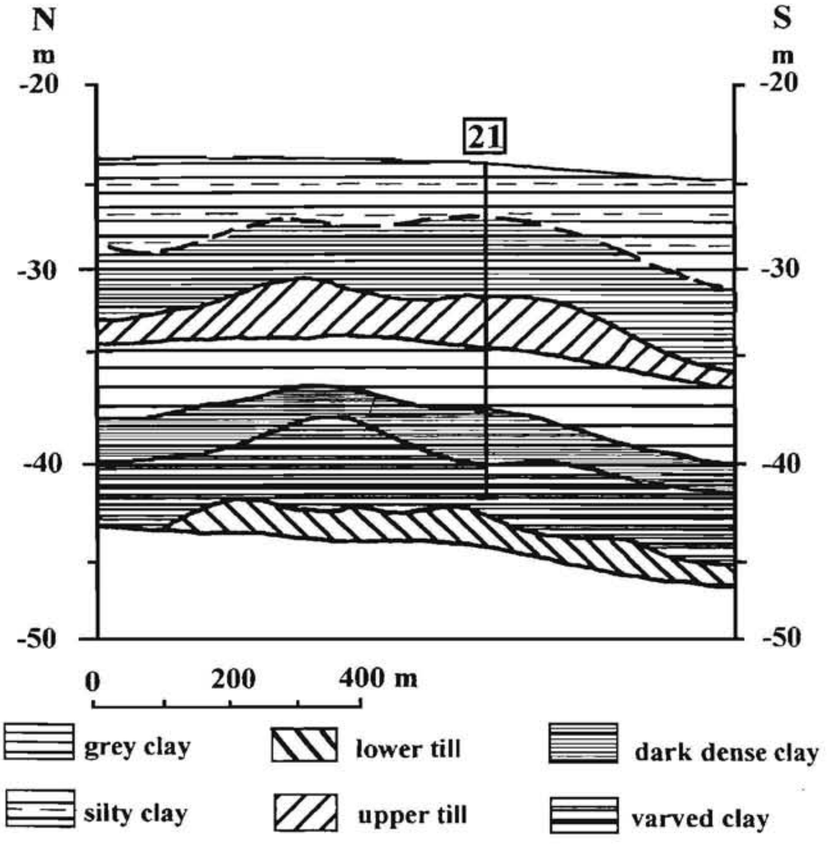


Fig. 44. Geological cross-section in the north-eastern part of the Gulf of Riga (Gulf of Livonia) (after Kalnina & Juskevics 1998a).

There are observable changes and differences in the structure of the sediments. In the interval 18.3-17.7 m, varved clay occurs (Fig. 43), obviously deposited under periglacial and late glacial conditions. Upwards, there is a change to grey clay tonality with organic remains (plants, shells) probably deposited under more favourable climatic conditions. In the interval 10-7 m diamicton and sandy diamicton are found covered by clays of changeable structure and colour and with interlayers of silt. The granulometric characteristics are shown in Fig. 45.

Foraminifera analysis

Foraminifera analysis was carried out by Kristian Schoning on 8 sediment samples from silt, clay and clayey silt in depth interval 18 to 10 m. Only one sample per m of the sediment sequence was available. Unfortunately all samples analysed were barren of foraminifera.

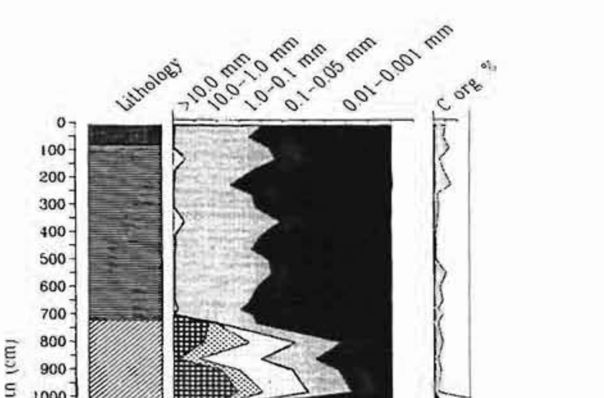


Fig. 45. Grain size composition (%) and values of organic matter content (%) in the Late Pleistocene deposits in core 21 from the Gulf of Riga.

Diatom analyses

Diatom analyses were carried out by Maire Sakson in 1994-1995, in connection with the interdisciplinary research project PACT Nordic/Baltic Program: "Environmental History of the Baltic region".

Sakson classified the diatom flora by the salinity preference as polyhalobous (salinity in the habitat 35-17‰), mesohalobous, halophilous (salinity in the habitat 35-0.2‰), oligohalobous (freshwater indifferent) and halophobous species (Figs 46a, b).

The samples in the lower part (18.80-18.30 m) and upper part of the sequence (10.2-0.0 m) were barren of diatoms. A rapid increase in the number of diatoms occurs in the dark clay (16.70-15.60 m), where all species noted indicate saline or brackish water. Meso- to polyhalobous diatoms, known to be characteristic of littoral environment of the Eemian Sea proper (Liivrand 1984, 1987; Forsström *et al.* 1987; Grönlund 1988, 1991), predominate *e.g.* *Paralia sulcata*, *Grammatophora oceanica*, *Hyalodiscus scoticus* and *Thalassionema nitszchoides*. Other common species typical of the diatom flora of the Eemian Baltic Sea include *Actinoptychus senarius*, *Dimerogramma minor*, *Stephanopyxis turris*, *Thalassiosira eccentrica*, *T. gravida*, *T. nordenskiöldii* and *Podosira* spp, all of which are polyhalobous. Among the mesohalobous species, several taxa that are characteristic of littoral conditions have been observed, *e.g.* *Diploneis smithii*, *D. didyma*, *Cocconeis scutellum* and *Chaetoceros* spp. (Sakson 1999). Some *Diploneis* species, *e.g.* *Diploneis chersonensis*, *D. notabilis*, *D. suborbicularis* and *D. vacillans*, which all prefer high salinity and relatively warm water are also present. Oligohalobous taxa occur with low values (<1%).

The diatom assemblages in the clay strata (15.0-12.5 m) suggest a brackish-marine littoral deposition environment. In the upper part of the submorainic deposits (12.5-10.2 m) there is again a marked increase in diatoms, but here it is mostly represented by mesohalobous (up to 45%) and oligohalobous (up to 48%) species. Polyhalobous taxa occur with values up to 6%. Predominant and frequent species among the oligohalobous taxa are the planktonic *Stephanodiscus astraea*, *Aulacoseira ambigua* and *A. italica*, together with species of the genera *Amphora*, *Eunotia* and *Fragilaria*.

The diatom assemblages from the submorainic deposits show that the water in this basin changed from saline to almost freshwater during the deposition of the sequence.

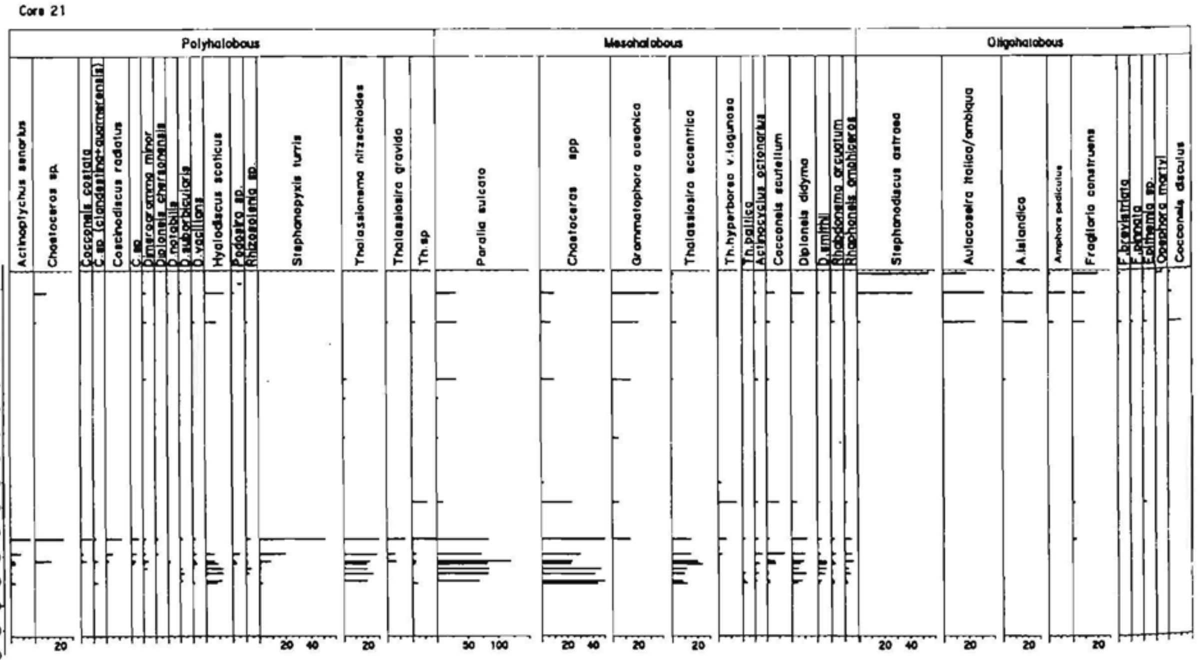


Fig. 46a. Diatom diagram of the Late Pleistocene deposits from the core Gulf of Riga-21.

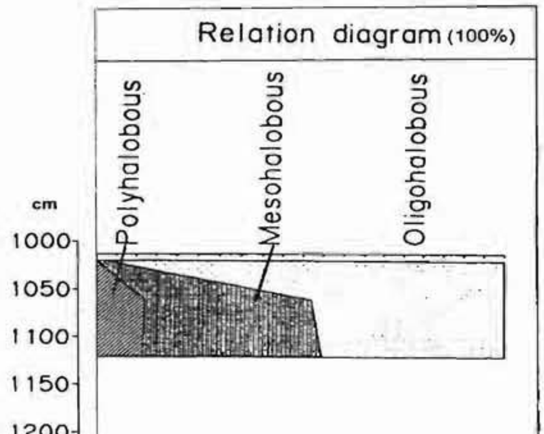


Fig. 46b. Relation of salt-ecological diatom groups in the Late Pleistocene deposits from the core Gulf of Riga-21.

Pollen analyses

In the pollen diagram an almost full late glacial-interglacial-early glacial vegetation cycle is reflected and divided into 16 local pollen assemblage zones (PAZ SA1-PAZ WE6, Fig. 47).

Saalian (Kurzeme) late glacial pollen and spore complexes have been distinguished in the lower part of the brown, varved clay (Figs 47 and 48). The following pollen assemblage zones (PAZ) have been distinguished:

PAZ SA1 - *Betula nana* type-*Juniperus-Duschekia*-NAP, depth interval 18.3-18.1 m (varved clay)
Among the herbaceous pollen, *Artemisia*, Chenopodiaceae and Cyperaceae prevail. The shrubby vegetation includes dwarf birch, *Juniperus* and *Duschekia*.

PAZ SA2 - *Pinus-Betula*, depth interval 18.1-17.8 m (varved clay)
Dominance of *Pinus* with admixture of *Betula* and some decrease in *Betula nana* type pollen, as well as presence of *Picea*,
Helianthenum and *Dryas* characterise this zone. The pollen composition indicates interstadial vegetation with spreading of a pine and birch forest.

PAZ SA3 - *Betula nana* type-*Duschekia-Artemisia*, depth interval 17.8-17.5 m (varved clay)
The composition of the pollen flora in this zone reflects a cooling of the climate, which can be correlated with the Saalian "Younger Dryas" style cold spell discussed by Seidenkrantz (1993).

The boundary between the Saalian Late Glacial deposits (SA3) and early Eemian sediments (E1) is marked by a decrease in NAP and a rise in the *Betula*, *Pinus* and *Alnus* curves. According to Zagwijn (1961) the criteria for defining this boundary are similar to those usually adopted for the boundary between the Late Glacial of the Weichselian (Latvija) and Holocene.

The Eemian (Felicianova) pollen spectra have been divided into eight pollen assemblage zones (E1-E8).

PAZ E1 - *Betula-Pinus*, depth interval 17.5-17.1 m (dense clay)
The character of the pollen composition allows a subdivision of the zone in two parts: PAZ E1a and PAZ E1b.

PAZ E1a - *Pinus*, depth interval 17.4-17.5 m
Pinus is completely dominant, while *Betula nana* continues to be present in very low values, but *B. nana* type disappears. Herb pollen decreases, but is still present with 10-15%, mostly consisting of *Artemisia* and Chenopodiaceae, however, in lower values than in the previous zone.

PAZ E1b - *Betula-Alnus*, depth interval 17.4-17.1 m
There is a peak of *Betula* tree pollen (45%) in the depth interval 17.2-17.4. *Alnus* increases in comparison with PAZ 1a, but *Pinus* decreases on account of *Betula*.

PAZ E2 - *Pinus*, depth interval 17.1-16.8 m (dark dense clay)
Pinus reaches 80%, while *Betula* decrease to 10% and other pollen (*Alnus, Salix*) are present in small numbers. At the end of the zone *Ulmus* and *Corylus* appear.

PAZ E3 - *Ulmus-Fraxinus-Corylus*, depth interval 16.8-16.6 m (dark dense clay)
Pinus gradually decreases, *Ulmus*, *Corylus* and *Fraxinus* rapidly increase and reach their maxima. The proportions of *Alnus* and *Quercus* increase.

PAZ E4 - *Quercus-Corylus- Alnus*, depth interval 16.6-16.5 m (dark dense clay)
Quercus reaches maximum values. *Alnus*, *Corylus* and *Tilia* are present in significant amount and *Picea* appears.

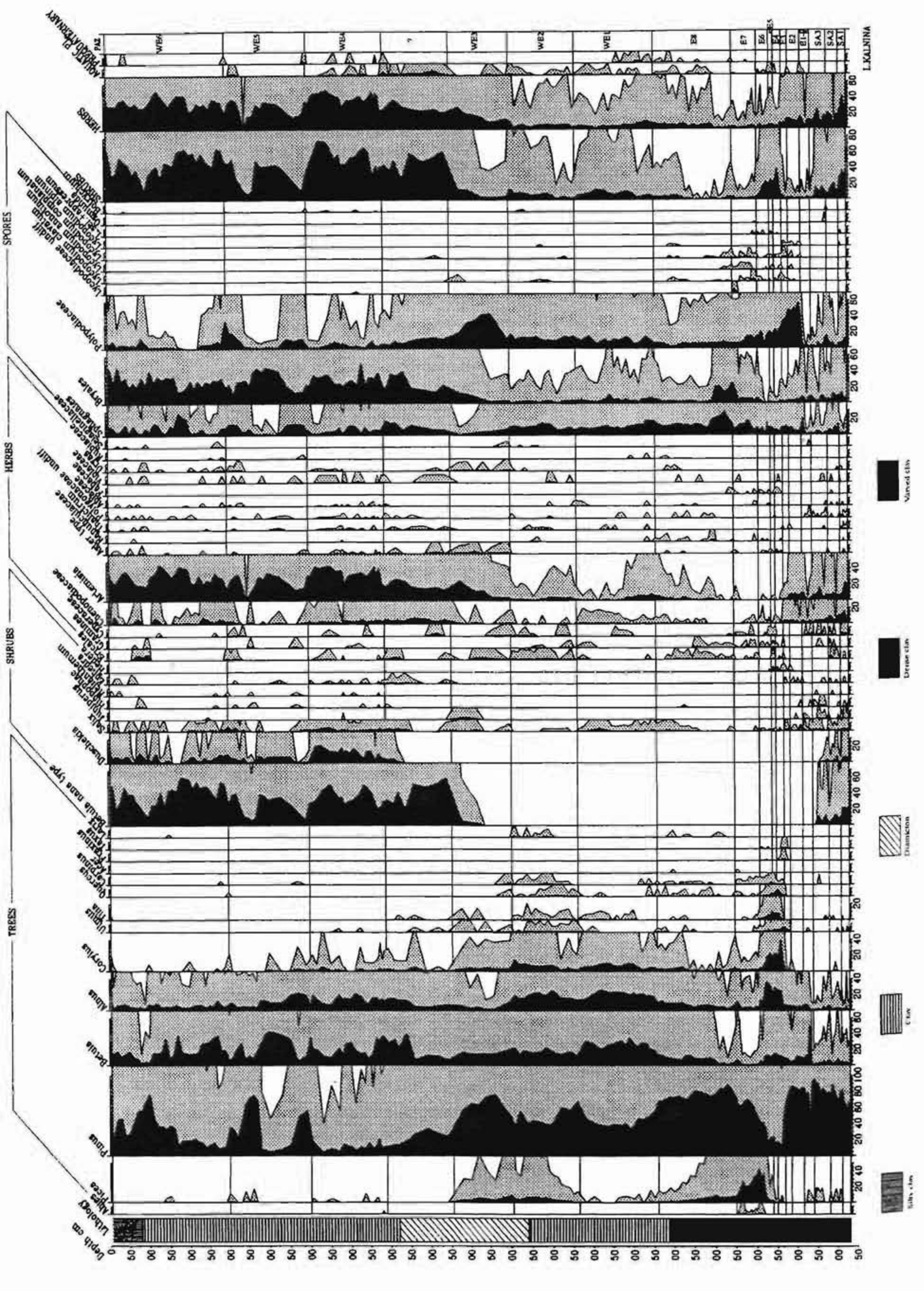


Fig. 47. Pollen diagram of the Late Pleistocene deposits from the core Gulf of Riga-21.

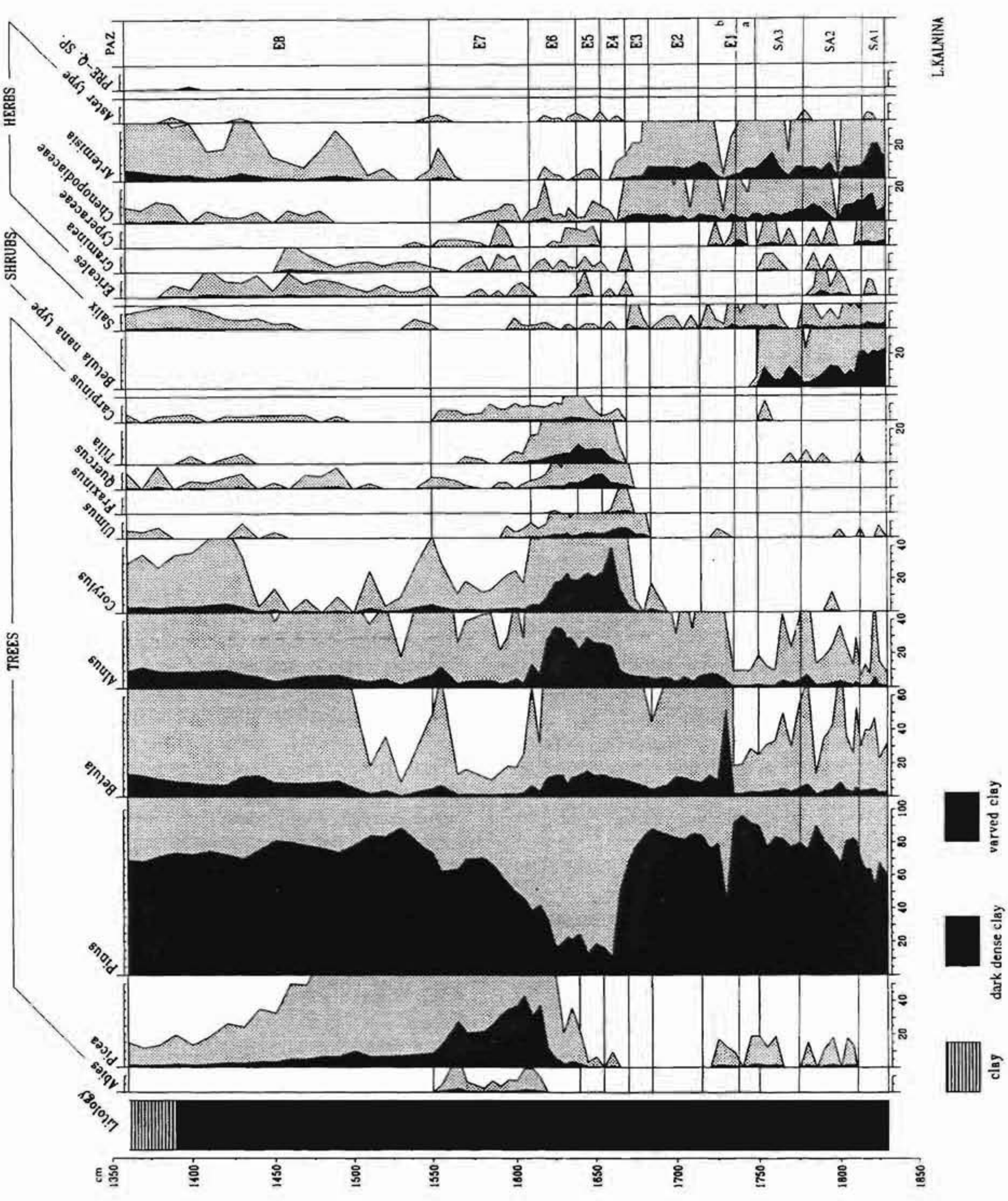


Fig. 48. Pollen diagram of the Eemian interglacial and Late Saalian deposits from the core Gulf Riga-21.

PAZ E5 -*Tilia-Carpinus*, depth interval 16.5-16.4 m (dense clay)
Tilia pollen increases and reaches a maximum. *Carpinus, Alnus* and *Corylus* are represented by high values as well.
PAZ E6 - *Carpinus-Alnus-Corylus* depth interval 16.4-16.1 m (dense clay)
Carpinus reaches a maximum, as well as *Alnus*. *Corylus* is very abundant and reaches a second maximum. *Picea, Abies* and *Pinus* gradually increase, something that contrasts with the decrease in thermophilous trees.
PAZ E7 - *Picea-Abies*, depth interval 16.1-15.5 m (clay)
Predominance and maximum of *Picea* is characteristic of this zone. *Abies* pollen appears, showing a continuous curve and has a maximum, but its values are moderate. To the end of the zone *Picea* gradually decreases, and *Pinus* increases.
PAZ E8 - *Pinus*, depth interval 15.5-13.6 m (clay)
Pinus pollen totally dominates, and *Picea* gradually decreases to 2-3% at the end of zone. The amount of other tree pollen is low, but *Betula* and *Alnus* gradually increase from 2-3% in the beginning to 10% at the end of zone.

The upper boundary of zone E8 *Pinus* PAZ is at the same time the Eemian (E8) - Early Weichselian (Latvija) (WE1) boundary. According to Zagwijn (1961) it should be placed at a level where a rise of herbaceous pollen indicates the decline of close forests and change to more open communities with a marked proportion of different heliophytes.

Significant changes in the vegetation composition are reflected in the part of the diagram corresponding to the depth interval 13.6-10.1 m (Fig.48). The following pollen assemblage zones can be distinguished in this interval:
PAZ WE1 - *Betula-Alnus-Salix*, depth interval 11.6-13.6 m (light grey and grey clay).
Values of *Pinus* pollen decrease, while pollen of *Betula* and *Alnus* increases to similar values. Herb pollen is represented by comparatively low percentages. Among the herb, pollen typical representatives of a periglacial flora appear, *e.g. Dryas, Hippophaë*. Reworked pre-Quaternary pollen and spores occur in this zone.
PAZ WE2 - *Pinus-Alnus-Picea-Larix*, depth interval 11.6-10.0 m (grey clay with shells and light grey clay with vivianite at the level 11.1 m)
Predominant position of pine, birch and alder and an admixture of termophilous tree pollen, represented by *Ulmus, Tilia, Quercus, Carpinus* and *Corylus*. Pollen of *Picea* is characteristic for this zone. It is present with comparatively low values, but forms a continuous curve in this interval. The sediments that comprise these spectra were deposited under post-temperate conditions, when climatic fluctuations obviously occurred. The preservation of the pollen grains is good.

Glacial conditions occurred during the formation of the sediment sequence upwards. However, besides redeposited pollen in the till (diamicton) the pollen of a periglacial flora is represented and it reflects a tundra-steppe vegetation, probably growing close to the ice front.
PAZ WE3 - *Betula nana* type-*Juniperus*-NAP, depth interval 10.0-8.5 m (sandy diamicton)
The sediments (sandy diamicton - till?) of this zone were formed under periglacial and glacial conditions and most of the pollen is probably redeposited, *e.g. Pinus, Picea*, QM. The vegetation in adjacent ice free areas is reflected by presence of a pioneer flora, *e.g. Betula nana* type, *Juniperus, Dryas* and *Selaginella*.
Redeposited pollen and spores - the interval 8.5-6.9 m is represented by diamicton and brown clay with some pebbles, which mainly contain redeposited pollen and spores. However, the pollen spectra demonstrate an increase in *Betula nana* type pollen, and in the second part of the zone also *Betula alba* type increases, but the number of other tree pollen is small. Herb pollen increases and among them *Artemisia* dominates. Pollen and spores of a pioneer flora, *e.g. Dryas* and *Selaginella*, have been noted. The pollen spectra at the end of the interval show signs of a transition from glacial conditions to periglacial.
PAZ WE4 - *Betula nana* type-*Duschekia-Artemisia*, depth interval 6.9-5.0 m (homogeneous brown clay)
Values of tree pollen are low, and shrubs and herb dominate. Beside *Betula nana* also *Duschekia* reaches comparatively high values (about 20%), and *Salix* pollen traces a continuous curve in the diagram. Pollen of *Helianthemum*, *Hippophaë* and *Ephedra* has been noted. The frequencies and diversity of herb pollen increase significantly.
PAZ WE5 - *Betula-Artemisia*, depth interval 5.0-3.0 m (brown clay and white clay at the level 4.8-4.2 m)
In general the composition of pollen in this zone is similar to the previous one, but the pollen curves fluctuate significantly. An increase of *Pinus* and *Betula* tree pollen has been noted in parts of the zone.
PAZ WE6 - *Pinus-Betula nana* type-NAP, depth interval 3.0-0 m (brown and brownish grey clay, and light brown silty clay upwards from 0.9 m)
The absolute values of pollen are low and all those noted in this zone probably are redeposited and do not reflect contemporary vegetation on adjacent land areas.

Interpretation of results

The obtained results suggest that the sediment sequence in core 21 from the Gulf of Riga contains an almost complete palaeoecological record since Saalian Late Glacial, through Eemian interglacial to Weichselian glacial (Table 10).

The lowermost part of the sequence - varved clay in the interval 18.3-17.5 m, comprises pollen suggesting periglacial conditions and the vegetation of an open landscape in the adjacent land with herbs and shrubs, which need virgin unleached mineral soils. Obviously, the coldest climatic conditions existed during formation of varved clays, which comprises the pollen assemblage SA1 with high percentage value of herb pollen, especially *Artemisia* (40 %) and Chenopodiaceae (25 %). The changes in the pollen curves indicate improving climatic conditions, which gradually got more favourable for widespread forests. The sediments in this interval are barren of foraminifera and diatoms.

According to the characteristics of their pollen-spore spectra, the clays that overlie the late glacial formation represent an interglacial cycle. This is supported by features characteristic for the Eemian Interglacial:

- the order of culmination of broad-leaved trees: *Ulmus*, *Quercus*, *Tilia*, *Carpinus*,
- the first maximum of *Corylus* pollen before the *Tilia* maximum,
- the late appearance of *Abies* together with a maximum of *Picea*.

The diatom data suggest interglacial and marine-brackish littoral basin conditions with the characteristic species of the Baltic Eemian proper during formation of the clays that comprise the pollen of PAZ E3 to PAZ E7. According to the pollen and diatom, data the clays overlying the interglacial sediments were accumulated under late-temperate to post-temperate brackish-marine littoral conditions, at the transition from an interglacial to glacial environment. Clays in the depth interval 11.6-10.0 m comprise some layers that are rich in vivianite grains and mollusc *Portlandia arctica* shell fragments, but there are no findings of foraminifera. Diatom and pollen data suggest a freshwater-brackish interstadial environment with sparse forest in the adjacent land areas.

PAZ WE3 with dominance of rede-posited pollen and low values of pollen and spores of a pioneer flora reflect climatic decline and transition to glacial conditions.

PAZ WE4 characterises the development of the vegetation under interstadial (interphasial?) conditions. In the total pollen sum trees and herbs, and spores are represented in equal values. *Betula nana* + *B. humilis* and *Duschekia*, as well *Artemisia* are represented by high values.

Palynological investigations have been carried out on samples from both the till beds and the intermorainic layers and show a long continuous vegetation development, starting with the Saalian (Kurzeme) Late Glacial Saalian "Younger Dryas", continuing through the Eemian (Felicianova) Interglacial, and ending in the Weichselian (Latvija) Glacial.

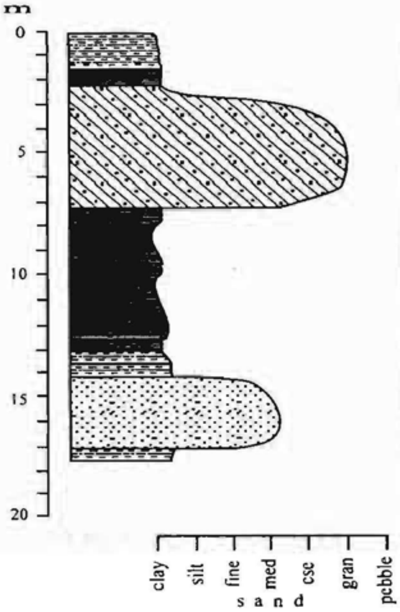
Table. 10. Comparison of diatom and pollen data from the Gulf of Riga-21 site.

Depth m below sediment surface	Diatom zones	Pollen assemblage zones (PAZ)	Environmental conditions
0-3.0	barren	WE6 - *Pinus, Betula nana* type NAP	?
3.0-5.0		WE5 - *Betula, Artemisia*	stadial
5.0-6.9		WE4 - *Betula nana* type, *Duschekia, Artemisia*	interstadial
6.9-8.5		redeposited pollen assemblage	glacial
8.5-10.0		WE3 - *Betula nana* type, *Juniperus*, NAP	stadial
10.0-11.6	freshwater-brackish	WE2 - *Pinus, Alnus, Picea, Larix*	freshwater-brackish interstadial environment
11.6-13.6		WE1 - *Betula, Alnus, Salix*	
	brackish marine littoral		posttemperate, brackish-marine littoral deposition environment
13.6-15.5		E8 - *Pinus*	
15.5-16.1	marine-brackish littoral species characteristic	E7 - *Picea, Abies*	interglacial, marine littoral basin with characteristic species of Baltic Eemian proper
16.1-16.4		E6 - *Carpinus, Alnus, Corylus*	
16.4-16.5		E5 - *Tilia, Carpinus*	
16.5-16.6		E4 - *Quercus, Corylus, Alnus*	
16.6-16.8		E3 - *Ulmus, Fraxinus, Corylus*	
16.8-17.1	no data available	E2 - *Pinus*	early temperate conditions
17.1-17.5		E1b - *Betula, Alnus* E1a- *Pinus*	
17.5-17.8	barren	SA3 - *Betula nana* type, *Duschekia, Artemisia*	late glacial meltwater basin
17.8-18.1		SA2 - *Pinus, Betula*	
18.1-18.3		SA1 - *Betula nana* type, *Juniperus, Duschekia*, NAP	

Core No.25

57° 50' 38"N Lat., 24° 11'16" E Long.
Water depth 21.30 m

Core-25 is located in the north-eastern part of the Gulf (Fig. 1), southeast of core-21. A sediment core of 17.2 m length was taken. Quaternary deposits are present down to 13.2 m. The depth interval 17.2-13.2 m is composed of Devonian bedrock.



Depth below deposit surface (m)	Description
0.00 - 1.70	clay, silty, light brown
1.70 - 2.15	clay, brown
2.15 - 7.15	diamicton, sandy
7.15 - 7.85	clay, varved, brown
7.85 - 9.85	clay, bluish grey homogeneous
9.85 - 12.80	clay, dark brown, with silty lenses and varves
12.80 - 13.00	clay, brown, varved
13.00 - 13.20	clay, silty, greyish brown
13.20 - 14.10	clay, silty, reddish brown with micas, Devonian
14.10 - 17.00	sandstone, reddish brown, Devonian
17.00 - 17.20	clay, reddish brown, silty, Devonian

Fig. 49. Log and description of the sediment sequence in core 25 from the Gulf of Riga.

Lithology

The 13.2 m long Quaternary sediment sequence deposited directly on the Devonian reddish brown silty clay, which is rich in micas, has been found in core-25. The lowermost Quaternary sediment layer is represented by a greyish brown silty clay, which is overlain by 0.2 m brown varved clay at the depth 13 m (Fig. 49). Upwards from 12.8 m, this thin layer is covered by dark brown clay with silty lenses and some varves. The silty lenses and varves make complex structures in this layer. At 9.85-7.85 m, a bluish grey, homogeneous clay layer with rare shell fragments and vivianite occurs. The brown varved clay has been accumulated at the depth interval 7.85-7.15 m and is covered by a brown, sandy diamicton. Pebbles and gravel in the diamicton are predominantly represented by Precambrian igneous and metamorphic rocks. The values of the sandy fraction in the diamicton varies from 45 to 54%, and clay constitutes 18-23%, (Fig. 50). The content of carbonates in the 0.5-1 mm grade varies from 17 to 20%, but the limestone to dolostone ratio is 8. The roundness of the hornblende grains in the size fraction 0.1-0.25 mm is between 18 and 20%. The results mentioned are characteristic for Weichselian (Latvija) till. The overlying brown clay from the depth 2.15 m and upwards becomes gradually more silty. Organic matter content is low in the whole sediment sequence, and in the clays above the till it is only 0.1-015 %, while in clays accumulated below, it varies from 0.3 to 0.85% and only in the depth level 8.0-7.8 m it reaches 1.1% (Fig. 50).

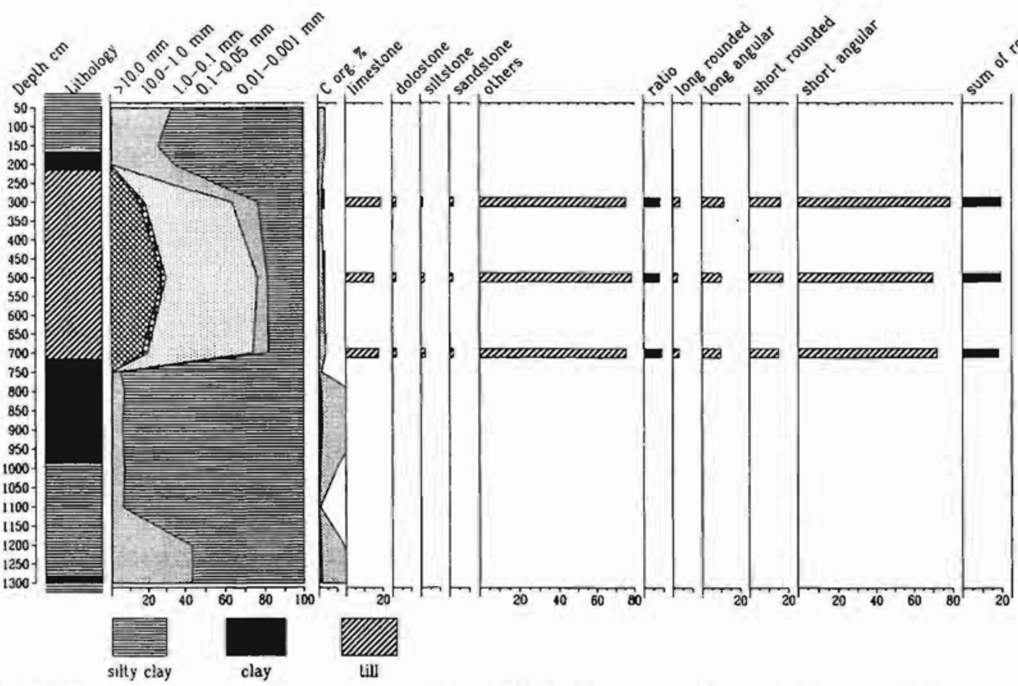


Fig. 50. Grain size composition, organic content, lithologica composition and limestone-dolostone ratio (fraction 0.5-1.0 mm) and roundness of hornblendes (%, fraction 0.1-0.25 mm) in the sediment sequence of the core Gulf of Riga-25.

Pollen analyses

Pollen analyses were carried out on 99 samples from the Quaternary deposits in core 25. Seven pollen assemblage zones (RG25/1 – RG25/7) were distinguished (Fig. 51). The sequence analysed contains a low amount of pollen grains, 10 to 80 per 1g dry sediment. Samples of about 100-200 g were taken and prepared for pollen concentration.

The pollen spectra are characterised by a dominance of *Pinus,* which is probably mostly redeposited or transported long distance. Shrubs are represented by *Betula nana* type and *B. humilis* in significant number and present in the clay and silty clay directly underlying the glacial sediments. Broad-leaved tree pollen is found in the same depth interval, but are considered to be redeposited. *Artemisia* and Chenopodiaceae are represented practically in the whole core in various values. Pioneer plants such as *Helianthemum, Hippophaë* and *Dryas* can be noted.

PAZ RG25/1 - *Betula-Pinus*-NAP (13.25- 12.00 m , clay and silty clay). Besides *Pinus, Betula* sect. *Albae* dominate. Pollen of *Betula nana* type, Ericales, *Artemisia*, Chenopodiaceae are present. Single pollen of *Dryas* and some *Selaginella selaginoides* spores have been found.

PAZ RG25/2 - *Pinus-Picea-Larix* (12.0-10.50, silty clay). Pollen spectra show occurrence of *Picea*, increase of *Pinus* and *Larix* and decrease of *Betula.* The disappearance of *Betula nana* type, *Dryas* and *Selaginella selaginoides*, suggests amelioration of climate and indicates interstadial conditions.

PAZ RG25/3 - *Betula nana* type-*Juniperus*-NAP (10.50-9.50 m), silty clay and clay). Disappearance of *Picea* pollen and decrease in *Pinus* is characteristic for this zone. An increase in *Betula nana* type, *Juniperus*, Ericales, Chenopodiaceae, *Artemisia, Dryas* and *Selaginella selaginoides* implies a deterioration in the climate and the establishment of stadial periglacial conditions.

PAZ RG25/4 – *Pinus-Larix-Picea* (9.50-8.0 m, clay). Increase in *Picea, Pinus* and *Larix* pollen, and disappearance of the periglacial flora elements indicate interstadial conditions.

PAZ RG25/5 – *Betula-B. nana* type (8.0-7.15 m, clay). There is an increase in *Betula alba* type, *B. nana* type and Poaceae pollen. Lower values of *Pinus* as well as disappearance of *Picea* and *Larix* pollen indicate a deterioration in the climate during the formation of the brown varved clay and point to a transition to glacial conditions in this zone.

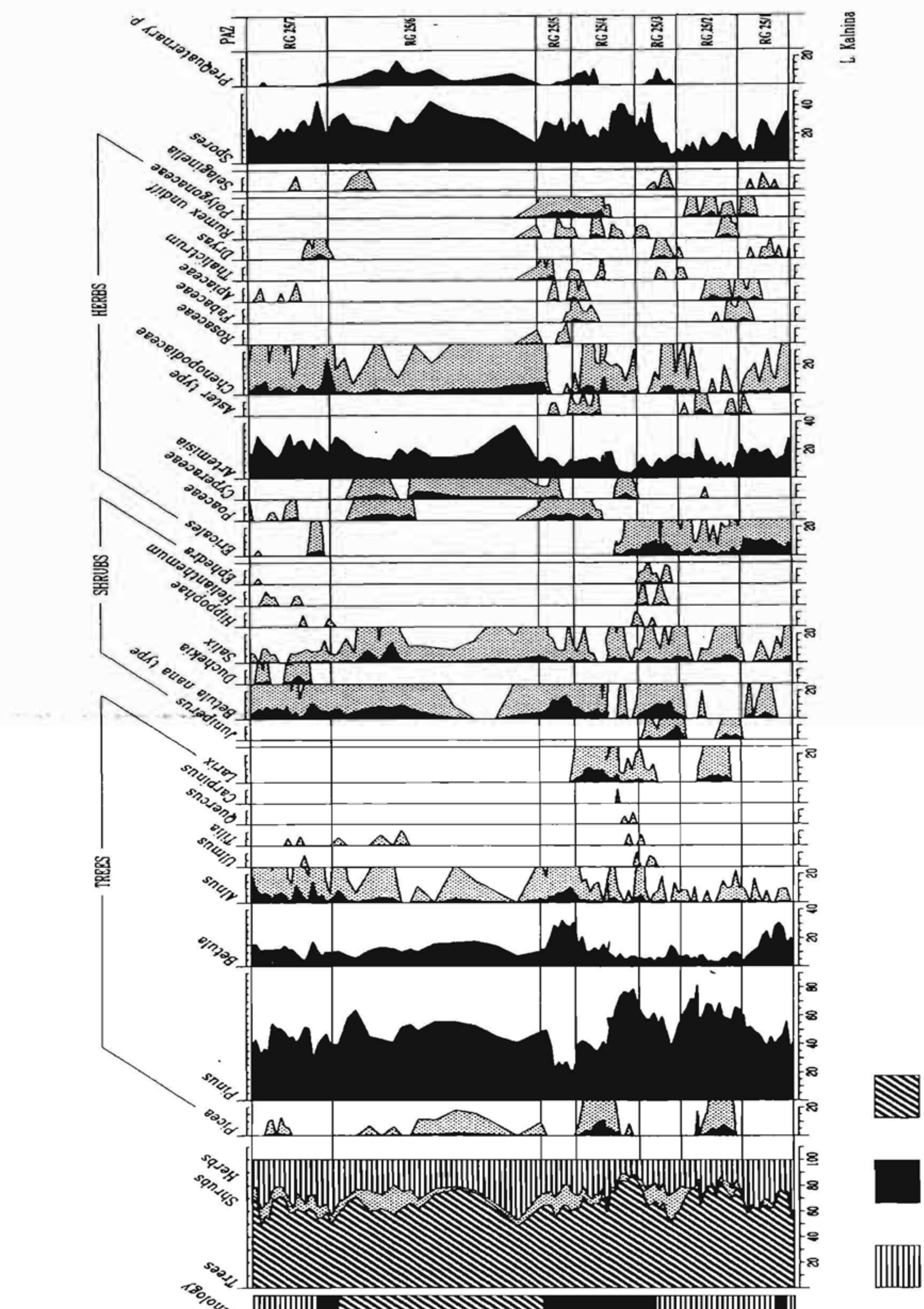


Fig. 51. Pollen diagram of the Late Pleistocene deposits from the Gulf of Riga core-25.

The diamicton at the depth of 7.15-2.1 m contains redeposited or long distance transported pollen, including pollen of periglacial plants, *e.g. Betula nana* type and *Artemisia* and *Selaginella selaginoides* spores. Redeposited pre-Quaternary palynomorphs, mainly represented by *Cyathes* type spores have also been found, which indicates an incorporation of Devonian rocks into the diamicton.

PAZ RG25/6 – *Betula nana* type-*Duschekia*-NAP (0-2.10 m, clay and silty clay). Pollen from the sediment sequence overlying the upper diamicton are represented by *Betula nana* type, *Duschekia* and by herbaceous pollen, mainly represented by *Artemisia* and Chenopodiaceae. Pioneer plant pollen, *e.g. Hippophaë*, *Helianthemum* and *Dryas* are noted.

Interpretation of results

The composition of the pollen spectra demonstrates that the Quaternary sediments from borehole 25 were formed under glacial and periglacial conditions, when a very scanty vegetation existed in adjacent land areas.

Correlation of the pollen assemblage zones from cores 21 and 25 shows that the Quaternary sediments in core 25 were deposited during Weichselian stadials and interstadials (Fig. 52). These sediments are lying directly on Devonian bedrock. Thus the interglacial sediments must have been eroded or were not accumulated here.

PAZ RG25/2 is possible to correlate with PAZ WE2 from core-21 from the Gulf of Riga (Fig.52). Pollen spectra in both PAZs reflect an interstadial vegetation type represented by *Pinus*, *Picea* and *Larix*. The PAZ RG25/4 also reflect interstadial conditions, represented by coniferous trees and *Larix* has its maxima, while in core-21 corresponding sediments probably were eroded by a glacier.

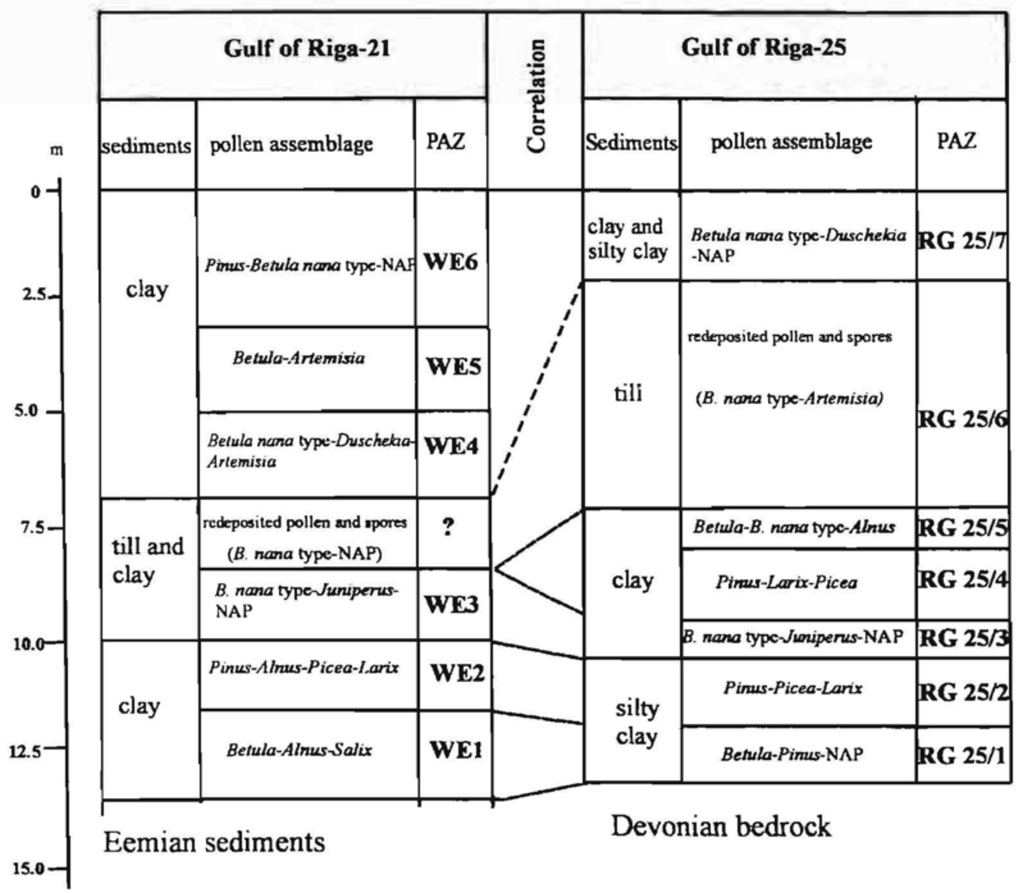


Fig. 52. Correlation of the PAZ between diagrams in the core Gulf of Riga-21 and 25

7 PALAEOENVIRONMENTAL CONDITIONS

The investigated area is situated on the coastal mainland in western Latvia, but during the Holsteinian and Eemian Interglacials, it was obviously submerged by the sea. Records from deposits accumulated under marine conditions during previous interglacials provide information as evidence for the existence of marine conditions. This area was a sub-littoral and shallow littoral coastal region influenced by inwash of material from the mainland. The depositional conditions are mirrored by the composition of the foraminifera fauna and the diatom flora as well as by the vegetation history as indicated by the pollen flora in the sediments studied.

7.1 Palaeoenvironment recorded in the deposits at the Holsteinian sites

7.1.1 Letiza (Elsterian) Glaciation

According to the lithostratigraphical data (Konshin *et al* 1970; Danilans 1973; Seglins 1987; Tracevski *et al.* 1989; Kalnina *et al.* 2000) the lowermost diamicton in the Ziemupe-Jurkalne area has been identified as till accumulated during the Letiza (Elsterian) glaciation. This till is

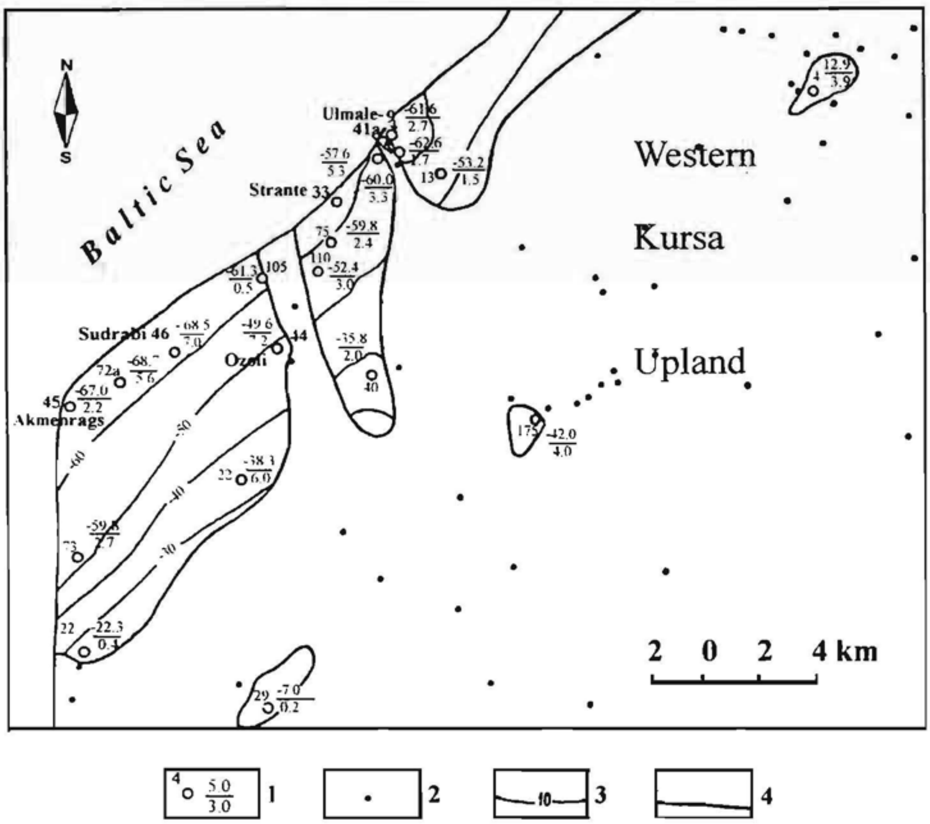


Fig. 53. The distribution of the till bed of the Letiza (Elsterian) Formation and isolines of its upper contact (after Murniece in Tracevskis *et al.* 1989). Contour interval 10 m. 1- No. of the core; above line elevation of the formation top, m; below line – thickness of the strata, m; 2 – cores not containing Letiza Formation deposits; 3 – isolines of top elevation, m; 4 – boundary of Letiza Formation distribution area.

distributed in the coastal area and the adjoing Western Kursa Upland (Tracevski *et al.* 1987) and it is also found below the bottom of the present Baltic Sea.

The top of the Letiza Formation is at a depth varying between 22 m below sea level at the foot of the Western Kursa Upland (Fig. 53), to 70 m below sea level on the present sea bottom. The thickness of the Letiza (Elsterian) till cover is from 0.4 m at Ziemupe to 7.2 m in the vicinity of Ozoli (Fig. 54) and it lies directly on the Devonian sedimentary bedrock.

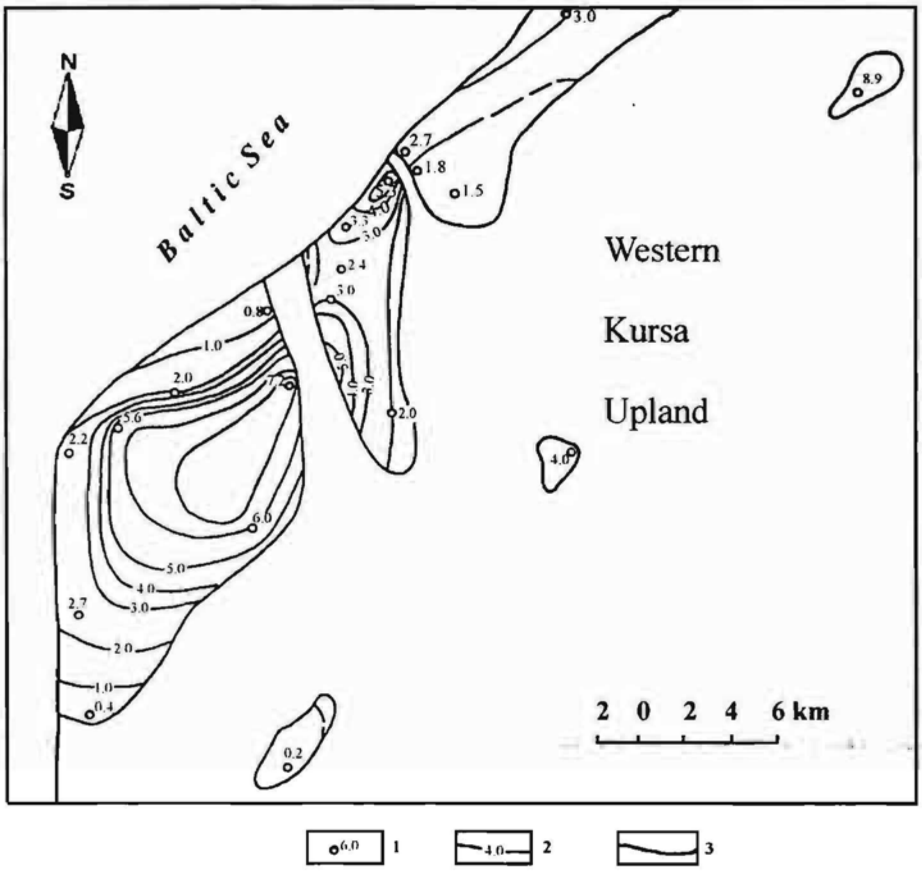


Fig. 54. The thickness of the Letiza Formation (after S. Murniece in Tracevskis *et al.* 1989). 1- thickness of the Letiza Formation strata, m; 2 – isolines of thickness, m; 3- boundary of distribution area of the Letiza Formation.

The Letiza till structure and the grain size, petrographical and mineral content in the study area have been discussed by Kalnina *et al.* (2000). This till consists of densely compressed and massive reddish brown to brown calcareous diamicton, with sandy or silty clay dominance in the matrix. The gravel and pebble content is relatively high, and limestone (30-40%) and dolostone (20-30%) are common. The carbonates in the 0.5-1 mm fraction of the Letiza till dominate with 54-58%. Such a relatively high content of carbonates might be explained by the location of the area close downglacier from the belt where carbonate bedrock outcrops on the pre-Quaternary surface. The limestone/dolostone ratio is 1.5 in the coastal area and 3.0 in the neighbouring areas of West Kursa Upland (Kalnina *et al.* 2000). In contrast the limestone/dolostone ratio in the Kurzeme till is 24.5 in the study area and 22.5 within the adjoining region.

Ulst and Maiore (1964) have distinguished the Letiza and Kurzeme tills by the rounding of hornblende grains in the entire area of the Baltic Countries, and they found that the Letiza till contains less rounded grains. The data from this study show only 8-10% rounded hornblende grains in the till of the Letiza Glaciation, but 28-37% in the tills of the Kurzeme Glaciation.

7.1.2 Transition from the Letiza (Elsterian) Glaciation to the Akmenrags (Holsteinian) Interglacial

The composition of the clays of the Sudrabi beds deposited on the Letiza (Elsterian) till in the study area indicates the termination of this glaciation. The reddish grey clay in the lower part of the Sudrabi clay sequence is compact, with thin silty clay interlayers, and contains only a few marine microfossils, probably redeposited since they are accompanied by pre-Quaternary palynomorphs.

In the upper part of the Sudrabi beds, the clay becomes more silty and the lamination is more abundant than in the lower part. The lower part is reddish grey because of incorporation of the underlying reddish Letiza till and Devonian bedrock. Higher up it becomes grey because of increasing organic content. In the upper part, the clay contains fragments of mollusc shells, *e.g. Portlandia arctica*, ostracods, foraminifera and diatoms. They suggest an influx of marine water in the basin at the end of the deposition of the Sudrabi clay. The plant and faunal remains indicate arctic-subarctic environmental conditions.

In the diagrams of the sediment sequences (Figs 17a, b, 22a, b), which correspond to the lower part of the Sudrabi beds, the pollen spectra of PAZ I suggest an open treeless landscape, characterised by shrubs and herbs of different plant communities, *e.g. Salix, Helianthemum, Hippophaë*, *Betula nana,* and *Ephedra* preferring arctic-subarctic climate and periglacial conditions. *Pinus* pollen was probably windblown from long distances, as is often observed in periglacial pollen spectra. A few *Betula* tree pollen grains have been found already in the lower part of the zone, while towards the upper boundary it becomes dominant among birches. Other tree pollen, including Tertiary exotics have been redeposited or reworked from older sediments by glacial meltwater.

The brief interval of stadial conditions is only weakly reflected in some sections and in addition it is indicated by a decrease of the absolute amount of palynomorphs (~10 grains per 1 g sediment) and increase in *Betula nana* type, *Artemisia* and *Dryas* pollen, and *Selaginella* and Bryales spores in some sections (Kalnina *et al.* 2000).

The pollen flora in the upper part of the Sudrabi clay indicates a vegetation change from a subarctic tundra to a forest tundra with an admixture of some boreal elements, and this probably reflects a gradual climate amelioration. Marine microfossils encountered in the upper part of the Sudrabi clay point to an influx of marine water in the basin. For instance, the presence of foraminifera in the clay deposited at the end of the Late Letiza suggests the earliest inflow of marine water in the Baltic Sea basin. Foraminifera, as represented by for example by *Elphidium subclavatum* Gudina, indicate severe periglacial conditions.

The diatom analysis of the Sudrabi beds shows that most species of marine, brackish and fresh water diatoms that occur in the upper part of these clays are not present in the underlying till (Charamisinava, 1971). If they are autochtonous, the clays were deposited in a marine environment. Comparing all data, it can be concluded that during the Late Elsterian (Letiza), marine conditions existed in the Baltic basin, which suggests an influx from the Atlantic Ocean, but it was also strongly influenced by glacier meltwater. The sedimentary facies, represented by calcareous laminated clays with dropstones and lumps of Letiza till, suggests aquatic deposition in moderately deep water in a proglacial freshwater basin, fed by meltwaters from the retreating Fennoscandian ice sheet (Kalnina *et al.* 2000). The margin of the ice sheet must have been at some distance, because the Sudrabi clay is finely laminated.

The transition from Late Letiza (Saalian) to Akmenrags (Holsteinian) Interglacial was gradual, probably interrupted only by a short, weakly expressed stadial. The thin laminated sediment sequence, accumulated during this interval, suggests calm water conditions without drastic sea level changes.

7.1.3 Akmenrags (Holsteinian) Interglacial

Silty and sandy sediment layers, which are present in the Akmenrags (Holsteinian) formation, are rich in disseminated organic, not only plant remains, but also ostracods, foraminifera, diatoms, fragments of marine mollusc shells, blue grains (0.5 – 3 mm diameter) of vivianite, pyrite concretions, limonite crusts along plant remains, and a few grains (about 0.5 mm) of amber and insect remains (Kalnina *et al.* 2000). These sediments occur in the coastal Ziemupe-Jurkalne area.

The top of the marine interglacial sediment complex ranges from 40 to 56 m below the present sea level. The thickness of the strata varies from 2.5 m at the foot of the Western Kursa Upland to 14 m in the area between Ozoli and Strante. As a rule the thickness increases towards the sea. The distribution of these strata with decreasing thickness eastwards on land probably represents a bay which was a part of the Holsteinian Sea (Figs 2, 55, 56.) The grain size composition of these sediments shows a predominance of a material with grade less than 0.25 mm in the entire interglacial sequence. The clay fraction prevails in the lowermost part, but upward the sediment becomes more silty, with an increasing role of the sand fraction.

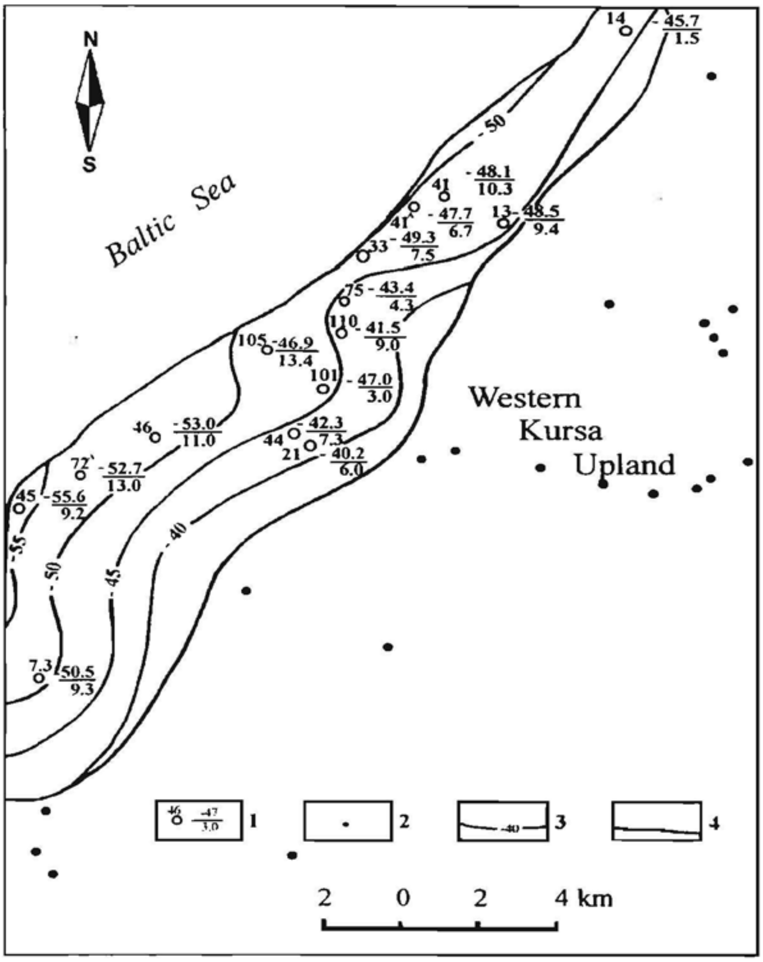


Fig. 55. The distribution of the deposits of the Akmenrags Interglacial and contour of its top below the present sea level (after Murniece in Tracevskis *et al.* 1989). The contour interval is 5 m. 1- No. of the core; above line elevation of the formation top, m; below line – thickness of the strata, m; 2 – cores not containing Akmenrags Formation deposits; 3 – isolines of top elevation, m; 4 – boundary of Akmenrags Formation distribution area.

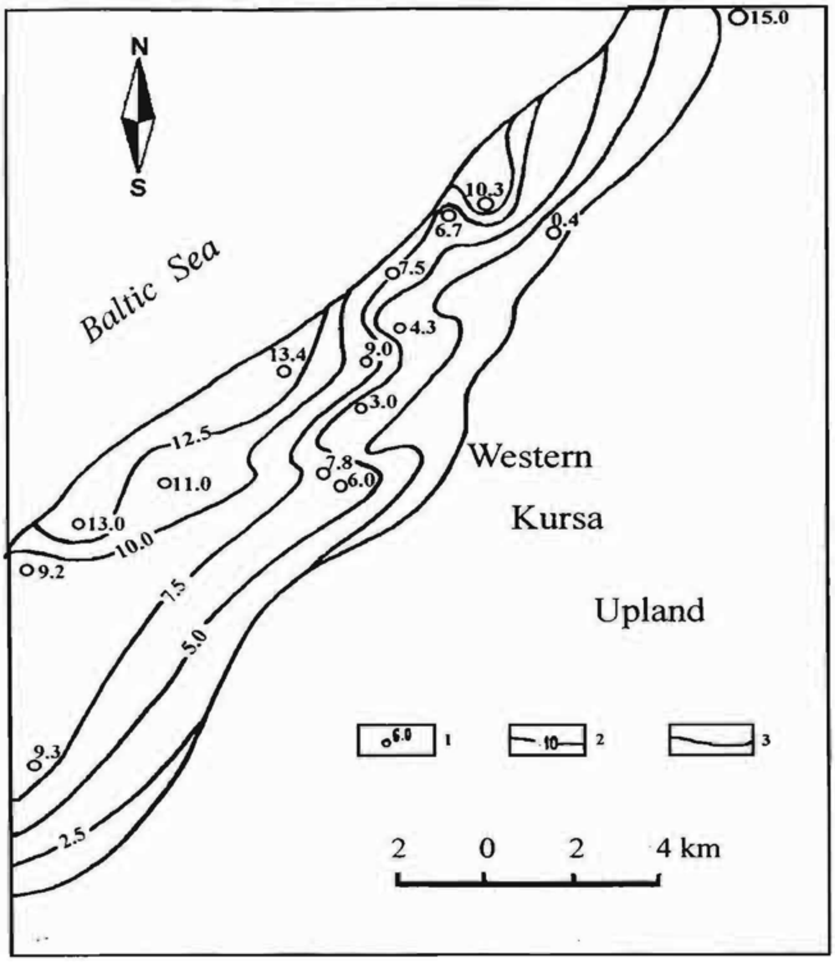


Fig. 56. The thickness (in m) of sediments deposited during the Akmenrags Interglacial (after Murniece in Tracevskis *et al.* 1989). The contour interval is 2.5 m.1- thickness of the strata, m; 2 – isolines of top elevation. m; 3 – boundary of Akmenrags Formation distribution area.

The foraminifera *Elphidium clavatum*, *E. granatum*, *E. incertum* and *Protelphidium orbiculare*, and a great variety of marine and brackish water diatoms are present in the sediments of the Akmenrags Interglacial. They definitely suggest a marine environment (Charamisinava 1971; Seglins 1987). However, several slightly brackish and freshwater diatoms, besides the marine-brackish species, indicate a considerable input of freshwater from the land area into the marine environment. This is also supported by the sandy formations of an estuary type, which has been found in some places (Tracevski *et al.* 1989) in the Ulmale area, as well as plant remains and finds of the freshwater ostracod *Cytherissa lacustris*.

The pollen assemblage zones II to VI reflect a succession of interglacial vegetation, which is in good agreement with that identified in the Pulvernieki (Holsteinian) interglacial in the Latvian mainland (Konshin *et al.* 1971). The pre-temperate stage (PAZ II) is represented by pine and birch forest, with a gradual increase of *Picea, Alnus, Corylus* and QM pollen, suggesting that the climate became warmer. Arboreal pollen dominates in the diagrams (Figs 12a, 22a), suggesting the spread of a boreal forest in the mainland. Before the climatic optimum *Picea* and *Alnus* had already immigrated and gradually increased their role in the forest composition. The pollen data suggest warm and relatively dry climatic conditions. Pollen of the broad-leaved trees *Corylus* and *Carpinus*, and the coniferous *Abies* appear near the top of PAZ II, before the climatic optimum (in PAZ III) when sediments became particularly rich in organic material. and the palynomorph concentration reached up to 800 grains per 1 g dry sediment.

Marine diatoms, *e.g. Coscinodiscus perforatus, Actinoptychus undulatus* and *Rhabdonema arcuatum* (Charamisinava 1971), dominate but other benthic neritic and oceanic forms that occur in seas with normal salinity were accumulated in the sediments during the climatic optimum.

The composition of the pollen flora suggests that the Holsteinian climatic optimum is reflected by PAZ III, where maxima of *Picea*, Quercetum mixtum, *Carpinus, Abies, Alnus, Corylus* occur. The role of *Picea* in the forest composition increases rapidly and at some sites it dominates already before the climatic optimum. During the domination of spruce forests, pollen of *Picea* sect. *Omorica* and *Pinus* sect. *Strobus* were identified. Also the contribution of *Alnus* is considerable, while QM and *Corylus* are less frequent in comparison with other interglacials. During the late temperate substage, *Abies* (*Abies alba* and *Abies* sp.) and *Carpinus* had their maximal distribution, while *Pinus* was less abundant.

Generally, during the Holsteinian Interglacial the pollen flora implies a wider distribution of broad-leaved trees in the coastal area than further inland and pollen assemblages probably often reflect the composition of the local flora. Thus, the pollen of broad-leaved trees culminates at the Ulmale and the Strante sites before the *Picea* and *Abies* maxima, but at the Akmenrags site, however, the QM maximum divides the *Picea* and *Abies* maxima into two peaks (Figs 12a, 17 a). This phenomenon can probably be explained by environmental differences.

More sandy sediment had accumulated in the second part of the interglacial. The thin sandy interlayers, and the fluctuations in the composition of the diatom flora, obviously point to changes of the sea level and the climate and an inwash of material by rivers. Cerina (1993) has found remains of plants in the study area, something that commonly occurs in Holsteinian interglacial sediments. Macrofossils of the following plants are especially interesting: *Azolla interglacialica, Caulinia goretskyi, Carex paucifloroides, Brasenia borysthenica, Ranunculus sceleratoides, Salvinia natans, Zannichellia palustris, Elatine hydropiper* and *Carpinus betulus*. The presence of macrofossils in the marine sediments may be explained by discharge from rivers and the location of the sites with the original plant habitat in the shallow coastal area.

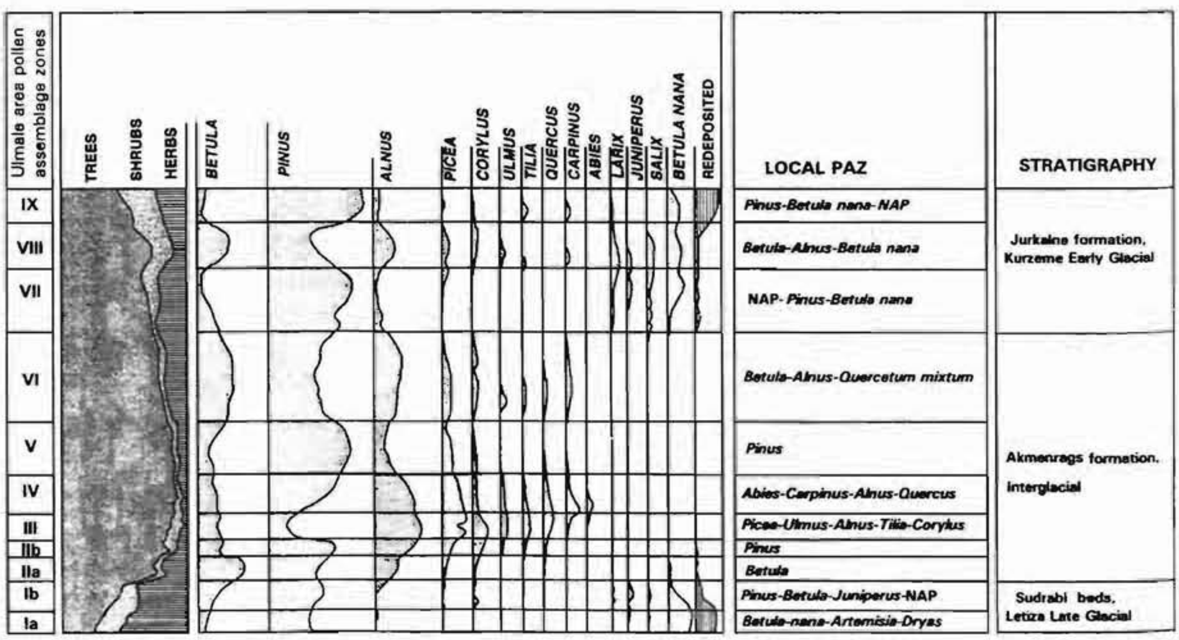


Fig. 57. Simplified pollen diagram of the Akmenrags Interglacial and Early Kurzeme Glacial.

The pollen spectra in the late temperate substage (PAZ IV) are characterised by changes among the tree components. The share of coniferous trees, which has been considerably high during the entire interglacial, increases, particularly pine. Still *Pinus* sect. *Strobus, Picea* sect. *Omorica* and *Abies* are present just after the climatic optimum, but towards the end of the interglacial (PAZ V), the role of *Pinus* increases to almost total dominance. In the pollen spectra of PAZ IV from the core Sudrabi-46, the dominance of *Pinus* occurs in the middle of this zone, but foraminifera data suggest a regression of the sea (Seglins 1987). These pollen spectra probably reflect the expansion of *Pinus* into the sandy areas emerging from the sea. This was probably of local character, because later on *Alnus* and *Corylus* increase in abundance.

A regression of the sea takes place during the post-temperate stage, and the sediments become more sandy and in addition to marine diatoms also contain brackish and brackish freshwater taxa. The sediments are, however, barren of foraminifera, only single ostracods represented by *Lymnocythere* are found.

The very end of the interglacial is represented only in a few sections, *e.g.* Akmenrags and Ozoli. The sediments deposited during this time interval have probably been eroded at the other sites or redeposited, because thick sandy strata poor in microfossils and organic matter often overlay the sediments of PAZ V.

The sediments accumulated at the end of the interglacial are generally not rich in organic matter, but some microfossils occur and the amount of palynomorphs increases slightly. Pollen data in PAZ VI indicate a decreasing forest distribution, while the amount of herbs increases, particularly Ericales and Cyperaceae. Complicated climatic and sedimentation conditions have been recorded in the sediment layer at the very end of the interglacial, where remains of subarctic flora elements, *e.g. Dryas* occur simultaneously with some pollen of broad-leaved trees, suggesting significant climatic fluctuations.

The climate prevailing during the post temperate stage, as reflected by the pollen flora of PAZ VI, gradually becomes cooler than that of the previous zone but, obviously, with some relatively short warmer periods, which could help to explain the mixed vegetation of the thermophilous and periglacial plants at the Akmenrags site. Clusters of open forest were probably present in association with tundra vegetation. The interpretation of mixed pollen spectra represented in PAZ VI is very complicated and there are two different alternatives. Grichuk (1989) explains a similar composition of pollen spectra that is found in diagrams of western Russia in terms of a second climatic optimum. Those spectra did not contain pollen of a periglacial flora, while in PAZ VI at the Latvian sites they are present, although, in low numbers.

The climatic conditions during the Akmenrags (Holsteinian) Interglacial were favourable for an early immigration of coniferous trees on adjacent land. The maximum distribution of *Picea* and *Abies* forests occurs either before the climatic optimum (Fig. 26a) or is nearly contemporaneous with it (Figs 17a, 22a).

7.1.4 Jurkalne formation - Early Kurzeme (Saalian) Glaciation

Sand is the main component in the sediment sequence overlying the Akmenrags Interglacial clayey silt sediments. It was proposed that the Jurkalne sediments (named also Staldzene in Danilans 1973) were related to the beginning of the Kurzeme/Saalian glaciation. A thin diamicton layer has been found in a few test drillings approximately 20-25 m below the sea level, dividing the Jurkalne sediments into two major subunits. The diamicton layer and an underlying silt bed occur mainly in the northern part of study area

(Strante - Ulmale - Jurkalne) although stones and gravely sand have been noted at a similar depth in other sections. Lithologically the diamicton is similar to the Kurzeme till (Kalnina *et al.* 2000). The near-level occurrence of the diamicton over a wider area, and the presence of small-scale deformations underneath this layer in the cores Ulmale-41, 41a, and Sudrabi-46 suggest that the diamicton may be deposited by a partly grounded ice lobe advancing into a proglacial water body (Kalnina *et al.* 2000).

The silts underlying the diamicton, in such a case, were deposited by muddy meltwater from the advancing glacier. Part of the diamicton layer may have been eroded by water currents, as suggested by the presence of clasts of various sizes. Strong reworking by water is also responsible for the low frequency of palynomorphs and their poor preservation at this level. After the retreat of the glacier lobe that had deposited the thin and discontinuous till layer, the deposition of the overlying sandy and gravely Jurkalne sediments continued in a shallow near-shore or lagoonal environment (Veinbergs & Savvaitov 1970, Tracevski *et al.* 1989, Kalnina *et al.* 2000).

The results of investigation of diatoms (Seglins 1987) in the Jurkalne sediments show that the aquatic environments of sedimentation gradually changed from marine to freshwater at the end of the depositional cycle. Some admixture of the marine and brackish water diatoms in the upper part of the Jurkalne sediments may have resulted from a reworking of the underlying deposits.

The diatom spectra suggest a Middle Pleistocene age of the Jurkalne sediments. The diatom flora is dominated by the genus *Cyclotella,* including *Cyclotella comta var. lichvinensis* Jousé and *C. temperei* Herib. et Perag. which became extinct at the end of Middle Pleistocene (Khursevich 1996, Seiriene & Sinkunas 1995).

Because of the prevalence of sandy sediments, in many layers the palynomorphs are poorly preserved, and redeposited pre-Quaternary and Quaternary thermophilous pollen is present, together with representatives of a subarctic flora. Redeposition and presence of long distance transportation pollen indicate that the sediments with higher sand content contain less pollen, and have higher *Pinus* percentages. The pollen, even *Pinus* and Polypodiaceae spores are more corroded in the sandy sediments.

Subarctic flora elements appear to be characteristic for PAZ (VII): an open tundra-steppe type vegetation was probably dominant in the coastal area, with prevalence of *Artemisia* in the composition of herb pollen and presence of pioneer plants and spore-bearing *Selaginella.* This is supported by the carpologic investigation of the Jurkalne sediments (Cerina 1993). According to Cerina (ibid.) plant macrofossils of *Salix polaris, S. herbacea, S. reticulata, Betula nana, Dryas octopetala, Sparganium hyperboreum, Selaginella helvetica* and *S. selaginoides* occur. Remains of these plants were found in the sediment sequences indicating outwash of terrestrial material by rivers.

The lower part of sandy strata of the Jurkalne (Jrk1) or Early Kurzeme (Saalian) contains thin layers of clay, with macrofossils and the presence of the ostracods *Cytheropteron* aff. *montrosiense* (Brady, Crosskey &t Robertson), preferring marine conditions (Seglins 1987; Meirons 1992). This and earlier mentioned data suggest that the lower strata of Jurkalne (Jrk1) was deposited in nearshore shallow water marine conditions with influx of freshwater from land.

The most severe climatic conditions are suggested by biostratigraphical data from the thin diamicton layer and an underlying silt bed distinguished as a middle part of the Jurkalne substage (Jrk2). The deterioration of the climate is indicated by the pollen spectra of PAZ VIII, suggesting an open tundra with *Betula nana* type and *Duschekia,* as well as a maximum of *Artemisia,* dominating among the herb pollen and presence of *Dryas*. The amount of tree pollen is low and probably redeposited, or part of them could have been transported long distances. Such features suggest a cold arctic-subarctic climate, which probably existed during the advance of the Kurzeme (Saalian) glacier. It seems that the silty sediments were accumulated under meltwater conditions, which could be partly explained by the presence in sediments of large number of redeposited Eemian interglacial pollen.

The upper sandy layer of the Jurkalne strata (Jrk3) is barren of marine microfossils and rich in calcite. It was probably deposited in the ice-dammed freshwater basin. During that time span the pollen flora (PAZ IX) has suggested a subsequent improvement of the climate, with an increase in *Betula alba* type and *Alnus* and a decrease in *Betula nana* type and *Duschekia*. Herb pollen has a high abundance, by dominance of *Artemisia*, Ericales and Cyperaceae, which imply continued domination of an open tundra vegetation with some sparse forest stands. This zone may represent an interstadial at the beginning of the Kurzeme glaciation. The sedimentological evidence at Strante (Fig. 17c, d) supports this conclusion: the clayey basin sediments of PAZ IX occur between two diamicton layers with Kurzeme till lithology (Kalnina *et al.* 2000).

The upper contact of Jurkalne sediments with the Kurzeme (Saalian) till is erosional, and therefore part of these sediments is probably absent.

7.1.5 Kurzeme Glaciation - till overlying the Jurkalne sediments

A fine-laminated silty to clayey diamicton, overlying the Early Kurzeme Glaciation sediments was interpreted as the Kurzeme (Saalian) till (Kalnina *et al.* 2000). It has been proven to belong to the Kurzeme glaciation on the basis of the high limestone content, in association with near-absence of dolostone (0-1% in the 0.5-1mm fraction) and the high content of rounded hornblendes (28-37%). All these characteristics are also present in the diamicton located between sandy layers of Jurkalne (Early Kurzeme) as discussed above.

7.2 Palaeoenvironmental conditions during the Eemian Interglacial

Latvia is located in the intermediate exaration-accumulation zone of the Late Weichselian glacier, which eroded most unconsolidated deposits of the Eemian Interglacial during its advance. Consequently only a few basins that were filled by Eemian deposits have been preserved. In Latvia more Eemian sites have been found than Holsteinian, but less than in the adjacent areas outside the maximum limit of the last glaciation, *e.g.* in south-eastern Lithuania, where continuous Eemian-Weichselian to Holocene sediment sequences are found (Satkunas & Grigiene 1997; Satkunas *et al.* 1998) and in Poland (Mamakowa 1989; Granoszewski 1998).
The area has been tectonically inactive, except for glacioisostatic vertical movements (Blazhchishin *et al.* 1976), probably supplemented by additional small-scale vertical movements due to loading by sediments and water and unloading by the proceeding glacial erosion. Although the pattern of isostatic rebound appears to be similar to that during the Holocene (Forsström *et al.* 1987; 1988), current evidence is very limited.

The palaeoenvironment of the Eemian Interglacial and Eemian Baltic Sea, as well as of the stages before and after marine conditions, has been investigated by several researchers both in the Baltic region (Liivrand 1991; Satkunas *et al.* 1998) and in NW Europe (Mangerud 1989, 1991; Litt 1990; Zagwijn 1996; van Kolfschoten & Gibbard eds. 2000). Thorough reconstructions of the development and palaeoenvironment of the Baltic Eemian Sea have been made in Denmark (Knudsen 1994; Kristensen *et al.* 2000; Funder *et al.* in print) and Finland (Grönlund 1991). Reconstructions for the Last Interglacial indicate that mean annual surface temperature in the northern hemisphere was 1-3°C higher than present (*e.g.* CLIMAP 1984), while geological evidence and oxygen isotope values suggest that global sea-level was 5-7m above present (Chappell & Shackleton 1986). In the last few decades, considerable interest has been directed towards the Eemian environment, the climate and its stability, and the correlation of events on land and in the sea (Zagwijn 1996; Kukla *et al.* 1997; Seidenkrantz & Knudsen 1997; Turner 2000). The last interglacial has become a focus for several reasons, including an urgent need to make more reliable predictions of future climate changes resulting from the anthropogenic "greenhouse effects" (Anderson *et al.* 1991a). A large number of competitive scientists from many countries have studied the relationships and linkages between land areas, atmosphere and oceans during the last interglacial. One of the findings is that the geological records of the Eemian provide evidence of a smaller global ice volume than the present one and correspondingly a higher sea level. They influenced the Eemian palaeoenvironment.

In Latvia, the Felicianovian (Eemian) Interglacial sediments found on the mainland consist mainly of deposits of terrestrial origin. The environment has been reconstructed predominantly from pollen and carpological remains. Marine Eemian sediments have been studied only in the last ten years (Kalnina 1993, 1996c, 1997a, b, c, d; Juskevics & Talpas 1997; Kalnina *et al.* 1997; Kalnina & Juskevics 1998 a, b, c). Pollen data from sediments accumulated under marine shallow-water conditions in the coastal area have been of particular importance in the reconstruction of the palaeoenvironment (Kalnina 1996a).

One of the purposes of this study was to reconstruct the palaeoenvironment of the Eemian Baltic Sea, and the most informative material is the sediment sequence in the Plasumi core, which contains foraminifera and diatoms. Sediments from core 21 in the Gulf of Riga contain a diatom flora, which suggests marine conditions and environmental changes during the Eemian, but they are barren of foraminifera, probably due to large freshwater input from nearby land areas. In the Gulf of Riga area, the diatom flora very clearly indicates marine conditions and changes in them, and in addition it contains taxa typical for the Eemian Sea (M. Sakson, pers. comm.). A comparison with other sites studied in the Baltic region, *e.g.* the Prangli site in northern Estonia (Liivrand 1991) allows us to obtain a general picture of the palaeoenvironment in and around the Eemian Sea within the area of Latvia and its surrounding countries.

7.2.1 Character of Kurzeme (Saalian) Late Glacial deglaciation

The deposits formed during the Kurzeme /Saalian deglaciation are not widely distributed either in Latvia, or in the adjoing region. There is a limited amount of data from the time span of the Saalian deglaciation, and in most publications describing the Saalian-Eemian transition very little attention is paid to the late-glacial interval and the conclusions have been of a general character.

The late-glacial sediments directly overlying the Kurzeme till are usually composed of clay or silty clay, occasionally varved or with silt and sand interlayers and they seldom contain diatoms or for a-minifera. The almost horizontal lamination or varves suggests comparatively calm conditions in the basin during their formation. These sediments are located 15 m below the present sea level (b.s.l.) at the Grini and Plasumi sites and 42 m b.s.l. in the Gulf of Riga-21 core (Table 11). At the Estonian regional stratotype Prangli they are at 79 m b.s.l.

Table. 11. Comparison of the Kurzeme/(Saalian) late-glacial records of marine and terrestrial sites in Latvia and the Estonian type locality Prangli (cf. Liivrand 1991).

site	lower boundary m a.s.l.	thickness of layer (m)	lithology	foraminifera	diatoms	PAZ	palaeo environment
Grini	-15.1	0.8	silty clay, slightly varved	no data	barren	*Betula*-NAP, low abundance	meltwater lake
Plasumi	-14.9	1.1	clay, grey with slightly undulating varves	arctic-sub-arctic	brackish to freshwater	*Betula-Juniperus*-NAP	ice-proximal glaciomarine
Gulf of Riga-21	-42.8	0.4	varved clay	barren	barren	LS3-NAP-*Betula nana* LS2- *Betula-Pinus-Picea*-Poaceae LS1-*B. nana* type-*Artemisia*	periglacial freshwater basin
Satiki	98.0	0.4	clay with silt and sand interlayers	___	not analysed	*Betula*-NAP	meltwater lake
Prangli	- 79.4	3.6	varved clay	no data	mixture of marine to freshwater diatoms	LS3-*B. nana* LS2-*Betula* sect. *Albae*-*Pinus* LS1-*Betula*-NAP	periglacial basin with inflow of saline waters

In the study area the most informative site is the Plasumi section. The presence of foraminifera (*Elphidium excavatum* f. *clavata*, *Cassidulina reniforme*, *Bucella frigida*, *B. hannai arctica*, *Elphidium albiumbilicatum*) and the composition of the diatom flora (*Epithemia zebra, Actinocyclus Ehrenbergii*) point to arctic to a sub-arctic and brackish to freshwater palaeo-environment in the Baltic basin during the Kurzeme Late Glacial.

The pollen flora reflects open sub-arctic tundra-steppe vegetation on the adjacent mainland. Pollen records from the investigated sections (Figs 34a, b, 40a,b, 47) indicate a dominance of *Betula* and herbs. In the lower part of the sequence, *Betula nana* prevails, in some sections together with *Betula humilis*, *Juniperus*, *Hippophaë* and *Duschekia*, but later they became replaced by *Betula* sect. *Albae* and *Alnus*. Similarly, *Artemisia* and Chenopodiaceae dominate the herbs in the lowermost part, but gradually together with an increase in the absolute pollen values (from 10 grains per 1 g dry sediments to 50) the number and diversity of other herb pollen increase, such as Cyperaceae, Poaceae, Polygonaceae and *Thalictrum*. A small number of *Dryas*, *Helianthemum* and *Ephedra* pollen grains and *Selaginella* spores are present. In general, the composition of the pollen spectra implies a gradual, but rapid replacement of the pioneer flora by vegetation of tundra-taiga vegetation type, without significant oscillations. Such a rapid vegetation development is characteristic also of the Late Latvian (Weichselian) deglaciation and usually only one PAZ has been distinguished in these intervals in western Latvia. A difference is seen in the varved clay in the Gulf of Riga-21 core, deposited above the Kurzeme till (Juskevics & Talpas 1997). It contains a pollen composition that reflects a climatic oscillation at the end of the Kurzeme (Saalian) Late Glacial. The pollen spectra in core-21 from the Gulf of Riga differ from the spectra in other marine sections by containing a high frequency of *Pinus* pollen, which mostly are long distance transported and therefore disturb the real pollen spectra of the site in question. The source of the presence of *Picea* pollen is not very clear. *Picea* pollen grains are heavy and cannot had been transported very far by air. The actual presence of spruce in the surroundings of the south-eastern Baltic areas during the Kurzeme Late Glacial has been questioned. However, Grichuk (1989) reports distribution of spruce during the Moscowian (Saalian) Late Glacial in the periglacial zone of the retreating glacier and also discussed the presence of a possibly warmer phase (interstadial) during deglaciation. Mamakowa (1989) has reported a very early short-lived expansion of spruce, together with pine, from the Saalian Late Glacial in north-eastern Poland.

The composition of the pollen flora in late-glacial layers indicates that the retreat of the Kurzeme glacier was rapid. The pollen data indicate a rapid improvement of climate mirrored in the sediments from Plasumi, Grini and Gulf of Riga-21. However, a Saalian late-glacial "Younger Dryas" event has been described from Denmark (Seidenkrantz & Knudsen 1995). This climatic oscillation just prior to the Oxygen Isotope stage 6/5 boundary has been stated by comparison of marine, lacustrine, and terrestrial records from 24 sites (Seidenkrantz *et al.* 1996). The warm Zeifen Interstadial and the cold Kattegat Stadial were distinguished by the authors, who proposed a geographically widespread distribution of the oscillation suggesting a two-step deglaciation. The lowermost parts of Plasumi and Gulf of Riga-21sediment sequences contain characteristics of the Kattegat Stadial, while the Zeifen Interstadial has not so far been detected in Latvian Late Saalian sediments.

A fairly rapid Saalian deglaciation is reflected also in the records from Poland (Mamakowa 1989), Estonia (Liivrand 1991) and Lithuania (Satkunas *et al.* 1998), as well as in those from northern and western Europe (Kolfschoten & Gibbard (eds.) 2000, Robertsson 2000, Turner 2000) and prove that marine palaeoenvironment in the Kattegat changed from arctic to boreal-luisitanian within 1000 years.

7.2.2 Eemian Interglacial

Evidence of the Eemian Interglacial is based on biostratigraphical characteristics, *e.g.* on palynological data reflecting an interglacial vegetation succession and on the graphical position over Saalian till and below Weichselian deposits. Eemian marine deposits at the Plasumi and Grini sites in Latvia have been deposited within small depressions, probably resulting from melting of dead ice blocks at the surface of the Kurzeme/Saalian sediments (Figs 33, 36). Most of the terrestrial Eemian sites (*e.g.* Satiki, Vilgale, Rogali, and Felicianova) have a similar situation - interglacial deposits occur in comparatively small depressions on the surface of the Kurzeme till. The Medininkai site in south-eastern Lithuania is located just outside the maximum Weichselian glaciation limit, where the most complete sediment sequence covering the time interval from the Late Saalian to the present has been found in the region of the Baltic States. The site consists of a small palaeolacustrine kettlehole filled with sediments (Satkunas *et al.* 1998). In contrast to the above mentioned terrestrial sites, marine interglacial deposits in the Gulf of Riga-21, and also in Prangli, have accumulated in almost horizontal layers on the surface of Saalian deposits. However, their distribution area, *e.g.* in the Gulf of Riga, is very limited, since already at one of the closest sites, Gulf of Riga core-25, only glacial deposits have been found.

Marine Eemian sequences are located at the depth intervals 14.3-12.8 m b.s.l. (Table 11) at the Grini site, and 13.8-4.3 m b.s.l. at the Plasumi site. They are located deeper in the Gulf of Riga (35.6-40.8 m b.s.l.), but at the Prangli site the marine interglacial deposits occur as deep as 60.5-67.5 m below present sea level (Liivrand 1991). In spite of different depths (about 20 m) the interglacial sedimentary records from the Prangli site and the Gulf of Riga-core 21 are comparable. At both sites coarser sediments with vivianite and mollusc shells appear in the upper part of the interglacial sediment sequence.

The marine origin of the sediment and palaeoenvironment during their formation at the investigated sites was determined by diatom, foraminifera and pollen analysis. Foraminiferal data were available only from the Plasumi site. The Eemian sediments from the Gulf of Riga were barren of foraminifera.

There was a rapid change of the composition of the interglacial vegetation development in the surroundings of the area investigated, as well as right across northern Europe at the beginning of the Eemian Interglacial. This may partly be connected with the weakly expressed Saalian Late Glacial climatic oscillations (Turner 2000), so that the migration of plants from refugia proceeded without interruption and possibly under even warmer conditions than during the early Holocene. The rapid warming can probably also be related to the ingression of warm Atlantic waters through the Strait of Dover, into the southern North Sea, and even farther into the Baltic Sea. The later shallowing of the central and northern part of the Baltic basin, which is indicated by foraminifera and diatom data, was caused by isostatic uplift (Turner 2000, Funnier et al. in print).

In the interglacial sediment sequence of the Plašumi site two foraminiferal zones PL-F2 and PL-F3 (Fig.38) reflect marine palaeoenvironmental changes. The diversity and abundance of foraminifera during the first part of the interglacial show gradual warming of the sea, as demonstrated by *Ammonia beccarii, Bulimina marginata, Cassidulina laevigata,* as well as *Elphidium excavatum boreale, Melonis sp., Haynesina nivea, H. orbiculare, Sangrina subspidencens* and *Quinqueloculina* sp. These foraminifera also indicate gradual increase of salinity and presumably also deeper (15 m) water conditions towards the climatic optimum. This composition of the foraminiferal fauna illustrates true Eemian interglacial conditions.

During the second half of the interglacial, after the climatic optimum, the abundance of foraminifera has decreased in zone Pl-F3. Rapid decrease in *Bulimina marginata, Cassidulina laevigata* and *Cibicides lobatulus* presumably reflects a shallowing of the water (Sejrup & Knudsen 1993), probably during a regressive phase of the Eemian Sea.
Diatom data have been obtained from all the studied sites (Sakson in print, pers. comm.,

unpublished materials). The amount of diatoms increases before the climatic optimum, and so do almost all species that indicate saline or brackish water, *e.g.* *Paralia sulcata, Grammatophora oceanica, Hyalodiscus scoticus* and *Thalassionema nitszchioides*, and that prefer the marine littoral conditions of the Eemian Sea proper (Liivrand 1984, 1987; Forsström *et.al.*, 1987; Grönlund, 1988, 1991), as well as other common species typical of the marine diatom flora of the Eemian Baltic Sea, including *Actinoptychus senarius, Dimerogramma minor, Stephanopyxis turris, Thalassiosira eccentrica, T. gravida* and *T. nordenskiöldii* and *Podosira* spp. The relict thermophilic species *Navicula abrupta* and *Coscinodiscus antiquus* found at the Plasumi and Grini sites, also suggest a brackish-marine littoral environment (Table 12).

Table 12. Comparison of the Eemian Interglacial record from sites studied in Latvia, N Estonia (cf. Liivrand 1991) and SE Lithuania (cf. Satkunas and Grigiene 1997).

Country	site	lower boundary interglacial sequence m a.s.l./b.s.l.	thickness of marine deposits (m)	thickness of interglacial deposits (m)	character of sediments	foraminifera	diatoms	Local PAZ (GR, SAT), regional PAZ (E1-E8)	palaeo environment
Latvia	Grini	-14.3	1.5	7.5	silty clay with sand interlayers	no data	marine littoral and warm demanding species	GR1-GR8, culmination order: *Betula-Pinus-Quercus-Corylus-Alnus-Ulmus-Tilia-Carpinus-Picea-Pinus*	littoral warm marine basin
	Plasumi	-13.8	9.5	10.5	clayey, laminated greenish grey silt	marine, warm demanding species, shallow at the end of interval	marine dominate	E1-E8, culmination order: *Betula-Pinus-Ulmus-Quercus-Corylus-Alnus-Fraxinus-Tilia-Taxus-Picea-Abies-Pinus*	marine conditions, shallowing at the end of interval
	Gulf of Riga-21	-42.4	3,0	3,9	dark clay, with vivianite and shells at the upper part of the interval	barren	brackish-marine	E1-E8, culmination order: *Betula-Pinus-Ulmus-Quercus-Fraxinus-Corylus-Alnus-Tilia-Carpinus-Picea-Abies-Pinus*	brackish-marine littoral basin
	Satiki	97.6	—	6,6	clay, gyttja	—	no data	SAT1-SAT8, culmination order: *Betula-Pinus-Quercus-Corylus-Alnus-Ulmus-Tilia-Carpinus-Picea-Pinus*	interglacial lake
Estonia	Prangli	- 68,3	7.0	8,2	greenish grey marine clay, coarse sand and vivianite in the upper part	not analysed	normal marine salinity, shallow water and warm demanding species	E1-E8, culmination order: *Betula-Pinus-Quercus-Ulmus- Corylus-Alnus-Tilia-Carpinus-Picea-Pinus*	littoral and sublitoral marine conditions
Lithuania	Medininkai	234.0	—	4.0	gyttja and sandy gyttja	—	no data	PAZ I-V, culmination order: *Pinus-Betula-Quercus-Ulmus-Corylus-Alnus-Tilia-Carpinus-Picea-Pinus-Betula*	lake

Pollen data from all sites studied show continuous interglacial vegetation development beginning with rapid replacement of a initial tundra-steppe vegetation by forest. The first interglacial forest development is characterised by the *Betula* zone (Fig. 58). Even among pollen from the sediments of the Gulf of Riga-21 core, the presence of *Pinus* during the entire interglacial is higher than in other sections, and a high *Betula* peak marks the beginning of birch forest expansion on the adjacent mainland. During the subsequent *Pinus* zone the first thermophilous trees (*Ulmus* and *Quercus*) began to appear and a widespread colonisation by *Corylus* took place. *Fraxinus* usually reaches its greatest abundance during this time.

The Eemian climate could be outlined on the basis of the climatic indicator species method (Zagwijn, 1996). It has been found that the mean temperature of the warmest month rose early during the Eemian - 1500 years after the begining of the interglacial. The interglacial climatic optimum is marked by the contemporary occurrence of *Hedera, Vitis, Sambucus nigra, Brasenia sp.* and *Viscum* in the *Tilia-Alnus-Corylus* zone (PAZ E5). These evergreen shrubs do not tolerate low subfreezing temperatures (Zagwijn 1996). The mean temperature of the coldest month reaches its maximum in the *Carpinus* zone (PAZ E6). The rise and fall in the sea level follow the same trend as the mean January winter temperature. It is suggested that annual precipitation increased during the later part of the interglacial period (Zagwijn 1996).

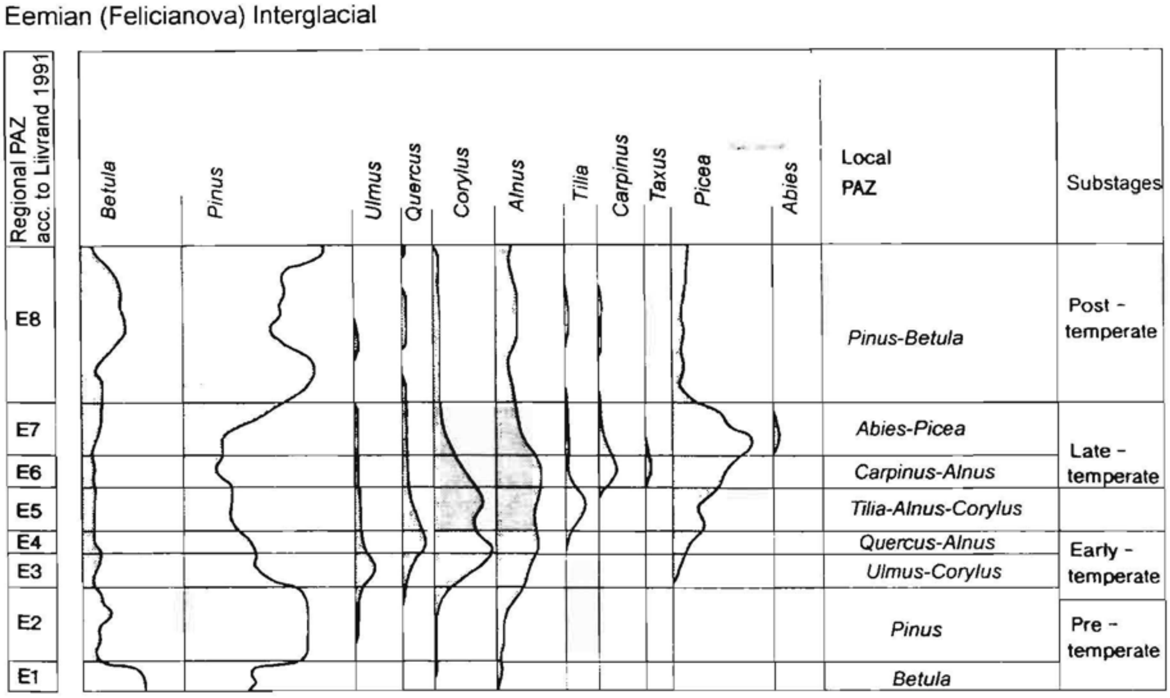


Fig. 58. Simplified pollen diagram put together from the studied Eemian Interglacial sediment sequences.

A gradual climatic deterioration begins during the *Carpinus* zone and continues through the *Picea-Abies* to the *Pinus* zone, which has been reflected also in the composition of foraminiferal fauna and diatom flora.

In general the vegetation development, as it is characterised by pollen spectra, shows the start of the Eemian with a re-immigration of *Betula* and *Pinus* (Fig. 58), which was followed by the appearance of *Corylus* and immigration of *Quercus* and *Ulmus*. The light *Pinus*-QM forest was rapidly joined by *Corylus*, later also by *Taxus* and *Tilia*. After the climatic optimum, *Carpinus* culminates followed by *Picea* and

Abies, and subsequently *Pinus* dominates, but later on also *Betula* plays a significant role in the forest composition.

The following palaeoenvironmental changes have been illustrated in the study area during the Eemian Sea stage by foraminifera, diatom and pollen data (Kalnina 1997b, c, Kalnina & Juskevics 1998a, b, c):

- The deglaciation of the Saalian ice sheet was followed by a rapid warming and a change from sub-arctic to boreal conditions with a water level rise in the Baltic Eemian Sea basin (at least 15 m above the present sea level) and the spread of forest in the adjacent mainland.
- A boreal forest immigrated, and was succeeded by a warm temperate forest, with the widest QM forest expansion during the entire Quaternary period.
- As suggested by foraminifera, diatom and pollen data, a warm Atlantic (oceanic) climate prevailed during the Eemian climatic optimum. Several thermophilous fauna and flora species have been noted in the sediments, *e.g. Ammonia beccarii, Cassidulina laevigata* and *Bulimina marginata,* as well as *Tilia tomentosa, Sambucus nigra, Brasenia* sp. and *Osmunda.* A sharp increase in salinity, indicated by *Bulimina frigida* and *Haynesina orbiculare*, occurs almost simultaneously with the distribution of broad-leaved forests in the land areas.
- After the climatic optimum the sea level became lower and the shallow marine-brackish water was gradually replaced by freshwater. Probably, the climate became drier, and the mean temperatures in July began to decline already in the *Carpinus* zone (Late temperate substage).
- On the basis of the available data, it can be concluded that during the last interglacial (Felicianova, Eemian) the climate in Latvia was warmer and wetter than during other interglacials. During the maximum transgression, the Baltic Eemian Sea level was 15-20 m above the present and even 5-10 m above the Littorina Sea maximum level at the Latvian coast, but at the end of the interglacial it lowered considerably (Donner 1995; Zagwijn 1996).
- The composition of fauna and flora reflects a more favourable climate than that of the Holocene.

The end of the Eemian Interglacial is characterised by a gradual cooling, and marked by an increase of herb pollen and an onset of coarser clastic sedimentation of the Weichselian glaciation. Some climatic fluctuations could have occurred in the course of the general and gradual cooling during the final stage of the Eemian, which probably lasted longer than the warming at the beginning of the interglacial. The second part of the interglacial was characterised by a wide expansion of coniferous forests, first spruce (*Picea*) and afterwards a re-expansion of pine (*Pinus*). In most sections pollen spectra demonstrate a comparatively long time span of the distribution and total dominance of pine with some small admixture of other pollen, including broad-leaved trees. The occurrence of broad-leaved tree pollen in the *Pinus* zone could be explained in two ways: 1) presence of these trees somewhere at more favorable places (*e.g.* river valleys, slopes exposed to the south), or 2) redeposition of pollen. Principally, both features are connected with a relatively warm climate. The small amount or absence of *Picea* pollen in this zone could speak against redeposition, since spruce dominated earlier. In case of redeposition, *Picea* pollen should have been more abundant.

Diatoms and foraminifera from sediments representing this time interval indicate slightly brackish or almost freshwater and shallow water conditions. Small and even significant, but short time fluctuations in the water level can not be recorded in the composition of the diatom flora, when the intervals between the analysed samples are too large. A general shallowing occurs in a wide area, accompanied by low salinity, as confirmed by an increase in shallow water, low salinity species of foraminifera in the Late Eemian also in northern Denmark at the Skærumhede and Apholm sites (Seidenkrantz *et al.* 2000). Also a major but gradual change of the environmental parameters from marine to more brackish was indicated at the Dagebüll site, Northern Germany (Winn & Erlenkeuser 1995), where the sediment types, as well as foraminiferal and molluscan assemblages, are indicative of shallower conditions resulting from a recession of the Eemian Sea. This presumably indicates a lowering of the sea level prior to the abrupt temperature decrease and a sea level lowering at the termination of the Eemian (Knudsen 1991). This could coincide with the occurrence of the shallow water foraminifera *Cibicides lobatulus*, and the appearance of interlayers or laminae of coarser material in the sediment sequences corresponding to the time span from the end of the *Carpinus* zone (E6) with transition into the *Pinus* pollen dominated period (E8) in the end of the interglacial, which have been observed at the sites studied.

7.2.3 Early Latvian (Weichselian) stadials and interstadials

The end of the Eemian seems to have been characterised by a gradual cooling until almost pure clastic sedimentation and a marked expansion of herb pollen grains mark the onset of the Weichselian. At the sites studied, the interstadials of the Early Weichselian were originally defined in the sediments overlying those identified as Eemian. In western Europe the Eemian sediments constitute the lower boundary for the overlying interstadial sediments, but the interstadial sediments in the study area are usually underlain by stadial deposits, although no glacigenic ones.

The Early Weichselian sediments have been investigated by means of various methods and compared with data from cores in other areas of the Baltic Depression and in neighbouring areas, for instance from deep borings in northern Jutland, *e.g.* Skærumhede and Apholm. These deposits show no fluctuations in the composition of the foraminiferal fauna that could be interpreted as reflecting changes between interstadial and stadial conditions (Knudsen 1986; Houmark-Nielsen 1990). The Early Weichselian sediment sequences from cores studied in Latvia are not rich in biostratigraphical information but the data obtained suggest slightly brackish to freshwater conditions. Climatic fluctuations between stadial and interstadial phases are not especially pronounced. The identification of interstadials was the same as when dealing with freshwater deposits almost entirely based on pollen diagrams (Donner 1996). The use of pollen results from Grini, Plasumi and Gulf of Riga is extremely important, when other indicators are not available. As in the marine sections at Nörre Lyngby (Glaister & Gibbard 1998) the sediments accumulated in a cold climate are correlated with the Early Weichselian on the basis of pollen data and sedimentary continuity.

The transition from Eemian interglacial conditions to the first stadial of the Early Weichselian was gradual, without a distinct rapid cooling or glacial advance. As suggested by the data obtained from the sites studied this gradual change from interglacial conditions into early glacial ones occurred after a comparatively long termination phase of the Eemian Interglacial. The palaeoecological inter-pretation of the litho- and biostratigraphical reconstructions and pollen data from the study area are based on regional correlations with other Baltic areas and marine proxy records, where sea level changes, changes in the hydrology and changing oceanic circulation patterns have been proposed by several authors (Kristensen *et al.* 1998a). Some changes may coincide with the opening and/or closure of the Baltic Sea - White Sea connection, the initial build-up of continental ice sheets, and the first major impact of meltwater-induced freshwater in key areas for thermohaline circulation (Björck *et al.* 2000). The climate during the

Early Weichselian seems to have been unstable because of recurrent advances and retreats of the Fennoscandian Ice Sheet and it was also influenced by changes in the hydrologic cycle of the Baltic Sea area (Nenonen 1995).

The lower boundary of the Early Weichselian (Latvian) is marked by a dominance of freshwater diatoms and arctic foraminifera species, *e.g. Bucella frigida, B. hannai arctica* and *Cassidulina reniforme,* in sediments that contained less organic matter than the underlying layers.

The first stadial (cryomer) of the Early Weichselian contains pollen spectra indicating a light demanding flora (Satkunas *et al.* 1998; Kalnina & Juskevics 1998), showing an open landscape - open pine-birch woodland with the presence of *Betula nana*, *Salix*, *Artemisia*, *Dryas* and *Selaginella* in the adjacent land areas.

The first interstadial (thermomer) is reflected by pollen data and some increase in organic matter (1-1.9%), suggesting climatic amelioration and re-expansion of coniferous forest (Figs 40a, b, 47, 51). The decrease of a pioneer flora and increase in tree pollen of *Picea*, *Alnus*, *Corylus* and *Larix* indicate significant changes in vegetation as well as in the climate in adjacent areas. The sediment layer, that contains this pollen, was accumulated under comparatively warm interstadial conditions. They were terminated by a rapid cooling with a decrease in tree pollen and expansion of the open landscape vegetation, with dominance of *Betula nana*, *Artemisia* and other herbs. These pollen spectra point to a second stadial (cryomer) with more strictly expressed periglacial characteristics in comparison with the first stadial.

Later the next climatic amelioration took place. Tree pollen prevails again, with significant increase in *Betula* tree species, *Alnus* and *Corylus*. Interstadial conditions were established once more. This next interstadial or part of an interstadial is not reflected in the section from the Gulf of Riga-21 core. Apparently the deposit layer accumulated during the second interstadial has been eroded by a later glacier advance. This is indicated by *Portlandia arctica* shell findings in the central part of Latvia, originating from clays underlying the till in the Gulf of Riga (Dreimanis 1970, Molodkov *et al.* 1998), which are also found in marine sediments at the Saint Petersburg area (Molodkov & Krasnov 1998).

The pollen spectra from the sediments in the upper parts of the investigated sections (Plasumi, Gulf of Riga) indicate cold periglacial conditions (Figs 40a, b, 47, 51).

7.3 The extent and character of the Holsteinian and Eemian Seas in the Baltic basin

7.3.1 Late Elsterian, Holsteinian and Early Saalian

Aquatic intertill sediments representing a long nonglacial interval of the Pleistocene in western Latvia were described already in the 1970s, but for a long time it was difficult to correlate this sedimentary sequence with the Holsteinian Interglacial. Most Latvian researchers (Danilans 1973; Meirons & Straume 1978; Meirons 1986, 1992; Seglins 1987; Cerina 1993; Kalnina *et al.* 2000) agreed that this sequence began with the late glacial phase of the Elsterian Glaciation, and continued almost without interruption through the Holsteinian Interglacial into the early part of the Saalian Glaciation. The palynological, carpological and other palaeontological, as well as lithological data were used to prove the marine origin of most of these intertill sediments in western Latvia (Charamisinava 1971; Konshin *et al.* 1971; Danilans 1973; Seglins 1987). Several researchers, however, suggested a younger age than the Holsteinian. For instance, Charamisinava (1971), Serebryanni *et al.* (1977) suggested a Middle Weichselian age of the marine sediments in western Latvia. Such disagreement could appear because of intense glaciotectonic deformation in this area, which resulted in the appearance of intertill deposits in exposures like lenses or diapirs. The glaciotectonic deformations and dislocations complicate the interpretation and correlation. This problem was solved, when numerous new test drillings were added in western Latvia and Holsteinian deposits were found in many boreholes at a depth of 50-70 m, while Eemian deposits occurred at a much higher elevation in a few boreholes. The intertill sediments, at the depth of 50-70 m in western Latvia, thus represent the most north-eastern occurrences of the Holsteinian Sea deposits in the Baltic basin (Kalnina *et al.* 2000).

During the Holsteinian Warm Stage, north-western Europe experienced a major marine transgression, which for North Germany was the first marine transgression since the Miocene and its extent was farther inland than during the Eemian or the Holocene (Ehlers 1996), for instance, the Holsteinian Sea flooded large areas in Schlezwig-Holstein (Hinsch 1993).

The extensive marine transgression in northern Germany, which began already in the Late Elsterian, is explained by Sarntheim *et al.* (1986) as a result of the glacioisostatic depression by the preceeding thick and extensive Elsterian ice sheet. The total amplitude of vertical movements since the end of the Holsteinian Interglacial is up to some 20-40 m subsidence at the coastal areas of the North Sea, and in the lower course of the Elbe River (Ludwig & Schwab 1995). This is probably also applicable to the study area. The marine transgression into the Baltic Sea basin began towards the end of the deposition of the Sudrabi clay, as proven by the appearance of marine and brackish diatoms and foraminifera (Seglins 1987). They have been found also at Uvarovo (Kaliningrad District), where marine waters entered a cold oligotrophic lake in the deep valley on the Pregel River. Some marine deposits of possible Butenai Interglacial (Holsteinian) age occur in the coastal area of Klaipeda, western Lithuania (Kondratiene 1966, 1967).

The eastern coast of the Holsteinian Baltic Sea was probably located in western Latvia and also farther south in western Lithuania and in the Kaliningrad District. The Holsteinian Sea extended farther to the north-east than had been assumed by Donner (1995) and Ehlers (1996). It is very complicated to draw any area of the Holsteinian Sea between North Germany and the Sambian peninsula, because there is still not any evidence of a marine sediment sequence older than Eemian in northern Poland. The coastline drawn in the schemes of Donner (1995) and Ehlers (1996) shows schematically the possible distribution of the Holsteinian Sea, but in detail the area was schematically the possible distribution of the Holsteinian Sea, but in detail the area was more varying than presented by these authors, because probably the sea mainly penetrated into deep buried valleys (Ehlers 1984).

Most marine diatoms in the Ziemupe-Jurkalne area were benthic neritic and oceanic forms occurring in the seas with normal salinity. Changes in their abundance and diversity indicate sea level fluctuations and different sedimentation processes. It has been concluded that the Holsteinian Interglacial silts were accumulated at a depth of at least 80-100 m, *i.e.* 40 m deeper than their present position below the present sea level (Kalnina *et al.* 2000). The boreal and arctic-boreal foraminifera and diatom species in the study area (Charamisinova 1971; Konshin *et al* 1971; Seglins 1987) suggest relatively cool saline water of the Holsteinian Baltic inland sea at the Latvian coast, with gradually decreasing water depth from about 100 m to less than 40 m (Kalnina *et al.* 2000). There existed a complete glacial-interglacial-glacial cycle, and the faunal evidence suggests a complete change from high arctic marine environments through a period with major influence of Atlantic water-masses and a return to high arctic marine conditions (Kristensen *et al.* 1998). This site located so far from the study area proves that marine conditions during Holsteinian were stable in a wide area and suggests only slightly ameliorated temperature conditions even during the climatic optimum.

A regression of the sea probably occurred at the end of the Holsteinian Interglacial and continued during the Early Saalian as in the lower part of the Early Saalian Jurkalne formation, when the water depth was probably less than 40 m. This is evident by its fauna and flora (Charamisinova 1971; Konshin *et al* 1971; Seglins 1987), indicating cool shallow brackish conditions, which later on became freshwater during the Saalian Glaciation.

7.3.2 Connections of the Late Saalian, Eemian and Early Weichselian Baltic Sea with the ocean

The main problem discussed among scientists who investigate the palaeogeography of the Eemian Baltic Sea is its possible connection with the North Sea and the White Sea. There is an evidence suggesting that, during the Eemian, the Baltic Sea was considerably more extensive than the present day, with a possible connection to the White Sea (Zans 1936; Gross 1967; Forsström & Eronen 1985; Forsström *et al.* 1988; Raukas 1991; Donner 1995; Zagwijn 1996; van Andel & Tzedakis 1996; Funder *et al.* in print). The nature, timing and duration of this connection, however, remain unclear, and it is also not known whether this was a single or multiple events. As Donner (1991) emphasises, considering that the Eemian sea-level was higher than that in the Holocene and that the crust in the central region of the Saalian glaciation was more depressed than during the Weichselian, it is likely that larger areas were submerged during the Eemian. Zagwijn (1996) and Aalbersberg and Litt (1998) have described the Early temperate substage of the Eemian Interglacial as subcontinental, but the late temperate substage as oceanic. The inflow of warm Atlantic water from the North Sea into the Eemian Baltic basin is suggested to have happened already in the earlier half of the Interglacial. This provides an explanation for the rapid and remarkably uniform immigration of vegetation in the area surrounding the Baltic Sea. Kristensen *et al.* (2000) have studied Ristinge Klint and suggest an early Eemian interglacial marine phase at Ristinge, which according to the authors: "...may be a result of a marine ingression over the eastern Baltic via a connection from the White Sea. However, an initial marine connection through North Germany cannot be ruled out either." An early Eemian connection through the eastern Baltic to the White Sea is supported by the fact that considerably higher salinity values seem to have occurred towards the east in the Baltic region than in the Ristinge area during the early Eemian, which is the opposite trend to the present situation. Numerous sequences across the region (*e.g.* Gross 1967; Sokolova *et al.* 1972; Nilsson 1983; Makowska 1986; Grönlund 1991; Liivrand 1991; Donner 1995) suggest that the Baltic during the Eemian had a greater salinity but with cold water influxes, and was thus more oceanic than the present brackish water body.

Resolving the question concerning a connection between the Baltic Sea and the White Sea is of principal importance. If no connection existed, the hydrological regime for the eastern part of the Eemian Sea developed during the course of the interglacial in a way similar to the Holocene (Flandrian) transgression. If a connection did exist, the situation must have been fundamentally different from that in the Holocene. On the basis of the results obtained in the eastern part of the White Sea coast and disposition of the marine deposits studied, the latter hypothesis seems to be more probable (Raukas 1991; Molodkov & Raukas 1998) and was also proposed by Zans (1936), Turner (2000) and Funder *et al.* (in print).

Continuous marine conditions from the Late Saalian through the Eemian and into the Weichselian are indicated by data from the areas of the proposed entrance-ways on the shores of the White Sea (Pleshivtseva 1972; Funder *et al.* in print) and in the Kattegat borings (Knudsen 1994; Seidenkrantz *et al.* 1996; Kristensen *et al.*1998), while in the central part of the Eemian Baltic basin marine conditions have been identified only during the temperate substage of the Eemian Interglacial, for instance at the Plasumi site. Influx from the North Sea is recorded first in the mollusc fauna of the Vistula valley from the beginning of the *Quercus* zone (Funder *et al.* in press).

The results of diatom and pollen studies indicate that the marine influx also reached the northern parts of the Gulf of Bothnia, where diatoms found at sites in Ostrobothnia suggest that marine littoral conditions began in the *Betula-Pinus-Quercus* PAZ (Grönlund 1991; Eriksson *et al.* 1999). According to data from the Prangli site in the Gulf of Finland marine conditions appeared already at the very beginning of the interglacial in the eastern part of the Baltic Sea (Liivrand 1991), but according to Kristensen *et al.* (2000) in the southwestern part of the Baltic Sea, at the Ristinge Klint, a marked change in salinity about 650 years after the beginning of the Eemian was presumably caused by an opening of the Danish Belts. An indication of a major change in sea current activity is registered there about 3000 years after the beginning of the interglacial.

The establishment of marine conditions during the *Alnus-Corylus-Quercus* PAZ is confirmed by foraminifera and/or diatom data from the Plasumi and Grini sites, as well as core-21 from the northern part of the Gulf of Riga (Tables 7, 9). The regression of the Baltic Eemian Sea began during the *Carpinus-Taxus* PAZ according to data from the present sites investigated. There is a contemporary evidence of shallowing of the water depth in the *Carpinus* zone, and in the *Picea* zone regression is recorded at the sites in Schleswig-Holstein, Vistula River valley, Prangli and Ostrobothnia (Funder *et al.* in press), as well as in Latvia.

During the Early Weichselian Brörup Interstadial there is again a marked increase in diatoms (Sakson pers. comm.) indicating some influence of brackish and saline waters. The sediments from the Gulf of Riga contain mollusc shells of *Portlandia arctica*, which were later eroded by the Weichselian ice stream. Relocated shells of *Portlandia arctica* have been found in the Daugmale and Licupe sections in middle Latvia. ESR dates suggest that they are 105 000 - 86 000 years old (Molodkov *et al.* 1998).

A correlation of the Boreal Sea transgression with the Eemian Interglacial is yet not accepted, since, up to now, researchers from different fields disagree as to the length of the last interglacial. In the geochronological subdivisions, based mainly on the correlation of north-central European continental stratigraphy with the deep-sea oxygen isotope stages (Shackleton & Opdyke 1979, Mangerud 1989; Behre 1989), the Eemian Interglacial is restricted to substage 5e only.

The dates have enabled to place the time of relatively small global ice volume between 140,000 and 70,000 years ago. There is an evidence of a distinct, relatively high sea-level stand during this time interval.

8 CORRELATION

8.1 Comparison of interglacial data recorded in marine and terrestrial sequences of Latvia

In some cases the use of foraminifera and diatoms in a stratigraphical study of marine sediments creates problems, because foraminifera and diatom sequences are very often fragmental from poor preservation and unfavourable living conditions. Then it is very useful to have pollen records for estimating climatic conditions, and comparing marine and terrestrial sequences, to get a better understanding of the similarities and differences between the sedimentary and palaeoecological conditions in the marine and terrestrial sites.

Pollen and plant macro-remains have often been incorporated in marine sediments that were first accumulated in shore areas. Today several small rivers cross the study area and flow into the Baltic Sea. Obviously, during previous interglacials this area also contained many rivers. In ancient seas it is probable that besides the wind, the main factor controlling pollen deposition was water transport (Moore & Webb 1978, Glaister & Gibbard 1998). Much of the pollen assemblages are likely to consist of pollen from adjacent land areas. In the marine environment, pollen assemblage zones may have more transitional boundaries, as a result of the presence of pollen from both local and distant sources. Pollen transported mainly by wind from south-westerly regions may have a strong effect on the relative proportions of pollen, and new pollen taxa that are uncharacteristic for the region may appear (Björck *et al.* 2000). Pollen, *e.g. Pinus,* may be transported from distant regions if strong winds prevail at the time of pollination.

The similarities and the differences in the pollen composition as compared to lithological characteristics will be used for comparison of marine and terrestrial sediment sequences.

8.1.1 Akmenrags (Holsteinian) or Pulvernieki Interglacial

The marine Akmenrags stratotype area is located on the Latvian western coast, in the Ziemupe-Jurkalne area, but the stratotype area of continental deposits of the Holsteinian Interglacial, the Pulvernieki site, is located in the Letiza region, about 70 km south-east of Akmenrags, and some important sites of this interglacial are located in south-eastern (Kraslava, Adamova) and central (Klekeri) Latvia (Fig.59).

At the continental sites the interglacial deposits are mainly represented by silt and clay rich in organic matter, and in some places displaying thin layers of gyttja and peat. Marine interglacial deposits consist of clay, silty clay and silt that contains shells of molluscs, foraminifera and frustules of diatoms.

In general, pollen data from both continental and marine sites show a comparatively similar succession. The comparison of pollen data from the Pulvernieki and Akmenrags sites is shown in Table 13.

The pollen spectra from the investigated sites that are related to the Holsteinian (Pulvernieki/Akmenrags) Interglacial are characterised by a dominance of coniferous (*Pinus, Picea, Abies*) pollen and a considerable amount of *Alnus* pollen. An early appearance and culmination of *Picea* has been noted in all pollen diagrams from the investigated sites.

Some sections are characterised by two *Picea* maxima, the first one before the culmination of broad-leaved trees, and the second one together with or just after the broad-leaved maximum. Two peaks of *Picea* occur in the pollen diagrams from the Pulvernieki, Akmenrags and Kraslava sites, while at other sites a single *Picea* maximum together with the culmination of broad-leaved trees, *Carpinus* and *Abies* is characteristic.

Fig. 59. Location of the stratotype and other important key sites in Latvia discussed in the text.

Table 13. Comparison of pollen spectra from Holsteinian interglacial pollen sequences of the continental type section Pulvernieki and the marine type section Akmenrags.

Pulvernieki (Meirons & Straume 1979)		Akmenrags	
Pollen zones	Pollen spectra	PAZ	Pollen spectra
P5	*Betula*	VI	*Betula, Alnus, Carpinus,* Ericales, Cyperaceae
P4	*Pinus, Picea, Alnus*	V	*Pinus*
P3	*Abies, Carpinus, Picea, Quercus*	IV	*Abies, Carpinus, Alnus, Quercus*
P2b	*Picea, Alnus, Corylus*	III	*Picea, Ulmus, Tilia, Corylus, Taxus*
P2a	*Picea, Alnus*		
P1c	*Betula, Alnus, Pinus*		
P1b	*Pinus, Picea*	IIb	*Pinus*
P1a	*Betula, Pinus*	IIa	*Betula*

Sediment sequences from marine sections are richer in redeposited pollen and spores of pre-Quaternary exotics, such as *Taxus, Zelkova, Ligustrum, Buxus, Hedera* and *Osmunda*.

The early appearance of *Carpinus* pollen already before the culmination of broad-leaved trees, in the Early temperate stage, is characteristic for the pollen diagrams of the Akmenrags (Pulvernieki) Interglacial (Kalnina 2000, 2001). *Carpinus* values are comparatively low (usually <5%) in both marine and continental sediment sequences in western Latvia, but increase towards the east and the south, and in the Lithuanian, Russian and Belarusian diagrams, where they reach 6-10% (Kondratiene 1996; Rylova & Khursevich 2001).

The end of the Holsteinian (Pulvernieki, Akmenrags) Interglacial is better preserved in the marine type sections, which are characterised by some decrease in tree pollen values, while dwarf shrubs and herb pollen values increase, particularly Ericales and Cyperaceae. In diagrams from the continental sections this evidence is not observed, because this part is eroded, including some indications of a warming at the very end of the Interglacial, which in marine diagrams is demonstrated by pollen such as *Quercus, Carpinus* and *Abies*, which appear again, with low, but continuous curves. Some subarctic floral elements, *e.g. Dryas*, occur simultaneously with broad-leaved tree pollen.

8.1.2 Eemian or Felicianova Interglacial

According to the palynological data of the interglacial sediments from the Plasumi, Grini and the Gulf of Riga sites (Kalnina, 1997a), as well as sites from the Latvian inland, *e.g.* Satiki, Rogali and Felicianova (Kalnina 1996b; Kalnina *et al.* 1998b), the Eemian succession of forest trees in the region began with a dominance of birch with some admixture of pine and spruce, which were gradually replaced by the dominance of pine (Figs 34a, 40a, 47). The following maximum distribution of broad-leaved trees began with the rapid appearance of elm and oak. In some sections, however, the highest values of elm occur in the latter part of the climatic optimum, together with a peak of linden or hornbeam (Figs 34b, 41, 48).

High percentages of *Tilia* are typical for the climatic optimum of the Last Interglacial in Latvia. Pollen of *Tilia tomentosa* and *T. platyphyllos* in sequences from the west coast are accompanied by pollen of *Sambucus nigra* and *Brasenia* sp., and spores of *Osmunda cinnamomea* type, while at the inland sites these taxa have not been observed.

Low values of *Taxus* just before the rise of *Tilia* are observed in the pollen diagram from the Gulf of Riga (Fig. 48). Most probably the *Taxus* pollen have been long distance transported by marine currents from the south (Kalnina 1997 b). *Taxus* pollen has been found in sections from south-western Latvia (Figs 34a, 41), but are absent in the pollen diagrams from the eastern part of Latvia (Kalnina *et al.* 1997; Kalnina & Juskevics 1998a,c).

Corylus pollen is abundant together with the occurrences of broad-leaved trees, and it has often two maxima values, the first one showing higher percentages (Fig. 48).

Alnus pollen is equally abundant, also with two maxima, the second one being higher. As *Alnus glutinosa* is associated with wet habitats, its abundance is probably related to an increase of distribution of mires and to higher water level in the lakes.

Hedera helix migrated into western Latvia during the climatic optimum, but its pollen has not been noted in eastern Latvia, because of a more continental climate (Kalnina & Juskevics 1998). Some early occurrences of *Hedera* pollen in the Gulf of Riga may have resulted from a transport by marine currents. The presence of *Hedera helix* indicates a temperate oceanic climate (Iversen 1944, Zagwijn 1996).

Carpinus pollen appears in the second part of the Last Interglacial, but its percentages are comparatively low.

Coniferous forests dominate the post-climatic-optimum part of the Last Interglacial: spruce and pine, changing later to pine with some alder and birch (Figs 34, 40).

Low frequencies of *Abies* pollen appear in the *Picea* zone in the Gulf of Riga site (Fig. 48) and the Plasumi site (Fig. 41), probably transported by marine currents from the south. *Abies* pollen is not characteristic of the Last Interglacial pollen diagrams of the Latvian mainland.

Pollen assemblage zones dominated by shrubs and herbs have been identified both before and after the interglacial forest assemblages in the pollen diagrams, both in the eastern and western part of the mainland and in the Gulf of Riga.

The early Weichselian glacial sediments, mainly lacustrine, contain pollen of a light demanding flora, which reflects an open landscape. The redeposited pollen is derived from the preceding Eemian Interglacial deposits (Liivrand 1990, 1991). The climate at the beginning of the Last Glaciation was obviously unstable because of recurrent advances and retreats of the Fennoscandinavian Ice Sheet. Therefore, the correlation of interstadials and glacial stadials is complicated by occassional azonal developments in the vegetation. A more certain distinction of different interstadials is possible in the continuous pollen diagrams such as that of the Grini site (Fig. 34a, b), where a complete pollen succession reflecting the vegetation history of the Last Interglacial is present.

The first Early Latvian (Weichselian) stadial (a cryomer) is represented by a spore-pollen complex, indicating an open *Betula* woodland with abundance of herbaceous taxa, mainly *Artemisia* and Cyperaceae. The herb pollen values decrease at the end of this stadial, and the percentages of tree pollen increase.

The next pollen complex indicates an interstadial, where *Betula* is replaced by *Pinus*, some *Picea* and *Larix*. An opposite development marks the second half of this interstadial, which is probably a correlative with Brörup in north-western Europe (Andersen 1961, Behre 1989).

The second interstadial is separated from the first one by a zone that contains pollen spectra of pioneer plants, which suggests periglacial conditions. This interstadial is characterised by an expansion of coniferous forests, with dominance of *Pinus* and presence of *Picea* and *Larix,* indicating a considerable amelioration of the climate during the optimum of this thermomer. The end of the interstadial is marked by a sharp decrease in *Pinus* and *Picea* pollen values. The pollen spectra indicate that this interstadial is probably a correlative with Odderade in north-western Europe (Behre 1989).

The pleniglacial of the Latvian Glacial is divided on land by the Lejasciems interstadial (Danilans 1973). Silts in this formation, containing plant remains, are extremely rich in herbaceous pollen and spores, which suggests an arctic periglacial open landscape with herb-dominated vegetation.

To sum up long records of Late Kurzeme (Saalian)-Felicianova (Eemian)-Early Latvia (Weichselian), both terrestrial and marine deposits, are found in Latvia. Marine sediments have been found between the glaciolacustrine deposits, and with the help of the pollen spectra they could be interpreted as representing the Eemian Interglacial. Their pollen composition allows us to reconstruct the vegetation of a warm climate with some oceanic influence (*Hedera, Ilex* and *Brasenia* grow in area, because macro-remains have been found), which is characteristic for Felicianova (Eemian) Interglacial. In pollen diagrams eight pollen zones could be distinguished in the pollen sequence corresponding to an interglacial interval (Figs 34b, 41, 48). In spite of different sedimentary conditions (marine, lacustrine) the macro-succession sequences of the sections are in agreement (Kalnina 1996c, 1997c, Kalnina & Juskevics

1998a). The generalised macro-succession for the Felicianova (F)/Eemian Interglacial across Europe is the following (Yelovicheva *et al.* 1998): *Betula+Picea* (F1), *Pinus* (F2), *Ulmus+Quercus* (F3), *Alnus+Corylus* (F4), *Tilia* (F5), (*Carpinus* (F6), (*Picea* (F7) and *Pinus+Betula* (F8).

After the Eemian Interglacial, a long period of periglacial conditions followed. During the Early Latvian (Weichselian), at least two interstadial warmings are traceable (Fig. 34a, 40a, 47) in both marine and lacustrine sequences.

The pollen diagrams that represent the Eemian Interglacial can therefore be correlated with similar regional pollen zones that have been recorded in both the marine and the continental deposits. The differences are more distinctly present in the earliest part of the Interglacial, indicating that the zone boundaries are not synchronous in the Early Eemian, but influenced by soil conditions besides the climate.

8.2 Correlation within the south-eastern Baltic region and with north-western Europe

8.2.1 Holsteinian Interglacial

The Holsteinian interglacial deposits in the south-eastern Baltic region are represented in both marine and continental sediment sequences. Although marine sites have been found less frequently than continental ones and mainly in western Latvia coastal region, marine sites have been identified also in the Kaliningrad District and in western Lithuania.

Diatom data

Cheremisinova (1970) has investigated the Uvarovo site (Kaliningrad District), where a 30 m thick layer of marine deposits is covered by a complex of glacial formations. She found a rich diatom flora (140 species), belonging to the flora of the Holsteinian Baltic Sea which also included some extinct species, *e.g.* *Cyclotella comta* var. *pliocaenica*, *C.* cf. *baikalensis* and *Melosira praegranulata*. A similar diatom flora has previously been noted in the sediment sequences from other sites in the Sambian peninsula (the Kaliningrad District), *e.g.* Pionersk, Romanovo and Krasnopolje Kondratiene (1966) and later in the core Ulmale-9 from western Latvia (Charamisinava 1971). The presence of cold marine and brackish water taxa (*Thalassiosira baltica*, *Thalassionema nitzschioides*, *Chaetoceros* spp, *Coscinodiscus* sp.) and the presence of Pliocene taxa, *e.g.* *Stephanodiscus niagarae* Heribaud, in the diatom assemblage from the lower sandy layer at the Uvarovo site, indicate the beginning of the ingression of saline water into the large glaciolacustrine basins that had been formed just after the retreat of the Elsterian glacier (Cheremisinova 1970). A similar diatom composition has been identified in the lower part of the Ulmale-9 sediments, where also marine and brackish taxa occur, *e.g.* *Chaetoceros* spp, *Rhabdonema arcuatum* and *Actinoptychus undulatus* besides freshwater species. These results are supported also by foraminifera, which are abundant in the late-glacial Sudrabi clays at the Sudrabi and Strante sites.

Diatoms found in the upper part of the marine deposits at Uvarovo suggest an increase in salinity and deepening of the basin. The results of diatom analysis from the Kaliningrad District show a direct connection between the Baltic Sea basin and the North Sea during the Holsteinian Interglacial (Cheremisinova 1970). In Table 14 a comparison between diatom taxa from the Ulmale, Uvarovo and Dockenhuden sites is presented.

Table. 14. Alphabetic list of diatom taxa from sites interpreted as marine Holsteinian in the Kaliningrad District (Uvarovo), western Latvia (Ulmale-9) and northern Germany (Dockenhuden). The taxa found in the lower and upper part of the sediment sequences are given separately. Salinity requirements are marked: M – marine (polyhalobous), B – brackish (mesohalobous), F – freshwater (oligohalobous). Legend for the relative abundance is: + rare, ++ abundant, +++ mass occurrence.

Diatom taxa	Salinity	Pionersk (Kondratiene 1966)	Uvarovo (Charamisinova 1970)		Ulmale (Cheremisinava 1971)		Dockenhuden (Benda 1993)	
			sand	clay	laminated silt		calcareous mud	clay, silt, fine sand
Actinocyclus ehrenbergii Ralfs	M			+	+	++		++
Actinoptychus undulatus (Bail.) Ralfs	M	+		+	+	+++		+
Aulacodiscus argus (Ehr.) A.S.	M					+		++
Auliscus sculptus (W. Sm.) Ralfs	M							++
Auliscus sp.	M					+		
Biddulphia aurita (Lyngb.) Breb. & Godey	M							+
Campylodiscus clypeus Ehr.	B-F					+		
C. echeneis Ehr.	B	++	+	++				+++
Chaetoceros sp.	M		+	+	+	+		
Cocconeis peltoides Hust.	M							+
C. placentula Ehr.	B-F	+			+			
Coscinodiscus antiquus (Grun.)	M	+				+		
C. excentricus Ehr.	M				+	+		+
C. lacustris var *septentrionalis* Grun.	M				+	++		
C. lineatus Ehr.	M			+		+		
C. oculus-iridis Ehr.	M							++
C. perforatus (Ehr.)A.Cl.	M				+	+++		
Coscinodiscus sp.	M		+	++				
Cyclotella cf. *baicalensis* Skv.	F		+	+				
C. comta (Ehr.) Kütz.	F			+				
C. comta var *lichvinensis* Jouse	F			+				
C. comta var. *pliocaenica* Krasske	F			+				
C. Kützingiana Thwait.	B-F		+	++				
Cymatopleura elliptica (Breb.) W. Sm.	B-F		+	+++			+	
Diploneis bombus Ehr.	M			+		+		++
D. didyma (Ehr.) Cl.	B							+++
D. domblittensis Grun. Cl.	F		+	+				
D. fusca (Greg.) Cl.	M							+
D. smithii (Breb.) Cl.	M		+	++				++
Epithemia Hyndmannii W. Sm.	F		+		+		+	
E. sorex Kütz.	B-F	+	+				+	
E. zebra (Ehr.) Kütz.	B-F				+	+	+	
Epithemia sp.	B-F		+	++				
Eunotia cf. *lunaris* (Ehr.) Grun.	B-F						+	
E. praerupta v. *inflata* Grun.	B-F			+	+	+		
Fragilaria brevistriata Grun.	F			+			++	
Fragilaria sp.	F		+	++				
Grammatophora oceanica (Ehr.) Grun.	M	+						
Grammatophora sp.	M			+		++		
Gyrosigma acuminatum (Kütz.) Rabh.	F			+			+	

G. attenuatum (Kütz.) Rabh.	F		+	++				
Hyalodiscus scoticus (Kütz.) Grun.	B			+		+		++
Melosira ambigua (Grun)O Müll.+ f. *curvata* Skabitsch.	F		+	++				
M. granulata (Ehr.) Ralfs	F	++	++	+++			++	
M. italica f. *curvata* (Pant.) Hust.	F		+	+				
M. sulcata (Ehr.) Kütz.	M	+		+				+++
Navicula lyra Ehr.	M			+				+
N. oblonga Kütz.	B-F	+		+				
N. placentula (Ehr.) Grun.	B-F						+	
N. scutelloides W.Sm.	B-F		+				++	
Nitzschia navicularis (Breb.) Grun.	B							+
N. punctata (W.Sm.) Grun.	M							++
Opephora martyi Her.	F						++	
Pinnularia sp.	F		+	+				
Pleurosigma angulatum (Quekett) W. Sm.	M							++
Podosira stelliger (Bail.) Mann	M			+				++
Podosira sp.	M				+	+		
Rhabdonema arcuatum (Lyngb.) Kütz.	M	+			+	++		
Rhaphoneis amphiceros Ehr.	M							++
Rhopalodia gibba (Ehr.) O. Müll.	B-F	+						
R. parallela (Grun.) O. Müll.	F						+	
Stauroneis acuta W. Sm.	F			+				
Stephanodiscus astraea (Ehr.) Grun.	B-F	++	+	++			+++	
S. niagarae Ehr.	F		++	+++				
Stephanopyxis turris (Grev. & Arn.) Ralfs	M							+
Synedra gaillonii (Bory) Ehr.	M			+		+		
S. parasitica (W.Sm.) Hust.	B-F						+	
S. ulna (Nitzsch) Ehr.	F						++	
Tetracyclus ellipticus (Ehr.) Grun.	F		+	++				
Thalassionema nitzschiodes Grun.	M	+	+	+				
Thalassiosira baltica (Grun.)	B	++	+	+++		++		
Th. baltica (Grun.) Ost. v. *fluviatilis* (Grun.) A. Cl.	B		+	++				
Th. excentrica	M					+		
Th. gravida Cl.	M	+						

Correlation of marine faunas

There is only a small number of foraminifer data from the south-eastern region of the Baltic Sea, but the results obtained can be compared with data from Danish marine shelf sequences, which cover the climatic shifts from glacial environments, through interglacial into early glacial conditions (Kristensen *et al.* 1998a). These selected marine glacial-interglacial palaeoenvironmental reconstructions are based on a multidisciplinary high-resolution study of lithology, foraminifera, ostracods, macro-fauna, diatoms and stable isotopes.

Results obtained from the area investigated in Latvia were also compared to and correlated with marine sediment sequences in north-western Europe. In the Hamburg-Dockenhuden area (south of Schlezwig-Holstein) three thoroughly studied boreholes have been selected to establish the Holsteinian Interglacial stratotype area, *i.e.* the Eggstedt borehole (dho5), the Dockenhuden borehole (dho4), and the Wedel borehole (dho2). These interglacial sediment sequences have been investigated by Hallik (1960), Menke (1970), Grube *et al.* (1986), Linke & Hallik (1993), Benda (1993), Ehlers (1993), Stephan (1993) and Knudsen (1993a). Results from the study area in western Latvia show a good correlation with Dockenhuden (dho4), where a complete Holsteinian interglacial sequence was recovered (Linke & Hallik 1993; Ehlers 1996).

Fauna and flora from almost all the sites studied in north-western Europe indicate that during the Holsteinian Interglacial the sea had already invaded the Baltic basin at the end of the Elsterian Glaciation, *e.g.* in Jutland and North Germany. In the Eggstedt borehole, in Schleswig-Holstein, a marine fauna has been encountered at a depth of 33.3 m below present sea level underlying 48 m of Lauenburg Clay (Knudsen 1993b). The upper parts of the Lauenburg Clay sequence contain an arctic-boreal foraminifera marine fauna, and the marine Late Elsterian deposits in Schleswig-Holstein can also be traced further inland. The early transgression may have been the result of a marked isostatic depression of the land surface during the Elsterian glaciation (Ehlers 1996). Foraminifera data from the investigated sites in western Latvia also show a very early invasion of saline water, even during the Elsterian Late Glacial, and this event can probably be compared with the second transgression established in the Eggstedt core.

In Latvia the sediments are very abundant in foraminifera at the depth 70-71 m of the Ulmale test drillings No.9, 41, 41-a, as well as in Strante and Sudrabi. The species *Elphidium excavatum*, *E. granatum*, *E. clavatum* and *E. albiumbilicatum* dominate in the composition of foraminifera assemblages in the Holsteinian type sections.

For several reasons (sediments barren of diatoms an/or foraminifera, absence of indicator species) it is not always possible to conclude whether the sediment sequences belong to the Holsteinian or the Eemian Interglacial using only diatom or foraminifer data. In most sections the occurrence of Holsteinian Interglacial deposits, both marine and continental, has been established mainly on the basis of their pollen content (pollen assemblage zones).

Pollen data

One of the first palynological investigations of marine interglacial sediments in the south eastern Baltic region was made by Kondratiene (1966), when she studied 30 cores taken in the Sambian peninsula (the Kaliningrad District). According to her pollen data the 27-30 m thick marine sediments have been deposited during the Holsteinian Interglacial.

The pollen diagrams from the Sambian peninsula show comparatively high and similar values of *Pinus, Betula* and *Alnus*, and presence of *Abies fraseri*, *A. alba*, *Taxus*, *Larix*, *Carpinus*, and low values of *Corylus* and QM. Single pollen grains of *Fagus* and *Ilex* were found, as well as spores of *Osmunda* and massulae of *Azolla filiculoides*. Pre-Quaternary palynomorphs of Taxodiaceae, Juglandaceae, *Rhus, Nyssa, Sciadopitys* and *Engelhardtia* are characteristic for these diagrams. The pollen spectra show good correlation with those in pollen diagrams from the Uvarovo site (at present located further from the sea than other sites investigated in the Sambian peninsula) and also with the pollen diagrams from the marine Holsteinian deposits from Tornskov, Denmark (Andersen 1963), and Hummelsbüttel in the Hamburg area (Hallik 1960). However, the frequency of *Abies* and *Picea* in pollen diagrams from the Sambian peninsula is much lower than from western Europe, but more similar to that of the marine sediments in the Ziemupe-Jurkalne area on the Latvian west coast. *Abies* and *Picea* pollen values are also higher in the diagrams of continental deposits in the south-eastern Baltic area than in the diagrams of marine sediments.

According to Kondratiene (1966) most pollen diagrams investigated from the Sambian peninsula, and also from the coastal area of Lithuania, reflect only part of an interglacial and have been correlated with the Butenai (Holsteinian) Interglacial, zone B4 (Kondratiene & Gudelis 1983).

The pollen data from the above mentioned areas may be correlated with PAZ IV from the Ziemupe-Jurkalne area, where *Abies* reaches its maximum and an almost full interglacial sequence is suggested as Holsteinian (Kondratiene & Gudelis 1983; Meirons 1986 a, b; Seglins 1987; Kalnina *et al.* 2000). However, *Picea* is much more abundant in the Ziemupe-Jurkalne area diagrams than in the Sambian peninsula and western Lithuania. The pollen sequences from Laukzeme (Kondratiene & Gudelis 1983) and Zadeikai (Kondratiene 1996) contain *Azolla* massulae, which are also characteristic for Holsteinian pollen diagrams from north Germany, *e.g.* Neuruppin area (Cepek & Erd 1975). *Azolla* has also been found in south-western Latvia (Laukzeme, Rucava), but is almost absent in the Ziemupe-Jurkalne pollen diagrams. Only a few *Azolla* massulae have been registered in the PAZ III of Strante-33 and Ulmale-41a site pollen diagrams.

The dominance of coniferous taxa during almost the entire interglacial, the high values of *Alnus* and low frequencies of *Corylus* and QM are characteristic features in almost all pollen diagrams from marine sediments in the coastal zone of the south-eastern Baltic Sea.

Sites with continental Holsteinian deposit have been found more often than marine ones in this region. Because of the conditions and influence of the continental climate, the pollen diagrams from the inland area differ to some extent from the marine ones, but the general features and pollen successions are similar and comparable between marine and continental sequences.

In Estonia, Holsteinian continuous continental organic sediment sequences occur at the Karuküla and Kôrveküla sites. However, at both sites the Holsteinian deposits are in a secondary position (Levkov & Liivrand 1988), although palynological and palaeocarpological analyses confirm a Holsteinian age for these deposits (Liivrand 1992). The pollen spectra in the diagrams from these sites are similar to other diagrams in the south-eastern Baltic region: a dominance of coniferous taxa during the entire interglacial, an early immigration of *Picea* and *Alnus*, which became widespread before the climatic optimum, simultaneous maxima of *Picea* and QM, high values of *Alnus* and comparatively low ones of *Corylus*. In contrast, we can mention a late appearance of *Carpinus* in Estonia during the second part of the regional PAZ IV.

The early immigration of *Carpinus* before the culmination of broad-leaved trees in the early temperate substage is characteristic for the pollen diagrams both of the marine Akmenrags Interglacial and the inland Pulvernieki Interglacial in Latvia (Table 15). The early appearance of *Carpinus* and abundance in the diagrams is particularly typical for the eastern part of Latvia, *e.g.* Kraslava, Adamova and Klekeri, and also for western Russia (Grichuk 1989). The maximum of *Carpinus* is commonly simultaneous with that of *Abies* and the values are higher in the diagrams from the eastern sites (eastern Latvia and western Russia), while in the western direction *Carpinus* maximum values become similar or even lower to those of *Abies*. A similar character of the *Carpinus* curve has also been observed in pollen diagrams from Lithuania (Kondratiene 1996), Byelorus (Makhnach *et al.* 1978; Rylova & Savchenko 2001), Ukraine (Gerasimenko 1999), the Sambian peninsula (Kondratiene 1966) and eastern Poland (Borowko-Dluzakowa & Stowanski 1991), while in pollen diagrams from western Europe *Carpinus* appears first at the end of the temperate substage (Erd 1970; Krupinski 1995; Grüger 1996). In many diagrams of the Butenai Interglacial in Lithuania, *Carpinus* pollen culminates together with *Picea* and *Abies*, and is more abundant than in pollen diagrams from the marine Holsteinian deposits in the Kaliningrad District and the western Latvian coastal area.

Table 15. Correlation scheme of regional PAZ from marine and continental Holsteinian sites in the south-eastern Baltic area and northern Germany. qsF=Saale-Frühglazial, qsDO= Dockenhuden interstadial, qeLT= Dangerstellt, B= Butenai Interglacial, P=Pulvernieki Interglacial, Sv = Sventoj interstadial, L=Lichvin Interglacial, K=Kosinskij interstadial.

		Dockenhuden, N. Germany (Linke & Hallik 1993)	Butenai, Lithuania (Kondratiene 1996)	Akmenrags Latvia (Kalnina *et al.* 2000)	Pulvernieki, Latvia (Danilans 1966)	Karuküla, Estonia (Liivrand 1991)	Likhvian, western Russia (Grichuk, 1989)
Deposit		Marine	continental	Marine	continental	continental	continental
Saalian	peri glacial	qsF – herbs, *Betula, Pinus*	B9 – herbs, *Betula nana*				K3 – *Betula, Pinus, Picea*
Saalian	interstadial	qsDO Dockenhuden interstadial- *Betula* (max), herbs, Poaceae, *Pinus, Picea*		IX - *Betula, Alnus, Picea*			K2 – *Pinus, Betula, Picea, Abies*
Saalian	stadial	qsHO Hochkamp stadial – Herbs, *Pinus, Betula, B. nana*	B8 – *Betula, Pinus, Betula nana*	VIII – *Pinus, B.nana, Duschekia, Salix*, herbs			K1 - *Pinus, Betula, Larix*
				VII - *Pinus*			
Holsteinian Interglacial		qho5 – *Pinus, Betula, Alnus*	B7 - *Betula, Pinus, Larix*	VI – *Betula, Alnus, Carpinus*, Ericales, Cyperaceae	P5 - *Betula*	V – *Betula, Pinus, with Picea, Alnus*, QM	L6 – *Betula, Pinus, Picea*
			B6 – *Pinus, Picea, Alnus*		P4 – *Pinus, Alnus, Picea, Betula*		
			B5 - *Betula, Pinus*	V - *Pinus*			
		qho4 – *Abies, Carpinus*	B4 – *Pinus, Picea, Abies*	IV- *Abies, Carpinus, Alnus, Quercus*	P3 – *Abies, Picea*, Q mix, *Carpinus, Alnus*	IV- *Picea, Abies, Carpinus*	L5 – *Pinus, Betula, Picea, Abies*
		qho3 – *Picea* b - *Picea, Corylus* a - *Picea, Betula*	B3 – *Abies, Picea, Carpinus* (*Ilex, Buxus, Vitis, Hedera, Pterocarya*)	III - *Picea, Ulmus, Alnus, Tilia, Carpinus, Corylus*	P2b – *Picea, Alnus, Abies, Carpinus*	III – *Tilia, Quercus, Ulmus*	L4 – *Picea, Abies*
						II – *Picea, Alnus*	L3 – *Carpinus, Abies, Picea*
		qho2 – *Pinus*	B2 – *Picea, Pinus*	IIb - *Pinus*			L2 - *Picea, Pinus*, Q M
		qho1 – *Betula*	B1b – *Pinus, Betula*	IIa - *Betula*	P2a - *Pinus, Picea, Alnus, Betula*	I – *Betula, Pinus*	L1 – *Betula, Pinus, Picea*
Elsterian		qeLT – *Pinus, Betula, Juniperus*, herbs	B1a – herbs, *Hippophae, Duschekia*	I – *Pinus, Betula, Alnaster*, herbs	P1c - *Betula, Pinus*	LE – *Betula nana*, herbs	Sv3 - *Pinus, Betula*
					P1b - *Pinus, Picea, Betula*		Sv2 - *Pinus, Picea*, QM
					P1a - *Betula, Pinus*		Sv1 - *Betula*

Also in the Byelorusian, Ukrainian and Russian diagrams, *Carpinus* pollen appears during the early temperate substage and is more abundant than in the diagrams from Western Europe. Sobolewska (1975) already suggested that: "Hornbeam and fir are more important in eastern and central Europe than in Western Europe". All these data suggest an immigration of *Carpinus* from the south-east into the study area during the Holsteinian Interglacial (Kalnina 2000).

In the Butenai interglacial diagrams in Lithuania the optimum conditions of the climate are characterised by pollen spectra of zone B3 (Kondratiene & Seiriene 2001). This zone contains high percentages of *Abies* (50%), and *Quercus* and *Carpinus* pollen occurs with 10-12%. Exotic species are represented by *Taxus, Larix, Ilex, Fagus, Buxus, Vitis, Zelkowa*, as well as some extinct species, *e.g. Azolla pseudopinnata* Nikit. and *A. interglacialis* Nikit. Palaeobotanical results suggest warmer climatic conditions than the present ones with mild winters during the climate optimum. The calculated mean temperature for January was probably -1° C and for July 19-22° C, and the precipitation was about 1000 mm/ year (Kondratiene & Seiriene 2001). In areas influenced by the sea the climate was not as mild, which can be seen in the lower pollen values of broad-leaved trees in the diagrams. A dominance of coniferous taxa has been observed even during the climatic optimum (Fig. 13).

A dominance of coniferous trees over deciduous ones and an absence of *Fagus* pollen are diagnostic features, expressed in the Mazovian (Holsteinian) interglacial pollen diagrams from continental deposits in Poland (Mojski 1985; Krupinski 1995). Coniferous trees are abundant, and among them the significant taxa are *Picea excelsa, Pinus, Larix* and *Abies* (A. *fraseri*).

The succession of the Holsteinian flora in Polish diagrams starts with a coniferous forest, with larch (*Larix*) and spruce (*Picea excelsa, Abies fraseri* and *Betula*, and also *Tsuga*, which is supposed to have occurred only in the Carpathians (Szafer 1953). Later a spruce forest developed, with *Picea excelsa* and *P.* sect. *Omorica*, as well as deciduous trees, hazel and *Osmunda claytoniana* type. During the thermal optimum, *Abies fraseri* appears with a biapial curve, and a *Carpinus betulus* maximum is registered between the *Abies* culminations. This feature is similar in the Akmenrags pollen diagram from the Ziemupe-Jurkalne area, where a QM maximum divides the *Abies* and *Picea* maxima into two parts. In the diagrams from Poland, like those from Lithuania, there is a well developed phase with high content of *Abies*. The end part of Polish diagrams represents coniferous forests, with *Pinus* and *Picea*, also with appearances of pollen of *Larix*. A sporadic occurrence of *Larix* was noted in the initial part of the interglacial, but this taxon is abundant in spectra of post-interglacial sediments (Krupinski 1995). Szafer (1953) indicated the presence of species that do not occur in the younger deposits of Poland, *e.g. Pterocarya fraxinifolia* Spach, *Vitis silvestris* C.C.Gmelin, *Euryale ferox* Salisbury and *Azolla filiculoides* Lamark. The pollen diagrams from north-eastern Poland, *e.g.* Wegorzewo (Sobolewska 1975) and Kozarki (Borowko-Dluzakova & Stowanski 1991) are more similar to those of south-western Lithuania with simultaneous maxima of *Carpinus* and *Abies*, and with a predominance of the last one.

The pollen spectra from Akmenrags/Holsteinian Interglacial correlate well with those from the Holsteinian type area (Linke and Hallik 1993) and show the same features:

- two climatic warming episodes in those diagrams that cover the entire Holsteinian interval (Kalnina *et al.* 2000)
- dominance of coniferous trees and *Alnus* during the entire interglacial
- almost simultaneously appearance of thermophilous trees

- comparatively low abundance of QM and *Corylus*
- presence of exotic conifers, *e.g. Picea* sect. *Omorica*, *Pinus* sect. *Strobus* and *Abies fraseri*

Some differences exist between the pollen diagrams in the Holsteinian stratotype area and in the south-eastern Baltic region. The North German Holsteinian Interglacial vegetation succession is characterised by an early appearance of *Abies* and a presence of *Celtis* and *Azolla*. Towards the end of the interglacial, as oak and elm decline, *Pterocarya* is regularly encountered in the Holsteinian sediments of West Europe (Turner 1975; West 1970; Ehlers 1996). One of the closest German marine/limnic Holsteinian interglacial sites, Pritzwalk (Erd 1973) is characterised by higher pollen values of *Taxus, Corylus*, *Carpinus* and *Abies* than are Latvian Holsteinian pollen sequences. There are high values of *Pterocarya* and *Buxus*, as well as presence of *Celtis* and *Fagus* (Cepek & Erd 1975), but in Latvian pollen diagrams only single pollen grains of these species have been found. There are similar pollen spectra to those from Ziemupe-Jurkalne marine sediments from Granzin (North Germany), where the maximum of *Alnus, Corylus* and QM occur simultaneously (Erd 1969, 1973). The differences are the large values of *Taxus* pollen and the late appearance of *Carpinus*. The real marine conditions in Granzin and brackish in Pritzwalk occur during the climatic optimum, while in Latvian Holsteinian sediments marine conditions are recorded already at the beginning of PAZ II (*Pinus*).

In comparison with the Latvian Holsteinian (Akmenrags Interglacial) sites, those from the Hamburg area in north-western Germany have longer sediment sequences from the early and late temperate substages – about 30 m instead of 5-10 m sequences in the Ziemupe-Jurkalne area. It is the result of the thick sediment sequence (~15 m) accumulated during the *Abies* zone, whereas in Latvian sequences this interval is thinner (in Strante-33 and Ulmale-41a 1-2 m). The upper parts of the sequences show good correlation: herbs and dwarf shrubs, particularly Ericales, increase markedly in zone V of Dockenhuden (dho 4) and also in PAZ VI in the Akmenrags pollen diagram. *Betula* sect. *Alba* also increases in both diagrams and presence of *Ulmus* and *Quercus* pollen is noticed. *Pterocarya, Celtis* and *Taxus* are also found in the uppermost parts of the pollen diagrams under discussion.

The nearest Holsteinian sites northwards from Latvia have been found in Estonia, the Karuküla and Kôverküla and in Finland, the peat bed at Naakenavaara, where the sequence includes wood of *Larix* (Nenonen 1995). Three lacustrine sites have been correlated with the Holsteinian Interglacial in Sweden. The Öje site in central Sweden, Snickarekullen in south-western and Hyby in the Alnarp valley southernmost Sweden are correlated with the Holsteinian Interglacial (Miller 1977; Robertsson & Garcia Ambrosiani 1992; Garcia Ambrosiani 1996; García Ambrosiani *et al.* 1998). These sites like the Latvian Holsteinian sites show that the vegetation was dominated by coniferous trees, including pine and spruce. Pollen and needles of *Larix* have been registered in the interglacial sediments in Öje, and also in the Latvian Holsteinian interglacial sediments it occurs, but only as single pollen grains. In contrast *Larix* plays a significant role in the Early Weichselian interstadial sediments in northern Europe (Behre 1989). The sediment sequence from Hyby shows low pollen frequencies of *Corylus* and mixed oak forest, together with *Picea, Abies* and *Taxus* (Miller 1977), which are similar to Akmenrags Interglacial, but pollen values of *Abies* and *Taxus* are much lower in Hyby. A different feature of the pollen spectra in the Latvian and the south-eastern Baltic region, as compared to western and northern Europe, is the occasional presence of *Duschekia* pollen in the late glacial spectra and its abundant occurrence in early glacial pollen spectra, where it appears together with a light demanding pioneer flora. The western limit of the distribution area of *Duschekia* during late and early glacial stages was probably located between Lithuania and Poland. In the south-eastern Baltic region, the presence of *Duschekia* (in earlier literature called *Alnaster*) in the interstadial spectra is rather common and its pollen values makes a continuous curve with maxima at 10-20%, but nowadays it does not grow in this area. *Duschekia* is a 5-7 m high shrub, growing in the Siberian taiga and the subalpine zone of mountains, where conditions are humid and the ground is covered in snow in the winter (Flora of the NE European part of USSR 1976). It is common in the sparse *Picea* and *Larix* forests of the forest tundra, on riverbanks and floodplains, overgrown by *Salix* and constitutes brushwood. The present distribution area of *Duschekia* is banks and deltas of rivers within the catchment area of the Arctic Ocean in northern Russia, particularly from the Mezen River along the Ural mountains, and in Siberia, the Far East, Sakhalin peninsula and Kurilian Islands, as well as on the western coasts of Greenland and in North America between 61° and 66° N latitude (Arctic flora USSR 1966).

8.2.2 Eemian Interglacial

The first Eemian marine interglacial sediments in the south-eastern Baltic region have been identified and studied in several cores from the Prangli Island, northern Estonia, in the Gulf of Finland, about 18 km north east of Tallinn (Kajak 1961, Raukas, 1978). The Pleistocene sequence comprises marine Eemian deposits at depth of 78-66 m, represented by a greenish grey marine clay with weak horizontal laminations and silt lenses including remnants of molluscs, plant remains and vivianit (Kajak 1961, Liivrand 1991).

Diatom data

The marine origin of the Prangli sediments was determined by diatom analysis (Cheremisinova 1961), distinguishing two stages of the Baltic Eemian Sea history. The beginning of the transgression is associated with the lower part of the marine clays, which are superimposed on varved clays (Liivrand 1991), containing cold freshwater relict species, *e.g. Cocconeis disculus*, *Diploneis domblittensis*, and species of the fresh/brackish water genera *Pinnularia* and *Epithemia*, together with marine, shallow water species, *e.g. Hyalodiscus scoticus, Actinocyclus Ehrenbergii* (*A. octonarius*) and *Grammatophora* spp (Cheremisinova 1961). The sediments are barren of diatoms in the lower part of the Gulf of Riga core-21 (Fig.46b). The sediments in the lower part of the Plasumi core contain less diatoms than the Prangli core. Only single marine diatoms occur, while the freshwater taxa dominate.

The second stage of the marine transgression at Prangli is associated with the deposition of the middle part of the marine clays (no diatoms were determined in its upper part). The diatoms provide evidence of normal marine salinity, however, shallow water marine species dominate, *e.g. Paralia sulcata, Actinocyclus Ehrenbergi* and *Hyalodiscus scoticus*; also marine neritic plankton, *e.g. Coscinodiscus* spp and *Thalassiosira* spp occur sporadically (Cheremisinova 1961; Liivrand 1991). Warmth demanding (thermophilous) Eemian diatoms are present, *e.g. Synedra gaillonii, Navicula abrupta, Coscinodiscus antiquus, C. granulosus* and *C. perforatus.* The first four of the species just mentioned have also been found in the Plasumi core, but not in the Gulf of Riga. Real marine conditions occur at Prangli at the beginning of the early temperate stage, while in the Gulf of Riga and Plasumi they occur in the second half of the early temperate substage, just before the climatic optimum. Marine and brackish water taxa dominate, *e.g. Paralia sulcata*, *Rhabdonema arcuatum*, *Hyalodiscus scoticus* and *Chaetoceros* spp, in all the three sections during the climatic optimum (Table 16).

Table 16. List of main diatom taxa in the Eemian interglacial marine sediments in the south-eastern Baltic region. Legend: M – marine, B – brackish, F – freshwater; * present, ** common, *** very abundant.

Diatom taxa	Ecology	Prangli (Cheremisinova 1961)	Riga Gulf-21 (Sakson in print)	Plasumi (Sakson in print)
Actinocyclus octonarius Ehr.	M	**	***	*
Actinoptychus areolatus	M	*		
A. undulatus (Bail.) Ralfs	M	*		
A. senarius Ehr.	M		***	**
Amphora libyca Ehr.	F		*	*
A. pediculus Kütz.			***	*
Chaetoceros spp	M	**	***	***
Cocconeis disculus (Sch.) Cl.	F	*	**	
C. costata Greg.	M		**	*
C. scutellum Ehr.	B	**	***	**
Coscinodiscus antiquus (Grun.) Cl.	M	*		*
C. granulosus Ehr.	M	*		*
C. lineatus Ehr.	M	*		
Coscinodiscus spp	M		***	*
Diploneis chersonensis (Grun.) Cl.			*	*
D. didyma (Ehr.) Cl.	B		***	*
D. domblittensis (Grun.) Cl.	F	*		
D. notabilis (Grev.) Cl.			*	*
D. Smithii (Breb.) Cl.	B		**	*
D. suborbicularis (Greg.) Cl.			*	*
Epithemia zebra (Kütz.) Grun.	F		**	*
Epithemia spp	B-F	**		
Fragilaria construens (Ehr.) Grun.	F		***	**
Grammatophora oceanica Grun.	B		***	***
Grammatophora sp.	M	***		
Hyalodiscus scoticus (Kütz.) Grun.	M(B?)	***	***	***
H. subtilis Bail.	M		*	
Melosira ambigua (Grun.) O. Müll.			***	**
M. arenaria Moore	F	*		
Navicula abrupta Greg. V. *lyra* Ehr.	M	**		**
N. tuscula (Ehr.) Grun.	B-F	*	*	*
Nitzschia granulata Grun.	B	*		
N. levidensis (W.Sm.) Grun.	B		*	*
Paralia sulcata (Ehr.) Cl.	M	**	***	***
Pinnularia spp	F	*		*
Podosira sp.	M	**	**	**
Rhabdonema arcuatum (Lyngb.) Kütz.	M	***	**	***
Stephanodiscus astraea (Ehr.) Grun.	B-F	*	***	**
Stephanopyxis turris (Grev.) Ralfs	M		***	*
Synedra gaillonii (Bory) Ehr.	M	**		**
S. tabulata (Agardh) Kütz.	B	**	*	*
Thalassionema nitzschoides (Grun.) Hust.			***	**
Thalassiosira baltica Grun. Ost.	B		*	
Thalassiosira eccentrica (Ehr.) Cl.	M		***	*
Th. gravida Cl.	M		**	**
Thalassiosira spp	M	*	**	*

The diatom assemblages from the upper interglacial and the subtill deposits from the Gulf of Riga-21 and the Plasumi site indicate that the basin changed from saline to freshwater with a minor influence of saline water.

Marine faunas

Similar biostratigraphical data are also recorded in the Pleistocene marine deposits in Poland, where repeated marine transgressions (Makowska 1986) formed deposits of the Tychnowy Sea, which flooded the Lower Vistula area and the Elblag Elevation during the Eemian (Makowska 1986, 1995). Representative results of the investigation were obtained from the Nowiny site, where the strongest evidence of the Eemian Sea development was recorded among other numerous sites studied in that area. At the beginning of the transgression the sea already was inhabited by a rich fauna, among which foraminifera and molluscs were the most numerous. In general, the fauna consisted of some 32 species of Lusitanian snails and clams, including, *e.g.* *Eulimella nitidissima* at Nowiny or *Brachydontes lineatus* found at other sites (Brodniewicz 1960; Makowska 1995).

Among the foraminifera, the *Ammonia-Elphidium* group was present during the maximum stage of the Eemian Sea, e.g. *Ammonia beccari, Elphidium albiumbilicatum, E. clavatum, E. gunteri, Proelphidium granosum* and *P. orbiculare* (Brodniewicz 1972). Almost all of them have also been found in the interglacial sediments of the Plasumi site.

In contrast to the Holsteinian, Eemian marine sediments have been found farther north and east *e.g.* in Finland and western Russia. Eemian marine deposits have been identified at relatively high altitudes in Finland, for instance, Ollala, Haapavesi (116 m a.s.l.), Norinkylä, Teuva (112 m a.s.l.) and Ukonkangas, Kärsämäki (106 m a.s.l.) (Forsström *et al.* 1987; Grönlund 1991). Also in the western Russian sites marine sediments usually are located above present sea level, *e.g.* at Mga near St. Petersburg at an altitude of 10 m a.s.l. Such altitudes of these sites are probably caused by glacioeustatic uplift, but the uplift might also be tectonic. It is surprising that at the Prangli site, which is comparatively close to Mga, marine sediments occur at 66-78 m b.s.l., also deeper than in the Gulf of Riga core-21 (36.5-40.7 m b.s.l.).

The Eemian (Mikulino, Mga) sites in western Russia in the Leningrad and in the Archangelsk district were dated by the ESR method applied on shells from these marine deposits. The ages yielded 105 000±100 to 120 000±80 years, being in good agreement with the estimates about the age of the Eemian deposits (Molodkov & Raukas 1988). Several investigations prove that the Eemian warm stage was characterised by a major transgression along the arctic coasts of Russia and the Baltic Sea transgressed into parts of Russia and the Baltic States (Ehlers 1996). In Poland Eemian marine sites have been found at the lower Vistula region, which underwent a major transgression (Makowska 1982, 1986, 1995).

Pollen data

Most of the Eemian marine sediment sequences in the region have been analysed in regard to their pollen composition, which allows us to reconstruct the palaeovegetation during the sediment formation and in some cases to clarify the age of these deposits. The vegetation history of western Latvia has features in common with Eemian sections described from Russian Karelia, the Saint Petersburg region (Znamenskaya 1959; Znamenskaya & Cheremisinava 1962; Plechivtceva 1998a, b), Finland (Gibbard *et al.* 1989; Eriksson 1993; Eriksson *et al.* 1999), Estonia (Liivrand 1991), Lithuania (Kondratiene 1996; Satkunas & Grigiene 1997; Satkunas *et al.* 1998) and Poland (Janczyk-Kopikowa 1976; 1991; Mamakowa 1989; Granoszewski 1998). The sediments at the stratotype site of south-eastern Baltic region Prangli were investigated by pollen (Liivrand & Valt, 1966) and subdivided into pollen assemblage zones E1-E8 by Liivrand (1991), c-I after Jessen & Milthers (1928) and M2-M8 according to Grichuk (1961). Along with increasing temperature (end of zone M2, beginning of zone M3) the transgression of the Eemian Sea has been established (Punning & Raukas, 1985). The pollen diagrams of the eastern Baltic region reveal a succession of typically overlapping culminations of the following trees: *Betula, Pinus, Ulmus, Quercus, Corylus, Tilia, Carpinus, Picea* and *Pinus* (Table 17).

The pollen assemblage zones in the pre-temperate and post-temperate substages are rather similar. Some differences appear more distinctly in the early temperate substage in the Interglacial, indicating that the zone boundaries may not be strictly synchronous in the Early Eemian, when changing soil conditions were of importance besides the climate.

The AP succession in the region began with a dominance of *Betula* and an admixture of *Pinus* and *Picea*, followed by a *Pinus* dominance. The presence of *Picea* during the pre-temperate substage is expressed more in the Russian (Grichuk 1982, 1989) and the Estonian pollen diagrams (Liivrand 1991). Farther to the west *Picea* is absent during this substage, and it appears only during the second part of the late temperate substage, always after the *Carpinus* maximum.

Pollen analysis from the Nowiny site in Poland, the closest western region from Latvia, where marine Eemian sediments are distinguished, show that the development and filling of the basin started and lasted through the E I PAZ (Janczyk-Kopikowa 1976; Makowska 1986, 1995), which corresponds to the Ed phase (*Pinus* and *Betula*) of the Eemian Interglacial according to Jessen and Milthers (1928). This zone might be compared with the E1-E2 regional pollen zones according to Liivrand (1991). Zone E II in Nowiny corresponds to Jessen and Milthers' (1928) phase Ee (*Quercus* with *Corylus*), phase Ef (QM with *Corylus*) and phase Eg (*Carpinus*) and might be compared with E3-E6 in Latvia and Estonia. In the upper part of the Nowiny sequence in Poland pollen zone E III has been distinguished (phase Eh according to Jessen & Milthers 1928), when *Carpinus* was replaced by *Pinus-Betula*. The pollen diagram from the Nowiny site is different from that of the marine sequences from Latvia and Estonia, which show low abundance of *Ulmus* and *Tilia* pollen and earlier immigrated, but weakly expressed *Picea*. *Abies* is represented in Nowiny, as in Latvian diagrams, by low values and appears after the maximum of *Carpinus*.

The maximum distribution of the broad-leaved (QM) forest during the Eemian Interglacial in the south-eastern Baltic is characterised by dominance of *Ulmus* and *Quercus*. The order of their culmination may vary from site to site, and it obviously depends on local conditions. *Quercus*, however, usually culminates before *Ulmus* and also reaches higher values. The pollen data demonstrate a diversity of broad-leaved trees during the climatic optimum, *e.g. Quercus petraea, Q. pubescens, Ulmus glabra, U. laevis, Tilia tomentosa, T. platyphyllos* and *T. cordata* (Kondratiene 1996; Kalnina 1997c). Pollen of *Tilia tomentosa* is mainly present before the *Tilia* maximum, while *Tilia platyphyllos* appears later. *Tilia* occurs in the Eemian diagrams from Estonia and western Russia, but is absent in the diagrams from Finland. *Quercus* and *Corylus* are strongly represented in almost all diagrams. *Corylus* is abundant during the early and late temperate substages, often with two maxima. The first maximum is usually more pronounced than the later one, which occurs simultaneously with *Tilia*. Several warm temperature and humidity demanding plants are present in the pollen diagrams from the coastal area of Latvia, Lithuania and Poland, e.g. *Ilex, Hedera, Sambucus nigra, Vitis,* Table.17. Correlation of Eemian interglacial pollen assemblage zones of various sites in Latvia and Estonia, and regional pollen zones from Poland, Lithuania and western Russia.

Prangli in the Gulf of Finland, Estonia (Liivrand 1991)		Core 21 in the Gulf of Riga (Kalnina 1997a)		Felicianova in the eastern part of Latvia (Danilans 1973)		Satiki in western part of Latvia (Kalnina 1997c)	
E8	*Pinus*	E8	*Pinus*			S8	*Pinus*
E7	*Picea*	E7	*Abies-Picea*			S7	*Picea*
E6	*Carpinus*	E6	*Alnus-Corylus*			S6	*Carpinus,*
E5	*Tilia-Corylus-Alnus*	E5	*Tilia-Carpinus-Alnus*	F5	*Corylus-Quercus-Tilia-Carpinus-Alnus*	S5	*Ulmus-Tilia*
E4	*Quercus-Ulmus-Corylus-Alnus*	E4	*Quercus-Tilia-Alnus-Corylus*	F4	*Quercu-Ulmus*	S4	*Corylus-Alnus*
E3	*Pinus-Betula-Quercus-Ulmus*	E3	*Ulmus-Fraxinus-Corylus*	F3	*Pinus-Betula-Ulmus-Quercus*	S3	*Quercus-Corylus*
E2	*Pinus-Betula*	E2	*Pinus*	F2	*Betula-Pinus-Picea*	S2	*Pinus-Betula-Picea*
E1	*Betula-Pinus*	E1	*Pinus, Betula*	F1	*Pinus-Betula-Picea*	S1	*Betula-Pinus*

Poland (Mamakowa 1988)		Lithuania (Kondratiene 1996)		western Russia (Grichuk 1989)	
E7	*Pinus*	M5	*Pinus-Betula*	M8	*Pinus-Picea-Betula*
				M7	*Picea-QM*
E6	*Picea-Abies-Alnus*	M4	*Picea*	M6	*Carpinus-Tilia-Quercus-Ulmus-Corylus-Picea*
E5	*Carpinus-Corylus, Alnus*	M3c	*Carpinus*	M5	*Tilia-Carpinus-Quercus-Ulmus-Corylus*
E4	*Corylus-Quercus-Tilia*	M3b	*Tilia-Corylus*	M4	*Quercus-Ulmus-Corylus*
E3	*Quercus-Fraxinus-Ulmus*	M3a	*Quercus-Ulmus*	M3	*Pinus-Betula- Quercus*
E2	*Pinus-Betula-Ulmus*	M2	*Pinus-QM*	M2	*Pinus-Betula- Picea*
E1	*Pinus-Betula*	M1	*Pinus-Betula*		

Ligustrum and *Brasenia*, while, except for *Sambucus*, they are absent in the diagrams from more continental areas.

The presence of some weakly expressed maxima of *Taxus* is observed in pollen diagrams from the Latvian marine sequences during PAZ E5-E6, which is later than in North German Eemian diagrams where it culminates already in zone E4. *Taxus* is weakly recorded in the diagrams from Poland. Probably the north-easternmost limit of *Taxus* was located in the coastal area of western Latvia, like it is at present.

Abies pollen appears in small numbers in the *Picea* zone (E7) in the Latvian Eemian marine pollen diagrams, and has been found also in small numbers in Lithuanian (Kondratiene 1996) and in Polish (Mamakowa 1988, 1989) diagrams.

The Last Interglacial pollen stratigraphy in the eastern Baltic region is characterised by a rapid rise in *Quercus* pollen values at the onset of the Interglacial and high *Corylus* pollen percentages, by a dominance of broad-leaved tree pollen during the climatic optimum, and a late immigration of *Picea* after the *Carpinus* maximum following the climatic optimum.

Correlation with north-western European data

The Eemian vegetation succession in adjacent areas of the Baltic Sea follows an almost similar pattern. The pollen succession from the sites studied has been correlated with complete diagrams in north-west Europe, which are characterised by a sharp expansion of broad-leaved trees. Foraminifer and diatom data suggest thermophilous and real marine conditions at the end of the early temperate substage.

The pollen stratigraphy at the sites representing the Eemian Interglacial is characterised by an initial interglacial forest development by the *Betula* zone. During the subsequent *Pinus* zone, the first thermophilous trees start to appear (*Ulmus* and *Quercus*). After a period of *Pinus* and mixed oak forest dominance, a widespread colonisation by *Corylus* occurs. The interglacial climatic optimum is marked by a combined occurrence of *Hedera, Viscum* and *Ilex* in the *Corylus-Taxus-Tilia* zone and in the *Carpinus* zone. A sharp rise and dominance of *Picea* is characteristic for the ending part of the late temperate substage. *Pinus* replaces *Picea* during the post-temperate stage of the Eemian Interglacial. A gradual climatic deterioration can be followed through the *Carpinus-Abies* and the *Pinus- Picea-Abies* zone forward to the end of the interglacial. The boundary between the post-temperate substage of the Eemian Interglacial and the Early Weichselian has been placed on the level, where the thermophilous trees have completely disappeared and elements of a sub-arctic flora appear (Andersen 1961; Behre 1989; Litt 1990; Eissmann & Litt 1995).

Marine fauna

Portlandia arctica shells have been found glacially redeposited at many locations in the inland of Latvia, for instance at Licupe and Daugmale. Molodkov dated mollusc shells from these sites with the ESR (Electro Spin Resonance) method (Molodkov *et al.* 1998) and obtained ages of 105,000 and 89,000 years for shells at the Daugmale site and 94,000 years for shells found in clays at the Licupe site. The source of these shells is probably Early Weichselian Brørup interstadial sediments the age of which corresponds to the marine isotope substage 5c (Molodkov *et al.* 1998). This interpretation agrees of the pollen results, which have a comparatively good correlation with Brørup interstadial pollen data from the Medininkai and Jonionys sites, located just outside the maximum limit of the Last Glaciation in south-eastern Lithuania (Satkunas & Grigiene 1997; Satkunas *et al.* 1998).

8.3 Comparison of the Holsteinian, Eemian and Holocene (Flandrian) Interglacials

Marine sequences of three interglacials will be compared in order to find out differences and similarities. The fauna and flora succession of each interglacial sequence in the Baltic area has its own characteristic features. By comparison with the Holocene, the evolution of the Baltic basin during previous interglacials is poorly understood.

8.3.1 Similarities and differences in foraminifera assemblages

On the basis of the foraminifera fauna, the marine Holsteinian deposits can be clearly differentiated from Eemian marine strata. In contrast to the Eemian Interglacial, when the transgression occurred after the onset of the Interglacial, the sea had already invaded parts of Jutland and Northern Germany by the end of the Elsterian Glaciation. Arctic species are especially common in the early part of the Holsteinian Interglacial in Eggstedt and Dockenhuden (Knudsen 1993). The co-occurrence of *Bucella frigida* and *Haynesina orbiculare* can also be considered a characteristic feature in marine Holsteinian sediments throughout north-western Europe (Knudsen 1988). Holsteinian sediments that are rich in foraminifera have also been identified in western Latvia (Ulmale, Sudrabi and Strante), where the Late Elsterian Sudrabi clays include a foraminifera assemblage with arctic-sub-arctic species, at present living in northern seas. Upward in these sequences the number of foraminifera decreases considerably.

In contrast to Holsteinian deposits, Eemian type sections are not rich in foraminifera in the lower part of the stratigraphy, accumulated at the very beginning of the Eemian Interglacial. The number of foraminifera increases shortly before the climatic optimum of the Eemian Interglacial, and boreal-lusitanian taxa dominate the fauna.

The benthic foraminiferal fauna distribution in the Eemian and Holocene sediments in the Baltic basin is quite similar, with higher numbers of boreo-lusitanian species than in Holsteinian deposits (Knudsen 1993). The occurrence of *Haynesina orbiculare* together with thermophilous species characterises the Eemian foraminiferal assemblage at the Plasumi site in western Latvia (Table 9).

Haynesina nivea is found in the Eemian marine deposits investigated in the Baltic area, including the Plasumi site. The recent distribution of *Haynesina nivea* is not known, but it has not been noted in Holsteinian or Holocene deposits of the Baltic areas (Knudsen 1985b). However, this taxon is not entirely restricted to the Baltic Eemian.

8.3.2 Characteristics of the diatom flora

Meso- to polyhalobous diatoms, known to be characteristic of littoral environment of the Eemian Sea proper, and common polyhalobous species typical of the diatom flora of the Eemian Baltic Sea, and several mesohalobous species taxa characteristic of littoral conditions, which prefer high salinity and relatively warm water, as well as a few oligohalobous taxa (values <1 %) have been observed in the marine Eemian interglacial sediments. These diatom assemblages suggest a brackish-marine littoral environment during the post-temperate sub-stage of the Eemian Interglacial, but those from the submorainic deposits show that the water in this basin changed from saline to almost fresh during their deposition of the sequence.

In contrast to the above-mentioned diatom complexes of dominantly littoral and warm water demanding species of the Eemian Sea, most of the marine diatom taxa from the Holsteinian Sea sediment sequences in the Ziemupe-Jurkalne area were benthic, neritic and oceanic forms occurring in the seas with normal salinity.

The diatom flora dominated by the genus *Cyclotella*, including such species as *Cyclotella comta var. lichvinensis* and *C. temperei* that became extinct at the end of Middle Pleistocene is characteristic for sediments overlying the Akmenrags (Holsteinian) Interglacial, but older than the Saalian Glaciation.

8.3.3 Comparison of vegetation history

The interglacial vegetation history has been influenced by numerous factors. Comparison of vegetation succession, and evidence of changing soil conditions supply information about the vegetation and also the climatic character of individual periods (Andersen 1964). Application of this comparative approach to pollen records from western Latvia offers an opportunity to find similarities and differences in the vegetation development of the two last Interglacials and the present one. The characteristic general interglacial vegetation succession was described by Iversen (1958) and Grichuk (1961, 1989) from open tundra through *Betula* and *Pinus* forest to temperate mixed oak forest and then back to coniferous forest, later replaced by *Pinus* and *Betula* forest. This succession is valid for the Holsteinian, Eemian and Holocene vegetation history (Iversen 1958, Birks 1986).

Differences in the vegetational succession may be related to particular features *e.g.* soil formation and transgression during the interglacial cycle (Table 14). The composition of the pollen flora demonstrates that the main differences can be observed during the early temperate and late temperate sub-stages in the order of immigration and spread of broad-leaved trees and spruce, while minor differences are observed during the pre-temperate and post-temperate substages.

The vegetation development of the Eemian Interglacial differs from that of the Holsteinian. If the early phase of the Eemian (the pre-temperate substage) Interglacial, which is characterised by immigration of *Betula* and *Pinus* (PAZ E1 and E2) is similar to other interglacials, then the early and late temperate substages are comparatively different (Table 18). In contrast to the Holocene, *Betula* and *Pinus* was followed – prior to the appearance of *Corylus*, by the immigration of *Quercus* and *Ulmus* (PAZ E3), while *Picea* and *Alnus* maxima occur during these substages in the Holsteinian Interglacial. The light pine-mixed oak forest in the Eemian was rapidly joined by *Corylus*, which became dominant in PAZ E4. Characteristic for the Eemian vegetational development is also the pronounced *Carpinus* phase (PAZ E5), succeeded by an equally strong *Picea* maximum, while in the Holsteinian, the *Picea* peak occurs before or simultaneously with the *Carpinus* maximum. Subsequently in the Eemian *Abies* and *Picea* immigrated during the late temperate substage (PAZ E6). *Picea* appeared slightly before or simultaneously with climatic optimum during Holocene and reached its maximum during late temperate stage, but presence of *Carpinus* is very low and *Abies* pollen is not found in the Holocene sediments in Latvia (Kalnina *et al.* 1999). Finally, *Pinus* gained dominance (PAZ E6) towards the end of the Eemian Interglacial, when *Betula* re-appeared. This interval is again similar for both the Holsteinian and Eemian Interglacial.

Menke (Menke &Tynni 1984) compares pollen spectra from the Eemian with the Holocene Interglacial and found that *Viscum* immigrated about 2000-5000 years after the beginning of the Eemian Interglacial and disappeared about 7000-8000 years after afforestation during both interglacials. *Viscum* is an indicator of warm summers. During their climatic optima both interglacials experienced July temperatures of about 2 °C higher than at present (Menke &Tynni 1984). Comparison of the ostracod fauna with pollen floras indicates that the temperature optimum coincides with Menke's pollen zones IVb-V (PAZ E3-E4).

Definite differences between the Eemian and the Holocene Interglacial can be found with regard to the frost-susceptible genera. In this respect *Ilex* is an important climatic indicator, since its recent easternmost boundary roughly coincides with the 0 °C January isotherm. In contrast, during the Eemian *Ilex* reached much farther east than today (Frenzel 1968). *Hedera* was also far more widely spread in the Eemian than in the Holocene and the distribution of the submediterranean *Buxus* and the spore plant *Osmunda* implies that the Eemian had much milder winters than the present Interglacial. After the Eemian climatic optimum, during the late temperate sub-stage *Abies* immigrated simultaneously with the increase in *Picea*, which can roughly be compared with the Subboreal chronozone of the Holocene. On the basis of the vegetation pattern, July temperatures in Schlezwig-Holstein were about 15 °C during the Eemian (Menke &Tynni 1984). Towards the end of this period Menke suggests that North Germany was once more close to the northern limits of the more demanding deciduous trees and *Abies*, and by the end of zone VII (Menke &Tynni 1984) the sub-arctic forest boundary again passed through Schleswig-Holstein. According to data from Latvian Eemian sediment sequences the northern limit of deciduous trees was reached earlier, probably in the middle of the discussed period, at the end of the late temperate substage.

Table 18. Comparison of vegetation succession and regional pollen assemblages zones showing the general vegetation history in the Holsteinian, Eemian and Holocene Interglacials in Latvia. Substages are named according to West (1970).

Substages	Holsteinian	Eemian	Holocene (Kalnina *et al.* 1999)
Post-temperate	*Betula-Alnus*-QM	*Pinus-Betula*	*Pinus-Betula-Poacea*
	Pinus		*Picea-Pinus-Alnus*
			Pinus-Betula
Late-Temperate	*Abies-Carpinus-Alnus-Quercus*	*Picea-Abies*	*Picea-Pinus-Alnus-Betula*
		Carpinus-Alnus-Picea	*Pinus-Picea-Alnus-Quercus-Carpinus-Corylus*
Early - Temperate	*Picea-Ulmus-Alnus-Tilia-Corylus*	*Tilia-Alnus-Corylus*	*Quercus-Ulmus-Tilia-Carpinus-Fagus-Picea*
		Ulmus-Quercus- Corylus	*Alnus-Corylus-Ulmus-Tilia*
Pre-Temperate	*Pinus*	*Pinus*	*Pinus-Betula*
	Betula	*Betula*	*Betula-Pinus*

The vegetation history and climatic development during the Eemian very much resembles that of the Holocene Interglacial and also some parts of Cromerian (Zidini) complex (Kalnina *et al.* 1995; Danilans & Kalnina 1999).

However, mean January and July temperatures seem to have been slightly higher during the Eemian Interglacial than in the Holocene (Anderson *et al.* 1991a, b, Zagwijn 1996). The land-sea distribution during the Eemian, in comparison to that in the Holocene, had a profound effect on climate in the highly sensitive Baltic Sea region. There was a significant influx of warm water from the Atlantic and Zagwijn (1996) considers that the presence of free interchange of sea-water would have been responsible for the pronounced maritime climate in western and central Europe during the Eemian, and that the increase in winter temperature may thus be related to the rise of sea-level through the interglacial. Furthermore, as Donner (1995) points out, there was a greater uniformity in vegetation around the Baltic region than in the Holocene. Palaeobotanical data show that during the last, or Eemian, interglacial, the climate in the northern Europe was warmer than during the postglacial climatic optimum. The main warm period of the Eemian is identiable in pollen and plant macrofossil analyses from the abundance of thermophilous species, many of which grew in Eemian time far beyond their Holocene (Flandrian) northern limits (Forsström *et al.* 1988).

Pollen and spores of plants characteristic for the Eemian Interglacial are - *Tilia tomentosa, T. platyphyllos, Sambucus nigra, Osmunda cinnamomea* and *Brasenia* sp. Among *Tilia* pollen, *Tilia tomentosa* is mostly observed before the *Tilia* peak, but *Tilia platyphyllos* is recorded after the *Tilia* maximum (Liivrand 1991; Kondratiene 1996; Kalnina 1997c), when the total number of *Tilia* pollen decreases.

Plant remains of *Picea omorica, Pinus cembra* and *Pinus strobus* have not been identified in interglacial deposits younger than the Holsteinian from the central area of the Fennoscandian Glaciation. Needles of *Picea omorica* and *Pinus cembra* are present in the Snickarekullen sediments (south-western Sweden), suggesting that these conifers were part of the local flora (García Ambrosiani *et al.* 1998). In western Latvia, pollen of the above mentioned species have been found.

Larix seems to have been a major forest component during the Holsteinian Interglacial in Scandinavia (García Ambrosiani 1996). During the Eemian Interglacial, *Larix* was present farther to the west and south, and especially in the north-eastern part of Europe, but only towards the end of the interglacial (Forsström 1990; García Ambrosiani *et al.* 1998). In Latvia *Larix* pollen appears in both the Holsteinian and Eemian pollen diagrams. Single pollen grains of *Larix* pollen have been found in late glacial spectra, as well as occasionally in the temperate substages, particularly in the late temperate PAZ VI, but it is more abundant in the Early Weichselian interstadials. In the Holsteinian pollen diagrams, *Larix* is present in PAZ VIII together with *Betula nana, Duschekia* and a herb pollen assemblage dominated by *Artemisia*.

8.3.4 Summary

The following comparisons can be made between the Holsteinian, Eemian and Holocene Interglacials:

- The distribution of the benthic foraminifera fauna in Eemian and Holocene sediments in the Baltic basin is comparable, with the number of boreo-lusitanian species, it being higher than in Holsteinian deposits. The Holsteinian foraminifera fauna suggests only boreal conditions even during the warmest part of the interglacial.
- The marine transgression thus occurred later in the Eemian than in the Holsteinian Interglacial, but considerably earlier than in the Holocene. In contrast to the Holsteinian, a direct connection existed from the North Sea into the Baltic Basin, so that a thermophilous Lusitanian fauna could easily immigrate.
- The climatic development during the Eemian Interglacial very much resembles that of the Holocene Interglacial. However, mean January and July temperatures seem to have been slightly higher during the Eemian.
- The composition of the pollen flora demonstrates that the main differences can be observed during the early-temperate and late-temperate substages in the order of immigration and spread of broad-leaved trees and spruce, while smaller differences are observed during the pre-temperate and post-temperate substages.
- Coniferous forests dominated during the entire Holsteinian Interglacial, while during the Eemian climatic optimum the distribution of coniferous trees decreased considerably, and they constituted only with a few percents of the vegetation composition. Coniferous trees are more abundant and have a wider distribution in the Holocene than in the Eemian, but less than during the Holsteinian, when they also had a greater diversity.

The composition of the vegetation was uniform in large areas and was influenced weakly by the ocean during the Holsteinian, while during the Eemian it was very diverse and great differences existed between the western coast and the eastern area of Latvia. The Holocene regional vegetation composition is less diverse than that during the Eemian, when it was influenced considerably by oceanic air masses, probably even more than during the Holsteinian. Human influence on the vegetation must be taken into account especially during the late-temperate substage of the Holocene.

9 CONCLUSIONS

9.1 Late Elsterian, Holsteinian and Early Saalian

According to the biostratigraphical record in the Late Letiza (Elsterian) to Early Kurzeme (Saalian) deposits, the sediment sequence, which accumulated during the Letiza deglaciation in the western Latvia Ziemupe-Jurkalne area originated from a shallow basin of a proglacial lake, where ocean water entered from the west already at the end of deglaciation. The basin became entirely marine already during the final stage of the Letiza Late Glacial and continued as such during the first half of the Akmenrags (Holsteinian) Interglacial. It turned into a shallow basin with significant freshwater inflow during the second half of the Akmenrags Interglacial (Kalnina *et al.* 2000) and to a periglacial basin during the Kurzeme Early Glacial.

According to the biostratigraphical data (foraminifera, diatoms, pollen) saline water entered the coastal areas in western Latvia, and probably the maximum altitude of the sea level was reached during the first half of the Akmenrags Interglacial. Due to insufficient biostratigraphical data and glacial erosion in the study area during the subsequent Saalian Glaciation, it has not been possible to reconstruct the position of the coastline across the region (Kalnina *et al.* 2000).

Litho- and biostratigraphical data indicate that aquatic, both saline and freshwater, intertill sediments in the Ziemupe-Jurkalne area represent a long non-glacial interval of the Middle Pleistocene. This sequence begins with a short freshwater episode during the Letiza (Elsterian) deglaciation and continues under marine conditions at its very end and proceeds without interruption through the first half of the Akmenrags (Pulvernieki, Holsteinian) Interglacial. After the climatic optimum, the water became semi-shallow brackish to fresh during the second half of the Interglacial as indicated by the diatom flora. Aquatic deposition continued during the Early Kurzeme (Saalian) Glaciation. The bio- and lithostratigraphical data (Charamisinava 1971; Konshin *et al.* 1970, 1971; Seglins 1987; Kalnina *et al.* 2000 and this study), supported by detailed pollen data, prove convincingly that:

1) western Latvia is at present the most easterly recognised area where marine Holsteinian sedimentation has been identified in the Baltic Sea basin (Kalnina *et al.* 2000);
2) saline water occupied the central part of the Baltic Sea basin during the Holsteinian Interglacial at least as far as the present Latvian coastal area;
3) the till beds superimposing the Holsteinian deposits are of Kurzeme (Saalian) age.

9.2 Late Saalian, Eemian and Early Weichselian

The Baltic Sea of the Eemian Interglacial has been described areas close to Latvia in several publications, *e.g.* Grönlund (1991) and Liivrand (1991) prior to the identification of Eemian marine deposits in Latvia. In their maps the Eemian shoreline appears to have been located at a similar altitude as during the post-glacial Littorina Sea stage.

Eemian marine deposits were first identified in the northern part of the Gulf of Riga (Gulf of Livonia) in core 21 (Kalnina 1993; Juskevics & Talpas 1997), where the sediment sequence began with sediments of Late Saalian age and continued through the Eemian Interglacial into the Early Weichselian. Absolute dates of these deposits are, however, missing. The pollen flora and the diatom data suggest formation of interglacial deposits under marine conditions. The overlying till in the Gulf of Riga was interpreted as Weichselian according to lithostratigraphical analyses.

Two marine Eemian sites were recognised in the coastal area of Latvia - Grini and Plasumi, (Kalnina 1996c, 1997b, d; Kalnina & Juskevics 1998a, b, c). Both sites occur in comparatively small depressions and the Eemian deposits were by some researchers considered as not "*in situ*" (Tracevski *et al.* 1989). At present it is problematic to draw the shoreline of the Eemian Sea in Latvia with certainty, but at least the schemes proposed until now (*e.g.* Knudsen 1994, Kristensen *et al.* 2000) can be accepted also for the Latvian coast.

Some differences have been found between the Latvian marine Eemian sites: characteristic features of the diatom flora and the pollen spectra in the Gulf of Riga core-21 sequence show a better correlation with data from the Estonian site Prangli (in spite of different depths of location), while results from the Grini and the Plasumi sites are more in accordance with western Baltic sites. The explanation to this difference might be the Baltic Eemian Sea connection with the North Sea and the White Sea, an hypothesis put forward in several recent publications (Turner 2000; Funder *et al.* in print).

10 SUMMARY OF RESULTS

The main results of this investigation are:

1. The characteristics of the composition and the distribution of Pleistocene sediments from the coastal (Ziemupe-Jurkalne) area of western Latvia and the northern part of the Gulf of Riga (Gulf of Livonia) have been investigated by means of data from geological mapping, as well as lithological, mineralogical foraminiferal, diatom and pollen analysis. Results from earlier investigations (Konshin *et al.* 1970, 1971; Seglins 1987; Tracevski *et al.* 1989; Kalnina *et al.* 2000) have been revised and supplemented by new results.

The marine Pleistocene, as well as the composition, distribution and sedimentation conditions of the overlying and underlying sediments and till beds are discussed and illustrated. The biostratigraphical results are used to interpret the sediment origin, palaeo-environment and climate, as well as the vegetation on the adjacent mainland.

2. The sediment sequences studied contain pollen records and reconstructions based on these of the climate has been carried out:

a) starting with the Elsterian deglaciation, continuing through the entire Holsteinian to the Early Saalian Glaciation in five pollen sequences;

b) starting in the Saalian deglaciation, continuing through the entire Eemian Interglacial into the Early Weichselian in three pollen sequences;

3. The palaeoenvironment and palaeo-ecology of the Holsteinian and Eemian Baltic Sea, as reflected in Latvia and in sequences from surrounding areas, have been reconstructed and compared with the Holocene Baltic Sea. The Holsteinian Sea was characterised by an early transgression and climatic fluctuations during this stage, while the marine transgression of the Eemian Sea occurred later than during the Holsteinian, but still considerably earlier than in the Holocene.

The vegetation history of the Eemian in western Latvia is very different from that of the Holsteinian. The early phase of the Eemian Interglacial, which was characterised by re-immigration of birch (*Betula*) and pine (*Pinus*) was shorter in contrast to the Holocene and Holsteinian. The immigration of oak (*Quercus*) and elm (*Ulmus*) began very early during the Eemian. The dominance of coniferous trees is characteristic for the entire Holsteinian Interglacial, while broad-leaved trees, especially oak, dominated during the Eemian Interglacial climatic optimum.

The climatic development of the Eemian resembles that of the Holocene. In general, however, the Eemian Interglacial seems to have been slightly warmer. Therefore, the Eemian global sea level rose slightly higher than that of the Holocene (Ehlers 1996). The highest sea level was reached during the climatic optima of all three interglacials. During the late- temperate substage the level of the Eemian Sea lowered rapidly, while probably for the Holsteinian and the

Holocene Baltic Sea the lowering occurred more gradually.

4. In the pollen study of long marine sediment sequences attention was paid to the following:

- the vegetation history and succession in the course of interglacials in western Latvia have been described and reconstructed. The differences between pollen spectra identified in the Holsteinian and Eemian aquatic sediments have been analysed and compared with Holocene ones;
- characteristic features of the interstadial pollen floras representing the late glacial, and early glacial cycles of the Elsterian, the Saalian and the Weichselian Glaciation were presented. One Late Elsterian (Sudrabi) interstadial, one Early Saalian and one Late Saalian interstadial and two Early Weichselian interstadials have been identified. Their boundaries to stadials and vegetation development, as well as correlation problems are discussed;
- comparison was made with the vegetation history as reflected by pollen spectra on local, as well as on regional levels by means on taphonomy. The pollen spectra from marine sediments reflect vegetation and climate changes from a much wider region than the terrestrial sequences. As a result of transport by marine currents, pollen originating from other regions may appear, for instance, occurrence of *Abies* pollen in the *Picea* zone during the Late Eemian in contrast to the pollen spectra from the mainland, where until now *Abies* has not been identified;
- a stratigraphical interpretation of the Pleistocene sediment sequences in the Baltic Sea basin, mainly based on results of pollen, diatom and foraminiferal analysis, has been performed (Table 1).

The final conclusion is that the presence and extension of the Holsteinian and the Eemian Baltic Sea in the coastal area of Latvia can be proven with certainty and palaeoenvironmental conditions during these two Interglacials can be reconstructed. There are still, however, major and interlinked questions to be answered, not just about the Eemian and the Holsteinian Sea, but also about corresponding inter-glacial sequences in the mainland of Latvia and within the entire Baltic region.

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Errata list

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Laimdota Kalnina:
Middle and Late Pleistocene environmental changes recorded in the Latvian part of the Baltic Sea basin

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98 / right	7	Fig. 43	Fig. 42
98 / right	8 (log text)	homogenous	homogeneous
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119 / left	11	Eemian	Holsteinian
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MIDDLE AND LATE PLEISTOCENE ENVIRONMENTAL CHANGES RECORDED IN THE LATVIAN PART OF THE BALTIC SEA BASIN

Laimdota Kalnina

Dissertation in Quaternary Geology to be publicly examined in De Geersalen, Geovetenskapens hus, Frescati, Stockholm on September 11, 2001, at 13.00 a. m. for the Degree of Doctor of Philosophy.

ABSTRACT: This thesis outlines the Middle and Late Pleistocene environmental changes as they are recorded in the stratigraphy in western Latvia in the Ziemupe-Jurkalne area and in the northern part of Gulf of Riga (Gulf of Livonia). Latvia is located in the exaration–accumulation zone of the Fennoscandian ice sheets, which affected the interglacial sediments, so they have been preserved mainly in buried valleys and in bedrock depressions.

Pleistocene sediment sequences have been analysed by means of lithological and biostratigraphical methods with an emphasis on pollen analysis. The presence of marine Pleistocene deposits accumulated in the Holsteinian and Eemian Seas has been established by an analysis of the foraminifera and diatom composition recorded in the interglacial sediments. New continuous Holsteinian and Eemian sediment cores have been characterised and compared with previously investigated sites in the same area, and put into a regional context. Holsteinian and Eemian interglacial marine sediment sequences, as well as Elsterian, Saalian and Weichselian late and early glacial deposits have been identified.

The results of the biostratigraphical investigations indicate a very early transgression of the Holsteinian Sea already at the end of the Late Elsterian Glaciation, while true marine conditions occurred in the Eemian Interglacial in the early temperate sub-stage before the climatic optimum. The sediment sequences, including the Eemian Interglacial, contain marine foraminifera and diatoms characteristic of the Eemian Sea. The identified foraminifera and diatom taxa reflect shallow brackish-freshwater conditions during the post-temperate sub-stage of both interglacials.

Pollen records from the Holsteinian sites show a succession of three main vegetation types in the coastal zone. Nine regional pollen assemblage zones are distinguished and they represent a periglacial vegetation (PAZ I), a temperate climate vegetation complex dominated by pollen of coniferous trees (PAZ II-VI), and an open landscape vegetation (PAZ VII-IX).

The Eemian interglacial pollen succession (regional PAZ E1-E8) in the study area began with a dominance of *Betula* (E1), which was gradually replaced by *Pinus* (E2). The maximum distribution of broad-leaved forest started with the spread of *Ulmus* and *Quercus* (E3), followed by *Tilia* (E5) and *Carpinus* (E6). *Picea* and *Pinus* (E7), dominated after the climatic optimum and were followed by *Betula* (E8). The presence of *Hedera* and *Brasenia* indicates a favourable climate with oceanic influence.

During the Eemian Interglacial, broad-leaved forests were widespread in the coastal area. In contrast, coniferous forests had a wider distribution and diversity during the Holsteinian Interglacial. The pollen diagrams from Latvian Holsteinian sites are more similar to those from north-western Europe than the Eemian ones, suggesting a greater difference in the coastal vegetation in the last Interglacial. Both interglacials are ending with a *Betula-Pinus* zone, rich in Ericales and with an admixture of broad-leaved tree pollen, whose presence "*in situ*" is still under question.

The results prove that western Latvia is a key area to the study of Pleistocene stratigraphy, since the north-easternmost extension of the Holsteinian Sea as far as we know has been identified in this area. New Eemian marine sites widen the knowledge of the Eemian Baltic Sea in the south-eastern Baltic area.

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